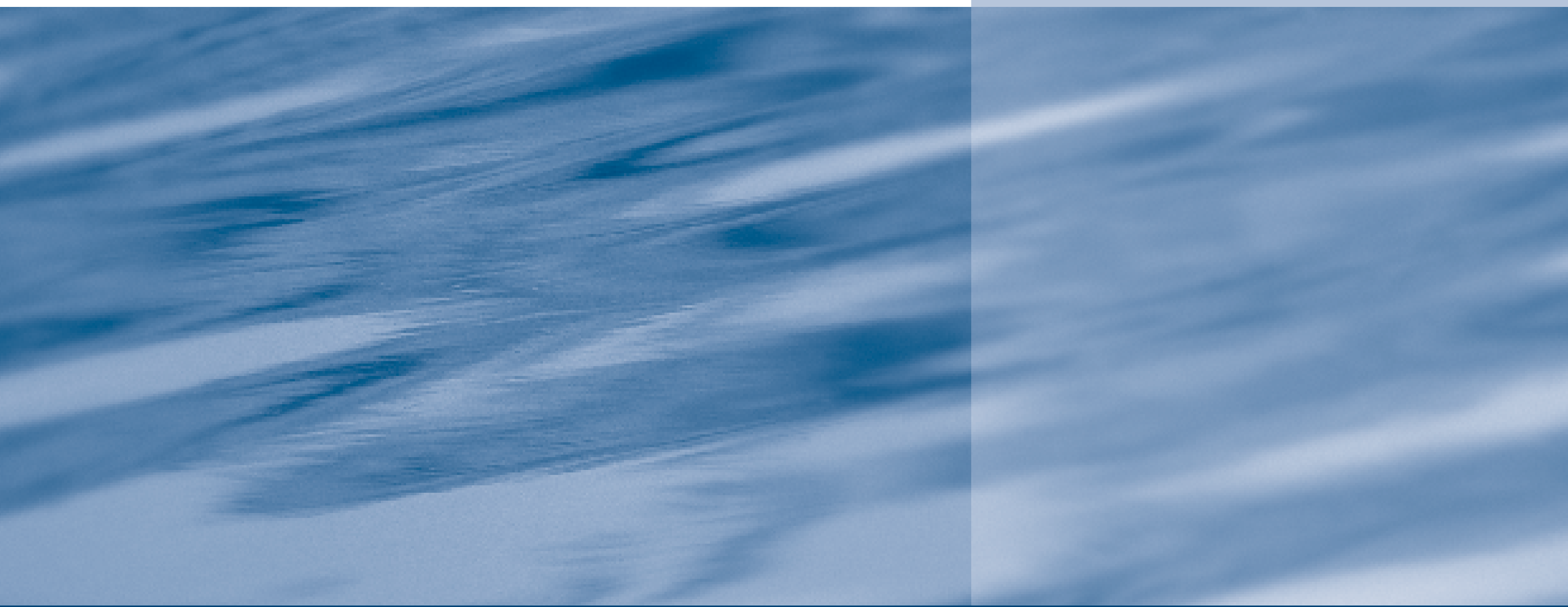

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The swimming speeds of twaite shad (Alosa fallax)

R&D Technical Report W2-049/TR3

Environment Agency

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Statement of Use:
This Technical Report describes a study to assess the swimming capability of twaite shad. This document is supported by a Literature Review and an updated Microsoft Excel spreadsheet (SWIMIT Version 2). These will principally be of interest to Fisheries staff and those involved with the design of in-river engineering works that may have an impact on shad populations, such as fish passes and water abstraction points.

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Professor Mike Depledge Head of Science

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Glossary

Burst swimming speed:

The highest swimming speed that can be maintained by a fish for ≥ 20 seconds.

Maximum swimming speed:

The theoretical maximum swimming speed that a fish is capable of achieving. Maximum speed can be determined through muscle twitch experiments.

Cruising swimming speed:

The cruising swimming speed test protocol differs from sustained swimming tests, as it estimates fish swimming ability in their stock pool, swimming with the flow.

Sustained swimming speed:

The maximum swimming speed which can be maintained for in excess of 200 minutes.

Critical burst swimming speed:

Is an approximation of the final velocity attained before exhaustion, in tests where the speed is increased by incremental amounts at fixed time intervals.

Exhaustion:

The point at which a fish in a swimming speed trial can no longer maintain its position against the flow and is subsequently carried downstream and caught against the screen. Exhaustion in this context therefore contains a behavioural component, and may not necessarily correspond to physiological exhaustion.

