Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Efficiency of a new artificial canal for safer release of sturgeon fry into the Caspian Sea through Bujagh Wetland, Northwestern Iran

Zohreh Ramezanpour*, Frozan Chubian, Esmaeil Farzaneh, Maryam Monsef Shokri, Korosh Hadadi Moghadam, Zabihollah Pazhand

International Sturgeon Research Institute, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Rasht, Iran, PO Box: 41635-3464

** Corresponding author's E-mail: zohreh.ramezanpour@gmail.com*

ABSTRACT

Numerous juvenile sturgeons are released into the Caspian Sea every year mainly through the Sefid-Rud River. This river has experienced various crises in the last decade including water drought, fishing, pollution, and especially the proliferation of hydraulic structures and lack of secured effective artificial canal for juvenile sturgeon release into the Caspian Sea. To challenge the problem of decreasing trends in sturgeon stocks of the Caspian Sea, a study was conducted to select and adapt a suitable, safe, and enemy-free artificial canal to safely release sturgeon juveniles to the Caspian Sea with the highest possible survival ratio. Therefore, the Kiashahr Waterway located in Bujagh Wetland, Southwest Caspian Sea was selected and investigated thoroughly as an alternative to the Sefid-Rud River. Water quality and quantity as well as sediment type were analyzed before and during the introduction of juveniles to the Kiashahr Waterway. Sturgeon juvenile release was conducted in June and July 2019 and 2020. The physical parameters of water, i.e., temperature, pH, transparency and chemical parameters including dissolved oxygen (2.41 ± 7.17 mg L^{-1}), and orthophosphate (0.10 ± 0.27 mg L^{-1}), nitrate (0.14 ± 1.37 mg L^{-1}), nitrite (0.02 ± 0.03 mg L^{-1}), ammonium (0.05 ± 0.43 mg L^{-1}) and COD (50.2 ± 120 mg L^{-1}) were determined. A huge pen was installed in the waterway and sturgeon fry were stocked in this pen for adaptation. Following days of adaption, some 192000 sturgeon juveniles were transported in floating cages and along the waterway to the estuary and released into the Caspian Sea safely in a very healthy shape and activity in 2019 and 2020. The survival rate of the released juveniles was monitored using a cast net (mesh size 0.7 cm) for several hours at the estuary (mesh = 0.7cm). No mortality was observed. All juveniles (100%) were transported in 12 portions, and released into the sea, and disappeared in its open waters. We suggest investigating other migration paths for the safer release of the precious sturgeon juveniles in the future to enhance the stocks in the Caspian Sea.

Keywords: Sturgeon, Kiashahr Waterway, Artificial channel, Fish releasing, Sefid-Rud, Bujagh.

INTRODUCTION

The design and construction of the fishway or fish passage facilities date back to at least the 17th century (Katopodis & Williams 2012). During migration, fishes move in specific and alternate paths. Fish density in a place and time is a very important variable that depends on the biotic and abiotic conditions of the environment. Diadromous fishes regularly migrate between fresh and saltwater for a definite time. Seasonal migration patterns have a decisive role in their life cycle. Currently, there is a sort of confusion and lack of knowledge about how fish migrate, especially sturgeon fry, which is sometimes reflected in the management of the rivers along the fish

Caspian J. Environ. Sci.
DOI:
Received:
Article type: Research

migration route (Cowx & Welcomme 1998). Silva *et al.* (2018) published a comprehensive discussion on the development of fishway science, engineering, the importance of integrating relevant scientific knowledge (i.e., Eco hydraulic analysis), as well as adaptive management. All efforts are aimed at improving the migration path of sturgeons so that the migration of fish is accomplished effectively and usefully (Winter *et al.* 2014). From the 17^{th} century, the design and construction of fishways began for the safer movement of fish to the river and the exit of fingerling to the sea (Katopodis & Williams 2012).

