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Shad Upstream Migration: Fishway Design and Efficiency

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Shad Upstream Migration : Fishway Design and Efficiency

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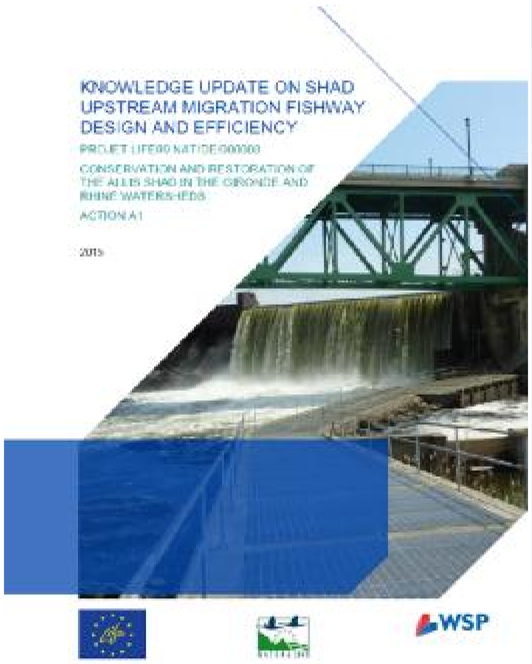
Contexte
Objectives

Cabot station fishway
Turners Falls - Connecticut

- In Europe, Allis shad (*Alosa alosa*) is in a vulnerable position throughout its distribution area.
- Upstream shad passage through obstacles is a very important issue for the management and restoration of the Allis shad populations in Europe.
- There is more significant information regarding the impact of dams on shad, its behaviour near obstacles and in fishways in North America than in Europe.
- It is generally accepted that the American shad *Alosa sapidissima* is a close relative of the European shad. Their behaviour and biological characteristics are similar.

Contexte Objectives

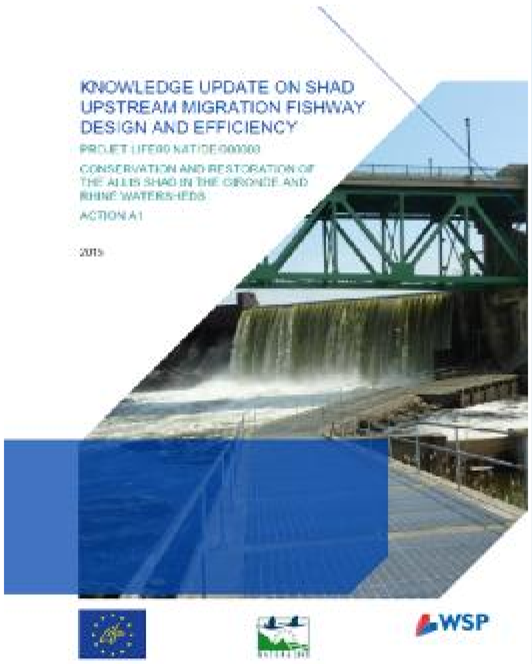


- As part of a LIFE+ European program, WSP worked with EDF and ONEMA to summarize the experience gained in France, Europe and the U.S. so as to update the design criteria currently used for the sizing of European shad fishways.

- The final report includes :
  - Ø Information on swimming abilities and migration patterns
  - Ø Fish count results and conclusions about periods, temperatures and flows during migration
  - Ø A sum-up of numerous monitoring studies in Europe and in the U.S. and conclusions about the main difficulties encountered by shad
  - Ø Recommendations to design fishways for shad

- The report is available on the European project website : http://lifealose2015.com/fr/life-alose/

What we did



- A large-scale literature review
- Sum-up and analysis of various data from:
  - Ø Fish count results
  - Ø Radio or Acoustic Telemetry
  - Ø Radio-Frequency Identification Technology (RFID)
- Sites visits on the U.S. (East Coast):
  - Ø Susquehanna River
  - Ø Connecticut River
  - Ø Merrimack River

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Swimming abilities and migration patterns

- Shad **cannot jump**
- Maximum velocities ranging from **3.5 to 5 m/s**
- Shad travel **in schools**
- Active upstream migration occurs **mainly during the day**
- Shad seem to be highly **sensitive to light variations**
- Shad swim in the water column, but **not directly under the surface**
- Shad seem to **seek out regular /laminar flow** and avoid heavy turbulence vortex areas and white water

Swimming abilities and migration patterns

- The shad exploratory behaviour downstream of the obstacles is less developed than the ones of other species such as salmon

- Most of the migration happens:

  - In May (mid-April to the end of June)

  - **Over a period of around 40 days**

  - In water temperatures between 13 to 21°C

Existing Fishways Efficiency

Definitions

- **Remote attraction** => the ability of fish to enter the area influenced by the flows from the fishway, near the entrance(s).

