PROHIBIDA SU PUBLICACIÓN

DELIVERABLE - Action A.1: Identification of potential spawning areas for European sturgeon (*Acipenser sturio*) in the lower stretch of the Ebro River

Lead Scientist preparing the Deliverable: Gisbert, E. (IRTA)

Other Scientists participating: Queral, J.M. (PNDE), K.B. Andree (IRTA)

This work has been divided in three different sections, as described as follows:

A1.1.1 A bibliographic revision of the hydrological and site characteristics of spawning sites for European sturgeon.

A.1.1.2 Fieldwork for identification and characterization of potential spawning sites for European sturgeon in the lower stretch of the Ebro River and their mapping.

A1.1.3. Conclusions

A1.1.1 A bibliographic revision of the hydrological and site characteristics of spawning sites for European sturgeon.

Objectives and methodology: In order to locate potential spawning habitats in the lower part of the Ebro River (Flix's dam – Xerta's weir), we decided to first analyse the literature regarding the characteristics of the spawning areas for the European sturgeon and other similar species. The literature search was conducted using the Web of Science™ (Thomson Reuters) including the following keywords: diadromous fish; spawning grounds; European sturgeon; Acipenserids; Acipenser sturio. The information for each spawning ground is structured considering the depth (m), water current speed (m/s), rate of river discharge (m^3/s), temperature (ºC) and substrate type for different spawning episodes reported in the literature and it was used as a reference for the field work (A1.1.2), which focused on locating potential spawning sites for European sturgeon in the lower stretch of the Ebro River.

It is important to mention that for most of the reviewed studies, spawning sites were located downstream of dams or obstacles, suggesting that these are forced spawning sites due to the impossibility of mature males and females

of getting further upstream. Regardless of the information presented, data for some parameters like water speed need to be taken with caution, since different authors measure this parameter at different water depths within the spawning sites (surface, mid-water column and/or bottom), which results in a large heterogeneity of values. It may be noted that the terminology used in this revision with regards to the granulometry of the substrate in the spawning grounds for twaite shad is that of the Wentworth grain size chart from the United States Geological Survey, (http://pubs.usgs.gov/of/2006/1195/htmldocs/images/chart.pdf), which is summarized in the following table (Table 1).

Table 1. Simplified Wentworth grain size chart from the United States Geological Survey used for characterizing the potential spawning grounds of twaite shad in the lower stretch of the Ebro River.

General term	Particle size class	Size (mm)
Silt-clay	silt-clay	<0.062
Sand	sand	0.062 - 2.0
Gravel	very fine	2.0 – 4.0
	fine	4.0 - 6.8
	medium	8.0 – 16.0
	coarse	16.0 – 32.0
	very coarse	32.0 – 64.0
Cobble	small	64.0 – 128.0
	large	128.0 – 256.0
Boulder	small	256.0 – 512.0
	medium	512.0 – 1024.0
	large - very large	1024.0 – 4096.0

Results: the revision of the literature regarding the characterization of the spawning grounds for several Acipenserid species, including the European sturgeon (*Acipenser sturio*) is shown Tables 2 and 3, respectively. It is noteworthy to emphasize that reproduction of *A. sturio* has never been observed in the wild, so most studies dealing with the characterization of the spawning sites for this species (Garonne-Dordogne river system and Rhône, France) have been conducted considering the concentration of spawners during the spawning season (Alcolas et al., 2011). In this sense, there exist a high coherence among the characteristics of the spawning grounds for different Acipenserid species (Jego et al., 2002); thus, for comparative purposes data on other sturgeon species have been included in separate tables for North American (Table 2) and Eurasian (Table 3) species, respectively. As there has been extensive work on North American species focused on recovering sturgeon wild populations and restoring their habitat, data on artificial and natural spawning grounds is also presented.

Table 2. Main physical (water depth, type of substrate) and hydrological (water current speed, river water discharge, temperature) characteristics of different spawning grounds for several North American sturgeon species.