Success in fish migration is highly dependent on the water or hydrodynamic conditions of rivers and water bodies, management protocols, migration opportunities, and the structure of fishways (Griffioen & Winter 2017). Different types of fishways are used to facilitate migration, including conventional and natural fishways, fish lifts, downstream bypasses, and fish transport boats (Katopodis & Williams 2012). Fish passage systems for salmon species are based on extensive ecohydraulic research, while passages for non-salmon species frequently rely on limited biological information, or simply duplicate salmon fishways with limited adaptation (Katopodis 2005). The development of effective fishways for two-way sturgeon migration is still in the experimental phase. Lessons learned from past failures and partial successes, as well as knowledge accrued from comprehensive studies, have improved understanding, provided instructive paradigms, and offered optimism for reconnecting sturgeon habitat (Jager et al., 2016; Katopodis and Williams, 2016). Although the international community has taken measures against overfishing and pollutant discharge, wild populations of sturgeon will continue to decline (Billard & Lecointre 2000; Jager *et al.* 2016). In recent years, scientists have tried to find out executive policies and special management routines to enable fish and fry to reach their target habitats in the river.

The present research was conducted in an artificial channel instead of a fishway in Bujagh Wetland. The main objective and mission were to install a channel and implement an ecological corridor, to cover the entire migration route during the whole period of sturgeon juvenile release activities. The alternative artificial channel for releasing sturgeon fry was proposed to be set up in the protected and hunting-prohibited area of Bujagh Wetland. The wetland is managed by the Environmental Protection Organization. The proposed location for the artificial channel setup was the closest one to the Sefid-Rud River, and indeed there is no significant climatic difference between these two ecosystems. This study was carried out to find complementary and alternative routes for regular and urgent release of juvenile sturgeons.

MATERIALS AND METHODS

Studied area

The waterway is located in the central part of the Bujagh Wetland or Bujagh Marine National Park in Kiashahr Port, Guilan Province, Iran. This Park is a protected area and unauthorized trespass is extremely prohibited. It is at a short distance from the mouth or rather estuary of the Sefid-Rud River. In terms of shape, formation, and appearance, the area is a typical coastal pasture and wetland (Fig. 1).

Sampling

Release of sturgeon fry was carried out in June and July along the waterway of Kiashahr Port. Three stations were selected based on the distance from the Caspian Sea coastal line along the waterway from the river estuary (Fig. 1). Water and sediment samples were taken at the selected stations and designated locations where juvenile sturgeons are released every year (Fig. 1). Water samples were taken by Ruthner sampler and sediment by Van Veen grab with a coverage area of 225 cm^2.

Measurement of physical and chemical factors

Physical and chemical factors of water such as temperature, pH, and dissolved oxygen (DO) were measured with a field thermometer, multi-parameter pH meter, and portable oxygen meter (Hach model) respectively. Nitrate, nitrite, phosphate, and COD were measured according to the standard methods.

Sediment samples were taken by grab and washed thoroughly with water on a 0.5 mm sieve and the retained materials on the sieve including organisms were collected and placed in a plastic container with a lid and preserved with 10% formalin. The samples were washed again in the laboratory and examined under the stereomicroscope for determination and enumeration of benthic organisms.

Caspian J. Environ. Sci.
Received:
DOI:
Article type: Research

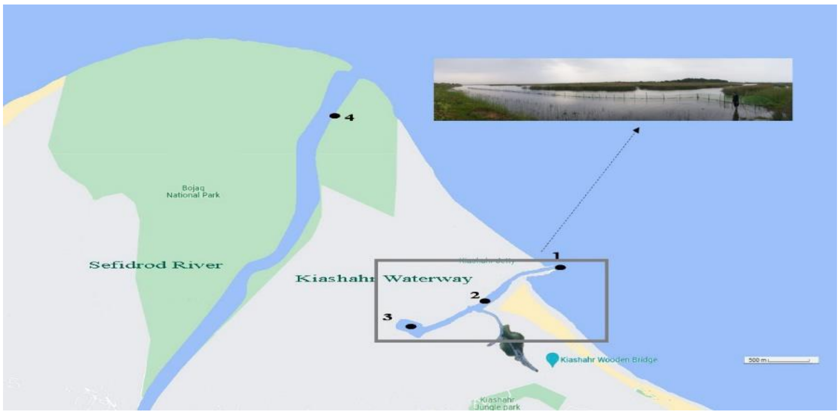


Fig. 1. Map of sampled stations (1, 2, and 3) in the Bujagh Wetland waterway, Kiashahr in Guilan Province, and (4) in the Sefid-Rud River