- **Close attraction** => the ability of fish within the fishway's area of influence to enter the fishway.

  Ø The **total attraction** of the fishway encompasses the remote and close attraction.

- **Passability** => the ability of fish to pass through the entire fishway after entering.

The ***overall efficiency*** of the fishway, resulting from these three elements.

Existing Fishways Efficiency

FINDING THE ENTRANCES AND ENTERING THE FISHWAYS

Turners Falls
Spillway fishway entrances

- The first difficulty for fish is to arrive near the fishway entrances:
  - **The remote attraction varies between 50 and 90%**.
- The second difficulty for fish is to enter the fishways. Having fish come close to the entrance is not enough. There is no site where all the fish that came near the fishway entrances actually entered them.
  - **The close attraction ranges from 31 to 81%.**
- Ultimately, **the overall attraction,** which encompasses the remote and close attractions, varies depending on the site, **from 15-20% to approximately 70%**. The **median is 53%**, independently of the development and the type of fishway.

Existing Fishways Efficiency

PROGRESSION INSIDE THE FISHWAYS

Modified Ice Harbor Fishway Spillway – Turners Falls

- Passage through the upstream migration fishways, **generally varies between 20 % and 80 %.**
- **For lifts, it is often greater than 50 %** and reaches a maximum of about 70%.
- For pool and weir fishways, it varies considerably depending on their type and characteristics. **Lower values are observed in Ice Harbor fishways**, originally designed for salmon. However, **more than 80% of fish overcome the vertical slot fishway** at Gate House (Connecticut River).

Existing Fishways Efficiency

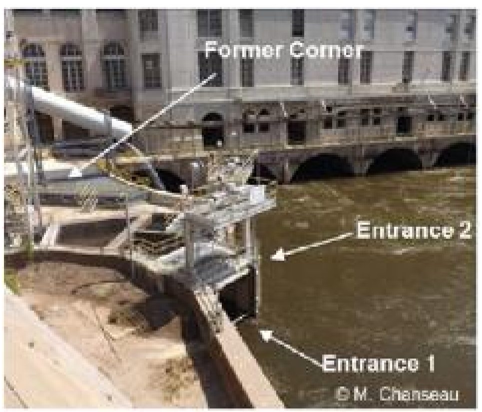
Conclusions

Modified Ice Harbor Fishway
Vernon – Connecticut

- An **overall efficiency of 75% is exceptional, 50% is excellent**, and 10-20% is unfortunately far too common *(Larinier, Travade).*
- A global efficiency lower or equal to 50% was observed in the vast majority of sites visited in the United States in 2015 (median: 26%; 1st quartile: 13%; 3rd quartile: 48%).
- Cumulated impacts caused by various structures constructed on a same migratory axis could rapidly become significant and make the management and restoration of populations difficult.
- However, it seems possible to further improve the efficiency of passage systems by being more ambitious when it comes to certain design criteria

Suggestions to design fishways for shad

Improve attraction



Fish lift entrances
Holtwood - Susquehanna

- Use significant flows corresponding to a minimum of **3% to 5% of the concurrent flow**.
- Ensure good attraction of entrances **up to flows of about twice the mean annual discharge** of watercourses.
- Promote **large sized entrances** : minimum width and depth should be of 2 m and 1.5 m respectively
- Maintain drops of 0.20 to 0.25 m at the entrance with streaming flows

  => **flows per entrance should be of 5 to 6 m^3/s**

  - For small rivers, dimensions should be reduced (1×0.7/0.8 m => flow of about 1.5 m^3/s)

Suggestions to design fishways for shad

IMPROVE ATTRACTION

East fish lift entrances Conowingo - Susquehanna

- Install **fishways in areas expected to be explored** by shad.
- **Multiply entrances** while making sure they are located in calm areas.
  - Should be studied when the obstacle is larger than 20 m
  - Necessary most of the time for obstacles larger than 100 m
- For hydroelectric stations, where possible, **implement rules of prioritization** with the aim of finding a compromise to attract fish near entrances without degrading their attractivity.

