Fisheries Research 191 (2017) 36–40

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Short communication

Successful external acoustic tagging of twaite shad *Alosa fallax* (Lacépède 1803)

Jan Breine[a,*], Ine S. Pauwels[a], Pieterjan Verhelst[a,b,c], Lore Vandamme[a], Raf Baeyens[a], Jan Reubens[c], Johan Coeck[a]

[a] Research Institute for Nature and Forest (INBO), Dwersbos 28, B1630 Linkebeek, Belgium
[b] Research Group Marine Biology, Gent University, Krijgslaan 281, 9000 Gent, Belgium
[c] Flanders Marine Institute, Wandelaarkaai 7, 8400 Oostende, Belgium

ARTICLE INFO

Article history:
Received 1 December 2016
Received in revised form 24 February 2017
Accepted 1 March 2017
Handled by George A. Rose

Keywords:
Twaite shad
Acoustic telemetry
External tagging
Fish migration

ABSTRACT

Although twaite shad (*Alosa fallax* Lacépède 1803) declined substantially in many European rivers, its numbers increased since 2007 in the Belgian Zeeschelde. Since twaite shad is of conservation concern, further knowledge on its migration and reproductive behaviour is needed and acoustic telemetry would be a relevant tool to assess these behaviours. Shads are very sensitive fish showing adverse reactions to handling and anesthesia, specifically twaite shad. Therefore, this species is rather unsuitable for internal implantation of electronic tags, such as acoustic, radio and data storage tags. Preliminary tests are needed to assess the impact of external tagging on twaite shad survival. Here we describe a fish friendly attachment procedure to externally tag the fish. The procedure is quick and may limit additional drag force on swimming as the tags are firmly attached to the body by a rubber plate. This procedure was developed in Belgium in spring 2015 to tag eight shads in the Zeeschelde. Five of these shads showed a migration pattern that generally corresponded with spawning activities observed visually in the river.

1. Introduction

Twaite shad (*Alosa fallax* Lacépède 1803) is an iteroparous, anadromous clupeid occurring along the European coast from Morocco to the Baltic Sea, throughout the Mediterranean Sea and along the Northeastern Atlantic Coast (Aprahamian et al., 2003a; Maitland and Lyle, 2005). It is a marine pelagic fish species, but migrates during spring into the middle and upper reaches of the river to spawn (Maes et al., 2008).

Since the early nineties, a strong decline in twaite shad populations has been observed due to anthropogenic influence, such as water pollution, modification of river habitat and hydrology and overfishing (Assis, 1990; Bervoets et al., 1990; Doherty et al., 2004). Following its decline, the species is classified as vulnerable and listed under the International Union for the Conservation of Nature (IUCN) World Red Data Book (IUCN, 2015), included in Appendix III of the Bern Convention (CE, 1979) and Annexes II and V of the EC Habitats Directive (Aprahamian et al., 2003b, 2010; E.U., 1992). Despite a recent population increase in the Rivers Seine, Rhone, Ebro, Schelde, Elbe and Curonian Lagoon (Belliard et al., 2009; Lebel et al., 2001; López et al., 2007; Maes et al., 2008; Magath and Thiel, 2013; Stankus, 2009), the effect of the above described human impacts on twaite shad remains unsolved. Being an anadromous fish, the species is particularly vulnerable during the estuarine phase due to increased predation risk, diseases or the energetic cost of migrating and osmoregulatory abilities (Lochet et al., 2009). Hence, successful conservation and restoration of twaite shad populations requires insight into the effect of environmental conditions on spawning migration behaviour to aid successful reproduction.