Releasing juvenile sturgeon

The first release of juvenile sturgeons was done in mid-June, 2019. Some 1000 juveniles were introduced into the cages and released in a carefully monitored manner. The weight range of fingerlings was 0.85 ± 0.15 g. In the next step, another 4,000 fingerlings were added to the cages, with an average weight of 1-1.2 g. The cages were cleaned every day. Every other day the floating cages were gradually moved to the middle of the waterway toward the Caspian Sea. About 500 m to the sea, fingerling sturgeons were transferred to the baskets in the waterway where freshwater was still dominant and rested there. After resting there for 3 hours, they were slowly moved towards the sea in such a way that they were kept for 2 hours in the salinity of 2 PSU, and 2 hours in the salinity of 5 PSU. Then they moved to the salinity of 9 PSU (inside the sea). After 3 hours in this salinity condition, the juveniles were released into the Caspian Sea. Juvenile sturgeons (n = 12000) were released in pen in the same waterway of Kiashahr as validation and re-control in 2020.

Floating cage

Two floating cages were built to control the adaptation status of fish fry to the ecological features of the Kiashahr Waterway. The internal dimension of cages was 5 × 5 m and external dimension was 6 × 6 m, the internal depth under water was 1.5 m, and the distance from the floor was 1m fitted with a silk net. Some 8 barrels were used to maintain each cage in floating condition. Some 66.5 m rods and connections were used in the cage frame and were installed in a place with a depth of 2.5 m (Fig. 2A).

Floating baskets

Floating baskets were prepared from 20-L buckets with a diameter of 30 cm and a height of 35 cm. In the body of each bucket, several holes with a diameter of 1 mL were made, so that they could be easily immersed, and free passage of water through these holes was secured. To keep the baskets floating in the water, each basket was placed inside a tube filled with air (Fig. 2B).

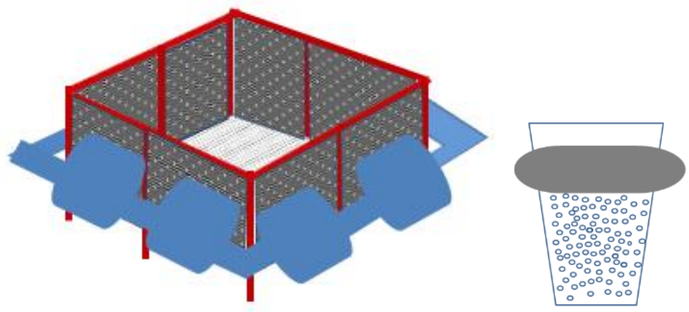
Corridor for transporting juvenal sturgeon to the sea

Kiashahr Waterway was used for transporting juvenile sturgeon to the Caspian Sea during the annual sturgeon releasing season in 2020 and 12,000 sturgeon juveniles were released through this waterway within 12 days. A protective fence with 1.5 m height and 200 m length was installed at a distance of 500 m from the entrance to the Caspian Sea using a net, to ensure the absence of predatory fish. The separated path was completely cleared of aquatic plants (Fig. 1).

Growth indicators

The final weight (Wt) and fork length (FL) of 30 fish were measured every other day and to the end of the experiment. The growth rate (Ronyai & Peteri 1990), specific growth rate, body weight increase (Wang *et al*. 2003), and survival rate were also determined (%).

Caspian J. Environ. Sci.
DOI:
Received:
Article type: Research



A B

Fig. 2. A- The design of floating cages. B-floating baskets, used for the transfer and adaptation of sturgeon fingerlings

RESULTS

The climatic parameters were recorded daily. The average rainfall was 0.042 mm at the end of June and in July 2019, it was just eight precipitation days (0.2-27.8 mm). The pH of the water was 8.60-9.60 with an average of 9.34 ± 0.29.

