1. Introduction

The Danube River is a European river that begins in Germany and flows southeast for 2850 km, flowing through 10 countries before draining into the Black Sea. The Danube River is the second largest river in Europe after the Volga River; it has an annual median discharge of 6473 m$^3$/s, a maximum discharge of 15,500 m$^3$/s, and a minimum discharge of 1350 m$^3$/s at the point before the river splits into 3 major branches to create the Danube Delta (Diaconu, 1963). The Lower Danube River stretches from the Black Sea to Baziaș at river kilometer (rkm) 1075 and includes the first dam (Iron Gate II dam, which was completed in 1984) located at rkm 864 on the border between Romania and Serbia (Gâştescu, 1990). The Lower Danube River, a complex system of beaches and islands, where a significant number of fish species live, is where wild sturgeon still migrate upstream to spawn. There are 3 anadromous long-distance migratory sturgeon species in the Danube River, the beluga sturgeon (*Huso huso*), stellate sturgeon (*Acipenser stellatus*), and Russian sturgeon (*Acipenser gueldenstaedtii*), and one freshwater species, the sterlet (*Acipenser ruthenus*). The Danube River, along with the Volga River, is at present one of the last remaining European rivers with a wild sturgeon population (Billard and Lecointre, 2000). In the past, the Danube sturgeon migrated over long distances to spawning sites located in the Middle Danube River (rkm 1866–1766) between Slovakia and Hungary (Hensel and Holcik, 1997); however, nowadays all Danube sturgeon species are highly threatened. At the beginning of the 20th century, Grigore Antipa, a Romanian biologist, described 6 sturgeon species living in the Danube River (Antipa, 1909); today, only 4 types are still found there (beluga sturgeon, stellate sturgeon, Russian sturgeon, and the sterlet). Stellate sturgeon reach sexual maturity between the ages of 5 and 7 years, but the beluga sturgeon reaches sexual maturity between the ages of 12 and 18 years and therefore requires a longer period of time for recovery (Otel, 2007).
areas between rkm 100 and rkm 860 (downstream of the Iron Gate II dam) (Oțel, 2007; Suciu et al., 2013). In the Danube River, there are limited data regarding sturgeon habitats that were identified and studied (Vassilev, 2003; Onără et al., 2011; Suciu et al., 2013). The stellate sturgeon’s spawning migration is also divided into two periods. The first one begins during the spring, from March to April (Oțel, 2007), with spawning occurring during the same year. The second migration begins in August and has a maximum intensity in September and October (Bănărescu, 1964). The stellate sturgeon also overwinters in the Danube River and spawns the next year. Although adult beluga and stellate sturgeon are not able to migrate further upstream of the Iron Gate II dam (rkm 864), they are still present downstream of the dam. There are limited data available concerning sturgeon migration behavior in the Danube River that could be used to find viable solutions for improving the living conditions of these fish species and stop the decline of their population. This study aims to report, for the first time, details concerning beluga sturgeon and stellate sturgeon swimming depth behavior during their migration in the Danube River sector with a length of 793 km (between rkm 71 and rkm 864). Due to the lack of scientific data on long-distance migration in the Danube River, telemetry equipment was used, which greatly facilitated the collection of data on sturgeon migration between the Black Sea and the Iron Gate II dam (Nelson et al., 2010; Crossman et al., 2013). Using acoustic telemetry, new data were collected that aided identification of sections of the Danube River used by sturgeon during their spawning migration. Before the data regarding the swimming depth of the sturgeons in the Danube River were collected, fishermen knew the location where the sturgeon could be captured in the Danube (Antipa, 1909; Kynard, 2002). It was generally known that the sturgeon were swimming upstream close to the bottom of the river because they were usually captured in deep water. It was also known that after sturgeon spawned, they swam downstream to the Black Sea close to the surface where the water speed is faster. However, all of these data consisted of estimations based on the information provided by fishermen; it was never exactly known how deep the water was the sturgeon were using when migrating upstream and downstream. For this reason, this article attempts to identify the most preferred depths used by stellate and beluga sturgeon during their upstream and downstream migration in the Danube River.

