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Migration and habitats of diadromous Danube River sturgeons in Romania: 1998–2000

By B. Kynard[1], R. Suciu[2] and M. Horgan[1]

[1]*S.O. Conte Anadromous Fish Research Center, Leetown Science Center (USGS), Turners Falls, MA, USA;* [2]*Danube Delta National Institute, Tulcea, Romania*

Summary

Upstream migrant adults of stellate sturgeon, *Acipenser stellatus* (10 in 1998, 43 in 1999) and Russian sturgeon, *A. gueldenstaedtii* (three in 1999) were captured at river km (rkm) 58–137, mostly in the spring, and tagged with acoustic tags offering a reward for return. The overharvest was revealed by tag returns (38% in 1998, 28% in 1999) and by harvest within 26 days (and before reaching spawning grounds) of the six stellate sturgeon tracked upstream. A drop-back of > 50% of the tagged sturgeon, some to the Black Sea, shows a high sensitivity to interruption of migration and capture/handling/holding. Harvesting and drop-back prevented tracking of sturgeon to spawning sites. Gill-netting and tracking of stellate sturgeon showed that the autumn migration ended in early October (river temperature 16°C) and identified a likely wintering area at river km (rkm) 75–76 (St George Branch). Thus, fishery harvesting after early October captures wintering fish, not migrants. Rare shoreline cliffs in the lower river likely create the only rocky habitat for sturgeon spawning. A survey for potential spawning habitats found five sites with rocky substrate and moderate water velocity, all ≥rkm 258. Drift netting caught early life-stages of 17 fish species and one sturgeon, a beluga, *Huso huso*, larva likely spawned at ≥rkm 258. All diadromous Danube sturgeons likely spawn at ≥rkm 258.

Introduction

The lower Danube River extends from the river mouth, with three branches, to the Cerno River at river km (rkm) 955 (Hensel and Holcik, 1997). This river reach has populations of three native diadromous sturgeon species, i.e., beluga, *Huso huso*; Russian sturgeon, *Acipenser gueldenstaedtii*; stellate sturgeon, *A. stellatus*, and one native riverine potomadromous species, the sterlet, *A. ruthenus* (Bacalbasa-Dobrovici, 1997). Two other native diadromous sturgeons, ship sturgeon, *A. nudiventris*, and European Atlantic sturgeon, *A. sturio*, may be extirpated, although rare individuals of ship sturgeon are captured by fishermen (R. Suciu, unpublished data). All countries bordering the river downstream of the lowermost mainstem dam (Iron Gates II) at rkm 859 participate in a declining sturgeon fisheries characterized by a great increase in Romanian fishermen during the 1990s (Navodaru et al., 1999). The other major cause of sturgeon decline is blockage of spawning migrations by damming: Iron Gates I Dam built in 1970 at rkm 939 and Iron Gates II Dam built in 1981 at rkm 859 (Bacalbasa-Dobrovici, 1997).

Historical spawning locations of Danube sturgeons are unclear, but prior to construction of Iron Gates II Dam, many adult beluga, Russian sturgeon and stellate sturgeon migrated upstream to the dam area at rkm 859 (Holcik, 1989). These stocks presumably spawned upstream; other stocks may have spawned (and may continue to spawn) downstream in the mainstem, in the tributaries, or in both. However, no information is available on spawning location or spawning habitat availability in the lower river. The recent capture of stellate, Russian, and beluga sturgeon yearlings at rkm 300 during the summer of several years (R. Suciu, unpublished data) shows that some Danube sturgeon spawn successfully in the lower river between rkm 300 and Iron Gates II. In addition to providing spawning habitat, the lower river provides juvenile rearing habitat, as indicated by presence of the previously noted captured juveniles. Dredging and pollution likely degrade rearing habitat in some reaches (Bacalbasa-Dobrovici, 1997). The mainstem downstream of Iron Gates II is relatively undeveloped and unlikely to be dammed further. This situation presents a unique opportunity among European rivers to preserve biodiversity and conserve diadromous sturgeons.

The main objective of the present research was to locate spawning sites and identify spawning reaches of diadromous Danube sturgeons in the lower river. Acoustic telemetry was used to track pre-spawning migrants and also to survey for potential spawning habitat. Spawning habitat of sturgeons has two important physical components: rocky substrate and a moderate water velocity (Bemis and Kynard, 1997). Spawning habitat of shortnose sturgeon, *Acipenser brevirostrum*, and white sturgeon, *A. transmontanus*, is similar: rocky substrate and a water velocity of 0.3–1.5 m/s (Kieffer and Kynard, 1996; Schaffter, 1997). Experiments with shortnose sturgeon recently found a preference for water velocity of 0.5–0.7 m/s (Kynard et al., unpublished data). Spawning habitat of beluga, Russian sturgeon, and stellate sturgeon in Russian rivers reported in the literature appears similar to shortnose and white sturgeon (review, Holcik, 1989). Thus, rocky bottom and moderate water velocity indicate potential spawning habitats. Drift nets have been used in some rivers, but not in the Danube River, to capture sturgeon early life stages (ELS = eggs-free embryos-larvae), which are aged and used to estimate drift distance and general spawning location. Examples from North America are, e.g. the Sacramento River (Kohlhorst, 1976), Merrimack River (Kieffer and Kynard, 1996), and Connecticut River (Kynard et al., 1999; Kynard and Horgan, 2001). In the lower Danube River, we set driftnets at several locations to capture sturgeon ELS and estimate spawning location.