The minimum dissolved oxygen (DO) during the day and night was 3 mg L^{-1} at 4:00 AM on the sediment surface and the maximum was 10 mg L^{-1} in the Station 2 waterway at 9:00 AM (Table 1). The DO levels showed significant differences between stations ($p < 0.05$). The changes in COD, nitrate, nitrite, ammonia, and orthophosphate levels in the Kiashahr Waterway and Sefid-Rud River are presented in Table 1. COD levels were also significantly differed between stations ($p < 0.05$) over time.

Table 1. Physicochemical properties of water in the Kiashahr Waterway and Sefid-Rud River during the experiment in 2019.

Area	**Do**	**N-NO_2**	**NH_3**	**N-NO_3**	**PO_4**	**COD**	**Saturation DO**
Unit	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	%
Kiashahr Waterway							
Avg ± SD	0.03 ± 0.02	0.43 ± 0.05	1.37 ± 0.14	0.27 ± 0.1	120 ± 50.2	7.17 ± 2.41	97.7 ± 28.9
Min-Max	0.009-0.055	0.34-0.49	1.23-1.60	0.15-0.42	71-182	2.90-11.30	47.2-145.2
Sefid-Rud River							
Average ± SD					0.047 ± 0.01	0.49 ± 0.16	0.87 ± 0.12
Min-Max					0.03-0.06	0.39-0.67	0.74-0.98

The Highest COD value was 182 mg L^{-1} measured in the middle part (Station 2) of the Kiashahr Waterway (Table 1). There were no significant differences in nitrates, nitrite, and ammonia between sampling stations. The highest amount of orthophosphate was observed in the middle of the Kiashahr Waterway, while the lowest was inside the freshwater-dominant part of the canal (Table 2).

Sediment texture which indicates the relative content of particles of various sizes in the waterway was a mixture of clay, silt, and sand. The average amount of sand was 76.6 ± 1.11%, silt 10.77 ± 0.09% and clay 12.61 ± 1.12%. The percentage of sand near the Caspian Sea where fingerlings entered the sea was higher than the other two stations, although the difference was not statistically significant (Table 2).

Caspian J. Environ. Sci.
Received:
DOI:
Article type: Research

Table 2. The texture of bed sediments in the Kiashahr Waterway**.**

Station No	Soil texture (%)			
	Sand	**Silt**	**Clay**	**Silt + Clay**
1	77.42	9.7	12.8	22.8
2	75.34	11.03	13.62	24.65
3	77.04	11.54	11.40	22.95

The range of total organic matter in the sediments of the Kiashahr Wharf riverbed was from 6.51% at the station inside the Kiashahr Wharf area to 3.53% at the entrance to the Caspian Sea station. The average amount of organic matter in the total substrate was calculated as 4.56 ± 0.83% in the waterway of Kiashahr dock (Table 2).
The average amount of organic matter (TOM) in the sediment of the waterway was 4.56 ± 0.83% ranging from 6.51% inside the waterway to 3.53% at the entrance to the waterway (Table 3).
Benthic samples were examined and 9 macro-benthic species were identified belonging to three phyla, i.e., Mollusca, Arthropoda, and Annelida. Four species including *Cerastoderma edule*, *Dreissena polymorpha*, *Abra ovata,* and *Lymnaea* sp. belonged to mollusks. Diversity of Arthropoda included families of Chironomidae (Diptera- Insects), Ceratopogonidae (Diptera - insect), and Balanidae (crustacean). *Lumbriculus* sp. and *Tubifex* sp. belonged to Clitellata. The most abundant benthos with 24520 ind.m^{-2} were observed at Station 3 of the waterway.
The estuarine part of the waterway, which was considered its exit station, exhibited the lowest abundance (80 ± 30 ind. m^{-2}; Fig. 3-3). In total, 45% of the benthic organisms belonged to mollusks, 33% to arthropods and 22% to annelids.

