FISHBOOST: results, plans and implications in common carp

Kocour M. and Prchal M.

University of South Bohemia in Ceske Budejovice, Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Vodnany, Czech republic

kocour@frov.jcu.cz
Presentation based on the results that arose with great input of:

• **Vandeputte Marc**: Ifremer, Chemin de Maguelone, F-34250 Palavas-les-Flots, France and GABI, INRA, AgroParisTech, Université Paris-Saclay, F-78350 Jouy-en-Josas, France and

• **Antti Kause**: Natural Resources Institute Finland, FI-31600 Jokioinen, Finland

• **Jérôme Bugeon**: GABI, INRA, AgroParisTech, Université Paris-Saclay, F-78350 Jouy-en-Josas, France

• **Jean-Michel Allamellou**: LABOGENA-DNA, Jouy-en-Josas, France

• **Anastasia Bestin**: SYSAF Sect Aquacole, Campus Beaulieu, F-35000 Rennes, France

• **Christos Palaiokostas, Ross Houston**: The Roslin Institute, Royal (Dick) School of Veterinary Studies, University of Edinburgh, Easter Bush, Midlothian, EH25 9RG, Scotland, United Kingdom

• **Tomas Vesely, Dagmar Pokorova, Lubomir Pojezdal**: Veterinary Research Institute, Hudcova 70, Brno 62100, Czech Republic

• **Veronika Piačková, Hana Kocour Kroupová, David Gela, Girish Kumar**: University of South Bohemia in Ceske Budejovice, Faculty of Fisheries and Protection of Waters, South Bohemian Research Centre of Aquaculture and Biodiversity of Hydrocenoses, Zatisi 728/II, 389 25 Vodnany, Czech Republic

• **Jean-Michel Allamellou**: LABOGENA-DNA, Jouy-en-Josas, France

• **Anna Sonesson**: NOFIMA, N-1431 As, Norway
Common carp

Present situation:
- 0 years of selective (modern) breeding
- Hybridization programs exist
- Many different breeds, strains, lines ...
- Breeding done by fish companies or research/governmental organizations
- Research on breeding aspects exists

Main performance traits:
- Growth, survival (resistance), fillet yield, scale cover (in mirror carp)

Important R&D challenges:
- Enhance production: growth, winter survival, fillet yield, diseases
- Enhance breeding: construction of efficient programs, inbreeding control

www.frov.jcu.cz   www.fishboost.eu
The impact of FISHBOOST - advancing aquaculture breeding to the next level

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic salmon</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>European seabass</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Gilthead seabream</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Turbot</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Common carp</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

How about selective breeding?
When might be the selective breeding applicable?

\[(h^2) \frac{V_G}{V_P} > 0.2\]

**Simple said:** Genetics (origin of fish) is responsible at least by 20% for the final value of a trait (e.g. weight)

What do we need to estimate heritability well?

- the relationships among the individuals (cost demanding – molecular methods must be used in fish otherwise we can not avoid environmental effects)
- the performance of the fish (the same age class, the same rearing conditions)

What is it important to know?

- The \( h^2 \) might differ based on the carp breed used, given experimental conditions = simply it might be experiment-specific
- We may generalize the \( h^2 \) value after several estimations were performed
- Most \( h^2 \) estimations (weight, fillet yield, disease resistance) until now were promising \((h^2 = 0.2 \rightarrow 0.6)\). However, the estimations were mostly done on lower-ranged experiments.
What FISHBOOST has been planning to do for European carp culture

1. Calculate heritability and genetic correlations
   • Growth
   • Fillet yield (looking for indirect measurements)
   • Fat content, other energetic reserves and biometrical indices
   • Survival
   • KHV resistance

2. Develop the genomics field
   • Map genes
   • Estimation of genomic breeding values

3. Deliver optimised breeding scheme taking into account:
   • Design
   • Genetic parameters
   • Evaluation methods
   • Economic evaluation of traits
   • Perception of producers and representative organisations
Experimental conditions

1. Breed used: Amur mirror carp (legally recognized new breed in the Czech republic by Ministry of Agriculture in 2014)

2. Establishment of experimental stock

```
[Diagram showing experimental stock setup with groups I, II, III, IV]
```
3. Rearing conditions

- C0 to C1 – 6 ponds (0.2-1.0 ha; stocking density 150,000 larvae . ha⁻¹)
- C1 wintering – one main pond (0.2 ha; 10,000 fish of which 5,000 P.I.T tagged)
- C1 to C2 – one main pond (1.0 ha; 6,000 fish of which 3,000 P.I.T tagged)
- C2 wintering – one main pond (0.2 ha; 2,000 P.I.T tagged fish)
- C2 to C3 – one main pond (4 ha; 1976 P.I.T tagged fish)