Acoustic telemetry is a relative recent, but commonly applied technique to study fish behaviour (Hussey et al., 2015). Fish are provided with an acoustic transmitter, which emits a signal with a unique ID code that can be detected by an acoustic listening station (ALS). This technique not only reveals the migration routes, but may also provide knowledge on the variables that influence migration and potential migration barriers when detection data, biotic and abiotic data are linked (Verhelst et al., in press). Surgical implantation is often used in tagging studies requiring pre- and post-operative care, anesthetics and confinement (Bridger and Booth, 2003; Huisman et al., 2016; Jepsen et al., 2002; Pauwels et al.,

* Corresponding author.
E-mail addresses: jan.breine@inbo.be (J. Breine), ine.pauwels@inbo.be (I.S. Pauwels), pieterjan.verhelst@ugent.be (P. Verhelst), lore.vandamme@inbo.be (L. Vandamme), raf.baeyens@inbo.be (R. Baeyens), janr@vliz.be (J. Reubens), johan.coeck@inbo.be (J. Coeck).

http://dx.doi.org/10.1016/j.fishres.2017.03.003
0165-7836/

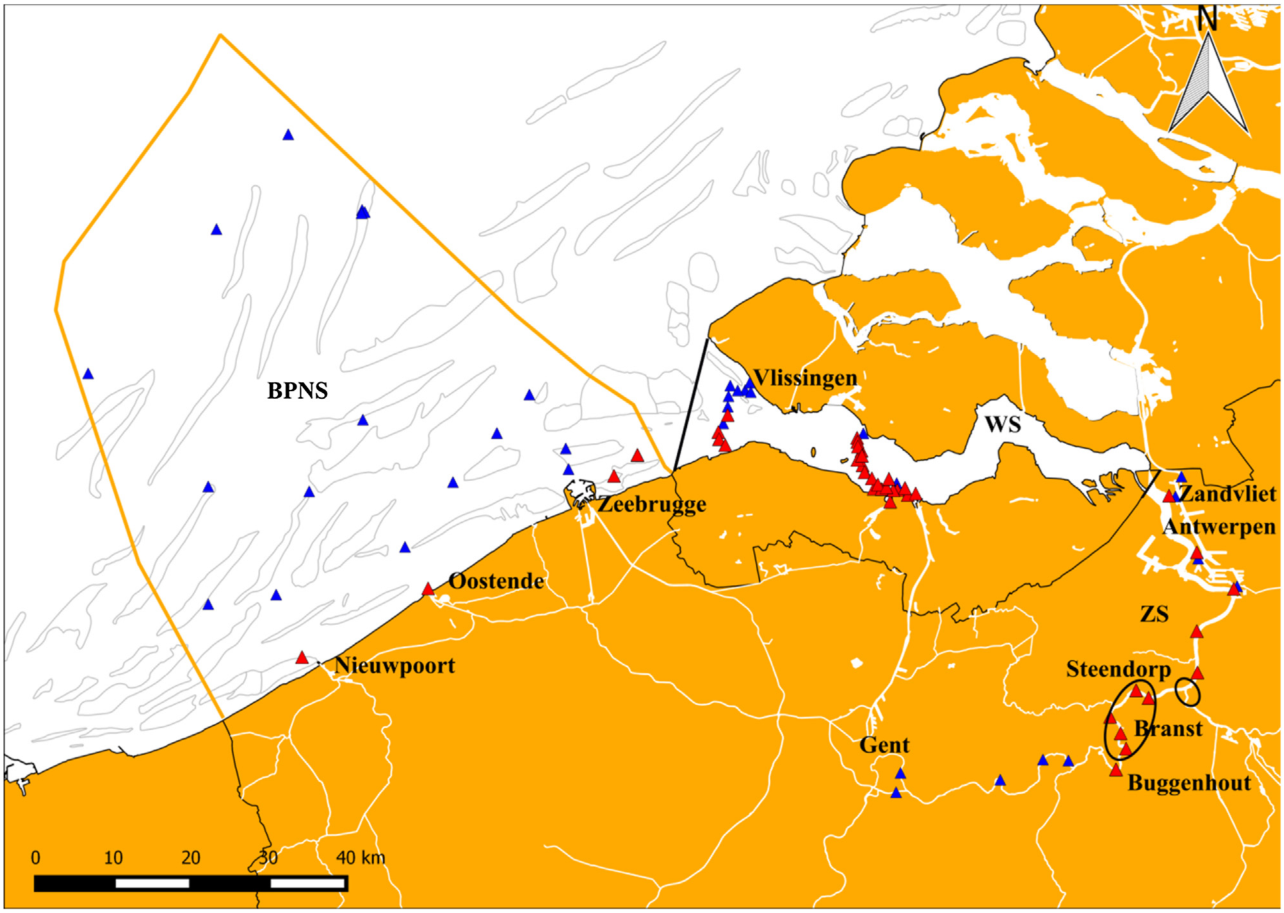

Fig. 1. The locations of the acoustic listening stations (red triangles where shad were detected and blue triangles where shad were not detected) in the Belgian part of the North Sea (BPNS), Westerschelde (WS) and Zeeschelde (ZS). The borders between each of the three systems are indicated by a solid line. Spawning activity visually observed by people within a voluntary network, are indicated by circles.