Table 3. Average of TOM (%) in the Kiashahr Waterway in June 2019.

Parameter	Sampling Station		
	1	2	3
TOM	4.05	4.32	5.30
SD	0.45	0.39	1.04

In the first experiment, some 5000 sturgeon fingerlings were released by floating cages along the waterway to the Caspian Sea. The growth factor, weight gain index, growth rate, and survival rate were 4.8, 150%, 0.9 and 73% respectively. In the second release experiment, 1000 sturgeon fingerlings were released following the adaptation period in floating baskets. The study showed a 100% survival rate with active swimming in the coastal part of the Caspian Sea.
In the third release experiment that took place in 2020, the release of sturgeon fingerlings was carried out on the actual and common scale, as fish released to the Sefid-Rud River in 12 replicates. Fingerling releasing was carried out using an installed pen in the waterway. Using a pen led to the appropriate management of fish movement towards the Caspian Sea in a closed and secured path. There were no injuries or mortality in juvenile sturgeons. The Juvenile sturgeons finally entered the Caspian Sea without any mortality whatsoever. The fish were very healthy and swimming actively in the seawater.

DISCUSSION

Environmental and endogenous parameters influence fish migration behavior, including water flow, temperature, and water quality. Environmental conditions have been reported to alter and change water quality (Lucas & Baras 2001) Sefid-Rud River is the main river for sturgeon spawner and juvenile migrations in the southern parts of the Caspian Sea in opposite direction de facto. However, due to various environmental issues, it is not as important as it used to be in the past. This study aimed to select an alternative location to release sturgeon fry in the river or supplement the Sefid-Rud River during the sturgeon juvenile releasing season.
Using a gradient-based array of acoustic telemetry receivers, we compared the seasonal incidence and movement behavior of Atlantic sturgeon in the near-shelf region of Maryl and the USA. Atlantic sturgeon incidence was highest in the spring and fall and tended to be biased toward shallow regions

Caspian J. Environ. Sci. Received:
DOI: Article type: Research

Water level fluctuations and low levels of water during the sturgeon-releasing season in the Sefid-Rud River are some of the most negative issues that deteriorate the ecological condition required for fingerling migration. Fadaei *et al.* (1998) in their investigation carried out in the Sefid-Rud River, through direct observation reported that a huge number of juvenile sturgeons were caught by fishing gear, nets, ghost nets, a gathering of predatory fishes and birds within the river, and concluded that the most destructive factor hindering juvenile sturgeon migration in the river was fishing gears deployed in the river rather than a deterioration of ecological features. Seasonal movements of short-nose sturgeon in the Altamaha River system, in Georgia were examined. The data revealed that during much of the year, the adults resided within the tidally influenced portion of the river, with most detections occurring near the freshwater-saltwater interface. Upstream movements to potential spawning habitat occurred during winter and early spring, and most fish returned to the lower estuary by April (Ingram & Peterson, 2018).

Kiashahr Waterway was selected and suggested as an alternative location to release sturgeon fry in case of necessity and disturbances in the Sefid-Rud River. The main reason for selecting this waterway was the fact that it is located in the protected and hunting and fishing prohibited Bujagh National Park. This is a huge advantage that secures safer release of the fish without any interference by local fishermen. The Bujagh National Land-Sea Park is under the management of the Environmental Protection Organization of Iran and provides a safe and secure route for sturgeons to enter the Caspian Sea. The canal is located 2 kilometers distant from the Sefid-Rud River. In addition, the temperature and atmospheric conditions in both habitats are entirely similar by comparing the data obtained from Sefid-Rud and the results of investigations carried out in the Kiashahr Waterway. The water pH was alkaline in both environments.

The COD levels increased in the Kiashahr canal in June due to the lack of rainfall, although its average value was similar to the data obtained from Sefid-Rud. However, the mean COD in the canal was suitable for sturgeons. Nagpal *et al.* (1995) believe that the maximum level of COD in water suitable for aquatic life is 215 mg L^{-1}. The COD values Gorgan Bay used for sturgeon fisheries have been reported 93.2 mg. L^{-1} in the sturgeon breeding cages (Gholizadeh & Heydari 2020).

