Bol. Inst. Esp. Oceanogr. 16 (1-4). 2000: 127-137

BOLETÍN. INSTITUTO ESPAÑOL DE OCEANOGRAFÍA
ISSN: 0074-0195

Sturgeon spawning grounds in the Odra River tributaries: A first assessment

J. Gessner[1] *and R. Bartel*[2]

[1] Society to Save the Sturgeon *Acipenser sturio* L. e.V., c/o Department of Biology and Ecology of Fishes, Institute of Freshwater Ecology and Inland Fisheries, PO Box 850123, D-12561 Berlin, Germany. E-mail: sturgeon@igb-berlin.de
[2] Inland Fisheries Institute, River Fisheries Laboratory, Reduta Zbik 5, 80-761 Gdansk and Sea Fisheries Institute, Kollataja, 81-332 Gdynia, Poland

Received September 1999. Accepted June 2000.

ABSTRACT

As part of a feasibility study for the re-establishment of *Acipenser sturio* L., 1758 in its previous range in German and Polish waters, a habitat assessment was initiated for the Odra River watershed. Spawning habitat for sturgeons is considered to be of major importance for the successful restoration and subsequent reproduction of the species, since it supports the most vulnerable life stages. The ongoing restoration project comprises three distinct phases; the first phase included the evaluation of readily available habitat. Habitat requirements were identified based on published information on sturgeon reproduction, historical catch data, and early life history. Potential spawning habitats were determined in a first step based on historic records. For the identified historic spawning sites, recent data on migration obstacles and water pollution were evaluated, thus excluding non-accessible or adversely affected sites. In the Drawa River –described as a sturgeon spawning habitat until 1939– potentially suitable habitats were determined to be readily available. Data were gathered on the dynamic of the discharge, water quality, longitudinal profiles and cross-sections of the river, as well as substrate composition. Five river stretches comprising approximately 15 000 m² were identified as being potentially suitable for sturgeon spawning. Assuming an average fertility of 1 million eggs per female and a maximum density of 3 500 eggs/m², the spawning-site surface required for an average female would comprise approximately 350 m². Thus, the Drawa River could provide a spawning habitat for approx. 50 females.

Key words: *Acipenser sturio*, Germany, Poland, North Sea, reproduction.

RESUMEN

Lugares de freza del esturión en los afluentes del río Oder: una valoración inicial

Como parte de un estudio de viabilidad para el restablecimiento de Acipenser sturio *L., 1758 en su distribución original en aguas alemanas y polacas, se inició una valoración del hábitat en la cuenca del río Oder. Se considera que el hábitat de freza para los esturiones es de mayor importancia para el éxito de la recuperación y subsecuente reproducción de las especies, ya que mantiene los estados vitales más vulnerables. El proyecto de recuperación en marcha comprende tres fases diferentes; la primera incluyó la evaluación de hábitat fácilmente disponible. Los requerimientos de hábitat fueron identificados a partir de información publicada sobre la reproducción del esturión, datos históricos de capturas, e historia natural temprana. Los hábitats potenciales de freza fueron determinados, en una primera fase, a partir de citas históricas. Para los lugares de freza históricos identificados, los datos recientes sobre obstáculos a la migración y contaminación del agua fueron evaluados, excluyendo los lugares no accesibles o adversamente afectados. En el río Drawa –descrito como un hábitat de freza para el esturión hasta 1939– los hábitats potencialmente apropiados fueron determinados para ser fácilmente disponibles. Se reunieron datos sobre dinámica de la descarga, calidad del agua, perfiles longitudinales y secciones transversales del río, así como de la composición del sustrato. Cinco* *secciones fluviales, comprendiendo aproximadamente 15 000 m², fueron identificadas como potencialmente apropiadas para la freza del esturión. Asumiendo una fecundidad media de un millón de huevos por hembra y una densidad máxima de 3 500 huevos/m², la superficie de lugar de freza requerida para una hembra media comprendería aproximadamente 350 m². Así, el río Drawa podría proporcionar un hábitat de freza para aproximadamente 50 hembras.*

Palabras clave: Acipenser sturio*, Alemania, Polonia, Mar del Norte, reproducción.*

INTRODUCTION

Historically, the European sturgeon *Acipenser sturio* L., 1758 inhabited all major Central European rivers, including the Njemunas, Vistula, Odra, Elbe, Eider, Weser, Ems and Rhine (Holčík *et al.*, 1989). Since the beginning of the 20th century, sturgeons have become rare due to habitat alterations and overexploitation (Gessner, 2000). Today the sturgeon is considered extirpated in the North Sea tributaries and extinct in the confluences to the Baltic Sea (Bless, Lelek and Waterstraat, 1994).