Notation

$bl\ s^{-1}$ = body lengths per second

EXECUTIVE SUMMARY

The twaite shad (*Alosa fallax*) is an anadromous clupeid fish whose swimming ability has been little studied. The aim of this study was to measure the maximum endurance and critical burst swimming speeds of twaite shad.

Shad were collected from the Rivers Severn & Teme during late May & early June 2003. Capture, handling, transportation and holding techniques were specifically selected to minimise scale loss and epithelial damage. A high-speed water tunnel and a low speed flume were used to test the burst and sustained swimming capacity respectively. In addition, the cruising speed of the fish in their stock tank was recorded.

Critical burst swimming speeds ranged from 1 to 2.5 m s^{-1}, with a mean of 1.73 m s^{-1}, while maximum sustainable swimming speed was estimated to be 0.5 m s^{-1}. Cruising speed, measured in the stock pool with rotational flow, ranged from 0.34 to 0.57 m s^{-1}.

A number of breakthroughs were achieved in fish collection, transport, handling, husbandry and feeding. These meant that the shad obtained this year were kept alive and in a healthy condition for several weeks, allowing robust data to be collected.

Conclusions & Recommendations

- Landing the fish directly into plastic bags, use of a large, circular, oxygenated transport tank with flow, and water at 15ppt salinity significantly reduced immediate post capture and in-transit mortalities compared with the previous study.
- Improved handling, husbandry and feeding methods resulted in a general improvement in the health of the shad stock, mainly due to the reduction in scale loss and epithelial damage. This allowed fish to recover after testing, and allowed each fish to be tested more than once.
- Despite the low numbers of fish captured, data sets for burst, sustained and cruising swimming speeds were collected. The maximum CBSS of shad was measured at 2.5 m s^{-1}. The maximum sustainable swimming speed (MSSS) was measured at around 0.5 m s^{-1}.
- The continuous circling behaviour of the shad whilst in the pool allowed downstream cruising speed to be measured. This gave a value of between 0.34 and 0.57 m s^{-1}, which was similar to the maximum sustainable swimming speed (MSSS).

KEY WORDS

Swimming, speed, fish passes, water intakes, weirs, twaite shad, *Alosa fallax*

1. INTRODUCTION

This report forms an addendum to the Swimming Speeds in Fish (Phase II) R&D Project, and investigates the swimming ability of twaite shad (*Alosa fallax*).

The twaite shad is an anadromous clupeid fish species. Their swimming ability has been little studied, and no controlled experiments have been carried out. Although a single study investigating prolonged swimming speeds[1] was carried out on twaite shad in 1929 (Magnan 1929, cited in Beamish, 1978), the majority of shad swimming experiments have been carried out with the closely related American shad (*Alosa sapidissima*).

The aim of this study was to measure the maximum endurance speed and critical burst swimming speed of twaite shad from individuals obtained from the Rivers Severn & Teme (a tributary of the Severn). An attempt to investigate the swimming speeds of shad was carried out in 2002, but was largely unsuccessful owing to high mortalities. Although only 15 fish were obtained this year (2003), improved transportation, handling and husbandry techniques kept initial mortalities low and allowed the fish to survive for several weeks, enabling testing to be carried out on relatively unstressed fish.