Supplemental feeding with plant based carp pellets and grain (wheat)
4. **Data recording**
   - **C1 (autumn 2014):** P.I.T. tagging 6,500 fish (5,000 fish for production efficiency experiment; 1,500 for KHV resistance experiment), fin clipping, weight and SL recording
   - **C1 (spring 2015):** P.I.T. tagging (3,000 fish for production efficiency experiment), fin clipping, weight and SL recording
   - **C2 (autumn 2015):** Individual picture taking, weight, TL, SL, BL, HL, BH, BW and fat content recording
   - **C2 (spring 2016):** weight, TL, SL, BL, HL, BH, BW and fat content recording
Experimental conditions
**Experimental conditions**

- C3 (autumn 2016): weight, TL, SL, BL, HL, BH, BW and fat content recording, ultrasound measurements, 3D arm measurement, picture taking, dress out parts weighing, flesh colour measuring in 1680 survived fish
Experimental conditions
1. **Resistance to KHV**

   - Heritability estimates ranged between 0.6 – 0.7 on the liability scale.
   - RAD sequencing identified 17,737 SNPs.
   - Prediction of the resistance to KHV using pedigree data had accuracy of 0.63, while using genomic data (SNPs) it was 0.63 – 0.67.
   - The SNPs with the highest effects for overall survival in the underlying scale were located on linkage groups 1 and 26.
   - Resistance to KHV is a polygenic trait which means that it will be difficult to find specific powerful QTL for KHV resistance.
## 2. Production efficiency

Genetic (above the diagonal; ± S.E.) and phenotypic correlations (below diagonal) between traits before second wintering and traits changes during second wintering. \( \text{BW}_1 \) = weight of fish before wintering, \( \text{SGR}_{1-2} \) = specific growth rate, \( \% \text{Fat}_1 \) = Distel muscle fat content before wintering, \( \text{FC}_1 \) = Fulton’s condition coefficient before wintering, \( \text{FatCh}_{1-2} \) = absolute fat change, \( \% \text{FatCh}_{1-2} \) = relative fat change, \( \text{Surv}_{1-2} \) = overall survival on observed scale, \( \text{N/A} \) = not applicable.

<table>
<thead>
<tr>
<th></th>
<th>( \text{BW}_1 )</th>
<th>( \text{SGR}_{1-2} )</th>
<th>( \text{FC}_1 )</th>
<th>( % \text{Fat}_1 )</th>
<th>( \text{FatCh}_{1-2} )</th>
<th>( % \text{FatCh}_{1-2} )</th>
<th>( \text{Surv}_{1-2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{BW}_1 )</td>
<td>x</td>
<td>0.27 ± 0.14</td>
<td>0.08 ± 0.14</td>
<td>0.32 ± 0.13</td>
<td>- 0.1 ± 0.18</td>
<td>0.05 ± 0.18</td>
<td>0.19 ± 0.31</td>
</tr>
<tr>
<td>( \text{SGR}_{1-2} )</td>
<td>0.11</td>
<td>x</td>
<td>0.50 ± 0.11</td>
<td>- 0.39 ± 0.16</td>
<td>0.63 ± 0.12</td>
<td>0.67 ± 0.15</td>
<td>0.47 ± 0.29</td>
</tr>
<tr>
<td>( \text{FC}_1 )</td>
<td>0.06</td>
<td>0.14</td>
<td>x</td>
<td>- 0.25 ± 0.14</td>
<td>0.21 ± 0.17</td>
<td>0.22 ± 0.16</td>
<td>0.26 ± 0.28</td>
</tr>
<tr>
<td>( % \text{Fat}_1 )</td>
<td>0.28</td>
<td>- 0.14</td>
<td>0.00</td>
<td>x</td>
<td>- 0.51 ± 0.14</td>
<td>- 0.16 ± 0.17</td>
<td>- 0.59 ± 0.26</td>
</tr>
<tr>
<td>( \text{FatCh}_{1-2} )</td>
<td>- 0.05</td>
<td>0.16</td>
<td>- 0.01</td>
<td>- 0.46</td>
<td>x</td>
<td>0.92 ± 0.04</td>
<td>0.68 ± 0.30</td>
</tr>
<tr>
<td>( % \text{FatCh}_{1-2} )</td>
<td>- 0.01</td>
<td>0.29</td>
<td>0.00</td>
<td>- 0.29</td>
<td>0.93</td>
<td>x</td>
<td>0.46 ± 0.33</td>
</tr>
<tr>
<td>( \text{Surv}_{1-2} )</td>
<td>0.02</td>
<td>N/A</td>
<td>0.03</td>
<td>- 0.01</td>
<td>N/A</td>
<td>N/A</td>
<td>x</td>
</tr>
</tbody>
</table>
## 2. Production efficiency