Water quality has improved recently in the Weser, Elbe and Odra Rivers. This has been a consequence of changes in industrial production and the increased efficiency of wastewater purification due to German unification and subsequent developments (Anon., 1998), –a major prerequisite for the return of diadromous fish species to the rivers (Sych *et al.*, 1996). In any case, historical reasons for the decline of *A. sturio*, *Salmo salar* L., 1758, *Alosa alosa* (L., 1758), *Petromyzon marinus* L., 1758 and others must be understood in detail in order to assess the requirements for future remediation measures (Kirschbaum and Gessner, 2000).

The Odra River was selected for the present work because its lower section is largely unaltered, thus providing flood plains, backwaters and side-arms. Large areas of the river are still freely accessible. The decreasing pollution following the effectuation of international agreements (HELCOM) (Anon., 1993) provides a sound basis for the future development of rheophilic fauna. Spawning runs of *Salmo trutta* L., 1758, *Vimba vimba* (L., 1758) and *Coregonus lavaretus* (L., 1758) are still observed in the river and *S. salar* was successfully re-established in the Odra River tributaries during the early 1990s (Bartel, 1997). Furthermore, the available infrastructure for joint research and planning in the Baltic Sea makes it possible to closely monitor tagged fish after stocking.

The Odra River system has a catchment area of 120 000 km², to which Poland contributes 89 %, the Czech Republic 6 % and Germany 5 % (figure 1). The river is 865 km long with an average slope of 0.07 ‰. The runoff during the year varies between 250-1 500 m³/s, with an annual mean of 17 km³ for the lower Odra River. The main tributary is the Warta River, which contributes 40 % of the runoff.

The main alterations to the Odra River system can be summarised as follows. In 1740, major dyking and regulation activities were begun to develop arable land. Between 1740 and 1850, further regulations to increase navigability and improve drainage of the pasture lands led to the transfer of the main stem to the eastern river arm. The river constructions resulted in a maximal reduction in length of up to 60 % in some mid-river sections (Meier, 1992). For the sturgeon, the historic spawning grounds in the upper reaches of the river near Raciborcz were blocked by dams and weirs since the early 18th century. In addition, these hydro-constructions reduced the accessible habitat for juveniles in the middle part of the river. The altered habitat structure resulted in drastic changes to the fish population's composition (Albrecht, 1964; Wolter and Vilcinskas, 1998). Since the middle of the 19th century, increasing loads of communal wastes and effluents from primary and secondary industries polluted the riverine ecosystems (Schiemenz, 1905). The last recorded *A. sturio* from the Odra tributaries was caught in 1952 in the Warta River (Przybyl, 1976).

In Germany, a programme for the re-establishment of *A. sturio* was begun in 1996. This remediation programme is divided into three phases. The first phase included the identification of readily available habitats for reproduction and early life stages in the Odra River tributaries. During the subsequent phase of the project, the actual status of historical spawning grounds are to be described and an assessment of necessary improvements will