When the study began, no information was available either on using acoustic telemetry in the lower river or on handling and tagging diadromous Danube sturgeon. Migrant adult stellate sturgeon and beluga were tagged externally with acoustic tags in the Volga River, Russia, during the 1970s (Poddubny, 1976); however, the studies were short-term (<2 weeks), handling/tagging methods unclear, and sensitivity of sturgeon to capture and tagging was not noted. Most importantly, the level of fisheries harvest on Danube sturgeon runs was not known.

Materials and methods

Equipment and training

Equipment was procured through the University of Massachusetts, Amherst, MA and shipped to Romania in the spring of 1998. Equipment included all items needed to conduct field research on sturgeon movements and habitats. Acoustic telemetry equipment (Lotek Wireless, Inc., Newmarket, Ontario, Canada) included components for mobile tracking and data-logging stations.

Romanian team members were trained on the Danube River in spring 1998 and at the S.O. Conte AFRC in 1999 (Kynard et al., 2000a). Telemetry training was also provided in Romania by Todd Lindstrom (Master Technician, Lotek Wireless, Inc.).

Spring/autumn – 1998

In May, we established four data-logging stations to detect tagged fish on the mainstem (down- to upstream): mainstem (rkm 90) near Tulcea, Galatz (rkm 150), Harsova (rkm 238), and Oltenita (rkm 430; Fig. 1). A data-logging station was also established on the St George Branch at Tulcea (rkm 119). A temperature logger was placed in the river at each data-logging station. Mainstem rkm are calculated from the Sulina Branch mouth, as are navigational markers along the river banks. A field camp was established at rkm 58 on the St George Branch (Fig. 1), where multi-filament gill nets were set in late May and early June, and from September to November, to capture and