Genetic (first line; ± S.E.) and phenotypic correlations (second line) between traits after overwintering (left hand side) and market size (upper heading). $\text{BW}_2$, $\text{BW}_3$ = weight of fish after the 2nd wintering and the 3rd growing season, $\text{SGR}_{1-2}$, $\text{SGR}_{2-3}$ = specific growth rate during the 2nd wintering and the 3rd growing season, $\text{FC}_2$, $\text{FC}_3$ = Fulton’s condition coefficient after the 2nd wintering and the 3rd growing season, $\% \text{Fat}_2$, $\% \text{Fat}_3$ = Distel muscle fat content after the 2nd wintering and the 3rd growing season, $\text{FatCh}_{1-2}$, $\text{FatCh}_{2-3}$ = absolute fat change during the 2nd wintering and the 3rd growing season, $\% \text{FatCh}_{1-2}$, $\% \text{FatCh}_{2-3}$ = relative fat change during the 2nd wintering and the 3rd growing season, $\text{Surv}_{1-2}$, $\text{Surv}_{2-3}$ = overall survival during the 2nd wintering and the 3rd growing season, $\% \text{Carss}$ = percent yield of headless carcass; $\% \text{Fill}$ = percent yield of fillets with skin.

<table>
<thead>
<tr>
<th></th>
<th>$\text{BW}_3$</th>
<th>$\text{SGR}_{2-3}$</th>
<th>$\text{FC}_3$</th>
<th>$% \text{Fat}_3$</th>
<th>$\text{FatCh}_{2-3}$</th>
<th>$% \text{FatCh}_{2-3}$</th>
<th>$\text{Surv}_{2-3}$</th>
<th>$% \text{Carss}$</th>
<th>$% \text{Fill}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{BW}_2$</td>
<td>0.74 ± 0.07, 0.72</td>
<td>-0.59 ± 0.10, -0.62</td>
<td>0.15 ± 0.14, 0.1</td>
<td>0.22 ± 0.14, 0.24</td>
<td>0.13 ± 0.15, 0.15</td>
<td>-0.14 ± 0.15, -0.07</td>
<td>-0.29 ± 0.22, 0.05</td>
<td>-0.19 ± 0.15, 0.06</td>
<td>0.03 ± 0.16, 0.19</td>
</tr>
<tr>
<td>$\text{SGR}_{1-2}$</td>
<td>0.62 ± 0.1, 0.34</td>
<td>0.11 ± 0.16, -0.06</td>
<td>0.54 ± 0.11, 0.22</td>
<td>-0.35 ± 0.13, -0.1</td>
<td>-0.33 ± 0.14, -0.09</td>
<td>-0.19 ± 0.15, -0.05</td>
<td>0.31 ± 0.24, 0.03</td>
<td>-0.37 ± 0.14, -0.05</td>
<td>-0.29 ± 0.15, -0.05</td>
</tr>
<tr>
<td>$\text{FC}_2$</td>
<td>0.55 ± 0.10, 0.29</td>
<td>0.34 ± 0.13, 0.08</td>
<td>0.94 ± 0.02, 0.73</td>
<td>-0.27 ± 0.13, -0.1</td>
<td>-0.22 ± 0.14, -0.11</td>
<td>-0.05 ± 0.15, -0.08</td>
<td>0.45 ± 0.21, 0.04</td>
<td>-0.14 ± 0.15, -0.06</td>
<td>-0.16 ± 0.15, -0.04</td>
</tr>
<tr>
<td>$% \text{Fat}_2$</td>
<td>-0.15 ± 0.15, 0.04</td>
<td>-0.54 ± 0.11, -0.33</td>
<td>-0.27 ± 0.13, -0.04</td>
<td>0.70 ± 0.08, 0.52</td>
<td>-0.42 ± 0.13, 0.16</td>
<td>-0.36 ± 0.13, -0.46</td>
<td>-0.53 ± 0.19, -0.02</td>
<td>0.15 ± 0.15, 0.05</td>
<td>0.23 ± 0.15, 0.14</td>
</tr>
<tr>
<td>$\text{FatCh}_{1-2}$</td>
<td>0.17 ± 0.18, 0.03</td>
<td>0.17 ± 0.18, 0.06</td>
<td>0.19 ± 0.17, 0.06</td>
<td>-0.50 ± 0.14, -0.11</td>
<td>-0.50 ± 0.14, -0.16</td>
<td>-0.26 ± 0.17, -0.17</td>
<td>0.32 ± 0.26, 0.02</td>
<td>-0.45 ± 0.16, -0.08</td>
<td>-0.38 ± 0.16, -0.08</td>
</tr>
<tr>
<td>$% \text{FatCh}_{1-2}$</td>
<td>0.24 ± 0.17, 0.04</td>
<td>0.05 ± 0.18, 0.01</td>
<td>0.18 ± 0.17, 0.06</td>
<td>-0.25 ± 0.17, 0.03</td>
<td>-0.34 ± 0.16, -0.12</td>
<td>-0.37 ± 0.16, -0.25</td>
<td>0.10 ± 0.27, 0.02</td>
<td>-0.38 ± 0.17, -0.08</td>
<td>-0.26 ± 0.18, -0.06</td>
</tr>
<tr>
<td>$\text{Surv}_{1-2}$</td>
<td>0.56 ± 0.31, -0.07</td>
<td>0.18 ± 0.30, -0.04</td>
<td>0.40 ± 0.27, 0.00</td>
<td>-0.18 ± 0.30, 0.08</td>
<td>-0.02 ± 0.30, -0.03</td>
<td>0.18 ± 0.33, -0.11</td>
<td>0.58 ± 0.35, 0.24</td>
<td>0.34 ± 0.30, 0.002</td>
<td>0.27 ± 0.30, 0.001</td>
</tr>
</tbody>
</table>
2. Production efficiency – main conclusions