The threshold values of nitrate tolerance are not available for juvenile sturgeon, however, Holcik (1989) and Chebanov & Galich (2013) have suggested 1 mg for the sturgeon fry hatchery. The mean nitrite values in the Kiashahr Canal were less than the Sefid-Rud River. The limiting value of nitrite expressed for a sturgeon hatchery with hard- and soft-waters are 0.2 and 0.1 mg respectively (Chebanov & Galich 2013). The range of ammonia in the waterway was lower than the values measured at the releasing site in the Sefid-Rud River. Ammonia at a level of 0.5 mg L^{-1} is the permissible range for the spawning grounds of sturgeons. Comparing the mean values of types of N obtained from the Kiashahr Canal and Sefid-Rud River did not exhibit any significant differences. The orthophosphate content in the Kiashahr Waterway was higher than the values obtained in the Sefid-Rud River. The results of orthophosphate values were lower than the limit of 0.3 mg L^{-1} suggested for sturgeon hatcheries (Chebanov & Galich 2013).

The sediment texture included three types of clay, silt, and sand, so that, sand counted for 75% of the sediment composition which seems to be suitable for sturgeons. A study of the benthic organisms indicated a high amount of benthos as food for juveniles in the Kiashahr Canal, while no benthic invertebrates were observed in the Sefid-Rud sediment samples. Therefore, given the abundance of benthic organisms in the Kiashahr Canal and Sefid-Rud River, it is apparent that the canal provides much better conditions for juvenile sturgeons concerning live feed availability during their movement to the Caspian Sea.

Dreissena polymorpha, a bivalve benthos, was the most abundant macrobenthic species in the Kiashahr Waterway followed by *Tubifex* (Annelida), *Balanus* (crustacean), and *Cardium edule* (bivalve) in descending order. During the releasing experiment in 2019, in which juvenile sturgeons were transferred to the sea in floating cages, the growth factor was 4.8, the percentage of weight gain index 150%, the growth rate 0.9, and fingerlings entered the sea with a survival rate of 73%. In another experimental release in the present study which was carried out using cages and floating baskets, the survival rate of fish fry entering the Caspian Sea was 100% with active swimming in the coastal part of the Sea. In 2020. Based on the results obtained from 2019, the release of sturgeon fry was carried out on an actual scale in 2020.

It is encouraging that sturgeon passage has received increasing attention in Europe, the United States, and Canada. For example, in California, USA, Cocherell *et al.* (2011) showed that adult White sturgeon ascended a 24.4 m fishway, swimming at 2.52 m s^{-1} against water velocities of 1.7-2.1 m s^{-1}. In Quebec, Canada, adult Lake sturgeon

Received:
DOI:
Article type: Research

used a vertical slot fishway with a slot width of 0.6 m, water level drop per pool of 0.15 m, and regular pools 3.50 m long by 3.00 m wide. This situation provided knowledge useful for facilitating migration and re-connecting sturgeon habitats interrupted by dams and other human activities (Thiem *et al.* 2011; Katopodis & Williams, 2016).

By movement of fish in a closed path, they are safe from the reach of waterfowls and predatory fish. There were no instances of fish mortality during the monitoring of the releasing activity, so that, healthy juvenile sturgeons were observed in the sea with active swimming and the survival rate was 100%. In conclusion, considering the abundance of benthic organisms and suitable physical and chemical conditions, the Kiashahr Waterway provides a much better condition for sturgeon juveniles during their migration period. On the other hand, the shorter path from the releasing site to the estuary and the absence of authorized and unauthorized fishermen guarantee a much safer release of sturgeons. The pen significantly enhanced the survival of fingerlings and reduced the risks of predation by predators. The experiment proved that the artificial channel could be considered as a routine path for sturgeon juvenile release rather than an alternative path with a very high survival rate and entry into the Caspian Sea. Similar artificial channels could be set up in different parts of the southern basins of the Caspian Sea to guarantee successful entry of the valuable sturgeon juveniles into the sea increasing the rehabilitation potential of already deteriorated stocks of sturgeon in the Caspian Sea.