Table 1
Used tag types and properties.

Transmitter type	Number of shads tagged	length (mm)	diameter (mm)	weight in air (g)	weight in water (g)	battery life time (days)
V7	4	18	7	1,4	0,7	64
V9	4	24	9	3,6	2,2	132

2014). Implantation has the potential to have both lethal and sublethal impacts on fish if performed incorrectly (Jepsen et al., 2002; Thiem et al., 2011). Due to the high sensitivity of twaite shad to handling and stress, surgical implantation could result in a high mortality and is therefore inadvisable. Rooney and King (2014) for instance stated that twaite shad shows adverse reaction to handling and sedation and is therefore an unsuitable species for surgical implantation. Telemetry studies on allis (*A. alosa* Linnaeus 1758) and American (*A. sapidissima* Wilson 1811) shad have been conducted by means of gastric implantation of tags (Acolas et al., 2004; Dutterer et al., 2015; Frank et al., 2009; Olney et al., 2006; Tétard et al., 2016). Gastric implantation is a less invasive method than surgical implantation but it might result in regurgitation or mortality due to stomach rupture (Nielsen, 1992; Winter, 1996). However, since twaite shad is more sensitive than allis and American shad (Larinier et al., 2000), few telemetry studies have been conducted on twaite shad. Recently, Rooney et al. (2013) successfully applied external tagging on twaite shad in Ireland. Here, we present a protocol for external tagging of twaite shad, which is partly based on the method of Rooney and King (2014).

2. Material and methods

2.1. Study area

The River Schelde is 435 km long originating on the plateau of Saint-Quentin in France. The Schelde estuary is approximately 160 km long and discharges into the North Sea. The estuary has a complete salinity gradient from polyhaline to a tidal freshwater zone, including extensive freshwater, brackish and salt marshes to its ecosystem. It is a well-mixed estuary characterized by strong currents, high turbidity and a large tidal amplitude up to 6 m (Seys et al., 1999). It can be divided in two sections (downstream to upstream): the Westerschelde (WS) in the Netherlands from Vlissingen to Zandvliet and the Zeeschelde (ZS) in Belgium, from Zandvliet to Gent. Further upstream the river is obstructed by sluices and weirs, which reduces tidal action and saltwater intrusion. Historical observations on the spawning sites of twaite shad in the River Schelde indicate they are located downstream of the first weir in the freshwater tidal reach of the watershed (Vrielynck et al., 2003). Therefore in this study no physical migration barrier was encountered by the fish species.

2.2. ALS network

Within the framework of the LifeWatch observatory, a permanent acoustic network of 74 automatic listening stations (ALS) (VR2W, Vemco, Halifax, Canada) has been present since the spring of 2014 in the Zeeschelde (20 ALSs), Westerschelde (34 ALSs) and the Belgian part of the North Sea (20 ALSs) (http://www.lifewatch.be/en/fish-acoustic-receiver-network). They are moored at strategic locations to maximise the probability of detection. Hence, ALSs are deployed longitudinally in the Zeeschelde, in arrays in the Westerschelde and scattered in the BPNS (Fig. 1), thus covering around 180 km of river. The Belgian part of the North Sea stretches up to 81 km north and has a coastline of approximately 72 km long, covering a surface of 3454 km^2.