[1] 'Prolonged' swimming speed lies between 'burst' and 'sustained' swimming

2. METHODS

2.1 Fish Collection, Handling and Husbandry

In total, 15 shad were collected by rod and line from the River Severn at Tewkesbury and the River Teme at Powick on the 13/5, 19/5 29/5 & 4/6/2003 by Fawley Aquatic Research and Environment Agency staff. At this time they were believed to be about to spawn or to have recently spawned. Each hooked fish was landed directly into a polyethylene dustbin liner containing river water, and unhooked using forceps. This technique virtually eliminated scale loss and epithelial damage. The fish were transported back to the laboratory in a 1.2 m diameter cylindrical tank, with a strong flow provided by 4 submersible bilge pumps (Johnson L750–12V) housed within a Netlon mesh cage (Figure 2.1, Plate A1 - appendix). The tank held 420 litres of water and the salinity was adjusted to 15 ‰ using sea salt. Oxygen was injected via a micro-bubble diffuser. To assist the shad in maintaining their position in the flow, lines of black tape were fixed vertically on the tank walls, approximately 250 mm apart. A circular lid was constructed, which fitted flush inside the tank and rested on the water surface. This reduced turbulence and spillage whilst in transit. Fish condition and water quality were monitored regularly along the journey. Compared with experience in 2002, scale loss was much reduced by this method of transportation and only three mortalities occurred in transit. On arrival at Fawley, the fish were transferred to a 3.6 m diameter pool, approximately 1 m deep, supplied with a strong flow provided by submersible pumps, and aeration (Figure A.2 – appendix). The salinity in the pool was held at 15 ‰. The fish quickly adopted a distinct pattern of behaviour within the pool, swimming steadily, and quite rapidly, around the circumference of the pool *with* the flow. Prior to testing, fish were captured from the indoor pool by herding them over a large tarpaulin with several drainage holes placed on the bottom of the tank and gradually drawing them into a confined corner before coaxing them into a large plastic bag. This eliminated the need to either net or handle the fish and thus reduced scale loss and epithelial damage. Initial attempts to stimulate the fish to feed were unsuccessful. After several weeks in captivity, however, a breakthrough was made when the shad were offered and took freshly killed juvenile herring (*c.* 50 mm S.L.). After this initial feeding, the shad readily ate maggots, juvenile herring, sand smelt and mullet, and later diced herring. After around a month, some of the fish started to appear emaciated and eventually died. On dissection, their stomachs were found to contain large numbers of parasitic worms and their gills were infested with flukes. It is not known whether these levels of parasites were the cause of death, but as the fish were feeding well and appeared otherwise healthy, it seems likely.

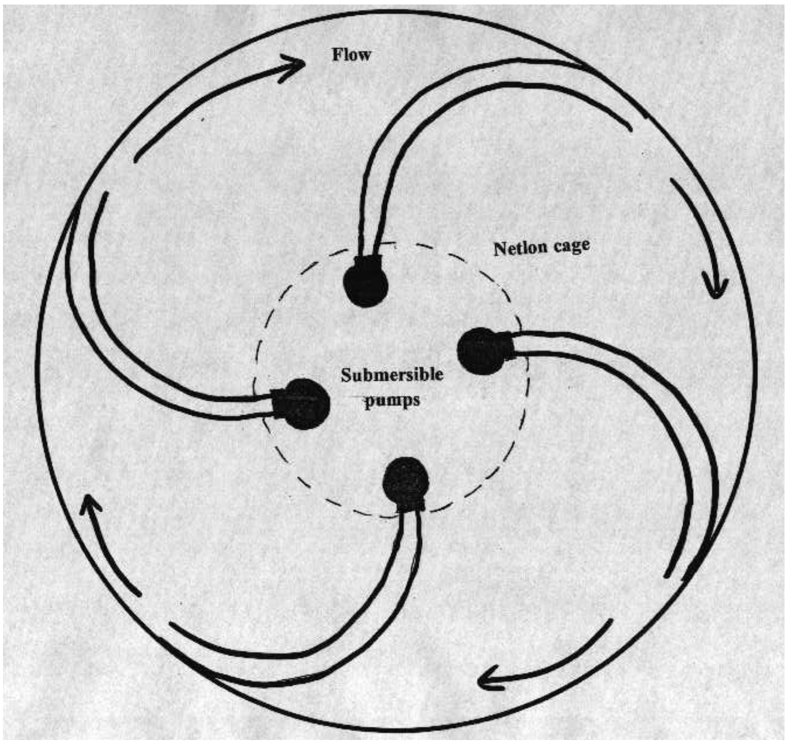

Figure 2.1 Plan view of the shad transport tank showing pumps and radiating circulation hoses.

2.2 Swimming Test Apparatus

A high-speed water tunnel was used to test the burst swimming capacity, and a low speed flume was used to test the sustained swimming capacity of the shad. Full details of the apparatus are given in Clough *et al* (2003).

2.3 Swimming Test Protocols

2.3.1 Burst swimming protocol

The burst experiments were carried out in the high-speed tunnel (Plate 1). Thirteen shad were tested. Prior to testing, the shad were placed in the transport tank, with both flow and aeration. The water supplying the tunnel was maintained at a salinity of 15 ‰ throughout. The tunnel was operated for at least five minutes prior to the test to ensure the water was fully aerated. Water temperature in the tunnel was recorded before and after the test. Water velocity through the test section was directly correlated to motor speed and was calibrated at a fixed point before testing. The smooth walls of the flume ensured that boundary layer effects were minimised.