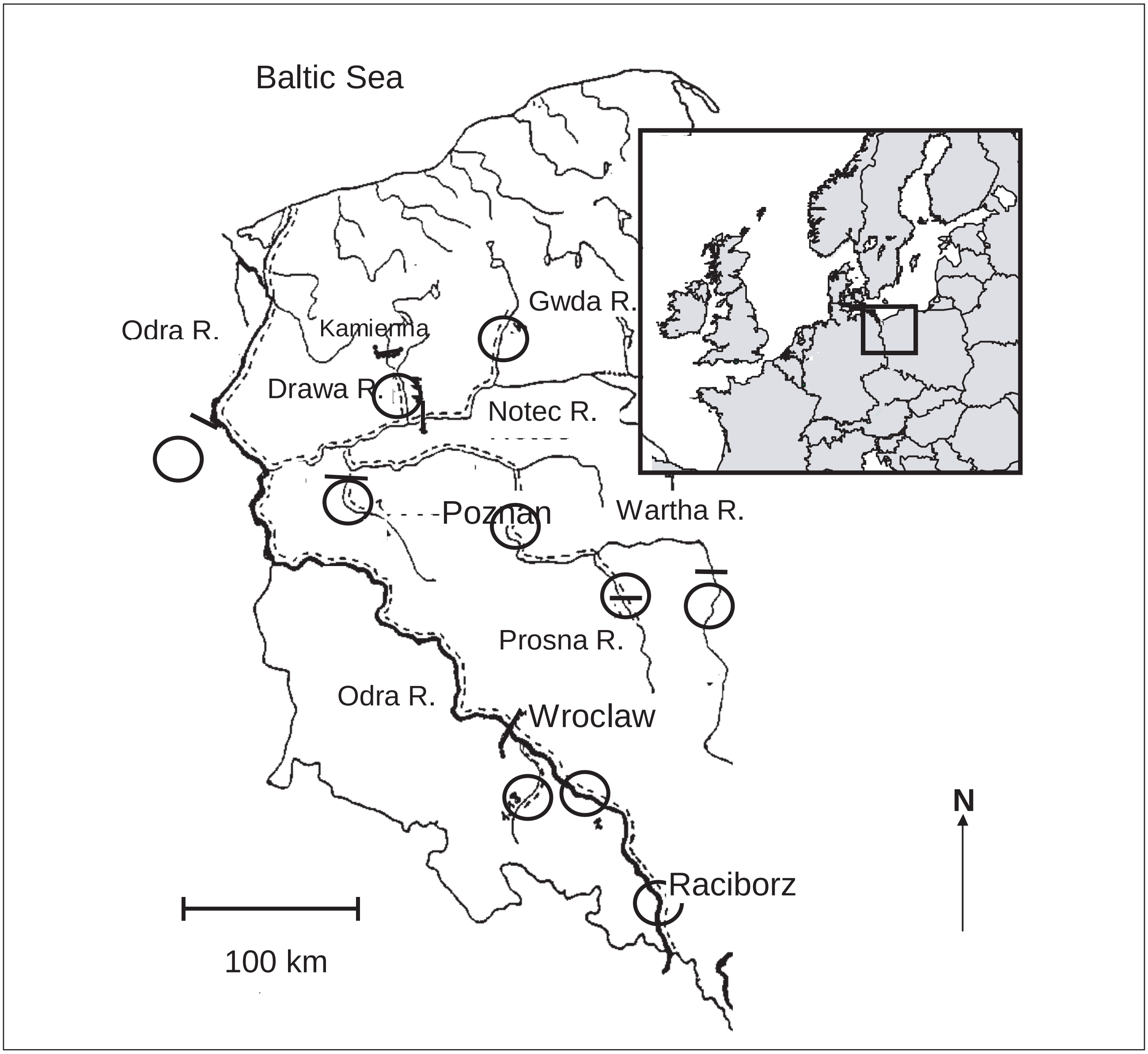

Figure 1. Odra River and tributaries, its localization, and the historic distribution of *A. sturio* (after Sych *et al.,* 1996); migration routes are indicated by dotted lines, migration obstacles are given by lines across the river, spawning sites are indicated by circles

be carried out. The third phase will deal with the experimental release and follow-up of *A. sturio* to determine habitat utilization and potential threats.

MATERIALS AND METHODS

A list of criteria for spawning habitats for *A. sturio* was compiled, based on published information (table I). This was used as a basis for a decision tree, to compare the suitability of potential sites with the given criteria (figure 2).

Identification of potential spawning grounds was based on data on the historic spawning grounds in the Odra River system from Wittmarck (1875), Grabda (1968), Przybyl (1976) and Sych *et al.* (1996). Migration obstacles and structural alterations were determined using maps. In cases where the degree of alterations were unclear, direct observation was carried out.

An impact assessment for habitat alterations and their potential effects upon the reproductive efficiency of *A. sturio* was performed, considering the degree of the alterations.

Table I. Criteria for spawning habitat of *A. sturio*, compiled after various authors. (1): determined for *A. oxyrinchus desotoi*; (2): determined for *A. brevirostrum*

Criterion	Quality	Reference
Substrate	Pebble > Ø3 cm or rock Ø10-Ø30 cm	Elie, 1997
Sedimentation	Absent	Sulak and Clugston, 1999(1)
Oxygenation	Interstitial	Richmond and Kynard, 1995(2)
Current velocity	0.4-2.0 m/s	Elie, 1997; Ninua, 1976
Temperature	17-20 °C	Ehrenbaum, 1936
Depth	1-12 m	Vlasenko, 1974
BOD	Low	

Firstly, the absence of migration obstacles (e.g. dams) was chosen as the primary criterion for potentially leading to blocking of migration routes. Modification of hydrology by effluent regulation disrupts the natural runoff in intensity and temporal scale. An alteration of temperature regime is likely under these circumstances.

Secondly, river-bed modification was evaluated. These impacts reach from gravel or sand removal to sealing of natural substrate with increasing structural uniformity. As a consequence, reduction of spawning habitat for rheophilic fish species occurrs, resulting in the alteration of community structure.

Thirdly, ameliorations (e.g. straightening of river) and disconnection of meanders results in the reduction of connected backwaters, the increase of flow velocity and the increase of runoff intensity.