Suggestions to design fishways for shad

IMPROVE PASSABILITY


Cabot pools and weirs fishway - Connectivut River

- Selection of the type of fishway :
  - **Avoid baffle fishways** and Borland-type locks
  - Consider **lift when head drop exceeds 8-10 m**
- Passage areas must be free flowing (**avoid orifice**), located along the banks, and available on all the water column depth (**depth passage areas**).
- Maximum **drops of around 0.20 to 0.25 m**, streaming flows (**avoid plunging flows**).
- Energy in the pools must be **less than 150 W/cm**.
- Volume of pools : minimum of **10 to 15 L per shad**.

Suggestions to design fishways for shad

IMPROVE PASSABILITY

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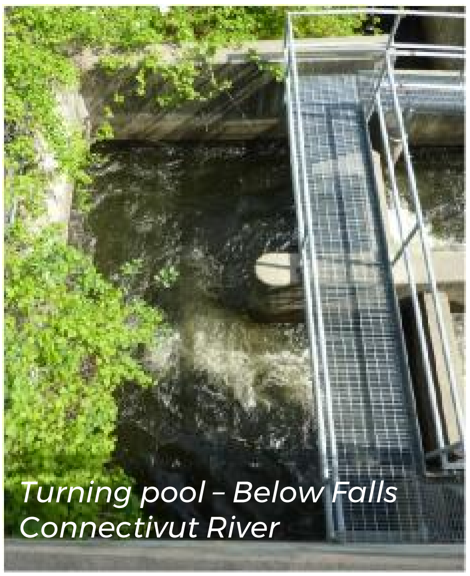
Ø **<u>For fish lifts</u>**:

- Water volumes in holding pool and lifting tank correspond to **at least 30 L and 10-15 L per fish**, respectively.
- The upstream migration **cycle must be short, about 15 min** during the main migration period, but less than 30 min at all times.
- Having **passage areas of 0.3 to 0.4 m wide** and establishing a very gradual narrowing of the funnel towards upstream.

Suggestions to design fishways for shad

IMPROVE PASSABILITY



Turning pool – Below Falls Connectivut River

For pool and weir fishways and lifts, special attention must be paid to:

Ø injection of attraction flow. It is recommended to **divide flows in several points** of the fishway to improve the attraction by upstream flow.

Ø **limit the number of entrances (3 to 4) connected to one gallery or one fishway**.

Ø make sure there is **no marked change in direction**. The installation of deflectors or guiding walls (which direct flows and guide fish) must be systematically assessed.

Merci ! – Thanks !

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Main Biological Characteristics of the European (*Alosa alosa*) and the American Shad (*Alosa sapidissima*), according to Beaudoin & *al.* (2014), Greene & *al.* (2009), Limburg & *al.* (2003), Baglinière & Elie (2000), MacKenzie & *al.* (1985).

Parameter	European Shad (*Alosa alosa*)	American Shad (*Alosa sapidissima*)
Average Length (cm)	45 - 70	35 - 55
Average Weight (kg)	1.5 - 3.5	1-3
Migration: Water Temperature (°C)	10 - 15	13-20
Migration Period	February - June	Period varies depending on temperature. Extends from November in Florida to June in Quebec
Spawning: Period	May - August	Period varies depending on temperature. Extends from January in Florida to July in Quebec
Multiple Spawners	Low (<2%)	Low in the South (0% in Florida) and increases towards the North (70% in New Brunswick, Canada) Can spawn up to 6 times during its lifetime

Main difficulties encountered by shad

FISH COUNTS DATA

Shad Transfer Rate between the Various Dams on the Susquehanna, Merrimack and Connecticut Rivers, U.S. East Coast.

RIVER	SECTION	DISTANCE BETWEEN DAMS (KM)	PERIOD	TRANSFER RATE (%)			
				AVERAGE	1ST QUARTILE	MEDIAN	3RD QUARTILE
Connecticut	Holyoke - Turners Falls (Cabot + Gate House or Spillway + Gate House)	59	1983 - 2015	4.7	1.4	3.3	7.2
	Turners Falls - Vernon	30	1983 - 2015	36.9	8.0	31.0	66.0
Merrimack	Lawrence - Lowell	22	1989 - 2015	14.7	9.5	11.6	18.0
Susquehanna	Conowingo - Holtwood	23	1997 - 2015	31.1	19.2	27.5	46.6
	Holtwood - Safe Harbor	11	1997 - 2015	69.1	66.4	72.3	74.0
	Safe Harbor – York Haven	38	2000 - 2015	9.2	2.4	7.3	11.2

Shad Transfer Rates between two dams of the Dordogne River, France.