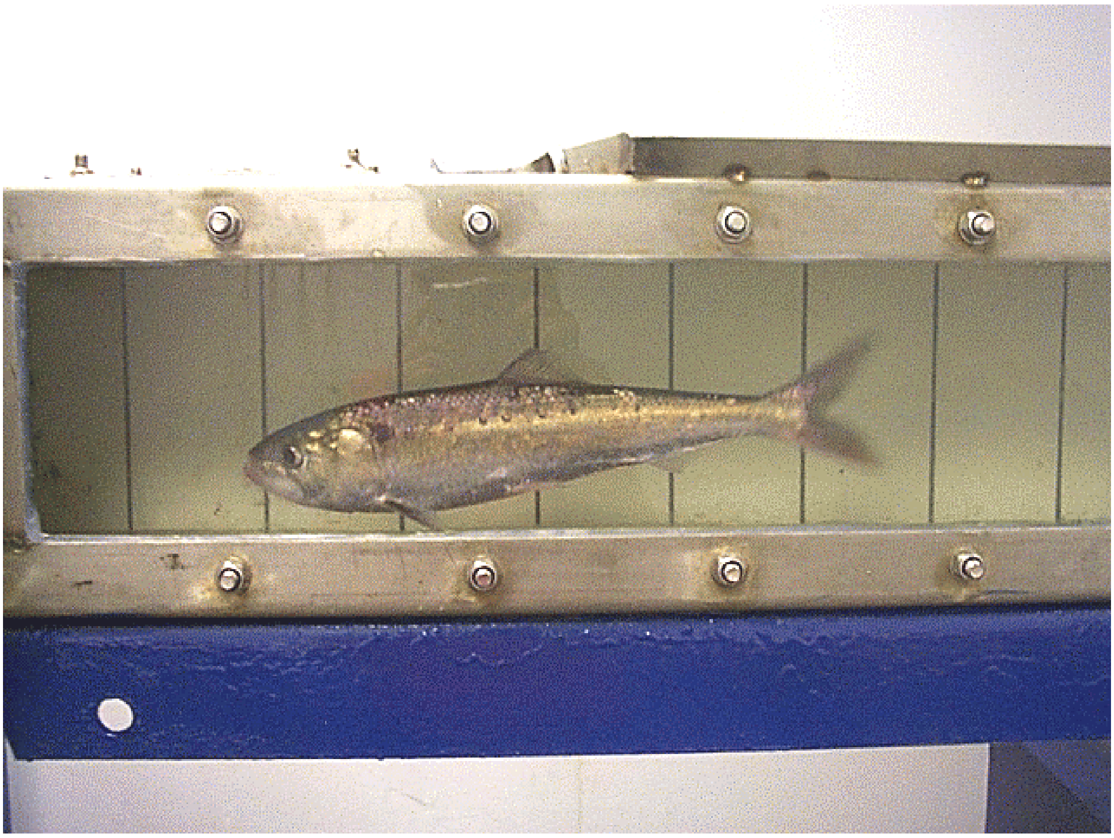

Figure 2.2 Shad in the burst flume during acclimation.

The shad were tested individually, and were carefully introduced to the tunnel to minimise handling stress. Each fish was allowed to acclimatise to the apparatus for 10 minutes. Water velocity during this period was approximately 1-1½ body lengths per second. After the acclimation period had elapsed water velocity was gradually increased to 0.8 m s^{-1}, and the stopwatch was started. After 20 seconds at 0.8 m s^{-1}, the speed was increased to 1.0 m s^{-1}. After a further 20 seconds, the speed was increased to 1.1 m s^{-1} and so on, with subsequent increases of 0.1 m s^{-1} occurring at 20-second intervals. The time at which the fish dropped back against the screen was recorded, and the water flow stopped. The fish was then removed from the tunnel, measured and returned to the pool. Critical Burst Swimming Speed (CBSS) was calculated assuming a gradual increase in speed i.e. a 0.5 cm s^{-1} increase with each second, in accordance with standard CBSS methodology (Brett, 1967). For example, if a fish achieved speeds of 0.8 m s^{-1}, 1.0 m s^{-1} and 1.2 m s^{-1} for 20 seconds but at 1.4 m s^{-1} it was able to swim for only for 11 seconds, CBSS is calculated as the speed at which the full 20 s was swum, plus 11/20^{ths} of the velocity increment (0.2 m s^{-1}), i.e.:

$$\text{CBSS} = 1.2 + (11/20 \times 0.2) = 1.31 \text{ m s}^{-1}$$

2.3.2 Endurance swimming protocol

An acclimation period of 2 hours was allowed before the start of the endurance-swimming tests. This allowed the fish to recover from any handling stress sustained during capture from the stock pool, and to acclimatise to their new surroundings. Water velocity during the settling period was set at approximately one body-length per second. After the settling period, the water velocity was increased gradually up to the test speed.