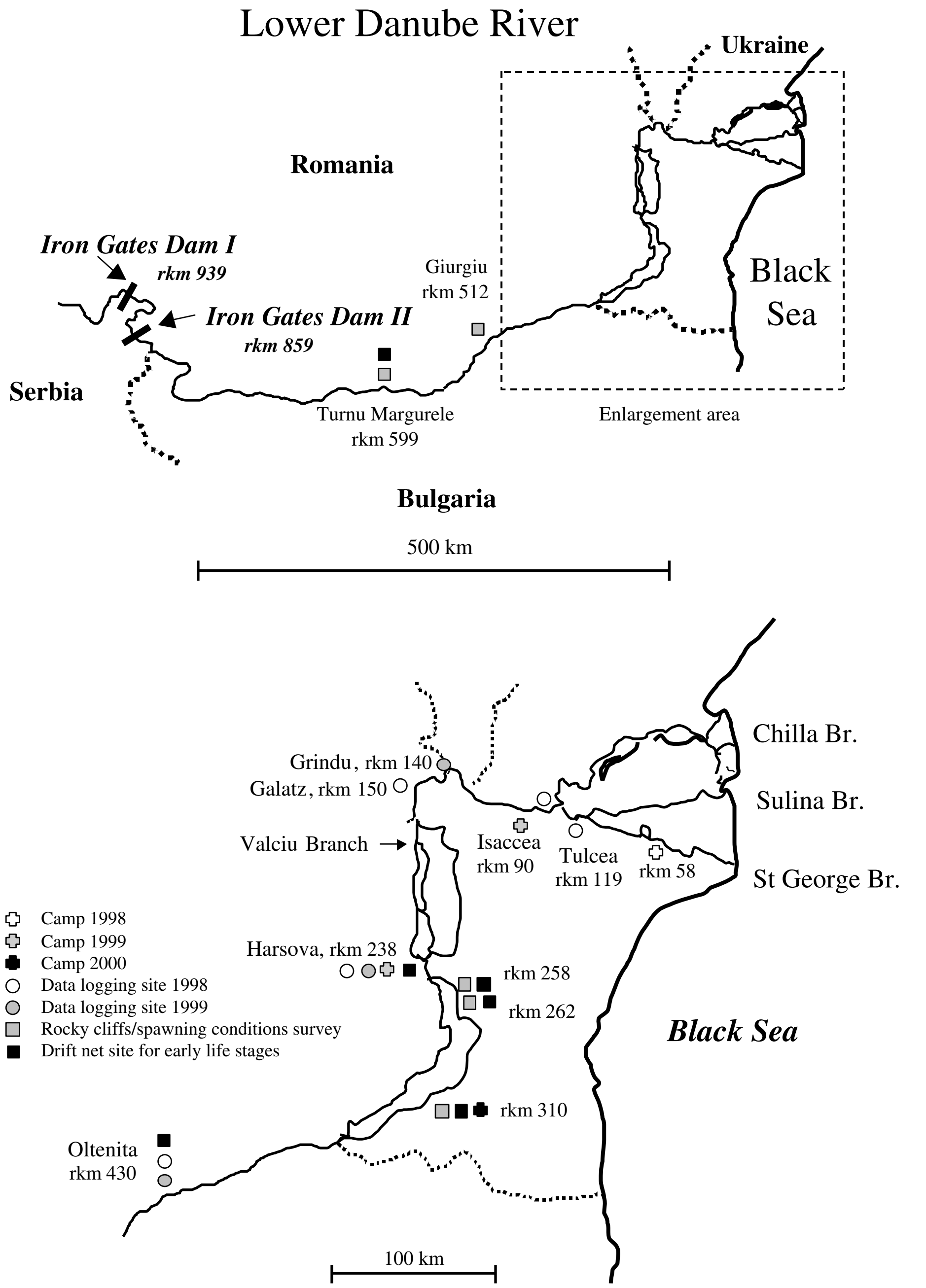

Fig. 1. Lower Danube River where 1998–2000 sturgeon studies were conducted. Camp sites show locations where fish were captured and tagged with acoustic tags. In 1998, tagged fish were released at the capture site; in 1999 fish were released at Galatz, upstream of the capture site. Tracking from Oltenita to Tulcea was done in winter 1998 and from Tulcea to rkm 835, near the Serbian border, in spring 1999. Potential spawning areas with rocky bottom and drift-net sampling sites for sturgeon early life stages were Giurgiu (rkm 505–512) and Turnu Margurele (rkm 594–599) and (insert) Pigeons Rock (rkm 258), Ghindareste (rkm 262), and Red Stone (rkm 310)

tag sturgeon. Nets were 92 m long × 2.4 m wide with 15-cm openings (stretch mesh) for stellate sturgeon nets, 20–22.5-cm openings for Russian sturgeon nets, and 30 cm for beluga nets. We fished 2–5 nets, mostly bottom-set for an 18-h set. For calculating catch per unit effort (CPUE), 1 net set overnight was 1 unit of fishing effort. Nets were set in the natural channel, not in the channelized navigation shortcut which tracking later revealed were avoided by fish. Stellate and Russian sturgeon nets were similar and might capture either species. When fish were captured, length (cm TL), weight (kg) were measured, and sex and sexual maturity of females determined using a bioscope (Kynard and Kieffer, this issue), and each tagged externally with an acoustic transmitter. Tags were 16 mm diameter × 85 mm long, weighed 36 g (<1% of fish body weight), and transmitted on 76 or 55 kHz frequency. Each tag carried a reward notice for return by fishermen. Tags were attached to fish along the dorsal fin base and held in place by two wires pushed through the fin with a plastic washer and copper crimp to hold the tag wire on the fish side opposite the tag. With time, the copper crimp corrodes and releases the tag. To reduce abrasion, a neoprene pad was placed between the fish body and the tag and washer.

Spring/autumn – 1999

After capturing only a few stellate sturgeon on the St George Branch in 1998, in April 1999 a new camp was established on the mainstem, where the dominant sturgeon runs occur. Data-logging stations were also re-established at Grindu, Harsova, and Oltenita. The telemetry plan was to capture and tag sturgeon near Isaccea at rkm 119 (field camp for 1999, Fig. 1). After tagging 40 sturgeon, we planned to move upstream to Harsova at rkm 238, relocate fish when they were detected by the Harsova data logger, and manually track fish upstream to spawning sites using two tracking crews and boats. Surveys from Galatz to Harsova found no rocky bottom areas (potential spawning sites), therefore all tagged sturgeon should move upstream of Harsova to spawn.

After 2 weeks of fishing, only two stellate sturgeon were captured; three (one from a fisherman) were tagged and released. One tagged fish, which was tracked upstream, was harvested by Galatz fishermen the following day. To prevent tagged sturgeon from being quickly harvested, the fish were transported 30 km upstream, then tagged and released at rkm 150, upstream of some of the Galatz fishery. Transportation of the fish did not allow time to set gill nets, therefore sturgeon for tagging were obtained from fishermen at Isaccea.

Sturgeon were held by fishermen in live pens for an unknown time before they were obtained, therefore their capture and handling history were unknown. For transporting sturgeon upstream on our boat, a canvas tank supplied with a constant supply of river water was used.