RIVER	SECTION	DISTANCE BETWEEN THE STRUCTURES (KM)	PERIOD	TRANSFER RATE (%)			
				AVERAGE	1ER QUARTILE	MÉDIANE	3E QUARTILE
Dordogne	Tuilières – Mauzac	15	1992 - 2015	14.0	1.6	7.8	19.0

Main difficulties encountered by shad

TELEMETRY DATA

Summary of the Various Studies Carried out Using the Radio Telemetry in Order to Define the Behavior of Shad and the Impacts of Dams.

River	Site (Year)	Reference	Type of fishway	Remote Attraction	Close Attraction	"Total" Attraction	Overcoming the Fishway	Overall Efficiency
Susquehanna (USA)	Conowingo (2010)	Normandeau and Gomez and Sullivan, 2011	Lift	90% (n = 80)	81% (n = 65)	73%	62% (n = 40)	45%
Susquehanna (USA)	Conowingo (2012)	Normandeau and Gomez and Sullivan, 2012	Lift	64% (n = 42)	69% (n = 29)	44%	59% (n=17)	26%
Susquehanna (USA)	Holtwood (2008)	Normandeau and Gomez and Sullivan, 2011	Lift	--	--	75% (n = 96)	15% (n = 14)	11%
Susquehanna (USA)	Holtwood (2010)	Tryninewski & Hendricks, 2012	Lift	--	--	63% (n = 86)	53% (n = 46)	34%
Susquehanna (USA)	York Haven (2010) [1]	York Haven Power Company, LLC, 2011	Pool and weir (slots + serpentine)	82% (n = 28)	32% (n = 9)	26%	56% (n = 5)	15%
Connecticut (USA)	Holyoke (1980)	Barry & Kynard, 1982	Lift (plant)[2]	--	--	--	--	42% (n = 5)
Connecticut (USA)	Holyoke (1981)	Barry & Kynard, 1982	Lift	--	--	--	--	67% (n = 4)
Connecticut (USA)	Holyoke (2011)	Sprankle, 2012	Lift	--	--	--	--	65% (n = 35)
Connecticut (USA)	Turners Falls - Gate House (2008)	Castro Santos & Haro, 2014	Pool and weir (slots) with collecting gallery	--	--	51% (n = 19)	47% (n = 9)	24%
Connecticut (USA)	Turners Falls - Gate House (2009)	Castro Santos & Haro, 2014	Pool and weir (slots) with collecting gallery	--	--	14% (n = 6)	50% (n = 3)	7%
Connecticut (USA)	Turners Falls - Gate House (2009) [3]	Castro Santos & Haro, 2014	Pool and weir (slots) with collecting gallery	--	--	36% (n = 5)	60% (n = 3)	21%
Connecticut (USA)	Turners Falls - Gate House (2010)	Castro Santos & Haro, 2014	Pool and weir (slots) with collecting gallery	--	--	47% (n = 18)	50% (n = 9)	24%
Connecticut (USA)	Turners Falls - Gate House (2010) [3]	Castro Santos & Haro, 2014	Pool and weir (slots) with collecting gallery	--	--	98% (n = 45)	27% (n = 12)	26%
Connecticut (USA)	Vernon	Castro Santos, 2011	Pool and weir (Ice Harbor)	58% (n = 19)	42% (n = 8)	24%	0%	0%

Main difficulties encountered by shad

RFID
DATA

Summary of the Various Studies Carried out Using the RFID Technology in Order to Define the Behaviour of Shad near the Fishways.