Water quality criteria of particular importance for spawning habitat evaluation were biological oxygen demand (BOD), oxygen contents, sanitary standards, chlorinated carbohydrates, and temperature. Water analysis for the Polish river stretches was performed by the regional water authorities (WIOS 1993-1997) (Anon., 1997). For the German part of the Odra River, data were provided by the Landesumweltamt Brandenburg (Anon., 1998; Prein-Geitner, Sonnenburg and Drewes, 1993).

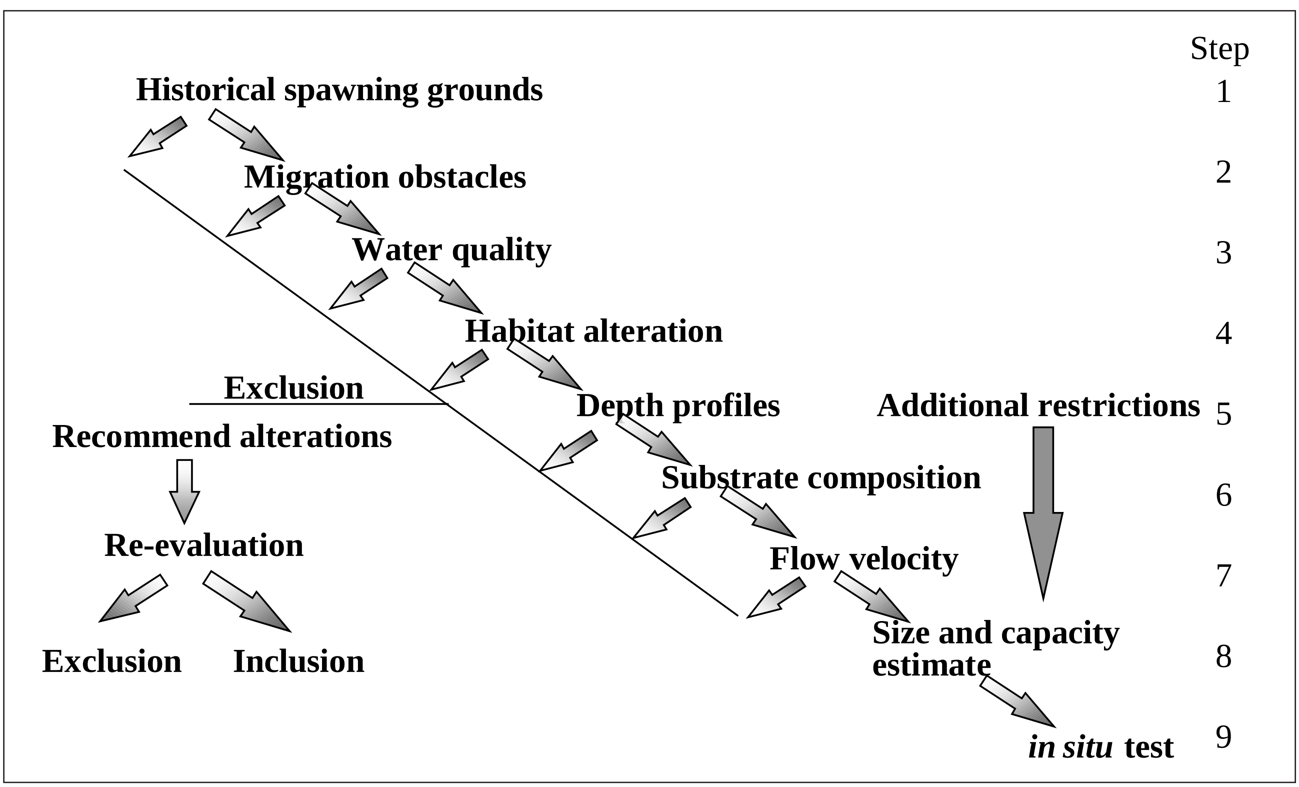

Figure 2. Basic decision tree for the determination of potential spawning grounds for *A. sturio*

The results of the impact assessment for hydro-constructions and their effects on the reproductive efficiency of *A. sturio*, based upon a ranking system using a scale from 0 to 10 for each of the given criteria, can be integrated into a model (after Wild and Kunz, 1992) for structural assessment of lotic waters, including additional indices for relevant aspects of structural properties, thus providing the potential to assess the structural quality of the river stretches in question.