After tracking ceased, we fished 1–2 anchored drift nets at Harsova to capture sturgeon ELS. Nets were D-shaped with a 0.4 m^2 mouth opening and 6-m long netting with 2-mm mesh opening (Kieffer and Kynard, 1996; Kynard et al., 1999). Nets were set in the channel.

Spring – 2000

In 2000, the telemetry plan was to capture and tag sturgeon upstream of Harsova (>100 km upstream of the 1998 capture site) that had survived the Galatz fishery, then track the fish upstream to spawning sites. However, no sturgeon were tagged because of delays obtaining telemetry equipment from Romanian Customs; stellate sturgeon migration had ceased at Harsova by the time the equipment was released. Instead, we field-tested the new equipment, quantified potential spawning habitat, and set drift nets for sturgeon ELS.

During 1998–1999, we surveyed the shoreline for occurrence of rocky cliffs in the St George Branch and in the mainstem upstream from the St George Branch to rkm 835, including all branches upstream of Galatz (Fig. 1). In 2000 we sampled the river below the rocky cliff shoreline areas between Galatz (rkm 150) and Turnu Margerelle (rkm 600, Fig. 1) to determine the riverine substrate type, water velocity, and presence of sturgeon ELS. At each site, inshore (4–13 m from shore) and offshore (5–35 m from shore) transects parallel to the shoreline were established. Along each transect we established sample stations and identified at each the substrate type (mud, sand, gravel, rocks), determined water depth, and measured water bottom velocity at 0.5 m above the bottom. Substrate type was determined by lowering a metal pipe to the bottom using a wire and earphone to listen to the sound made by the pipe on contact with the bottom. Water depth was determined with a fathometer. Bottom velocity was determined with an electronic velocity meter (Marsh-McBirney, Inc., Gaithersburg, MD) attached to a bottom weight lowered by winch from the anchored boat. We fished 1–2 drift nets for sturgeon ELS at rocky cliff sites located at rkm 258, 262, 310, 599, and at Oltenita.

Table 1
Characteristics, movement, and fate of 10 migrant adult stellate sturgeon captured in 1998 at rkm 58 or rkm 55 (fish no. 78) on the St George Branch, Danube River and acoustically tagged. The tag offered a reward for return. Direction is (U = upstream, D = downstream). Blank spaces in table = no data

Fish code	Sex	TL (cm)	Weight (kg)	Capture/ tag date	Tracking date	Tracking location (rkm)	Harvest date	Harvest location (rkm)	Number of days free	Direction/km moved
78	M	108	4.8	28 May	29 May	50				D-5
Died	F	120	7.5	2 Jun						
92	M	101	4.5	6 Jun						
57	M	108	4.5	27 Sep	28 Sep	75	20 Oct	75	23	U-17
150	F	119	7.0	28 Sep	29 Sep	76	22 Oct	76	24	U-18
Died	M	130	8.8	30 Sep						
98	F	108	5.5	1 Oct	8 Oct	56				D-2
48	M	128	8.0	3 Oct	3 Oct	51				D-7
97	M	118	6.3	6 Oct	7–9 Oct	57	23 Oct	Sulina[a]	17	D->90
154	M	119	5.9	7 Oct	7–8 Oct	57				D-1

[a] Sulina is on the Black Sea at the mouth of the Sulina Branch, Danube River.

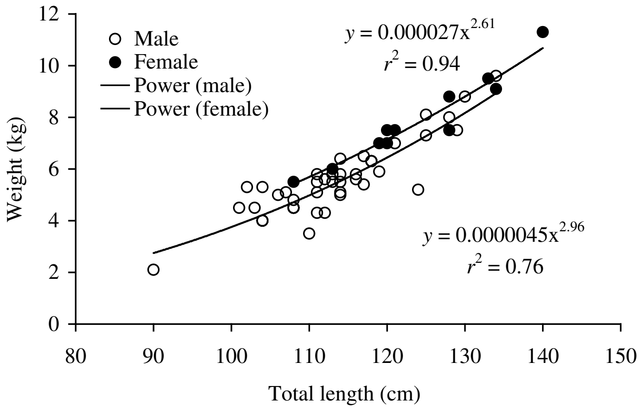

Fig. 2. Length–weight relationship of male and female stellate sturgeon tagged during Danube sturgeon telemetry studies, 1998–1999. n = 42 males and 11 females

Results

1998

In spring, 39 net sets on 28 May–6 June captured three stellate sturgeon, CPUE = 0.077 (Table 1). One female died in the net. Fish no. 78 was tracked moving downstream after tagging; fish no. 92 was not tracked. Maximum daily water temperature was 19.5–22.5°C during fish capture.