Scientific name	Common name	Depth (m)	Current (m/s)	Water discharge (m^3/s)	Temperature (ºC)	Substrate type	Site	River	Reference
North American species									
A. transmontanus	white sturgeon	4.0-13.0	0.1-0.8 0.1-1.0	141-1265	7.5-14-0 8.5-12.0	gravel, cobble	natural	Kootenai River *rkm* 229-240	Paragamian et al. 2001, 2002
A. transmontanus	white sturgeon	np 3.0-23-0	0.8-2-8 0.6-2.4	np 3890-9600	10.0-20.0 10.0-18.5	cobble, boulder, bedrock	natural	Columbia River *rkm* 223-234	Parsley et al. 1993 McCabe & Tracy 1994
A. fulvescens	lake sturgeon	9.0-12.0	0.4-1.0	np	13.0-15.0	cobble, coarse gravel, coal cinders	natural	channels Laurentian Great Lakes	Manny & Kennedy 2002
A. fulvescens	lake sturgeon	0.8-5.5	0.5-1.4	780-1900	12.0-17.0	coarse gravel, boulders, smooth outcrops	artificial	Des Prairies River	Dumont et al. 2011
A. fulvescens	lake sturgeon	6.0-10.0	0.5-0.7	np	12.0-20.0	limestone shot rock, sorted limestone, rounded igneous rock	artificial	Detroit River	Bouckaert et al. 2014
A. brevirostrum	shortnose sturgeon	1.2-10.4 1.0-5-0	0.4-1.0 0.3-1-3	301-679 121-901	9.0-18.0 6.5-15.9	cobble, rubble gravel, pebble	natural	Connecticut River	Buckley & Kynard 1985 Kieffer & Kynard 2012
A. brevirostrum	shortnose sturgeon	6.0-9.0	0.8	np	9.0-12.0	gravel, rubble, cobble	natural	Savannah River *rkm* 179-190 *rkm* 275-278	Hall et al. 1991
A. brevirostrum	shortnose sturgeon	1.8-5-5	0.3-0.7	240-390	10.0-14.0	boulder, rubble	natural	Merrimack River *rkm* 30-32	Kieffer & Kynard 1996
A. oxyrinchus desotoi	Gulf sturgeon	1.9-7.4	np	40-120	18.0 -22.0	gravel, limestone	natural	Choctawhatchee River *rkm 110*	Fox et al. 2000

Although in spawning grounds for *A. sturio* were reported in the River Guadalquivir close to Cordoba (*rkm* 230), no reproduction has been reported there after the construction of the Alcala del Rio dam in 130 at *rkm* 100. Consequently, the information that exists about the characteristics of that spawning site is almost absent (Williot et al., 2011), so authors have decided to not include it in this report.

Table 3. Main physical (water depth, type of substrate) and hydrological (water current speed, river water discharge, temperature) characteristics of different spawning grounds for several Eurasian sturgeon species.

Scientific name	Common name	Depth (m)	Current (m/s)	Water discharge (m^3/s)	Temperature (ºC)	Substrate type	Site	River	Reference
Eurasian species									
A. sturio	European sturgeon	>5.0	>0.5-1.5	600-1100	14.0-22.0	Heterogeneous: from gravel, cobble to rock blocks	natural	Garonne-Dordogne river system *rkm* 170-270 (Garonne) *rkm* 100-210 (Dordogne)	Jego et al. 2002
A. sturio	European sturgeon	>5.0	>0.5	np	>18.0	gravel, pebble	natural	Rhône River *rkm* 50-60	Brosse et al. 2009
A. oxyrinchus	Baltic sturgeon	0.5-6.0	0.2-2.2*	np	13.0-26.0*	pebble, sand, fine gravel, cobble*	natural*	Drawa River, Warta River, Prosna River	Arndt et al. 2006
A. stellatus	Stellate sturgeon	2.0-3-0	0.3-1.2	6000-6500	9.0-16.0	pebble, cobble, gravel	natural	Lower Volga *rkm* 105-347	Veschev 2009
A. sinensis	Chinese sturgeon	7.8-15.2	0.2-1.0	5830-27600	17.0-20.0	boulder, pebble, cobble, gravel	natural	Yangtze River *rkm* 2206-2817	Yang et al. 2006 Du et al. 2011 Gao et al. 2013

*, estimated by authors from the literature; np, not provided.