After criteria 1-4 of the decision tree (figure 2) were met, a depth-profile of the river was determined in the river channel by echo-sounding. The profile was recorded during downstream passage on the lower 32 km of the river, below Kamienna dam. The data were collected using a Simrad® echosounder (Model EA300) with a Trimble NT200D GPS. Oxygen, temperature, pH and conductivity were determined every 100 m using Oxyguard® probes to expand data from Poland's Inspectorate for Environmental Protection, known as WIOS. Based on these data, potentially suitable river stretches were selected. Here, transects including flow velocity, depth, temperature, oxygen contents, Secchi depth, and substrate composition were taken. Flow velocity was determined using a Höntzsch ZS25GFE-mn40/60/p3 meter with a 1 m extension grip. Measurements were made at a water depth of 75 cm in order to allow comparison with previous publications (Ninua, 1976).

Substrate composition was determined using an Eckman dredge. However, when this was not applicable sediment was inspected by a diver and/or by sampling with plasticiline attached to a pole, to which < 1 cm particles could adhere, reproducing the image of larger substrate items.

Spawning grounds comprise river habitats with gravel substrates, sufficient water exchange in interstitial water, and absence of sedimentation (Sulak and Clugston, 1999; Elie, 1997; Richmond and Kynard, 1995). Direct observations of the spawning process have not been made for *A. sturio* (Trouvery, Williot and Castelnaud, 1984), although various attempts have been made to identify spawning grounds. They were restricted to the detection of fertilised eggs (Quantz, 1903), localization of potential spawning habitats based on hydrography, the catch of ripe females and early juveniles (Ehrenbaum, 1923) and the catch of ripe (running) females (Blankenburg, 1910), or the catch of predators with sturgeon eggs in their stomachs (Letaconnoux, 1961; cited after Guerri and Pustelnik, 1995). Only Sulak and Clugston (1999) were able to precisely identify and describe the spawning habitat for the closely related *A. oxyrinchus desotoi* Vladykov, 1955. Be that as it may, hydrography and hydrobiology of the river (Suwanee, Florida) limit a general application of the results. However, a distinct preference for certain habitat features (e.g. sedimentation, substrate, flow pattern) became obvious. Data gathered from other sturgeon species indicate that flow patterns as well as substrate quality have a major impact on the acceptance of spawning habitat. Limitations with regard to water depth have been suggested for various species, but the validation of these findings is still lacking.

Carrying capacity can be estimated based on incubation density (Derzhavin, 1947). Assuming an average fertility of 1 million eggs per female and an optimum density in the range of 1 000-3 500 eggs/m^2, the average spawning site for one female is calculated to cover 350 m^2.

RESULTS

Suitability of historic spawning sites

Historic sturgeon distribution in the Odra River has been reported up to Raciborz (figure 1). However, these sites have been inaccessible since the construction of a dam in Wroclaw (Breslau) in the 19th century. In the Warta River migration, obstacles are found only in the upper reaches of the river, as well as in some of its tributaries (Notec, Obra, Prosna).

In order to assess the potential suitability of the present habitat, the historic spawning sites of *A. sturio* in the Warta system, as given in figure 1, were evaluated according to the decision tree (figure 2) using the habitat criteria as outlined in table I.

Alterations to the river stretches of Odra, Warta and Drawa due to hydro-constructions were assessed using the structural index. The results for the Odra River, the Warta and the Drawa Rivers sum up to 61.5 %, 52.3 %, and 21.5 % of the maximal alteration for the given criteria, respectively.

Table II gives the assessment of habitat for sturgeon spawning in the Odra River and its tributaries. Especially, in the Odra River sediment transport can be observed throughout the river-bed in

Table II. Assessment of the present conditions of historic spawning sites for utilization by *A. sturio*. (+): suitable/favourable; (–): unsuitable; (?): status unknown

Criterion	Lower Odra (National-park)	Middle Odra (Frankfurt-Wroclaw)	Wartha (Poznan)	Prosna	Notec	Drawa
Migration obstacle	+	+	+	–	+	+
Substrate	– (small scale)	+	?	?	–	+
Sedimentation	–	–	–	–	–	+
Adjacent feeding habitat	+	+	+	+	+	+
Flow dynamics	+	+	+	+	+	+
Temperature	+	+	+	+	+	+
Depth	+	+	+	+	+	+
BOD	–	–	–	–	–	+
Other adverse criteria	Water quality	Water quality	Water quality	Water quality	Water quality	

the middle and lower part of the river. This sediment transport excludes the main river channel as potential spawning sites for sturgeons. Only very limited areas of suitable substrate could be found in groyne fields and river-bank structures where sedimentation was not detectable.

In the Warta River, at least two historic spawning sites are readily accessible; hydro-constructions for increased navigation capacity have altered the river's structure. As shown in table II, the high nutrient load is the main reason for the negative assessment.

Drawa River

The only tributary which already matches the postulated requirements for a sturgeon spawning habitat today is the Drawa River. In all other tributaries with historic spawning sites, substantial impact from pollution and hydro-construction reduces their suitability.