In the autumn, nets set from 23 September to 22 November captured seven stellate sturgeon (five males : two females, sex ratio = 2.5 : 1; Table 1). The number of bottom nets for each species by month was September: stellate-24, Russian-17, beluga-8; October: stellate-37, Russian-9, beluga-6; and November (bottom set): stellate-0, Russian-23, beluga-13; and November (net 1–2 m above bottom): stellate-22, Russian-17, beluga-14. No sturgeon was captured in November, although netting was the most intensive in that month. Catch and effort (month : CPUE) was: September (0.061), October (0.077), November (0.00). One male died during autumn netting.

The temporal pattern of stellate sturgeon capture and the upstream movements of two fish (no. 57 and no. 150; Table 1) indicated that migration ended in early October at 16°C. Although nets were set until 22 November, no sturgeon were caught after 7 October (river temperature, 15.8°C). Two fish (no. 57 and no. 150) were tracked upstream to the curve at rkm 75–76 on 28–29 September and were harvested there by fishermen 23–24 days later at 12–13°C.

Although fish were handled gently, tagged quickly, and released, five of seven (71%) were either tracked or harvested downstream (drop-back behavior). Fish that dropped-back were not tracked or harvested upstream, suggesting they did not return upstream. Only two of seven (28%) tagged fish were tracked moving upstream after tagging.

Tags of three of eight fish (38%) tagged in 1998 were returned by fishermen. Fish no. 97 returned to the Black Sea and was harvested 17 days after tagging (Table 1, Fig. 1). No tagged fish was detected by data-logging stations. Manual tracking in winter from Oltenita to Tulcea also found no missing tagged fish in mainstem wintering areas.

1999

Tagged were 41 stellate sturgeon and three Russian sturgeon (39 stellate sturgeon and all Russian sturgeon were obtained from fishermen). The length–weight relationship of stellate sturgeon tagged in 1998–1999 is shown in Fig. 2. Males ranged from 90–135 cm TL and females were 108–140 cm TL. Females weighed more than males; over their common body length range, females were about 0.75 kg heavier than males of the same length.

During spring, movement data was gathered on 14 stellate sturgeon (five were tracked, 11 were tag returns from fishermen; Table 2). A summary of the information on the five tracked sturgeon was: no. 83 was tracked moving upstream 1 day after tagging; no. 102 was tracked moving upstream from rkm 137 to rkm 142 where it was harvested, released, and harvested again downstream at rkm 101; no. 115 and no. 140 were detected moving downstream by the Grindu logger; and no. 72 was tracked moving upstream at rkm 238 by the Harsova logger, then was harvested the following day at rkm 247. The Grindu data-logger detected only two of 10 fish (20%) that were harvested downstream of Grindu (Table 2). Fish no. 72 that moved 97 km upstream to Harsova in 13 days moved at an estimated 7.5 km/day ground speed; tracked downstream fish (n = 3) moved at 10–20 km/day ground speed.

Fishermen returned tags from 12 of 43 (28%) stellate sturgeon tagged in spring and autumn 1999 (Table 2). We have no estimate of unreported harvest; it was likely high. Tagged stellate sturgeon were free 0–26 days, a mean of 11.4 days, before being harvested. The two fish tracked moving upriver were captured before stopping to spawn and after moving only a short distance, i.e., no. 102–5 km and no. 72–97 km (Table 2). Fish that dropped-back also moved a short distance before harvest (n = 10, mean = 41 km; Table 2). Tracking and harvest data show that a total of four of 16 stellate sturgeon (25%) moved upstream after tagging in the spring and autumn (Table 2).

Two stellate sturgeon (no. 84 and no. 90) dropped-back to the river mouth (Table 2). One of three Russian sturgeon was detected by the Grindu data logger as the sturgeon dropped-back to the Black Sea where it was harvested at Sulina on 6 May (10 days after release).

The data-logging system did not reliably detect the code of tags at distances > 0.5 km range in the noisy river discharge during spring. After finding that the Harsova data-logger could miss tagged fish, we tracked 40–50 km/day upstream from Harsova (including all branches) to rkm 835, attempting to locate tagged sturgeon that may have moved undetected past the Harsova data logger. We found no sturgeon and stopped just downstream of the Serbian border, to avoid the Kosovo War.

In autumn 1999, a more powerful tag (CAFT-3) was tested. Two males were captured on 1 November at mainstem rkm 131, transported upstream, tagged, and released 8 km upstream from the mouth of the middle branch (Valciu Branch) which enters the mainstem at Galatz (Table 2, Fig. 1). Fish no. 49 moved downstream at 20 km/day (ground speed) and no. 98 was tracked for several days moving upstream at 8 km/day (ground speed) before being harvested (Table 2).

Drift netting captured one beluga larvae at rkm 238 (Harsova) on 26 May. It was captured in the channel (10–12 m water depth) at a water temperature of 19°C. The feeding larva was 23 mm TL and age was estimated at 14 days post-fertilization.