2.3. Tagging

Fish were caught in the Zeeschelde, near Antwerpen and Branst, with two mid-water beam trawls from an anchored boat in April 2015 (Breine et al., 2015). Each trawl consisted of a net fixed between two eight meter long steel beams. The lower beam was dropped to the bottom of the river while the upper beam was held at the surface. Both ends of the beams were attached to the anchor that keeps the boat at a fixed place. Two nets were submerged for one or two hours during flood and ebb-tide, respectively. Fish caught in the nets remain unharmed as flood tide prevents the nets to collapse. Landed shad were checked for external damage and the general condition (i.e. the capture effect). For each fish, total length (to the nearest mm) and weight (to the nearest gram) were measured, where after they were transferred to a 50 L oxygenated tank. Eight twaite shads were tagged with coded acoustic transmitters (V7 and V9, Vemco, Halifax, Canada), which emit signals at 69 kHz (Table 1). The tags had the capacity to emit signals for 2 (V7) and 4 (V9) months. The weight of the tags never exceeded 2% of the body mass of the captured shads (Jepsen et al., 2005).

To tag the captured fish, they were transferred to a surgery basin filled with sufficient aerated water to cover the head whilst exposing the dorsal surface. Fish were held partly under water with the head covered by a wet towel during the tagging procedure. Two to three scales were removed under the dorsal fin with a medical forceps to allow easy perforation of the two hollow needles (20G). A surgical thread (Ethilon) attached to the tag by a heat-shrinkable sleeve was passed through each needle so that they pass through the body of the fish while withdrawing the needles. A two mm thick rubber plate attached to the needles was then slid over the threads to reduce friction from the tag. Finally, the tag was drawn tightly against the dorsal fin and the plate was stabilized with two aluminium sleeves (Fig. 2). After tagging, the fish were placed back in the oxygenated tank for approximately 30 s until they started swimming. Then they were released into the Zeeschelde at their catch location. An overview of the tagging protocol is given in Table 2. Handling never took more than 90 s and could be reduced to this minimum by not anesthetizing the fish. The experiment was approved by the Ethical Committee of the Research Institute for Nature and Forest in Brussels (LA 1400559) and complies with the national legislation in Belgium transposing EU Directive 2010/63/EU (2010) on the protection of animals used for scientific purposes.

Table 2
Procedure external tagging of twaite shad.

Preparation	• Necessary material: ○ Tag ○ Surgical thread (Ethilon) ○ Two hollow needles (20G) ○ Heat-shrinkable sleeve and aluminium sleeves ○ Rubber plate (2 mm) ○ Aerated tanks for surgery and recovery ○ Medical forceps • Prepare the tags by attaching a 20 cm long Ethylon thread to the tag with the heat-shrinkable sleeve. Each thread-end should later be passed through one of the two hollow needles that perforate the shads' dorsal fin.
Transfer caught fish	• Place shad in aerated tank and check its condition. • Evaluate the tag/fish weight ratio. • Transfer the shad to the surgery basin.
Position caught fish	• Position the fish with the dorsal fin upwards and above the water. • Gently cover the head with a wet towel to reduce handling stress.
Performing the surgery	• Remove two to three scales below the dorsal fin with a medical forceps. • Perforate the rubber plate with the two hollow needles. • Perforate the shad with two hollow needles just below its dorsal fin where the scales were removed. • Pass the surgical Ethilon thread through the hollow needles (one thread per needle) and pull the tag against the shads' body. • Gently remove the hollow needles. The thread now perforates the shad below its dorsal fin, attaching the tag to the shads' body. • Slide the rubber plate over the thread to the shads' body. • Stabilize the rubber plate with two aluminium sleeves.
Transfer tagged fish	• Transfer the tagged shad back to the aerated tank to evaluate its welfare for approximately 30 s. • Release the tagged shad at the catch location.

3. Results and discussion

In this study, we present a method for external tagging of twaite shad, adapted from a protocol described by Rooney and King (2014). The difference with the method of Rooney and King (2014) was attachment of the tag to the body to reduce friction. In Rooney and King (2014), the tag could freely move, which might enhance the chance of irritation. However, our results were similar to Rooney and King (2014) and in both studies, no recapture of tagged individuals occurred to draw conclusions about potential skin irritation due to tagging. Nonetheless, based on the telemetry results twaite shads may not be strongly affected by the tags during the tracking period. In total, 22 adult twaite shads (mean total length 39.7 cm, range: 33.9–47.3 cm) were caught during upstream spawning migration in the Zeeschelde near Antwerpen and Branst (Fig. 1). Two of these shads were injured after landing. Probably they got wounded by debris carried by the currents into the nets. Eight of all caught twaite shads were acoustically tagged. One of these eight shads was never detected while two were detected at only one location for less than a day and 31 days respectively. A plausible explanation would be that the tag was detached or the fish died due to the tagging procedure. Predation by cormorants (*Phalacrocorax carbo*, Brisson, 1760) is neither ruled out. Five of the eight shads were detected at on average 21 ALSs (range 8–30 ALSs), and all together they were detected at 39 out of 74 ALSs between April 22th 2015 and June 28th 2015 (Table 3). The tracking period hereby varied per shad between 23 and 65 days. Specifically, the most