The Drawa River flows from north to south through Pomerania with its mouth being situated 270 km from Pomeranian Bay, in the southern Baltic Sea. It is accessible via the Odra, Warta, and Notec Rivers. The river has a length of 186 km, and its catchment area comprises 3 295 km^2. The flow rate varies from 13.8-65.9 m^3/s, with an annual mean of 37.9 m^3/s (Anon., 1997). The river is freely accessible for 32 km up to Kamienna dam, built in 1898. The catchment area is dominated by agriculture and forestry.

Historically, sturgeons utilised the spawning grounds in the lower 15 km of the Drawa River until 1939. The river section studied below Kamienna dam appears largely unaltered. It meanders through a glacially formed moraine refuge. Backwaters and side-arms are still present, but are temporarily disconnected. Identified salmon and sea trout spawning habitats comprise 12 400 m^2 throughout a 6 km stretch below Kamienna dam.

In its lower 20 km the river has an average width of 20 m and a mean depth of 2.2 m, increasing towards the river mouth. Depressions in the lower part of the river reach depths below 5 m.

The river below the dam can be divided into three sections. The upper part of the river (river km 32-24) is comparatively shallow, with an average depth of 1.6 m. Here, sandbanks and cobblestone riffles frequently form in the channel. Submerged macrophytes are abundant. The middle river segment (river km 24-17) is a transition area. Mean water depth increases to 1.9 m. The main channel shows sand banks on inner bends and in areas of reduced flow only. Macrophytes are limited to bank structures.

The lower part of the river (river km 17-0) becomes increasingly narrow, especially in the lower 3 km. The mean water depth increases to an average of 2.2 m, with deep pools exceeding 5 m depth. The flow velocity in the main river channel at a depth of 0.75 m varies between 1.1 and 1.4 m/s at mean discharge. The substrate in the main channel is dominated by compacted cobbles and stones (diameter < 30 cm). Gravel and cobble dominate the banks of the river channel. Sandbanks are present