Table 2
Characteristics, movements, and fate of 16 stellate sturgeon captured in the mainstem Danube River in 1999 and tagged with acoustic tags offering a reward. Release and harvest locations are mainstem rkm or Branch name/Branch km. Manual tracking location is mainstem km, tracking by data logger is rkm 140 (Grindu) or rkm 238 (Harsova). Direction is U = upstream, D = downstream. Blank spaces in table = no data

Fish code	Sex	TL (cm)	Weight (kg)	Tagging date	Release location (rkm)	Tracking date	Tracking location (rkm)	Harvest Harvest date	Number location (rkm)	Direction/ of days free	rkm moved
83	M	112	5.6	29 Mar	131	30 Mar	133				U-2
102	F	128	8.8	21 Apr	137	22 Apr	142	3 May[a]	101	12	U-5, D-41
59	M	125	8.1	22 Apr	134			22 Apr	134	0	0
38	F	121	7.5	25 Apr	150			19 May	132	24	D-18
115	F	134	9.1	26 Apr	151	26 Apr	140				D-11
84	M	125	7.3	27 Apr	151			17 May	20[b]	20	D-131
96	M	121	7.0	27 Apr	151				140		D-11
73	M	111	5.1	30 Apr	150			30 Apr	150	0	0
91	M	104	5.3	30 Apr	150			26 May	113	26	D-37
90	M	111	5.8	1 May	150			8 May	20[b]	7	D-130
160	F	140	11.3	1 May	150			12 May	113	11	D-37
140	M	114	5.8	2 May	150	3 May	140				D-10
72	M	113	5.8	3 May	150	15 May	238	16 May	247	13	U-97
142	M	117	5.4	4 May	150			16 May	141	12	D-9
98	M	116	5.6	1 Nov	8[c]	4 Nov	9–33	5 Nov	34[c]	4	U-26
49	M	107	5.1	1 Nov	8[c]	3 Nov	140	5 Nov			D-18

[a] First harvest date at rkm 142; fish was released and reharvested at rkm 101.
[b] Chilia Branch.
[c] Valciu Branch, the middle branch just upstream of Galatz (Fig. 1).

Table 3
Five rocky cliff areas in the lower Danube River surveyed for potential sturgeon spawing habitat (rocky substrate and bottom water velocity) on 28 May–2 June 1999. River kilometer shows location of cliff site, length (m) is the length of the shoreline rocky area sampled for substrate type, water depth, and bottom velocity on two transects parallel to the shoreline. Substrate type at all sites was rock/rubble

Location	Rkm (length, m)	Number of samples	Mean depth (range)	Mean velocity (range)
Pigeons Rock	258 (350)	6	10.3 (6.1–12.7)	0.24 (0.21–0.27)
Ghindareste	262 (55)	4	10.5 (5.5–17.4)	0.41 (0.32–0.52)
Red Stone	310 (200)	6	7.2 (1.5–10.9)	0.65 (0.47–0.82)
Giurgiu	505–512	3	6.1 (5.5–6.7)	0.39 (0.31–0.45)
Turnu Margurele	594–599	9	8.0 (3.0–12.2)	0.45 (0.17–1.20)

2000

We returned to the only (five) rocky cliffs located between rkm 150–600; from 30 May to 2 June, each was characterized for potential spawning habitat (Table 3). All five cliffs were on the south side of the river and rocky substrate did not extend beyond mid-river.

All stations on each transect had rocky substrate of boulders, rubble and gravel. The lowermost site (Pigeons Rock at rkm 258) had low water velocity when sampled, and was unsuitable for spawning. Earlier, at higher river discharge, velocity may be suitable. Ghindareste (rkm 262) was the smallest site with only 55 m of rocky bottom. The Red Stone site (rkm 310) with 200 m of rocky bottom had better spawning substrate and velocity than either of the previous two sites. The two upriver sites (Giurgiu at rkm 505–512 and Turnu Magurele at rkm 594–599) had the most potential spawning habitats (7 and 5 km, respectively). The largest cliffs were not on the Romanian, but rather on the Bulgarian side of the river.