The start of the experiment was taken as the point at which the test speed was reached, and any fish unable to maintain their position prior to this were removed and recorded as "Time = 0". Water temperature was recorded at the beginning of the test. The endurance test lasted for 200 minutes. As each fish became unable to maintain its position it was removed from the flume, measured and the time recorded. Each fish was returned to the stock tank as soon as possible after being removed from the flume. When all fish had been removed, the water flow was slowed to a stop, and the water temperature recorded again.

2.3.3 Cruising swimming protocol

The normal behaviour for the shad when in captivity was to swim continually round the pool with the flow (i.e. downstream). In addition to the burst and endurance swimming tests, a cruising test was carried out to assess their ability when not under test conditions. This involved measuring the time taken for a group of shad to complete one lap of the circular pool. A tarpaulin covered the pool leaving a window. The time was noted when the first fish swam past this window, and this was repeated 30 times. The lap length and velocity of the water were taken into account when working out the shad's actual speed. Lap length was determined by measuring the radius of the circle in which they were swimming and working out the circumference using the formula $2\pi r$ (r = pool radius). The radius of the base of the pool was larger than the upper rim, therefore it was possible for shad to swim immediately under the rim of the pool. The water velocity in the pool was determined by measuring the time taken for a floating marker to travel 1 metre (10 readings were averaged). As the fish were swimming with the flow, the water velocity was subtracted from the final speed. This final cruising speed should be comparable to the speeds obtained in the endurance experiments, but is included in a separate section as the test protocol is different.

3. RESULTS

3.1 Critical Burst Swimming

The burst swimming tests were carried out at temperatures between 19.75 and 21.45 ^{o}C. The maximum CBSS achieved was 2.5 m s^{-1} (8.3 BL s^{-1}). The raw data can be found in Table A.3.

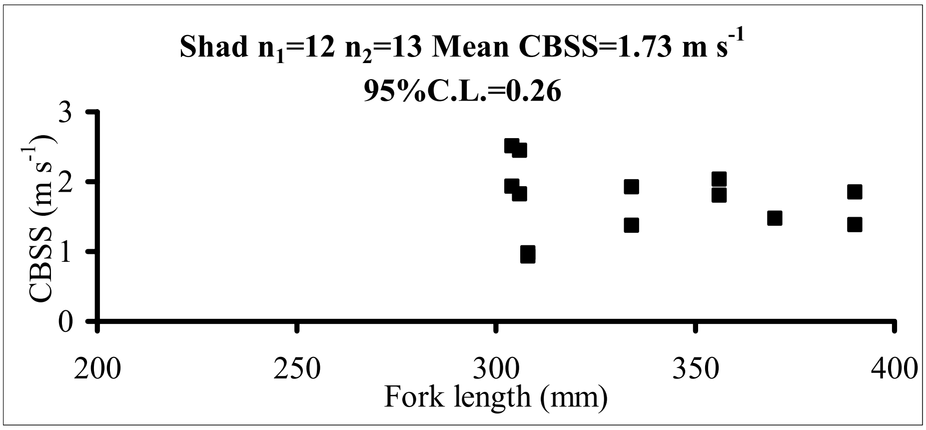

Figure 3.1. Critical burst swimming speed results for shad, n_1= number of fish used for tests, n_2 = number of fish tested.

3.2 Endurance Swimming

The fork lengths of the fish tested ranged from 300-390 mm. The test temperatures ranged from 12.8-17 ^{o}C. The maximum sustainable swimming speed (MSSS) was estimated to be around 0.5 m s^{-1}. The raw data can be found in Table A.4..