2. Materials and methods

2.1. Study site
In the Lower Danube River spawning area (rkm 0 Sulina–rkm 1075 Baziaș), only 864 km are available for fish migration due to the Iron Gate II dam that was built at rkm 864 and put into operation in 1984. In 2011, Vemco VR2W acoustic receivers were installed at rkm 71, 100, 178, 253, and 300. Five more receivers were installed in 2013 downstream of the Iron Gate II dam to record sturgeon behavior close to the dam (located close to Romanian Turbine No. 1, Gogosu Branch Spillway, Gogosu br. Turbine, Gogosu br. Navigable Ship Lock, at the mouth of Gogosu br. Pristol village at rkm 847). One more Vemco VR2W acoustic receiver was installed in 2015 at rkm 500 (Figure 1).

2.2. Detection range
Range test results at rkm 300 revealed that V16TP tags were detected from a distance of 300–400 m, and this

Figure 1. Locations with installed VR2W acoustic receivers 2011–2015.
range increased up to 1200 m at rkm 860 where the water is less turbid.

The sturgeon were captured by fishermen using special trammel nets with a mesh size of 140–170 mm. The fishermen were subcontracted by the project with a special fishing permit issued by the National Agency for Fishing and Aquaculture in Bucharest to capture sturgeon on the Borcea branch at km 30–57 and in the Danube River at km 800–864. The adult beluga sturgeon’s average length was 184–245 cm (Table 1), and the stellate sturgeon’s average length was 92–135 cm (Table 2). The captured sturgeon were tagged using Vemco V16TP acoustic tags with temperature and pressure sensors, with an estimated battery life of 7 years. The Vemco V16TP acoustic tags have good signal propagation in deep and turbid water, and these are the conditions in the Danube River (Thorstad et al., 2013). The signal power and interval between signals (delay) were programmed by the manufacturer according to project-specific needs and according to the fish species’ migration calendar (the first 300 days at high power with a maximum delay of 45 s and afterwards at low power with a maximum delay of 90 s). The Vemco V16TP acoustic tags were surgically implanted into the abdominal cavity of captured sturgeon (Taylor et al., 2017) on the Danube riverbank using an electronarcosis method to immobilize adult sturgeon during surgical tagging (Iani et al., 2017). A special electronarcosis tube was manufactured for tagging in order to reduce fish handling stress. The tube was placed in the river, attached to a boat, and a captured sturgeon was inserted directly from the river into the tube where it was then tagged. Before starting the tagging, the fish were locally anesthetized to reduce the stress caused by implanting the acoustic tag.

To identify the preferred swimming depths of tagged sturgeon during their spawning migration, a large number of depth detections recorded by the Vemco receivers were analyzed. Sturgeon ground speed was estimated by calculating the time needed for the tagged sturgeon to travel upstream or downstream between two installed receivers in the river. Separate ground speed calculations