The **synthesis** of the above-mentioned data suggests that potential spawning habitats for *A. sturio* in the lower stretches of the Ebro River may have a heterogeneous substrate, ranging from fine gravels (2.0 mm) to coarse gravels (20.0 mm) and cobble/pebbles (100.0 mm) to rocks/boulders (100.0 – 250.0 mm in granulometry). These places are characterized by water currents exceeding 0.5 m/s and up to 1.5 m/s, which guarantee the removal of silt and fine particles that may cover and negatively affect the development of eggs in the spawning sites. Minimum water depth in spawning grounds has been estimated at 5 m (spawning takes place in the water column and adhesive eggs sink and stick rapidly to the substrate), although there may be some variability depending on the river and species considered. The presence of macrophytes in sturgeon spawning sites has rarely been reported in the literature.

Although there is not previous information about historical spawning grounds for European sturgeon in the Ebro River, the revision of the literature conducted within Action A.1 for the twaite shad indicated that in this river the European sturgeon may use the same spawning sites than the twaite shad (*Alosa fallax*). In this sense, we used the data on those sites that have already been identified and described down-stream of the Xerta's weir in the Ebro River (López et al., 2011) as a guide for the fieldwork of this Deliverable.

A.1.1.2 Field work for identification and characterization of potential spawning sites for European sturgeon in the lower stretch of the Ebro River and their mapping.

Objectives and methodology: the aim of this task was to locate within the river stretch comprised between the Xerta's weir and Flix potential spawning grounds for European sturgeon. For achieving this goal, the river was surveyed during July 2015 in order to cover the entire area delimited by MIGRATOEBRE. The fieldwork was performed in five different river sections that were chosen according to their accessibility by boat from the river shore (*i.e.* pier / boat launch) and not dictated by their ecological or hydrobiological characteristics. These sections (order from upstream to downstream direction) are the following ones (topographical coordinates expressed in UTM coordinates):

- Flix dam (31 T 294502.6 m E, 4567984.4 m N) – Ascó weir (31 T 296796 m E,4563915.8.7 m N)
- Ascó weir (31 T 296707.9 m E; 4563687.1 m N) – Móra d'Ebre (31 T 302054.9 m E, 4551941.1 m N)
- Móra d'Ebre (31 T 302054.9 m E; 4551941.1 m N) – Miravet 31 T 298993.5 m E, 4545056.0 m N)
- Miravet (31 T 298993.5 m E, 4545056.0 m N) – Benifallet (31 T 291205.2 m E, 4539088.5 m N)
- Benifallet (31 T 291205.2 m E, 4539088.5 m N) – Xerta's weir (31 T 288637.4 m E, 4533495.0 m N)