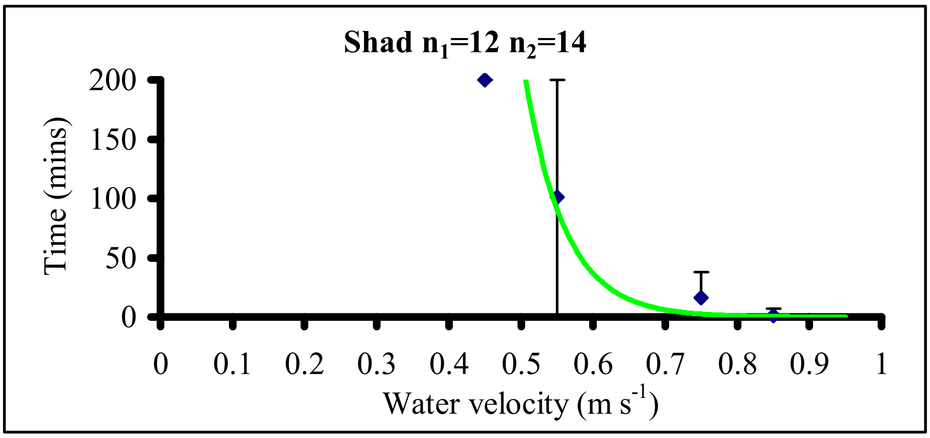

Figure 3.2. Endurance swimming speed results for shad, n_1= number of fish used for tests, n_2 = number of fish tested. Error bars represent upper and lower quartiles.

3.3 Cruise Swimming

The diameter of the pool was 3.6 m, therefore the lap distance was 11.3 m, and the water velocity in the pool was 0.15 m s^{-1}. Average lap time for 5 shad was 15.9 seconds, and the cruising speed was calculated to be 0.57 m s^{-1} for fish swimming at the edge and 0.34 m s^{-1} for fish swimming around 0.5 m from the edge. The speeds calculated for fish further towards the centre of the pool would be slightly underestimated, as the water velocities would be lower, and vice versa. The cruise speeds obtained seem to be comparable to the maximum sustainable swimming speeds obtained in the endurance tests. Individual lap times for the shad, and the surface marker times can be found in Tables A1 & A2, respectively.

4. DISCUSSION

A number of breakthroughs were achieved in fish collection, transport, handling, husbandry and feeding. These meant that the shad obtained this year were kept alive for longer periods and were in a considerably healthier condition. In addition, the shad recovered after being tested, allowing for repeat testing. The net result of these breakthroughs was that a significant quantity of swimming speed data was collected, despite the fact that only a few fish were caught.

Data for the American shad (*Alosa sapidissima*) show their burst speeds to be in excess of 3.5 m s^{-1} (Weaver 1965, cited in Beamish 1978). These data, however, were extrapolated by timing the fish over a known distance, and no indication of fish size or water temperature is given. The mean CBSS obtained by the twaite shad in our experiments was half that obtained by the American shad but the test conditions and sizes are properly documented in the present case. In addition, American shad tend to be considerably larger than *A. fallax*, and higher burst speeds are to be expected.

Data on prolonged swimming speed of twaite shad given by Magnan (1929, cited in Beamish, 1978) show the maximum prolonged swimming speed to be 0.75 m s^{-1} (2.5 BL s^{-1}). 30 fish were tested, with total lengths of 297 mm (*cf.* 300-390 mm fork length in this study). As information on the test protocol is unavailable, the results cannot be compared to this study. Prolonged speed, however, lies between burst and sustained speed, and probably involves the use of some white muscle. It would be expected therefore, that the prolonged speeds recorded by Magnan (1929) would lie somewhere between the sustained and burst speeds recorded in the present study.

Individuals of the larger *A. fallax rhodanensis* (a subspecies from southern France and Italy) have been found to be able to swim at speeds of up to 1.4 m s^{-1} for several hours. Their maximum burst swimming speeds were found to be between 2.4 and 3.1 m s^{-1} (Gendre 1997a). The sustained speeds of *A. fallax rhodanensis* are higher, but the burst speed range is comparable to the 2.5 m s^{-1} maximum speed obtained in this study.

At water velocities greater than 1.5 m s^{-1}, it has been found that individuals of *A. fallax rhodanensis* avoid entering a fish pass (Anon, 1975 and Larinier *et al*. 1978). That observation is supported in this study, where the maximum velocity tested was only 0.87 m s^{-1}, resulting in a median endurance time of just 1 minute.

Previous burst swimming data obtained on *A. alosa* show them capable of swimming at speeds of between 3.1 and 4.7 m s^{-1}, at 16-17 ^{o}C (Litaudon, 1985). This is higher than speeds observed in this study, but apart from being different species, differences in test protocols may mean that results are not fully comparable. In addition, adults of both *A. alosa* and *A. fallax rhodanensis* are larger than the species tested in our study

Observations of the shad whilst under test conditions show that they were easily stressed, and performance could easily be compromised. When fish showing signs of stress were relocated to their stock pool, their behaviour very quickly reverted to cruising around in a shoal. The behaviour observed in the shad pool suggested that the fish seemed keen to swim in a downstream direction. When speeds were measured, however, their performance was similar to the upstream endurance measurements. The cruising speed of a shad species was investigated by Larinier (1996) and found to be between 0.8 and 1.5 m s^{-1}. Those speeds were higher than found in this study, but again, different species and protocols mean that results are not fully comparable.