| No. | Tagging date | Total length [cm] | Sex  | Date of exit | Date of return |
|-----|--------------|------------------|------|--------------|----------------|
| 1   | Nov 2, 2011  | 210              | Male | May 1, 2012  |                |
| 2   | Nov 9, 2011  | 203              | Male | May 31, 2012 |                |
| 3   | Nov 9, 2011  | 205              | Male | Nov 17, 2011 | Apr 4, 2016    |
| 4   | Nov 9, 2011  | 205              | Male | Dec 3, 2011  |                |
| 5   | Nov 14, 2011 | 196              | Male | Nov 24, 2011 |                |
| 6   | Nov 14, 2011 | 211              | Male | Mar 19, 2012 |                |
| 7   | Nov 14, 2011 | 210              | Unknown | Nov 21, 2011 |                |
| 8   | Nov 23, 2011 | 221              | Unknown | May 12, 2012 |                |
| 9   | Nov 25, 2011 | 225              | Female | Nov 29, 2011 |                |
| 10  | Nov 25, 2011 | 196              | Male | Dec 2, 2011  |                |
| 11  | Nov 26, 2011 | 186              | Male | Mar 18, 2012 |                |
| 12  | Nov 29, 2011 | 212              | Female | May 23, 2012 |                |
| 13  | Dec 6, 2011  | 184              | Unknown | Apr 3, 2012  |                |
| 14  | Dec 6 2011   | 198              | Unknown | May 15, 2012 |                |
| 15  | Dec 7 2011   | 213              | Unknown | May 17, 2012 |                |
| 16  | Dec 29, 2011 | 220              | Unknown | May 2, 2012  |                |
| 17  | Mar 27, 2012 | 245              | Male | Jun 2, 2012  |                |
| 18  | Mar 28, 2012 | 207              | Male | Apr 7, 2012  |                |
| 19  | Mar 31, 2012 | 200              | Unknown | Apr 8, 2012  |                |
| 20  | May 24, 2012 | 210              | Unknown | May 29, 2012 | Nov 1, 2014    |
| 21  | May 27, 2012 | 220              | Unknown | May 30, 2012 |                |
| 22  | Nov 10, 2012 | 230              | Male | Nov 15, 2012 | Nov 6, 2017    |
| 23  | Nov 17, 2013 | 200              | Male | Apr 26, 2014 |                |
were made for upstream versus downstream migration for the first 30 days after being released into the river and 90 days after the sturgeon were released into the river (Table 3). Beluga and stellate sturgeon, like other fish species, do not swim in a straight line (Guy, 2007), so this analysis is just an estimation of sturgeon movement over short or long distances. Determination of the months when beluga and stellate sturgeon were recorded swimming upstream or downstream was done by analyzing detections downloaded from a VR2W receiver installed at rkm 100. This receiver was installed upstream of the bifurcation of the Danube River branches that form the delta to record sturgeon entering or exiting the study area.

3. Results
A total of 8111 detections were used for analyzing beluga sturgeon swimming depth movement, which were collected from 23 tagged fish and recorded between November 2011 and April 2015 (Table 1).

For stellate sturgeon, 472 detections were collected for analysis from 21 tagged fish between May 2012 and April 2014. Data recorded by the receiver installed at rkm 100 over a period of 3 years (2012–2014) were used for determining the months in which stellate and beluga sturgeon detections occurred. During these years, 2727 temperature and depth detections were recorded from 44 sturgeon specimens; 2279 detections were from beluga sturgeon and 448 records were from stellate sturgeon.

3.1. Beluga sturgeon swimming depths
The swimming depth data from beluga sturgeon, recorded by the VR2W receivers installed in the Danube River between rkm 71 (Tulcea branch) and rkm 847, reveal that the swimming depth range was between 1 and 35 m (Figure 2). Most of the depth data detected during downstream migration (77%) and upstream migration were in the range of 8 to 22 m, with the highest frequency at a depth of 10 m (11%). For downstream migration, most of the depth detections were in the 2- to 19-m interval, with the highest frequency at a depth of 8 m (13%). Half of these depth detections were in the interval of 8 to 12 m (Figure 2). In the case of upstream migration, 82% of detections were in the interval of 8 to 21 m deep, with the highest frequency at a depth of 10 m (11%). More than half of these depth detections were in the interval of 9 to 15 m (Figure 2).

3.2. Stellate sturgeon swimming depths
A total of 472 swimming depth detections were analyzed from 21 tagged stellate sturgeon, downloaded from 7

