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Saffron cod fluctuations in the Japan Sea: an evidence of match/ mismatch hypothesis

Outline:

1. Fluctuation of the saffron cod population in Peter the Great Bay
2. Match/mismatch mechanism for saffron cod
3. Nature of winter climate change in Peter the Great Bay
4. Schemes of the saffron cod stock formation in 1990s and 2000s
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Catch: collapse in the 1990s

Saffron cod is one of the main subjects of fishery in Peter the Gray Bay, along with walleye pollock and Japanese sardine.

Its annual catch was rather stable until the early 1990s, when its fishery was almost collapsed, at one time with the sardine fishery.
The main spawning grounds of saffron cod are located in the shallow Amur Bay where it spawns under the ice in winter.

Larvae of saffron cod are distributed mostly in the same area that is high-productive in spring.

Yearlings of saffron cod dwell the sallow areas, as well.

Adults of saffron cod feed on benthos and distribute widely over the bottom of Peter the Great Bay.
## Data sources:

The catch changes were compared with fisheries, biological, and environmental data series

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<td>1942-2009</td>
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Results: *recruits-spawners dependence*

The catch decreasing was not inspired by economical reasons (because of political changes) so far as CPUE of the saffron cod fishing decreased even more drastically than the annual catch.

Saffron cod shows positive dependence of its year-class strength on the number of spawners recalculated to the population fecundity. The dependence could be approximated by Ricker equation

\[ R = aS e^{-bS} \quad \text{with } r^2 = 0.43. \]

However, this dependence reflects only the difference between two states of the cod stock:
- the high stock before the late 1980s and
- the low stock after the late 1980s

Within the first period the recruits-spawners dependence was negative, and within the second period it was insignificant.

*That means that the recruitment success depends on other factors, as environments.*
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Results: seasonal dynamics of spawning

The saffron cod spawns under the sea ice, in December-February. Its eggs develop at the sea bottom in conditions of temperature below zero.

On average, the mass spawning of saffron cod occurs in early January.

Mean for 1954-2009 dynamics of maturing for the saffron cod in Peter the Great Bay (bars) and dynamics of the portion (%) of pre-spawning and spawning females (stages IV, IV-V, V, V-VI) averaged for the 1970-1980s and 1990-2000s.

The level 50% of pres-spawning and spawning females corresponds to the peak of spawning.
Results: **year-to-year change of mass spawning time**

The time of mass spawning differs from year to year. Generally, it became earlier in the last decades. The dates of the spawning peak are opposite to water/air temperature in January ($r = -0.66$; $1^\circ$C SST causes the shift 25 days), so the warming in the late 1980s caused the shift to earlier spawning.

**Timing of the spawning peak dependence on SST in Vladivostok**

**Mean month SST anomalies in Vladivostok in January of 1954-2008 ($r = -0.66$)**

**Shift to earlier spawning in the late 1980s**

**Short period of late spawning in early 2000s**

**Year-to-year changes of the date of spawning peak. Shift to earlier dates occurred in late 1980s**

*Portion (%) of the saffron cod spawning females (stage V) in 1970-1980s and 1990-2000s*
Results: **seasonal succession of plankton**

The larvae of saffron cod feed on small-sized zooplankton, mostly nauplia of Copepoda.

Seasonal development of plankton in the coastal waters of the Japan Sea is a succession of “seasons” with specific features. Zooplankton is the most abundant in the spring season (immediately after the spring bloom of phytoplankton) and in the early summer. The larvae hatched in April, so they prey upon the spring bloom of cold-water copepods juveniles.

<table>
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<tr>
<th>Season</th>
<th>Abundant groups of plankton</th>
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<tr>
<td>Winter</td>
<td>Low abundance of all groups</td>
</tr>
<tr>
<td>Early spring</td>
<td><strong>Phytoplankton (spring bloom)</strong></td>
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<tr>
<td>Spring</td>
<td><strong>Phytoplankton, cold-water Copepoda</strong></td>
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<td>Late spring</td>
<td>Phytoplankton, Sagitta, Euphausia</td>
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<td>Early summer</td>
<td>Large-sized cold-water Copepoda</td>
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<td>Summer</td>
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</tr>
<tr>
<td>Late summer</td>
<td>Cladocera, warm-water Copepoda</td>
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<td>Early autumn</td>
<td>Phytoplankton, warm-water Copepoda</td>
</tr>
<tr>
<td>Autumn</td>
<td>Sagitta, warm-water Copepoda</td>
</tr>
</tbody>
</table>

SeaWiFS data on Chl a concentration (mg/m³) in the Amur Bay on April 6-13, 2008 (spring bloom)

Total biomass of zooplankton in different seasons in the main spawning grounds of saffron cod
Results: phytoplankton blooms

There are 2 phytoplankton blooms in the Amur Bay in winter-spring. The latter develops under SST about 3°C, and therefore its timing depends on SST anomaly: the higher SST, the earlier the spring bloom (r = -0.84; 1°C causes the shift 25 days). Thus, the next season beginning (with small-sized zooplankton abundance) depends on SST, too.