• Selecting for lower decrease in weight ($SGR_{1-2}$) and muscle fat content ($FatCh_{1-2}$) during winter period may lead to better winter survival.

• Selecting for lower fat content ($\% Fat_1$ and $\% Fat_2$) may lead to better survival in both periods (winter and growing period) and higher growth rate during successive growing season.

• Muscle fat content is a trait likely playing important role in biological functions of common carp with changing its importance for fish performance according to external and internal factors.

• Selecting for higher values of condition factor (FC) could lead to better performance during winter and especially during growing season and at market size.
2. Production efficiency – main conclusions

- It seems that using of non-invasive measurements to predict carcass and fillet yield is feasible.
- When $s = 0.9$ we can expect about 1% of edible parts yield improvement.
- However, this would need deeper-logistic selective breeding program.
Implications

Prediction of results of selective breeding (selection coefficient „s“ = 0,9)

<table>
<thead>
<tr>
<th>Generation</th>
<th>Weight of fish at market size (g)</th>
<th>Headless carcass yield (%)</th>
<th>Duration of SB (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1500</td>
<td>55.0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1658</td>
<td>56.0</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1832</td>
<td>57.0</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>2024</td>
<td>58.0</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>2236</td>
<td>59.0</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>2471</td>
<td>60.0</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>2731</td>
<td>61.0</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>3017</td>
<td>62.0</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>3334</td>
<td>63.0</td>
<td>40</td>
</tr>
<tr>
<td>9</td>
<td>3684</td>
<td>64.0</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>4071</td>
<td>65.0</td>
<td>50</td>
</tr>
</tbody>
</table>
What do we need to start with the basic selective breeding program?

• A facility for artificial fish reproduction, short term storing the fish, manipulation with the fish and performance data recording
• Skilful staff
• Very well organized records about broodstock, fish spawnings, fish stockings, pond productions, fish feeding, fish performance etc.
• A suitable facility for occasional fish performance testing
• A place for basic population and improved broodstock maintenance
Is it really so simple?

• Much easier in more controlled conditions (e.g. trout and salmon rearing systems)
• The selective breeding in common carp would require changes in the rearing management (feeding strategy, oxygen level control, larvae production and distribution)

Taken from Hartman and Regenda (2014) according to Füllner et al. (2007)
Acknowledgement

- The work was supported mainly by EC through project FISHBOOST no. 613611
- The USB participants were supported also by MEYS, CR through projects CENAKVA (no. CZ.1.05/2.1.00/01.0024), CENAKVA II (no. LO1205 under the NPU I program), by GA USB (project no. 125/2016/Z) and by Czech NAAR (project no. QK1710310)

Thank you for your attention