| No. | Tagging date | Total weight [kg] | Total length [cm] | Sex | Date of exit | Date of return |
|-----|--------------|-------------------|------------------|-----|--------------|---------------|
| 1   | May 6, 2012  | 4                 | 106              | Male | May 14, 2012 | -             |
| 2   | May 5, 2012  | 3                 | 93               | Male | May 24, 2012 | -             |
| 3   | May 7, 2012  | 3                 | 92               | Male | May 24, 2012 | -             |
| 4   | May 9, 2012  | 12                | 135              | Female | May 11 2012 | -             |
| 5   | May 10, 2012 | 6                 | 120              | Unknown | May 13, 2012 | -             |
| 6   | May 15, 2012 | 5                 | 107              | Unknown | May 16, 2012 | -             |
| 7   | May 15, 2012 | 3.5               | 99               | Unknown | May 20, 2012 | -             |
| 8   | May 15, 2012 | 3.5               | 110              | Male | May 17, 2012 | -             |
| 9   | May 18, 2012 | 4.5               | 110              | Male | Jun 1, 2012  | -             |
| 10  | May 21, 2012 | 4.5               | 110              | Male | Jun 7, 2012  | -             |
| 11  | May 24, 2012 | 3.5               | 107              | Unknown | May 27, 2012 | -             |
| 12  | May 30, 2012 | 5.5               | 115              | Unknown | Jun 16, 2012 | -             |
| 13  | May 30, 2012 | 4                 | 112              | Female | Jun 2, 2012  | -             |
| 14  | Jun 4, 2012  | 6.5               | 127              | Male | Jun 8 2012  | Apr 30, 2014  |
| 15  | Jun 4, 2012  | 3.5               | 102              | Male | Jun 7, 2012  | -             |
| 16  | Jun 4, 2012  | 3.5               | 102              | Unknown | Jun 7, 2012  | -             |
| 17  | Jun 10, 2012 | 4                 | 103              | Unknown | Jun 12, 2012 | -             |
| 18  | Jun 14, 2012 | 6.5               | 123              | Unknown | Jun 19, 2012 | -             |
| 19  | Jun 15, 2012 | 5                 | 119              | Male | Jun 25, 2012 | Apr 29, 2014  |
| 20  | Jun 15, 2012 | 4.5               | 107              | Male | Jun 24, 2012 | -             |
| 21  | Nov 3, 2012  | 5.3               | 119              | Male | Nov 9, 2012  | -             |
VR2W receivers installed in the Danube River between rkm 71 and rkm 200. Most of the stellate sturgeon upstream and downstream depth detections were in the range of 2 to 17 m. The highest frequency depth (13% of all records) was approximately 5 m. For downstream migration, most of the detections were in the depth range of 1 to 17 m, with the highest frequency at a depth of 5 m (14%). In the case of upstream migration, most of the detection was in the depth range of 5 to 19 m (73%), with the highest frequency (13%) at a depth of 12 m (Figure 3).

3.3. Detection distribution for a period of 3 years at rkm 100

The data provided by the receiver installed in the Danube River at rkm 100 revealed that most of the detections for beluga sturgeon were in November and May, but there were also detections in March, April, and December (Figure 4).

In the case of stellate sturgeon, most of the detections were recorded in May and November, but there were also detections in April and June. More than half of the beluga sturgeon detections analyzed (64%) were in November (2012, 2013, and 2014). The next highest month was May with 22%, followed by December and April, both with 5%; the lowest months were June and March with 2%. For stellate sturgeon, 52% of all detections were in May (2012, 2013, and 2014), 24% in November, 14% in June, and 10% in April. For both species, the intensity of migration increases in May when the temperature and water level in the Danube River increase (Figure 5).

3.4. Sturgeon ground speeds

Beluga sturgeon average ground speed for upstream movement was in the range of 1.1–2 km/h, which was higher than the stellate sturgeon average upstream speed (0.34–0.36 km/h). The speed during the downstream migration increased by up to 6 km/h for beluga sturgeon and 4.83 km/h for stellate sturgeon (Table 3).

When comparing speeds recorded shortly after tagging with the speeds recorded 90 days later for beluga sturgeon, there was a difference for minimum downstream values.
Figure 3. Recorded upstream (u/s) and downstream (d/s) movement preference in different depth frequencies for Beluga sturgeon at rkm 71 and rkm 200 stations.

Figure 4. Recorded frequency on a monthly basis at the rkm 100 station for beluga and stellate sturgeon.

Figure 5. Danube River water levels and water temperature at rkm 100 in 2014.
recorded and no difference for maximum values. It is not possible to make a comparison for stellate sturiones due to a lack of data (Table 3).