Fig. 2. Dorsal view of fixed tag under the dorsal fin.

Table 3
Number of tagged twaite shad with tag type, total length (cm), weight (g), catch location and date, first and last detection, tracked time (days), number of locations and different areas where the fish were detected. (Belgian part of the North Sea (BPNS), Westerschelde (WS) and Zeeschelde (ZS)).

Length (cm)	Weight (g)	Catch location (Fig. 1)	Catch date	First detection	Last detection	Tracked time (days)	Acoustic Listening Stations (ALSs)	Areas
35.2	378	Antwerpen	23/04/2015	24/04/2015	17/05/2015	23	8	ZS – WS
37	456	Antwerpen	23/04/2015	24/04/2015	28/06/2015	65	30	ZS – WS – BPNS
34.5	360	Branst	22/04/2015	22/04/2015	17/05/2015	25	21	ZS – WS
45.6	822.4	Branst	22/04/2015	22/04/2015	17/05/2015	25	22	ZS – WS
33.9	325	Branst	22/04/2015	22/04/2015	22/05/2015	30	26	ZS – WS – BPNS
35.3	365.6	Branst	22/04/2015	23/04/2015	23/04/2015	0	1	ZS
40.5	591.1	Branst	22/04/2015	NA	NA	0	0	NA
44	800	Branst	30/04/2015	30/04/2015	31/05/2015	31	1	ZS

upstream detection location was about 110 km upstream the estuary and, interestingly, the furthest detection location in the BPNS was near the coastline in Nieuwpoort about 135 km from the catch location of the shad detected there. Further, all five shad showed upstream and downstream movement behaviour. The extent of their movements was a ratio similar to the study of Rooney et al. (2013), who found six of eight shad providing extensive tracking data. In the Zeeschelde, in 2015, twaite shad spawned in the tidal freshwater part between Buggenhout and Steendorp (90 km upstream) (visual observations).

We chose not to use anesthesia to reduce handling time, as this might be a crucial aspect to improve twaite shad survival. Notably, the effectiveness of a certain dose of anesthesia can vary according to the water temperature (Jepsen et al., 2002). Although Hao et al. (2006) and Ross et al. (1993) indicated a positive effect of anesthesia on American shad (*A. sapidissima*), we hypothesize that the related recovery time of 6–7 min (Ross et al., 1993) prolongs the procedure too much, thus increasing the chance of death after release of the twaite shad (De Laak, 2009). The absence of anesthetics in the external tagging of Salmon (Thorstad et al., 2000) and the gastric implantation of tags in other shad species (e.g. Bailey et al. (2004) for American shad and Tétard et al. (2016) for Allis shad) might further support this. Nonetheless, the potential positive effect of anesthesia on twaite shad handling stress should be further investigated (Ross et al., 1993; Hao et al., 2006).

4. Conclusions

The new external tagging technique is promising as it did not prevent tagged shads from extensive up- and downstream migrations in the Schelde estuary and the BPNS for a period up to two months. Since tagged shads were not recaptured, it is unknown to what extent external tags affect the fish's physiology and how movement behaviour is affected. Therefore, further research can aid to understand the direct effects on the shads welfare, so that the method can be further improved and applied to other *Alosa* species as well. In this respect, further research on the effect and doses of anesthesia, of handling and tagging twaite shads is strongly encouraged. Tagging more individuals, accompanied by laboratory monitoring of tagged fish, could reveal information about movement behaviour, tag loss, lesions and infections. Telemetry studies on a larger number of twaite shad are important, because they can provide the essential information on the shads' spatio-temporal behaviour for the establishment of successful species management and conservation plans.