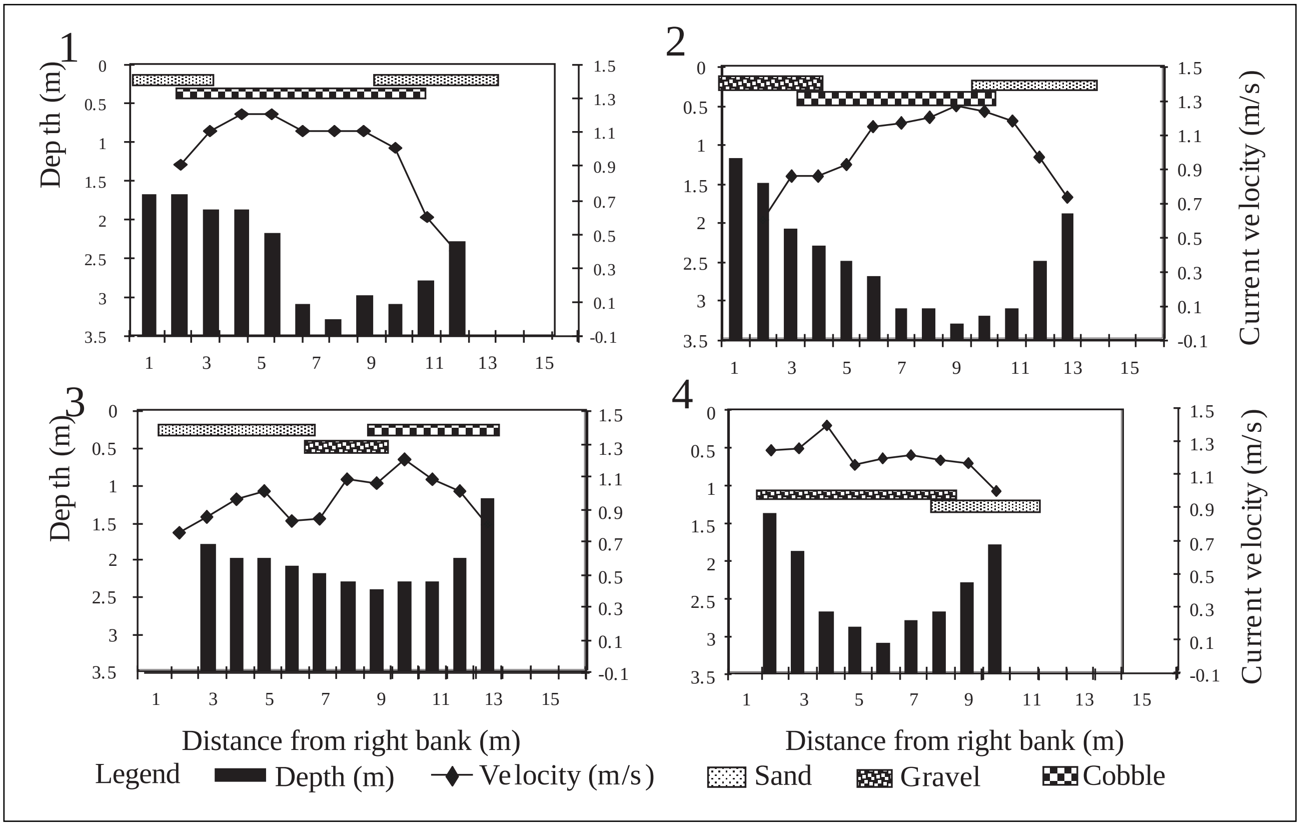

Figure 3. Depth profiles and current velocities of four transects in the lower 15 km of the Drawa River, substrate composition is indicated according to the legend

and sedimentation largely depends upon the flow pattern. Debris is found in the backwaters and in zones of low current. Examples for the transects displaying river morphology are given in figure 3. Here, the pronounced slope with gravel and stone substrate becomes clearly visible.

When comparing the criteria for spawning habitat with the structures in the Drawa River, five areas in the lower 15 km of the river were identified that should be suitable habitats for *A. sturio*.

According to the outlined technique to calculate carrying capacity, the Drawa River substrate would be sufficient for up to 50 females, under the assumption that simultaneous spawning would take place evenly distributed over the available substrate.

DISCUSSION

Outline of suitable habitat

Information about spawning habitats in *A. sturio* is very rare. No observed spawning has been recorded. Data on spawning habitat derive from catches of ripe females, of simultaneous catches of males and females in one spot, or from occasional detection of eggs, either in predators or on site. Additionally, the spawning sites have mainly been recorded under conditions already altered with regard to turbidity, flow regime, hydro-construction and damming.

The substrate requirements outlined by various authors have been summarised by Elie (1997). Bedrock or stones are frequently described as the preferred substrate for *Acipenser oxyrinchus* Mitchill, 1815. For *A. sturio*, *Acipenser stellatus* Pallas, 1771 and *Acipenser gueldenstaedtii* Brandt & Ratzeberg, 1833, larger gravel to cobble seems to be utilised for depositing the eggs in lowland rivers (Holčík *et al.*, 1989). An adjacent habitat for yolk-sac larvae is essential for the acceptance of spawning habitat. The experimental data on tigmotaxis in larval sturgeons (Richmond and Kynard, 1995; Jatteau, 1998; Gessner, unpublished) indicate that gravel exceeding 1.7 cm in diameter is an effective substrate for the developing yolk-sac larvae.

The role of water depth and current velocity are not yet fully understood. According to Vlasenko

(1974), the role of water depth is mainly a function of turbidity and light exposition. He described sturgeon spawning on suitable substrate in turbid water at depths of 1-5 m compared to clear water, where spawning took place at depths of 2-24 m. Furthermore, the reported depth requirements might be related to the fact that the spawners utilised the depressions or pools as resting areas between subsequent spawns, where they were frequently caught. Additionally, in northern European lowland rivers, suitable gravel/cobble substrate is available only in exposed sites, which are subjected to erosion. In the Oste and Eider Rivers, spawning was described in deep areas on the outer bench of meanders where coarse gravel to rocky structure (of dyke foundations, sunken groynes or bedrock) was exposed which resemble the only areas where suitable substrate, from a hydrological viewpoint, can occur. This combination of high current velocity and coarse substrate leads to even distribution of eggs on the surface during spawning and good oxygenation for the developing embryo, as well as to avoidance of sedimentation on the eggs. The latter criteria were also met on alternative spawning substrates, such as branches and plants, which have been described in the Oste River (Ehrenbaum, 1923; Quantz, 1903).

The morphology of spawning sites is difficult to determine. The identified habitat for *A. oxyrinchus* in the Hudson River consists of irregularly shaped bedrock (Bain *et al.*, 2000). Substrate conditions that match the situation in European lowlands and marshes were experimentally determined below dams in the Kuban and Volga rivers for *A. stellatus* (Khoroshko and Vlasenko, 1970). According to Alyavdina (1953, cited after Khoroshko and Vlasenko, 1970), the slope of the gravel bed should preferably be convex and exposed to the current, with a 20-30 cm thick layer of 7-10 cm cobble, imitating a bank sunken in spring flood.