4. Discussion
Migratory fish migrate to feed and to breed. In the case of beluga and stellate sturgeon, the best place to feed is not necessarily the best place to feed. They need to migrate farther upstream to the spawning sites that meet the conditions for laying eggs. During migration, beluga sturgeon can travel long distances. For example, a beluga was tagged in November 2013 and passed rkm 100 moving downstream and came back upstream in March 2014 past rkm 100. It then migrated 747 km upstream to rkm 847 in 18 days, covering an average of 41.5 km/day (1.7 km/h), and then travelled downstream 747 km in the same number of days (18 days). A second beluga sturgeon tagged in 2011 returned to the Danube River in 2016 when it was recorded downstream of the Iron Gate II dam in April. It then migrated downstream 747 km in 13 days between rkm 847 and rkm 100, moving downstream at an average of 57.5 km/day (2.4 km/h). Beluga and stellate enter the Danube River in spring and during the fall. The spring migration for beluga sturgeon occurs from February to May and for stellate sturgeon it begins in March and ends in May (Oțel, 2007). The fall migration for beluga sturgeon begins in August and lasts until November to December, depending on the water temperature. For stellate sturgeon, the fall migration is from August to November (Banarascu, 1964). Sturgeon that migrate in the fall overwinter in the river and spawn the next year, and those that migrate during the spring spawn in the same year (Oțel, 2007; Suciu et al., 2016). It is generally accepted that sturgeon entering the river during the fall migration want to get farther upstream because they are able to continue their migration early in the spring. In the Danube and Volga Rivers, more beluga sturgeon enter the river during the fall than the spring (Holcik, 1989). In this study, most of the detections analyzed at rkm 100 are also from the fall migratory beluga sturgeon. According to Holcik (1989), more migratory stellate sturgeon were captured during the spring migration, the same pattern being observed in the Danube River, where most of the recorded detections at rkm 100 from tagged stellate sturgeon were obtained during spring. The biologist Grigore Antipa (1916) described an early 19th century fisherman’s method for installing hooks in the Danube River to catch sturgeon during their migration. In the spring, they placed hooks at a depth of 7.5 m and in the fall at 30 m. The results for beluga sturgeon in this study reveal a preference of 8 to 12 m swimming depth for downstream migration and 9 to 15 m deep for upstream migration. The shallowest depth recorded was 1–2 m, and the deepest depth recorded was 35 m (Figure 2). Stellate sturgeon swimming depths recorded in the Danube River for downstream migration were 1–17 m and for upstream swimming 3–27 m depths were measured. The results of this study reveal that beluga sturgeon swim in deeper waters during their spawning migration in the Danube River than stellate sturgeon.

Although there was a similar number of tagged beluga sturgeon (23) and stellate sturgeon (21) tracked in the Danube River, the number of swimming depth detections recorded for each species was very different (472 stellate vs. 8111 beluga). Both species displayed a high sensitivity to interruption of migration (handling and tagging), resulting in a drop-back behavior soon after release—a situation that was also encountered before (Kynard et al., 2002). It seems that stellate sturgeon are more sensitive than beluga, which usually return upstream several months after their release and continue their migration. Most of the tagged stellate sturgeon specimens swam downstream towards the Black Sea, leaving the river soon after release. Previous studies reporting on migration ground speeds recorded in the Danube River revealed that stellate sturgeon moved upstream at 7–8 km/day (0.33 km/h) and downstream at 20 km/day (0.83 km/h) (Kynard et al., 2002). The estimated migration speed relative to the riverbank for stellate sturgeon in the Volga River was 18–20 km/day (0.83 km/h) up to 110 km/day (4.6 km/h) (Holcik, 1989; Khodorevskaya et al., 2009). In the Kura River, the estimated ground speed was 20 km/day (0.83 km/h) and for the Kuban River 24 km/day (1 km/h) (Khodorevskaya et al., 2009). The estimated ground speeds recorded before for stellate sturgeon in the Danube, Volga, Kura, and Kuban rivers are close to or in the interval of recorded ground speed found in this this study. This study provides a more detailed picture of beluga and stellate sturgeon migration in the Lower Danube River regarding the swimming depths and swimming ground speeds, and this will contribute to a better understanding of sturgeon behavior during their spawning migration. It also contributes to a better understanding of sturgeon migration in order to establish longitudinal connectivity of the river by building fish passages at the Iron Gate II dam. In the future, additional research will be carried out in these directions to protect sturgeon species in the Lower Danube River.

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