Computational model of fish swimming through Mississippi River locks and dams demonstrates ways to stop carp

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1. How to protect Minnesota water/ecosystem?
2. Why Minnesota is safe?
3. How many fishes is sufficient for reproduction of Asian carp?

Locks and Dams system on the Mississippi River (1. How...?)

Graphic diagram of the 9-foot navigation channel “stairway of water” created by the Upper Mississippi River lock and dam system to maintain a depth of 9 feet for navigation.
Existing system of dam create fluid flow, which prevents the passage of weak fishes, but strong fishes are able to pass through the gate.
Changing of the gate operation increases velocity and provides blocking even strong 

Tainter gate in maximum raised position: this called gate out of water, and flow does not have any obstacles

For example, if the power of wind will significantly increase you hardly can go against the wind.
Map of dams in Minnesota, upper Mississippi River, (2. Why...?)
Percent of time Gates are out of water at Mississippi River.

Figure VI-2. Percent of time that gates are raised out of the water at Upper Mississippi River navigation dams (Source: COE Fish Passage Report’s Figure 6)
The Concept of Computational Fluid Dynamic + Agent-Based (CFD-AB) Model: universal and can be used for any L&D.

Why do we use computer model?

1. **Solid Model**
   Construction of L&D solid model (AUTO CAD)

2. **CFD Model.**
   Simulations of fluid flow through L&D (ANSYS-FLUENT: 3D, non-steady, turbulent fluid flow)

3. **Agent-Based Model.**
   Simulation of fish swimming through L&D
   Individual properties:
   - length;
   - preferable depth;
   - swimming performance.

4. **Gate Regulations.**
   Analyze results with recommendations of gate regulations to US ACE

Pathway Selection Rules

1. Fish assumed to only swim upstream (i.e. no backtracking).
2. Swim at distance maximizing speed (sustainable-burst modes).
3. Fish follows (searching algorithm) path causing the least fatigue.
4. Pathway finished when fish:
   A. Reach the upstream side of the dam
   B. Completely exhaust and get pushed back downstream
5. Repeat 1000 times.

Figure. Simulated pathway of a carp trying to pass through dam. Bars indicate the amount of fatigue each potential direction will cause. Fish assumed to follow lowest fatigue path.
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Step 3. Bighead and Silver Carp Swim Tests

Swim at distance maximizing speed (sustainable-burst modes)

3-5 m/s
At this situation (close to tainter gates) fish exhausted

Hoover, Zielinski and Sorensen
*J. Appl. Ichthyol.* 2017; 33: 54–62
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Step 3. Fish Passage Model – Move fish through flow field

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Fish passage through LD4

Current gate regulations

Problem=M2
Q= 40000.0 (cfs)
P1= 666.5
P2= 661.9
Fish passage through LD4

Modified gate regulations
Fish passage through LD4

Fish Passage Index for Silver Carp

Current gate regulations
Modified gate regulations

Gates out of water

% FPI

Q (K, cfs)

20 40 60 80 100
Conclusions

• Computational high fidelity CFD-AB Model to block invasive carp passing through lock and dams has been developed;
• Numerical simulations based on CFD-ABM show very promising results to block invasive carp;
• Minor modifications of Lock and Dam #5, #4 lead to block more than 50% of invasive carp trying to pass through the dam. *What is important - these modifications do not require additional expenditure.*
Acknowledgments
Thanks!