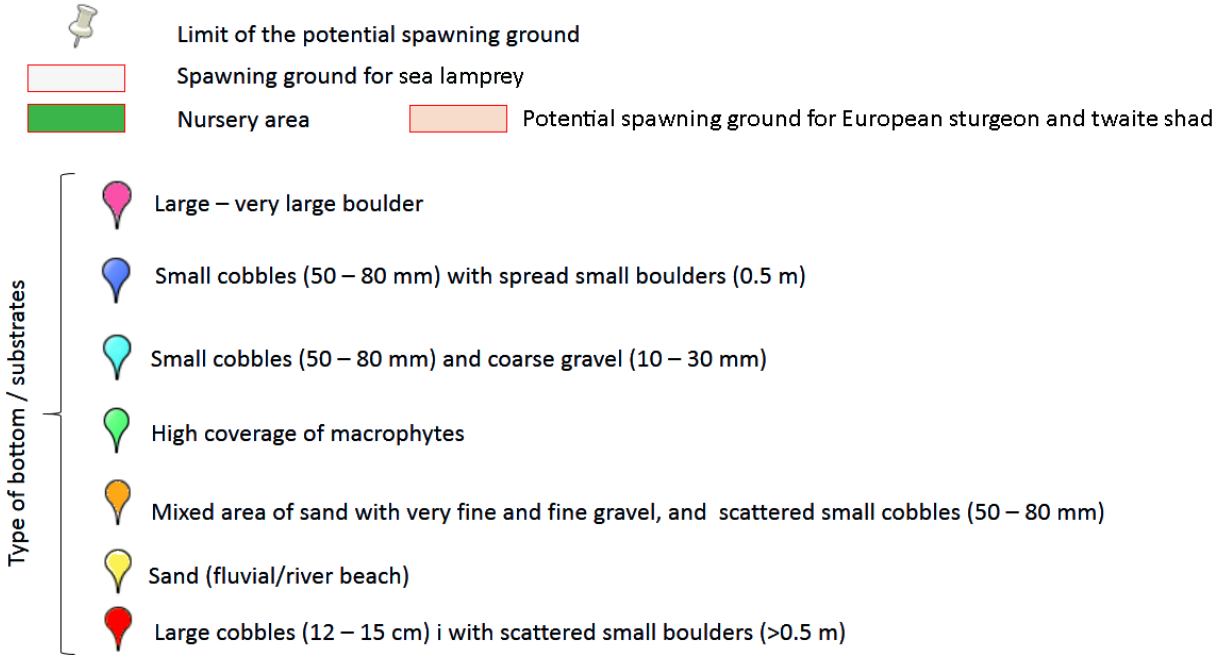
Each river section (full river width) was monitored from a boat (upstream and downstream transects) in which the following parameters/information were recorded from each potential point of interest:

- Type of bottom/substrate according to the simplified Wentworth grain size chart from the United States Geological Survey (Table 1).
- Level of bottom macrophyte coverage (semiqualitative scale according to the visual criterion of the observer: absent, low, moderate, high); the position of the macrophytes (i.e. prostrate, semi-erect and upright) was considered according to Rovira et al. (2016).
- Water current (units: m/s; FP111 Flow Probe; Global Water Instruments, USA). This parameter was measured at the level of the river bed whenever possible (max. depth 1.8 m).
- Water depth (units: m; Sonda Echotest II, Plastimo, France). When water depth recordings were doubtful (*i.e.,* deep areas with macrophyte covering), data on water depth for a specific point of interest was compared to the bathymetry mapping from the IDECE used for river navigation purposes.
- GPS coordinates (units: UTM coordinates; Garmin eTrex 30x, Garmin, Spain).
- Photography (underwater and aerial photographs of the point of interest).
- As the river conditions (*i.e*., water depth, water current) may substantially change depending on the river water discharge (m^3/s), data on this parameter was obtained from the Confederación Hidrológica del Ebro – SAIH Ebro (www.chebro.es) - for each of the days in which the field work was conducted.

In addition to the potential spawning grounds, we decided to also map and include in the present deliverable information about potential nursery areas for European sturgeon and other fish species that may reproduce in the river. In this sense, several authors have recognized that knowledge regarding spawning sites and natural nurseries is valuable because it serves as a tool for the protection of fish populations and the management of fishery resources (Silva et al., 2012). Baumgartner et al. (2004) also emphasizes that the preservation of these sites is of great importance to ensure good recruitment of any fish species.

Data on potential spawning grounds for twaite shad, as well as other information of relevance from the studied river section was mapped using Google Earth (https://earth.google.es/). This platform was chosen due to its good acceptance and free access by the general public, as well as its availability on a wide array of devices, and the use of historical data that allows to evaluate potential changes in a site of interest linked to changes in river water discharge values. Places were named according to the topographical nomenclature from the Institut Cartogràfic I Geològic de Catalunya using the VISSIR v3.26 application (http://www.icc.cat/vissir3/).