Acknowledgements

P. Verhelst holds a doctoral grant from the Flemish Agency of Innovation & Entrepreneurship (VLAIO). A. De Bruyn, L. Galle, E. Gelaude, I. Lambeens, N. De Maerteleire, Y. Maes, K. Robberechts, Y. Jacobs and S. Pieters assisted with the data collection. This work was supported by data and infrastructure provided by the INBO and VLIZ as part of the Flemish contribution of the LifeWatch ESFRI observatory. We would like to thank DAB VLOOT and Rijkswaterstaat for their cooperation and the permission to use their marine buoys. We would also like to thank the VLIZ (RV Simon Stevin and RHIB Zeekat) and the Royal Belgian Institute of Natural Sciences, Operational Direction Natural Environment (RHIB Tuimelaar) for the infrastructure provision to retrieve the data. We are grateful to the people from Zates (Koningsrek) who helped in detecting spawning activities. Finally, we thank S. Rooney (Inland Fisheries Ireland) for providing information on the tagging methodology used in Ireland.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2017.03.003.

References

Acolas, M.L., Bégout Anras, M.L., Véron, V., Jourdan, H., Sabatié, M.R., Baglinière, J.L., 2004. An assessment of the upstream migration and reproductive behaviour of allis shad (*Alosa alosa* L.) using acoustic tracking. Ices J. Mar. Sci. 61, 1291–1304.

Aprahamian, M.W., Aprahamian, C.D., Baglinière, J.-L., Sabatié, M.R., Alexandrino, P.J., 2003a. *Alosa alosa* and *Alosa fallax* Spp.: Literature Review and Bibliography. RandD Technical Report W1-014/TR. Environment Agency, Bristoll.

Aprahamian, M.W., Baglinière, J.L., Sabatié, M.R., Alexandrino, P., Thiel, R., Aprahamian, C.D., 2003b. Biology, status, and conservation of the anadromous Atlantic twaite shad *Alosa fallax fallax*. Am. Fish. Soc. Symp. 35, 103–124.

Aprahamian, M.W., Aprahamian, C.D., Knights, A.M., 2010. Climate change and the green energy paradox: the consequences for twaite shad *Alosa fallax* from the River Severn, U.K. J. Fish Biol. 77 (8), 1912–1930.

Assis, C.A., 1990. Threats to the survival of anadromous fishes in the River Tagus, Portugal. J. Fish Biol. 37(A, 225–226.

Bailey, M.M., Isely, J.J., Bridges Jr., W.C., 2004. Movement and population size of American shad near a low-head lock and dam. Trans. Am. Fish. Soc. 133, 300–308.

Belliard, J., Marchal, J., Ditche, J.M., Tales, E., Sabatié, R., Baglinière, J.L., 2009. Return of anadromous allis shad (*Alosa alosa* L.) in the River Seine, France : a sign of river recovery? River Res. Appl. 25, 788–794.

Bervoets, L., Coeck, J., Verheyen, R.F., 1990. The value of lowland rivers for the conservation of rare fish in Flanders. J. Fish Biol. 37(A, 223–224.

Breine, J., De Bruyn, A., Galle, L., Lambeens, I., Maes, Y., Pauwels, I., Van Thuyne, G., 2015. Monitoring van de visgemeenschap in het Zeeschelde-estuarium: ankerkuilcampagnes 2015. INBO.R, 59 (2015.11338975).

Bridger, C.J., Booth, R.K., 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Rev. Fish. Sci. 11 (1), 13–34.

CE, 1979. The Convention on the Conservation of European Wildlife and Natural Habitats. European Treaty Series 10. Strasbourg: Council of Europe. Available at http://conventions.coe.int/Treaty/en/Treaties/Word/104.doc (Accessed July 2010).

De Laak, G.A.J., 2009. Kennisdocument Fint Alosa fallax (Lacépède, 1803). Kennisdocument 26. Sportvisserij Nederland, Bilthoven, 46 pp.

Directive 2010/63/EU, 2010. Legislation on the protection of animals used for scientific purposes.