Apart from the status of maturation when the fish were reaching the spawning sites, the current pattern was determined to limit habitat acceptability. Khoroshko and Vlasenko (1970) described the effect of current pattern in two adjacent artificial spawning sites on the Volga River. The upper, bank-like structure was subjected to eddies along its length. The downstream site was exposed to laminar flow. Although, both sites revealed low spawning activity, which was attributed to the maturational status of the fish. In any case, the site exposed to laminar flow showed higher spawning activity.

The structural index provides an assessment for the alterations to river structure due to hydro-constructions. The results for the Drawa River indicate a deviation of approx. 22 %. From a practical viewpoint, 15 % deviation could indicate an absolute insufficiency for natural reproduction if reached with only one criterion. In this case, the alterations could be interpreted as a warning sign as long as they do not directly affect the spawning habitat. Since it is not known to what extent alterations to river habitat affect natural populations, assessments of the determination of potential habitat are, to some degree, speculative. Perhaps the only realistically feasible way to run a test involving introductions of *A. sturio* to determine the suitability of the habitat would be by close control (e.g. radio-tracking the fish).

Habitat identification

In the Odra River system, only the Drawa River currently meets the requirements for sturgeon spawning habitat. Substrate suitable for spawning can be found in at least 5 sections of the river, comprising approximately 15 000 m^2.

Limitations for the utilization of spawning habitat in the Drawa River might be imposed by the altered flow regime caused by the Kamienna dam. Therefore, it might become necessary to alter the spring runoff to a magnitude providing sufficient discharge to relocate gravel and to increase flow enough to attract the migrants. Modification of dam discharge to match the requirements of the species has to be established before the return of adults into the river.

Future studies

For the years 2000-2004, additional studies are planned to determine and effectively characterise the available habitat. These include video-documentation of the identified habitat, as well as a more precise size estimate for potential spawning grounds. Furthermore, current patterns are to be determined by Acoustic Doppler Profiles. Since ide *Leuciscus idus* (L., 1758) and asp *Aspius aspius* (L., 1758) utilise the same habitat for spawning as sturgeons do (Khoroshko and Vlasenko, 1970), these indicator species will be used to more precisely narrow the potential habitat.

In addition to refining our determination of potentially suitable habitats in the Drawa River, during these future studies historical spawning grounds in the Odra River catchment area, which are currently considered unsuitable, are to be subjected to in-depth analysis over the next four years. Analogous procedures are planned for the Elbe River. Potential habitats are to be identified, and the requirements for necessary alterations will be defined. Attempts to reconnect backwaters and side-arms of the river are in the planning stage for the lower Odra River in the international park along the border (Köhler and Chonjacki, 1996). If performed properly, these measures might be well suited to increase the habitat requirements of early life stages of the sturgeon in the upper reaches of the river, as well. Additionally, they will provide sufficient experience with the management of the reconnected waters to allow transfer of the results to other parts of the river, where comparable measures are planned for flood prevention.

Perspective

The removal of migration obstacles might be one option to alter the adverse situation for diadromous species in some parts of the river systems. The improvement of water quality standards via installation of effective purification plants is considered more urgent. These measures are currently being implemented by the Polish government in order to comply with international agreements to protect the Baltic (Anon., 1993).

A significant concern is the future development of the rivers for shipping, since the environmental alterations needed to accommodate the increasing size of ships will further decrease available spawning habitat for sturgeon. Of particular importance in this respect are increased water depth, steep bank profiles, and building of additional dams in order to provide navigable waters for bigger ships leading to canal-like structures (Hermel, 1995). Thus there is a conflict of interest between commercial and natural users of the river. This largely contrasts with the identified requirements for the connection of backwaters to the river systems in order to increase natural habitat and floodplains. From a conservational point of view, the reduction of navigable waterways would be the desired aim (Köhler and Chonjacki, 1996).

After the preparatory work has been finished and stocking material is available, the subsequent life stages of the sturgeon will find suitable habitat, as can be derived from the findings on exotic sturgeons in the area (Arndt *et al.*, 2000). Improved fisheries management will be required to adapt fishing pressure along the migration routes (Gessner and Nordheim, 1998).

In general, future objectives have to be dealt with including all partners involved (Holland, 1996). International collaboration is essential, not only on a bilateral basis but, considering the migration distances covered as given by Rochard, Lepage and Meauzé (1997), the planned activities must also count on the co-operation of the states adjacent to the Baltic Sea, thus aiming at the most effective and well co-ordinated approach possible to minimise the potential for failures.

ACKNOWLEDGEMENTS

The work described was carried out under the E&E Programme of the Federal Agency for Nature Conservation, Az. Z1.2-892 11-4/96. The authors are especially grateful for the support of the team at Drawenski Park Narodowny, Drawno, Poland, who made this work possible.

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