Although the former Soviet Union spent time and effort on sturgeon passage development, but reports on research and facilities were limited. The Gezhouba Dam, the furthest downstream in a cascade of hydroelectric stations on the Yangtze River, obstructs the migration of Chinese sturgeon (*Acipenser sinensis*) and rather than building fishways, cultured sturgeon were tagged and released below the dam (20,000 annually from 1998 to 2001) to conserve the downstream population (Chang & Cao 1999). However, the artificially bred sturgeon made up only 0.00%–0.45% of the juvenile population at the mouth of the Yangtze River (Wei 2003). Some investigators anticipated that Chinese sturgeon would use the large ship channel at Gezhouba Dam for passage, but this has not been verified and there are a few spawning grounds below the dam (Chang & Cao 1999). Chinese sturgeon populations have continued to decline (Turvey *et al.* 2010) and, while overfishing and pollution threaten Chinese sturgeon (Hu *et al.* 2009; Turvey *et al.* 2010), dam construction plays an even more important role.

A proper understanding of swimming performance is necessary for designing artificial channels. For decades, swimming performance and types of artificial channel have been investigated. The best results need to use AI in design and sturgeon behavior.

REFERENCES

Billard, R & Lecointre, G 2000, Biology and conservation of sturgeon and paddlefish, *Reviews in Fish Biology and Fisheries*, 10: 355-392.

Chang, J & Cao, W 1999, History and prospect of conservation on Chinese sturgeon in the Yangtze River, *Acta Hydrobiologica Sinca*, 23: 712-720 (In Chinese).

Chebanov, MS & Galich, EV 2013, Sturgeon hatchery manual. FAO Fisheries and Aquaculture Technical Paper, Food and Agriculture Organization of the United Nations Ankara, No. 558, p. 338.

Cocherell, DE, Kawabata, A, Kratville, DW, Cocherell, SA, Kaufman, RC, Anderson, EK, Chen, ZQ, Bandeh, H, Rotondo, MM, Padilla, R, Churchwell, R, Kavvas, ML & CechJr, JJ 2011, Passage performance and physiological stress response of adult White sturgeon ascending a laboratory fishway, *Journal of Applied Ichthyology*, 27: 327-334.

Fadaei, B, Bahmani, M, Parandavar, H, Yakhu, MR, Imanpour, J & Jooshideh, H 1998, The study of released sturgeon fry from the beginning of release to entering the sea in 1998. *International Research Institute of Caspian Sea*, p. 166.

Gholizadeh, M & Heydari, O 2020, surface water quality indicators in Gonbad Kavous. *Iranian Journal of Health and Environment*, 13: 33-48.

Griffioen, AB & Winter, HV 2017, Fish migration river monitoring plan monitoring program on the effectiveness of the FMR at Kornwerderzand. *Wageningen Marine Research*, Report C012, 17C, p. 50.

Holcik, J 1989, Freshwater fishes of Europe (Vol. I, part II), General introduction to fishes and Acipenseriformes. Wiesbaden, Aula Verlag, 469 p.

Hu, J, Zhang, Z, Wei, Q, Zhen, H, Zhao, Y, Peng, H, Wan, Y, Giesy, JP, Li, L & Zhang, B 2009, Malformations of the endangered Chinese sturgeon Acipenser sinensis, and its causal agent. *Proceedings of the National*