Doherty, D., O'Maoiléidigh, N., McCarthy, T.K., 2004. The biology, ecology and future conservation of twaite shad (*Alosa fallax* lacepede), allis shad (*Alosa alosa* L.) and killarney shad (*Alosa fallax* killarnensis tate regan) in Ireland. Biol. Environ.: Proc. R. Irish Acad. Threat. Irish Freshw. Fishes 104B (3), 93–102.

Dutterer, A.C., Pine III, W.E., Miller, S.J., Hyle, A.R., Allen, M.S., 2015. Spatial distribution and habitat use of spawning American shad in the St. Johns River, Florida River. Res. Appl., http://dx.doi.org/10.1002/rra.2990.

E.U., 1992. Council Directive92/43/EEC on the conservation of natural habitats and wild fauna and flora. Official Journal of the European Union L206, 1–66. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG.1992L0043:20070101:EN:PDF (Accessed July 2010).

Frank, H.J., Mather, M.E., Smith, J.M., Muth, R.M., Finn, J.T., McCormick, S.D., 2009. What is "fallback"?: metrics needed to assess telemetry tag effects on anadromous fish behavior. Hydrobiologia 635, 237–249.

Hao, D., Qiwei, W., Fang, G., Jianyi, L., Deguo, Y., Xihua, C., Yan, Z., 2006. Transport stress catabatic effect anesthetic benzocaine on American shad Alosa sapidissima. J. Fish. Sci. China 13 (5), 787–793.

Huisman, J., Verhelst, P., Deneudt, K., Goethals, P., Moens, T., Nagelkerke, L.A.J., Nolting, C., Reubens, J., Schollema, P.P., Winter, H.V., Mouton, A., 2016. Heading south or north: novel insights on European silver eel *Anguilla anguilla* migration in the North Sea. Mar. Ecol. Prog. Ser. 554, 257–262. Hussey, N.E., Kessel, S.T., Aarestrup, K., Cooke, S.J., Cowley, P.D., Fisk, A.T., Harcourt, R.G., Holland, K.N., Iverson, S.J., Kocik, J.F., Flemming, J.E.M., Whoriskey, F.G., 2015. Aquatic animal telemetry: a panoramic window into the underwater world. Science 348 (6240), http://dx.doi.org/10.1126/science.1255642.

IUCN, 2015. 2015 IUCN Red List of Threatened Species. Available at www.iucnredlist.org (Accessed July 2007).

Jepsen, N., Koed, A., Thorstad, E.B., Baras, E., 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483, 239–248.

Jepsen, N., Schreck, C., Clements, S., Thorstad, E.B., 2005. A brief discussion on the 2% tag/bodymass rule of thumb. In: Lembo, M.T., Marmulla, G. (Eds.), Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe. Ustica, Italy, 9–13 June 2003. Rome, FAO/COISPA. 2005, pp. 255–259.

López, M.A., Gázquez, N., Olmo-Vida, J.M., Aprahamian, M.W., Gisbert, E., 2007. The presence of anadromous twaite shad (*Alosa fallax*) in the Ebro River (western Mediterranean, Spain): an indicator of the population's recovery? J. Appl Ichthyol. 23, 163–166.

Larinier, M., Travade, F., Dartiguelongue, J., 2000. La conception des dispositifs de franchissement. In: Baglinière, J.L., Elie, P. (Eds.), Les aloses (*Alosa alosa* et *Alosa fallax* spp.): Ecobiologie et variabilité des populations. Inra-Cemagref, Paris, pp. 249–263.

Lebel, I., Menella, J.Y., Le Corre, M. 2001. Balance sheet of the migratory fish program actions for the twaite shad population (*Alosa fallax rhodanensis*) on the Rhone-Mediterranean-Corsica basin. B. Fr. Pêche Piscic. 362/363, 1077–1100.

Lochet, A., Boutry, S., Rochard, E., 2009. Estuarine phase during seaward migration for allis shad *Alosa alosa* and twaite shad *Alosa fallax* future spawners. Ecol. Freshw. Fish 18, 323–335.

Maes, J., Stevens, M., Breine, J., 2008. Poor water quality constrains the distribution and movements of twaite shad *Alosa fallax fallax* (Lacépède, 1803) in the watershed of river Scheldt. Hydrobiologia 602, 129–143.