5. CONCLUSIONS / RECOMMENDATIONS

- Landing the fish directly into plastic bags, use of a large, circular, oxygenated transport tank with flow, and water at 15ppt salinity significantly reduced immediate post capture and in transit mortalities compared with the previous study.
- Improved handling, husbandry and feeding methods resulted in a general improvement in the health of the shad stock, mainly due to the reduction in scale loss and epithelial damage. This allowed fish to recover after testing, and allowed each fish to be tested more than once.
- Despite the low numbers of fish captured, data sets for burst, sustained and cruising swimming speeds were collected. The maximum CBSS of shad was measured at 2.5 m s^{-1}. The maximum sustainable swimming speed (MSSS) was measured at around 0.5 m s^{-1}.
- The continuous circling behaviour of the shad whilst in the pool allowed downstream cruising speed to be measured. This gave a value of between 0.34 and 0.57 m s^{-1}, which was similar to the maximum sustainable swimming speed (MSSS).

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APPENDIX

Table A.1 Lap times for 5 shad in pool (21^{o}C)

Test	Lap time (s)	m s^{-1}
1	15.41	0.9
2	14.80	1.0
3	15.00	1.0
4	14.80	1.0
5	15.20	1.0
6	16.37	0.9
7	14.89	1.0
8	15.83	0.9
9	14.74	1.0
10	17.20	0.8
11	15.17	1.0
12	15.90	0.9
13	16.91	0.9
14	18.18	0.8
15	14.74	1.0
16	16.63	0.9
17	17.10	0.8
18	16.87	0.9
19	17.25	0.8
20	14.47	1.0
21	15.64	0.9
22	17.72	0.8
23	16.97	0.9
24	14.27	1.0
25	14.84	1.0
26	14.33	1.0
27	16.13	0.9
28	18.74	0.8
29	16.61	0.9
30	13.94	1.0

Table A.2 Surface marker measurements, time taken to travel 1m.

Test	Time (s)	Velocity m s^{-1}
1	6.66	0.15
2	6.50	0.15
3	6.47	0.15
4	8.63	0.12
5	6.25	0.16
6	7.39	0.14
7	7.07	0.14
8	8.38	0.12
9	5.74	0.17
10	6.14	0.16