The mapping key used in Google Earth, as well as in the images included in this deliverable, is the following one:



The area of potential spawning grounds for twaite shad and nursery areas (polygons) was calculated using the aerial images captured from Google Earth using an image analysis software (ANALYSIS™; Soft Imaging Systems GmbH, Germany) and corrected with the scale at which the image was captured. In this sense, the topographic coordinates of each of the identified potential spawning grounds is presented as the midpoint of the up- and downstream limit of the area, whereas the detailed mapping of the river stretch comprised between Flix and Xerta's weir is provided as a compressed file (*.*kmz) for Google Earth.

The impact of improving river connectivity by constructing a fish lift at Xerta's weir and a fish ramp at the level of the Asco Nuclear power station weir was assessed by comparing the actual area (2.0 Ha) available as spawning grounds for twaite shad (Figure 1; as described in López et al., 2011) and the new potential spawning areas for this diadromous species detected during river monitoring. This information was presented considering the five different sections in which the river was divided, as well as the whole area covered within Migratoebre.

Figure 1: Aerial view (Google Earth) of the actual spawning grounds for twaite shad in the lower part of the Ebro River, downstream the Xerta's weir (López et al., 2011).

Results: the information about potential spawning grounds and nursery habitats for European sturgeon is shown considering the five different river sections used for monitoring the river stretch comprised between Xerta's weir and Flix's dam within the Migratoebre project.

❶ **<u>Section Flix dam – Ascó weir</u>** (average river water discharge: 125 m^3/s – value from the SAIH - Tortosa station).

Nursery area (Figure 2). Name/location: Flix meander; coordinates (midpoint): 31 T 294939.7 E, 4568023.3 N (upstream limit) - 31 T 295233.4 m E, 4567276.3 m N (downstream limit); average water depth: 0.5 – 1.1 m; type of bottom substrate: mixed substrate characterized by small cobbles (50 – 80 mm) with coarse gravel (10 – 30 mm), some areas with scattered large cobbles (150 mm); average water current: <0.5 m/s; macrophyte abundance: moderate level of macrophyte coverage (50-60%); macrophyte position: upright; area: 30.3 Ha.