We fished drift nets at four rocky sites and at Oltenita for a total of 45.7 h to capture sturgeon ELS between 25 May–2 June (site, no. net hours): Pigeons Rock, 4.5; Ghindaresti, 5.2; Red Stone, 22; Oltenita, 3.6; and Turnu Margurele, 10.4. Debris load usually limited the set time of nets to 1 h, therefore the nets were pulled and reset. Water temperature during drift net sets was 21–24°C and river discharge was slowly decreasing. We captured no sturgeon ELS, but did capture 406 larvae and early juveniles of 17 fish species (in alphabetical order: *Abramis ballerus*, *A. brama*, *Alburnus alburnus*, *Barbus barbus*, *Chondrostoma nasus*, *Gobio gobio*, *Gymnocephalus baloni*, *G. schraetser*, *Leuciscus cephalus*, *Neogobius fluviatilis*, *Pelecus cultratus*, *Proterorhinus marmoratus*, *Sabanejewia aurata*, *Silurus glanis*, *Stizostedion lucioperca*, *Zingel streber*, and *Z. zingel*). Drift nets captured for the first time the ELS of two fish species (*Z. streber* and *Z. zingel*) considered rare or endangered in the lower Danube River. However, on the channel bottom, *Z. streber* was abundant, comprising 23% of captures; *Z. zingel* was rare comprising only 1%. Large numbers of *Gymnocephalus schraetzer* (21% of the sample) were captured, which extends their downstream range in the river. Captures of larval *Silurus glanis* (3% of captures) and *Pelecus cultratus* (1% of captures) show for the first time he use of the river channel by ELS of these species. The recently introduced Asiatic clam *Corbicula fluminaea* was found at all locations. Additional information on the riverine fish species is in Kynard et al. (2000a).

Discussion

Migration timing, movement characteristics, and winter habitat

The autumn capture of upstream migrant stellate sturgeon provides the first scientific evidence of the timing and temperature conditions when the late summer–autumn migration ceases, i.e. at 16°C in early October. Previous estimates of migration timing have been inferred from fishery harvest. Navodaru et al. (1999) showed that the fisheries harvest of stellate sturgeon in the lower Danube River continues to the end of November. Our data indicate that the fisheries catch after early October is non-migrant wintering fish, not migrants. The harvest date in late October–November only indicates when stellate sturgeon are captured and has no relationship to migration.

Some stellate sturgeon were captured migrating upstream at rkm 58 on the St George Branch in late May 1998 when river temperature was 18.5–22.5°C. The higher temperature is near the upper limit for spawning of stellate sturgeon (23°C) in the Danube River (Holcik, 1989). If the sturgeon captured in May 1998 migrate upstream at 7 km/day, then it would take 28 days to reach rkm 258 (late June) and 63 days to reach rkm 500 (late July), when water temperatures would be even higher. Thus, spawning for late migrants could occur at much higher water temperatures than 22.5°C. Stellate sturgeon spawn in other rivers at 26–27°C (review by Holcik, 1989); Danube stellate sturgeon may be similar.

Although gill-net captures are few, most stellate sturgeon were captured on the channel shoulder, a similar finding of Poddubny (1976) for migration location of stellate sturgeon. Most were in the upstream 20% of the net's length, suggesting that fish were guiding along the net.

The four stellate sturgeon tracked upstream moved at 7–8 km/day (ground speed) during spring or autumn. This is less than one-half the downstream movement rate (20 km/day). The upriver movement rate of Danube stellate sturgeon is less than one-half that reported by Holcik (1989) for the species in other rivers.

The curve at rkm 75–76 is probably a wintering area of stellate sturgeon, but more data are needed. It is not known if the two sturgeon remained at rkm 75 for 3 weeks before harvest, but information on other wintering sturgeon suggest that they did. Shortnose sturgeon migrants stopping in a deep curve in October have chosen winter habitats, and the same sites are occupied each year (Kynard et al., 1999, 2000b). Danube sturgeons (and other sturgeon species) may behave similarly. Fishermen likely learn the location of wintering sites and thus return each year to capture all wintering fish.

Drop-back

After disruption of the upstream migration of stellate sturgeon by capture and tagging, most exhibited drop-back behavior (autumn 1998, 71%; spring 1999, 80%; and autumn 1999, 50%). Drop-back occurred regardless of year, season, or capture method (gill net and careful handling by us, or drift net and unknown handling by fishermen). A short drop-back was expected after migration was interrupted, but the high incidence, distance traveled, and a lack of resumption of upstream migration was unexpected. Some sturgeon returned to the river mouth or Black Sea. It is rare for other sturgeons in other rivers to abandon migration after capture and tagging [Atlantic sturgeon, *A. oxyrinchus oxyrinchus* (Dovel and Berggren, 1983); gulf sturgeon, *A. o. desotoi* (Foster and Clugston, 1997); shortnose sturgeon (Buckley and Kynard, 1985); Lake sturgeon, *A. fulvescens* (Thuemler et al., unpublished Data); and white sturgeon, *A. transmontanus* (Schaffter, 1997)].

Transporting fish upstream of the Galatz fishery to avoid harvest was a failure (all upstream migrants were harvested anyway). Handling likely contributed to additional drop-back. However, these were not the only factors because non-transported fish also dropped-back. The high frequency of drop-back indicates an extreme sensitivity to capture/handling, interruption of migration, or both. It may be that migration strategy is also involved: sturgeon that have migrated only a short distance have invested little energy and could abandon migration if disturbed.