River	Sites (Year)	Reference	Type of Fishway	Passability	Median Transit Time in the Fishway (h)	Median Time per Pool (min)
Connecticut (USA)	Turners Falls Cabot Plant (1999)	Haro & *al.*, 1999	Pool and weir (Ice Harbor)	18% (n = 19)	24.6	22.4
Connecticut (USA)	Turners Falls Cabot Plant (2000)	Haro & *al.*, 2001	Pool and weir (Ice Harbor)	17% (n = 26)	8.3	7.5
Connecticut (USA)	Turners Falls Cabot Plant (2001)	Sullivan & al., 2002	Pool and weir (Ice Harbor)	16% (n = 67)	5.6	5.1
Connecticut (USA)	Turners Falls Cabot Plant (2011)	Castro-Santos & Haro, 2014	Pool and weir (Ice Harbor)	34% (n =11), but 63% for multiple spawners	--	--
Connecticut (USA)	Turners Falls Cabot Plant (2012)	Castro-Santos & Haro, 2014	Pool and weir (Ice Harbor)	18.5% (n = 5)	--	--
Connecticut (USA)	Turners Falls Spillway (1999)	Haro & *al.*, 1999	Pool and weir (Ice Harbor)	14% (n = 7)	4.5	7.7
Connecticut (USA)	Turners Falls Spillway(2000)	Haro & *al.*, 2001	Pool and weir (Ice Harbor)	8% (n = 6)	6.4	11
Connecticut (USA)	Turners Falls Spillway(2001)	Sullivan & al., 2002	Pool and weir (slots)	32% (n = 24)	6.9	11.8
Connecticut (USA)	Turners Falls Spillway (2012)	Castro-Santos & Haro, 2014	Pool and weir (Ice Harbor)	8% (n =1)	--	
Connecticut (USA)	Turners Falls Gate House (1999)	Haro & *al.*, 1999	Pool and weir (slots)	88% (n = 80)	< 10 min.	Few dozen seconds (max.)
Connecticut (USA)	Turners Falls Gate House (2000)	Haro & *al.*, 2001	Pool and weir (slots)	81% (n = 59)	< 2 min	Few dozen seconds
Connecticut (USA)	Turners Fall Gate House (2001)	Sullivan & al., 2002	Pool and weir (Ice Harbor)	84% (n = 180)	< 2 min.	Few dozen seconds (max.)
Connecticut (USA)	Turners Falls Gate House (2012)	Castro-Santos & Haro, 2014	Pool and weir (Ice Harbor)	87% (n = 91)	< 2 min.	Few dozen seconds (max.)
Connecticut (USA)	Vernon (2011)	Castro-Santos, 2011	Pool and weir (Ice Harbor)	0% (n = 18)	--	--
Dordogne (France)	Mauzac (2005)	Chanseau & *al.*, 2006	Pool and weir (slots)	60% (n = 3)	--	Average of 11 s.

Main difficulties encountered by shad

FINDING THE ENTRANCES AND ENTERING THE FISHWAYS

Tuilière Dam an station Dordogne

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What can explain a poor attraction efficiency?

- Ø Insufficient number of fishways on a site (dam VS spillway)
- Ø Insufficient flows in fishways
- Ø Badly positioned or unattractive entrances
    - ü Location of entrances
    - ü Hydraulic conditions near the entrances
    - ü Dimensions of the entrances

Main difficulties encountered by shad

PROGRESSION INSIDE THE FISHWAYS

Cabot station fishway
Turners Falls - Connecticut

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What can explain this high variation in passability efficiency?

- Ø in the downstream sections of the fishways, problems in moving forward through the collector galleries and traveling through the injection zones of the attraction flows
- Ø further upstream, difficulties linked to internal hydraulic conditions and to the fishway length
- Ø at various levels of the fishways, problems related to the presence of steep turns
- Ø for lifts, problems linked to the entrance and staying long enough in the holding pool.

Main difficulties encountered by shad

AVAILABLE DATA USED TO ASSESS EFFICIENCY

To assess the fishway's efficiency at each of these 3 steps, we need monitoring

- **Fish counts :**
  - Ø cannot be used to determine the effectiveness of the fishway, nor the blocking time…
  - Ø But fish counts can allow a transfer rate calculation between two dams. This transfer rate corresponds to the *minimum* efficiency of the fishway
- ***Radio or Acoustic Telemetry:***
  - Ø helps for the precise study of fish behaviour around dams, near and in the fishways
  - Ø the biases related to the capture and marking of fish can be significant.
- ***Radio-Frequency Identification Technology (RFID):***
  - Ø cannot determine the behaviour of fish around dams
  - Ø provides information in addition to the telemetric data obtained at fishways : number/% of fish entering the fishways, duration of passage, …