Caspian J. Environ. Sci.
DOI:
Received:
Article type: Research

Academy of Sciences (PNAS), USA, 106: 9339–9344.
Ingram, EC & Peterson, DL 2018, Seasonal movements of shortnose sturgeon (*Acipenser brevirostrum*) in the Altamaha River, Georgia, John Wiley & Sons, 1-10, Ltd, DOI: 10.1002/rra.3322.
Jager, HI, Parsley, MJ, Cech, JJ, McLaughlin, RL, Forsythe, PS, Elliott, RF& Prachell, BM 2016, Reconnecting fragmented sturgeon populations in North American rivers. *Fisheries,* 41: 141-148.
Katopodis, C 2005, Developing a tool kit for fish passage, ecological flow management, and fish habitat works. *Journal of Hydraulic Research* (*JHR*), 43: 451-467.
Katopodis, C & Williams, JG 2012, The development of fish passage research in a historical context. *Ecological Engineering*, 48: 8-18.
Katopodis, C & Williams, JG 2016, Not all fishways are created equal. Paper 26152. In: JA, Webb, JF, Costelloe, Casas-Mulet, R, Lyon, JP, Stewardson, MJ (Eds.), Proceedings of the 11th International Symposium on Ecohydraulics. University of Melbourne, Melbourne, Australia, 7-12 February 2016 ISBN: 978 0 7340 5339 8.
Lucas, MC & Baras, E 2001, Migration of freshwater fishes, Blackwell Science Ltd, 440 p.
Lu, Cai & Johnson, D 2019, Sturgeon survival: The role of swimming performance and fish passage Research, Christos Katopodis. *Fisheries Research*, 212: 162-171.
Nagpal, NK, Pommen, LW & Swain, LG 1995, Approved and working criteria for water quality. Water Quality Branch, Environmental Protection Department. British Columbia Ministry of the Environment. Victoria, British Columbia, 45 p.
Ronyai, A & peteri, A 1990, Comparison of the growth of sterlet (*Acipenser ruthenus*) and its hybrid with Siberian sturgeon (*Acipenser ruthenus*, *Acipenser baeri*) in recirculation system. Aq*uaculture Hungrica (Szarwas),* 5: 185-192.
Silva, AT, Lucas, MC, Castro-Santos, T, Katopodis, C, Baumgartner, LJ, Thiem, JD, Aarestrup, K, Pompeu, PS, O'Brien, GC, Braun, DC, Burnett, NJ, Zhu, DZ, Fjeldstad, H, Forseth, T, Rajaratnam, N, Williams, JG & Cooke, SJ 2018, The future of fish passage science, engineering, and practice. *Fish Fisheries*, 19: 340-362.
Thiem, JD, Binder, TE, Dawson, JW, Dumont, P, Hatin, D, Katopodis, C & Cooke, SJ 2011, Behaviour and passage success of upriver-migrating lake sturgeon *Acipenser fulvescens* in a vertical slot fishway on the Richelieu River, Quebec, Canada. *Endangered Species Research*, 15: 1-11.
Turvey, ST, Barrett, LA, Hao, Y, Zhang, L, Zhang, X, Wang, X, Huang, Y, Zhou, K, Hart, T & Wang, D 2010, Rapidly shifting baselines in Yangtze fishing communities and local memory of extinct species. *Conservation Biology*, 24: 778-787.
Wang, Y, Crawford, MA, Chen, J, Li, J, Ghebremeskel, K & Campbell TC 2003, Fish consumption, blood docosahexaenoic acid and chronic diseases in Chinese rural populations, *Comparative Biochemistry and Physiology*, *Part A*, 136: 127-140.
Wei, Q 2003, Reproductive behavioral ecology of Chinese sturgeon (*Acipenser sinensis* Gray) with its stock assessment. Institute of Hydrobiology-Chinese Academy of Sciences, Wuhan, 121 p. (In Chinese)
Welcomme, RL & Cowx, IG 1998, Rehabilitation of rivers for fish, FAO and Fishing News Books, Wiley–Blackwell, 304 p.
Winter, HV, Griffioen, AB & Keeken, OAV 2014, De Vismigratierivier: Bronnenonderzoek naar gedrag van vis rond zoet - zout overgangen [The Fish Migration River: Source research into fish behavior around fresh-salt transitions]. *IMARES* (Institute for Marine Resources & Ecosystem Studies), Ijmuiden. 127 p.

Caspian J. Environ. Sci.
DOI:
Received:
Article type: Research