Before new telemetry studies are attempted, the problem of drop-back needs to be minimized, otherwise only about 25% or so of the tagged fish will likely continue to move upstream. Perhaps drop-back can be reduced by tagging sturgeon further upstream (with more energetic investment and fewer fishery nets to escape), by minimizing handling using brief net sets, and by quickly tagging and releasing fish. Wintering fish can be internally tagged in autumn for later tracking the following spring, as is done for shortnose sturgeon (Kynard et al., 1999). In autumn 2000, stellate sturgeon were again gill-netted and tagged at rkm 58 on the St George Branch. It was found that stellate sturgeon could not be held for days in a pen (similar to the 1999 situation in the fishermen's pens); thus, holding them likely greatly increased the 1999 incidence of drop-back. All evidence indicates that stellate sturgeon migration interference must be brief. One of three Russian sturgeon dropped-back, but no conclusion can be reached due to the small sample size.

Recapture of tagged sturgeon by the fishery

Stellate sturgeon tag returns from the fishery of 38% in 1998 and 28% in 1999 (plus an unknown large unreported catch) indicate a high harvest rate. The recapture data is the first mark-recapture estimate of harvest for Danube sturgeon; data is biased low due to unreported harvest. Loss to harvest of all six upstream migrants (two in autumn 1998; three in spring 1999; and one in autumn 1999) within a few weeks after moving <97 km and before spawning shows the low probability of sturgeon surviving the fishery to spawn. The farthest upstream a tagged sturgeon swam before being harvested was rkm 247, downstream of major rocky habitat.

The harvest results clearly show that telemetry cannot be successful in a river with a high harvest rate. Tagging migrants at Harsova or farther upstream should reduce the percent loss of tagged fish to harvest, but losses would still occur because a fishery continues upstream in Bulgaria to Iron Gates II Dam (Navodaru et al., 1999). All evidence suggests that diadromous Danube sturgeons have the almost impossible task of avoiding harvest while traveling 258 km (or farther) upstream to reach spawning grounds. Until harvesting is reduced, drift net studies will be more successful for locating spawning reaches than the telemetry tracking of adults.

Most of the tag returns from fishermen likely came from sturgeon moving downstream. Because the stellate sturgeon body is coated with sharp scutes that entangle in any net they contact, the capture rates are likely similar for fish moving up- or downstream. If the high harvest rate of untagged sturgeon is similar to that of tagged sturgeon and this high harvest rate continues, the stocks will collapse.

Potential spawning locations

Geology of the lower river, which determines the location of rocky cliffs, likely also determines the spawning sites of sturgeon; the sandy river bottom dominating the lower river is unsuitable for spawning. Sand lacks crevices required for high survival of eggs and free embryos; thus, females have evolved preference for rocky substrate, which has crevices (Kynard and Horgan, 2001). Diadromous Danube sturgeons have likely evolved homing migrations to rocky areas. Whereas a few rare small rocky areas occur downstream of rkm 258, major rocky reaches do not occur until rkm 258 or farther upstream. Additionally, overharvest downstream of rkm 150 would likely have removed any stocks that historically spawned (or wintered) there. Spatial distribution of rocky areas is patchy, with patches separated by many kilometers, a spatial situation that could favor homing (and imprinting) of sturgeon to rocky spawning areas and the formation of many separate genetic demes within each species. This conceptual model of Danube sturgeon spawning is supported by genetic studies that found a high level of genetic polymorphism in all diadromous Danube sturgeons (Ferguson et al., 2000).

Drift nets set at rocky bottom sites should have captured sturgeon ELS if they were present, as they had earlier captured the beluga larva and have captured sturgeon ELS in other rivers (see 'Introduction'). Because the nets captured 17 fish species and no sturgeon ELS, and nets were fished for many hours at some sites, no sturgeon were likely present. Sturgeon ELS would be absent if spawning had not occurred because of natural factors or if overharvest had caused the collapse of stocks and spawning failure.

Capture of the beluga larva at Harsova shows that some beluga spawn upstream of rkm 238. This result is consistent with our conceptual model of the spawning location (>258 rkm) of diadromous Danube sturgeon. Recent studies of a species closely related to beluga, the kaluga *Huso dauricus* showed downstream migration from the spawning site was initiated by hatchling free embryos and that embryo migration lasted only 3 days (Zhuang et al., 2002). If Danube beluga larvae also migrate a few days and then stop, the larva at Harsova was likely spawned a short distance upstream of rkm 238, at a rocky area between rkm 258–310.

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Author's address: Boyd Kynard, S.O. Conte Anadromous Fish Research Center, Leetown Science Center (USGS), Box 796, Turners Falls, MA 01376, USA.
E-mail: kynard@forwild.umass.edu