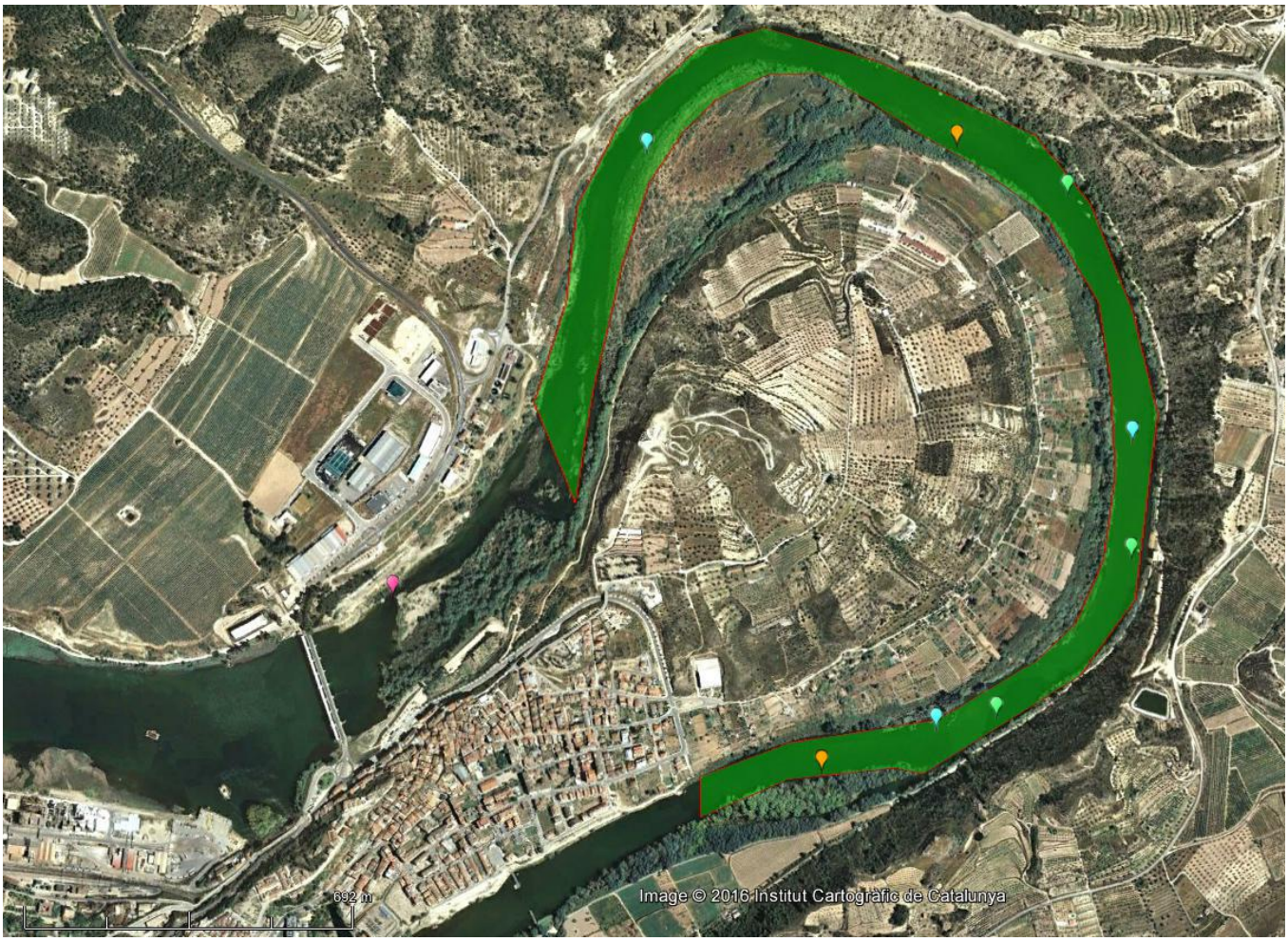


Figure 2: Aerial view (Google Earth) of the nursery area in the Flix meander, see text for details.

❷ **<u>Section Ascó's weir - Móra d'Ebre</u>** (average river water discharge: 139 m^3/s – value from the SAIH Tortosa station).

Nursery area (Figure 3). Name/location: downstream the Ascó village; coordinates (midpoint): 31 T 296218.4 m E; 4561422.7 m N (upstream limit) – 31 T 296337.8 m E, 4561109.1 m N (downstream limit); average water depth: 0.5 -1.0 m (upstream) and 1.3 – 3.3 m (downstream); type of bottom substrate: gravel (coarse, 20 – 30 mm) covered by large quantity of green algae; average water current: < 0.3 m/s; macrophyte abundance: low + presence of filamentous green algae; macrophyte position: upright; area: 20.9 Ha.

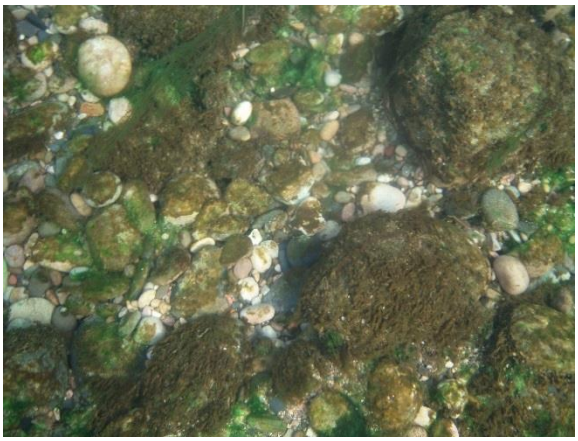


Figure 3: Aerial view (Google Earth) of the nursery area located downstream the village of Ascó, see text for details. An image of the site from the water surface (lower left) together with an underwater image of the site showing the type of substrate (lower right).

Potential spawning ground (Figure 4). Name/location: downstream the Ascó village; coordinates (midpoint): 31 T 296375.5 m E, 4561058.5 m N (upstream limit) – 2964591.1 m E, 4561007.8 m N (downstream limit); average water depth: 3.5 - 4.6 m; type of bottom substrate: rocky river banks with scattered small boulders (0.5 m) with small cobbles (50 -80 mm) towards the central river channel; average water current: 0.8 – 1.5 m/s (area with small whirlpools and turbulences next to the rocky river bank); macrophyte abundance: absent; area: 0.31 Ha.