Magath, V., Thiel, R., 2013. Stock recovery, spawning period and spawning area expansion of the twaite shad *Alosa fallax* in the Elbe estuary, southern North Sea. Endanger. Species Res. 20, 109–119.

Maitland, P.S., Lyle, A.A., 2005. Ecology of allis shad *Alosa alosa* and twaite shad *Alosa fallax* in the solway firth, scotland. Hydrobiologia 534, 205–221.

Nielsen, L.A., 1992. Methods of marking fish and shellfish. Am. Fish. Soc Special Publication 23, Bethesda, Maryland, USA, 208 pp.

Olney, J.E., Latour, R.J., Watkins, B.E., Clarke, D.G., 2006. Migratory behavior of american shad in the York river, Virginia, with implications for estimating in-river exploitation from tag recovery data. Trans. Am. Fish. Soc. 135, 889–896.

Pauwels, I., Goethals, P., Coeck, J., Mouton, A., 2014. Movement patterns of adult pike (*Esox lucius* L.) in a Belgian lowland river. Ecol. Freshw. Fish 23, 373–382.

Rooney, S., King, J., 2014. Presentation: Use of acoustic telemetry to monitor behaviour during the upriver spawning migration of a diadromous fish, the twaite shad (Alosa fallax). IMF Tagging and Telemetry Workshop Leeds England, 22–23 July 2014.

Rooney, S.M., O'Gorman, N.M., King, J.J., 2013. National Programme: Habitats Directive and Red Data Book Species Executive Report 2012. Inland Fisheries Ireland, Swords Business Campus, Swords, Co, Dublin, Ireland56.

Ross, R.M., Backman, T.W.H., Bennett, R.M., 1993. Evaluation of the anesthetic Metomidate for the handling and transport of juvenile American shad. Progress. Fish Cult. 55, 236–243.

Seys, J., Vincx, M., Meire, P., 1999. Spatial distribution of oligochaetes (Clitellata) in the tidal freshwater and brackish parts of the Schelde estuary (Belgium). Hydrobiologia 406, 119–132.

Stankus, S., 2009. Spawning migration and population condition of twaite shad (*Alosa fallax*, Lacépède 1803) in Lithuania. Environ. Res. Eng. Manage. 4 (50), 20–29.

Tétard, S., Feunteun, E., Bultel, E., Gadais, R., Bégout, M.-L., Trancart, T., Lasne, E., 2016. Poor oxic conditions in a large estuary reduce connectivity from marine to freshwater habitats of a diadromous fish. Estuar. Coast. Shelf Sci. 169, 216–226.

Thiem, J.D., Taylor, M.K., McConnachie, S.H., Binder, T.R., Cooke, S.J., 2011. Trends in the reporting of tagging procedures for fish telemetry studies that have used surgical implantation of transmitters: a call for more complete reporting. Rev. Fish. Biol. Fish. 21, 117–126.

Thorstad, E.B., Okland, F., Finstad, A.G., 2000. Effect of telemetry transmitters on swimming performance of adult Atlantic salmon. J. Fish Biol. 57 (2), 531–535.

Verhelst, P., Reubens, J., Pauwels, I., Buysse, D., Aelterman, B., Van Hoey, S., Goethals, P., Moens, T., Coeck, J., Mouton, A., in press. Movement behaviour of large female yellow European eel (Anguilla anguilla L.) in a freshwater polder area. Ecol. Freshw. Fish.

Vrielynck, S., Belpaire, C., Stabel, A., Breine, J., Quataert, P. 2003. De visbestanden in Vlaanderen anno 1840–1950. Een historische schets van de referentietoestand van onze waterlopen aan de hand van de visstand, ingevoerd in een databank en vergeleken met de actuele toestand. Instituut voor Bosbouw en Wildbeheer en Afdeling Water (AMINAL), Groenendaal, 271 pp.

Winter, J.D. 1996. Advances in underwater biotelemetry, In: Murphy, B.R., Willis, D.W. (Eds.), Fisheries Techniques, second edition. Techniques. Am. Fish. Soc. Bethesda, Maryland, USA, pp. 555–590.