Dependence of Chl a concentration on SST in the Amur Bay (SeaWiFS data)

Dependence of the timing of the end of spring phytoplankton bloom in the Amur Bay (SeaWiFS) on SST anomaly in Vladivostok in April

Shift to earlier blooming in the late 1980s

Period of high variability

SST and Chl a concentration in the Amur Bay (SeaWiFS data for 1998-2008)

Time of the end of spring bloom of phytoplankton (spring season beginning) in the Amur Bay (restored from SST). High variability occurred in 1990-2000s
Results: **period for embryonic development**

For reproductive success, the eggs of saffron cod have to develop in the period from the spawning to the end of spring bloom, to be hatched in conditions of their prey (zooplankton) abundance.

Length of this period differs from year to year, because both of the time of mass spawning and the time of spring bloom changes. There was a tendency to its shortening before the late 1980s; it became highly variable in 1990-2000s, with extremely long periods in several years (1988, 1995, 1996, 1999, 2007-2009) and mainly short periods in the early 2000s.
Results: **match**/**mismatch**

In fact, both extremely long and extremely short periods between the spawning and zooplankton bloom are unfavorable for the saffron cod reproduction. In opposite, an optimal length of this period provides the best match of the larvae hatching with prey abundance.

To determine the optimal length, dependence of the year-class strength \( N \) on the length of period from mass spawning to zooplankton bloom \( T \) is approximated by resonance function:

\[
N = \frac{a}{1 + \left[ Q \cdot \left( \frac{T}{T_R} - \frac{T_R}{T} \right) \right]^2}
\]

where \( T_R = 111 \) days – resonance length;
\( Q = 26.6 \) – Q-factor of vibrating system;
\( a = 9.0 \) – empiric coefficient \( (r^2 = 0.43) \)

If the period \( T \) is close to \( T_R = 111 \) days, the saffron cod larvae is hatched in conditions of high abundance of their prey.

If this period is shorter or especially longer than \( T_R \), the prey abundance is lower, so weak generations of saffron cod are formed.

In 1990s, this period was usually longer than \( T_R \) (or too short sometimes) that caused the population collapse. It became optimal again in early 2000s, and several strong generations had formed, but was too long again in 2007-2009.
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Results: winter warming in the Japan Sea

Winter warming was observed in the late 1980s both in the spawning area of saffron cod and in the whole Japan Sea. Obviously, it was driven by a large-scale mechanism.

Air temperature in January correlates strongly ($r = +0.62$) with winter Arctic Oscillation Index, and the temperature in February – with the Siberian High Index ($r = -0.57$). The indices are interdependent. They both have a prominent shift in the late 1980s.

Siberian High Index changes. Its lowering means weakening of winter monsoon that prevents the sea surface cooling in the Japan Sea.

Arctic Oscillation Index changes. Its heightening means strengthening of zonal transfers which make warmer the winters in the Far East of Russia (from http://jisao.washington.edu/analyses0302/)
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Discussion: **scheme of global climate influence on the saffron cod population in Peter the Great Bay**

- **1970–1980s, early 2000s**
  - Gradual change to negative phase of AO
  - Water cooling in winter
  - Winter monsoon strengthening
  - Late spawning
  - Match
  - Strong generations
  - Stock restoration

- **1990s, recent times?**
  - Shift to positive phase of AO
  - Winter monsoon weakening
  - Water warming in winter
  - Early spawning
  - Longer the time from spawning to spring
  - Mismatch
  - Weak generations
  - Stock decline
Conclusions:

1. Strong generations of saffron cod in Peter the Great Bay form in the case of optimal period between the spawning and zooplankton bloom (about 111 days)

2. Generally, cold winters and moderate springs are favorable for this saffron cod population; its mass spawning shifts to later dates in conditions of low water temperature, so the period between spawning and zooplankton bloom is optimal for the eggs development (match). On the contrary, warm winters and moderate springs are unfavorable for its reproduction because of too long this period, as well as moderate winters and warm springs because of too short this period (mismatch, the latter is less dangerous)

3. Decadal changes of winter environments at Primorye coast of the Japan Sea are driven by Arctic Oscillation: its shift to positive phase in the late 1980s caused the winter monsoon weakening and warming. Subsequently, the saffron cod reproduction was successful before the climate shift in 1988/89 and mostly unsuccessful in the last decades