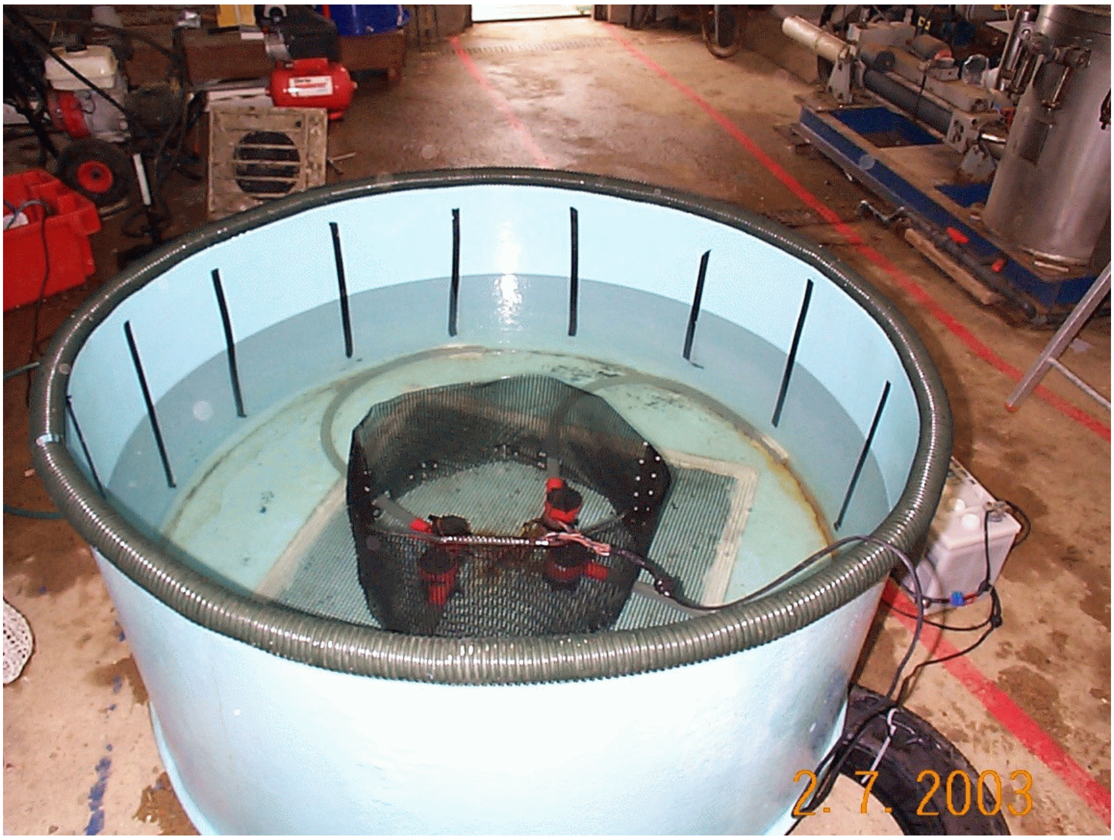

Figure A.1 Photograph of the tank used for shad transport, showing the 4 submersible bilge pumps used to circulate the water.

Figure A.2 Photograph of the shad pool showing the fish cruising with the flow.

Table A.3 Raw burst data

DATE	OPERATORS	ACCLIMATION	END	AV.Temp	FORK LEN(mm)	EXHAUSTION	TIME OF CHANGE	DIFF	MOT/SPEED END	WATER VEL m s^{-1}	CBSS m s^{-1}
07/03/2002	CH IL-E	13.3	13.35	17	293	156	140	16	18.75	1.5	1.58
17/6/2003	DD/ IL-E	14.06	14.11	19.75	308	28	20	8	13.9	0.9	0.94
17/6/2003	DD/ IL-E	14.15	14.25	19.95	356	202	200	2	21.25	1.8	1.81
17/6/2003	DD/ IL-E	14.35	14.45	20.3	334	116	100	16	17.2	1.3	1.38
17/6/2003	DD/ IL-E	15.26	16.36	20.45	390	210	200	10	21.25	1.8	1.85
17/6/2003	DD/ IL-E	15.53	16.03	20.65	304	323	320	3	27.2	2.5	2.515
17/6/2003	DD/ IL-E	13.32	16.42	20.9	306	309	300	9	26.3	2.4	2.445
26/6/03	SH IL-E	14	14.1	20.55	334	225	220	5	22.15	1.9	1.925
26/6/03	SH IL-E	14.2	14.3	20.7	308	36	20	16	13.9	0.9	0.98
26/6/03	SH IL-E	14.5	15.02	20.85	356	248	240	8	22.98	2	2.04
26/6/03	SH IL-E	15.3	15.47	20.95	304	227	220	7	22.15	1.9	1.935
26/6/03	SH IL-E	16	16.15	21	306	205	200	5	21.25	1.8	1.825
26/6/03	SH IL-E	16.3	16.45	21	390	117	100	17	17.2	1.3	1.385
22/7/03	DD/ IL-E	14.22	14.32	21.45	370	136	120	16	18.1	1.4	1.48

Table A.4 Raw endurance data

Date	Av. Temp °C	Section	Flo-probe	Velocity cm s^{-1}	Time (mins)	Length (mm)	BL s^{-1}
06/07/2002	15	1	135	77.4	2	370	2.1
06/07/2002	15	1	135	77.4	14	220	3.5
06/07/2002	15	1	135	77.4	16	350	2.2
06/07/2002	15	1	135	77.4	38	395	2.0
16/05/03	12.8	4	*	72.4	49	370	2.0
06/09/2003	16.2	3	22	46.3	200	300	1.5
06/09/2003	16.2	3	22	46.3	200	385	1.2
06/09/2003	16.2	3	22	46.3	200	355	1.3
06/09/2003	16.2	3	22	46.3	200	330	1.4
06/10/2003	16.7	3	28	57.8	0	300	1.9
06/10/2003	16.7	3	28	57.8	2	385	1.5
06/10/2003	16.7	3	28	57.8	200	355	1.6
06/10/2003	16.7	3	28	57.8	200	330	1.8
13/6/03	17	4	43	86.7	0	335	2.6
13/6/03	17	4	43	86.7	0	304	2.9
13/6/03	17	4	43	86.7	1	308	2.8