Figure 4: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located downstream the village of Ascó, see text for details. An image of the site from the water surface is also included.

Nursery area (Figure 5). Name/location: Mas de l'Aullor (secondary river arm of a fluvial island – this island does not appear in Google Earth photographs from 2008, 2009 and 2015, which indicates its temporal presence depending on river water discharge); coordinates (midpoint): 31 T 297783.0 m E; 4560581.0 m N; average water depth: <0.5 m; type of bottom substrate: gravel (coarse, 20 – 30 mm); average water current: < 0.1 m/s; macrophyte abundance: low + presence of filamentous green algae; macrophyte position: upright; area: 0.37 Ha.

Figure 5: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the municipality of Ascó named Mas de l'Aullor (secondary river arm of a fluvial island), see text for details. An underwater image of the site from the water surface is also included.

Potential spawning ground (Figure 6). Name/location: road C-12, km 75.5 (Municipality: Vinebre); coordinates (midpoint): 31 T 299199.7 m E, 4560671.7 m N (upstream limit): 31 T 299216.3 m E, 31 T 4560509.7 m N (downstream limit); average water depth: 5.1 – 6.6 m; rocky river banks in which water depth increases abruptly; type of bottom substrate: large boulders (>1.5 m) with medium small and large cobbles located in river pools; average water current: 1.0 -1.5 m/s; macrophyte abundance: absence of macrophytes; area: 0.41 Ha.

Figure 6: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the municipality of Vinebre next to the road C-12 (kilometer: 75.5), see text for details. An image of the site from the water surface is also included.

Potential spawning ground (Figure 7). Name/location: Santa Paulina (Minicipality: Ascó); coordinates (midpoint): 31 T 300042 m E, 4558986 m N (upstream limit) - 31 T 300229.0 m E, 4558902.1 m N (downstream limit); average water depth: 7.0 - 8.5 m; type of bottom substrate: large boulders (>1.5 m) with medium small and large cobbles located in river pools; average water current: 0.5 – 0.8 m/s; macrophyte abundance: absent; area: 0.39 Ha.

Figure 7: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the municipality of Ascó named as Santa Paulina, see text for details. An image of the site from the water surface is also included.

Potential spawning grounds (Figure 8). Name/location: Garcia (village); coordinates (upstream and downstream limits): location 1 (upstream): 31 T 302139.8 m E / 4557682.2 m N – 302371.8 m E / 31 T 4557387.1 m N; location 2 (downstream): 31 T 302545.1 m E, 4556710.1 m N / 31 T 302505.6 m E, 4556525.2 m N; average water depth: 4.7 – 9.0 m; area of rocky river banks in which water depth increases abruptly; type of bottom substrate: small boulders (0.5 -1.5 m) with small cobbles (50 -80 mm) located in river pools spread between boulders' area; average water current: 1.0 -1.5 m/s; macrophyte abundance: absence; area: location 1: 1.53 Ha, location 2: 0.80 Ha.

Figure 8: aerial view (Google Earth) of the potential spawning ground for European sturgeon located close to the village of Garcia, see text for details. An image of the site from the water surface is also included.

Potential spawning ground (Figure 9). Name/location: Fluvial beach Pont de Garcia (Municipality: Garcia); coordinates (midpoint): 31 T 300042 m E; 4558986 m N (upstream limit) - 31 T 300229 m E; 4558902 m N (downstream limit); average water depth: 1.0 -7.6 m (area of variable water depth with several pools); type of bottom substrate: secondary river arm with bank with small cobbles (50-80 mm) and coarse gravel (10 -30 mm), main area with small cobbles (50 -80 mm) with spread small boulders (0.5 m); average water current: 1.0 – 1.2 m/s; macrophyte abundance: low or absent presence of macrophytes; macrophyte position: semi-erect; area: 1.21 Ha.

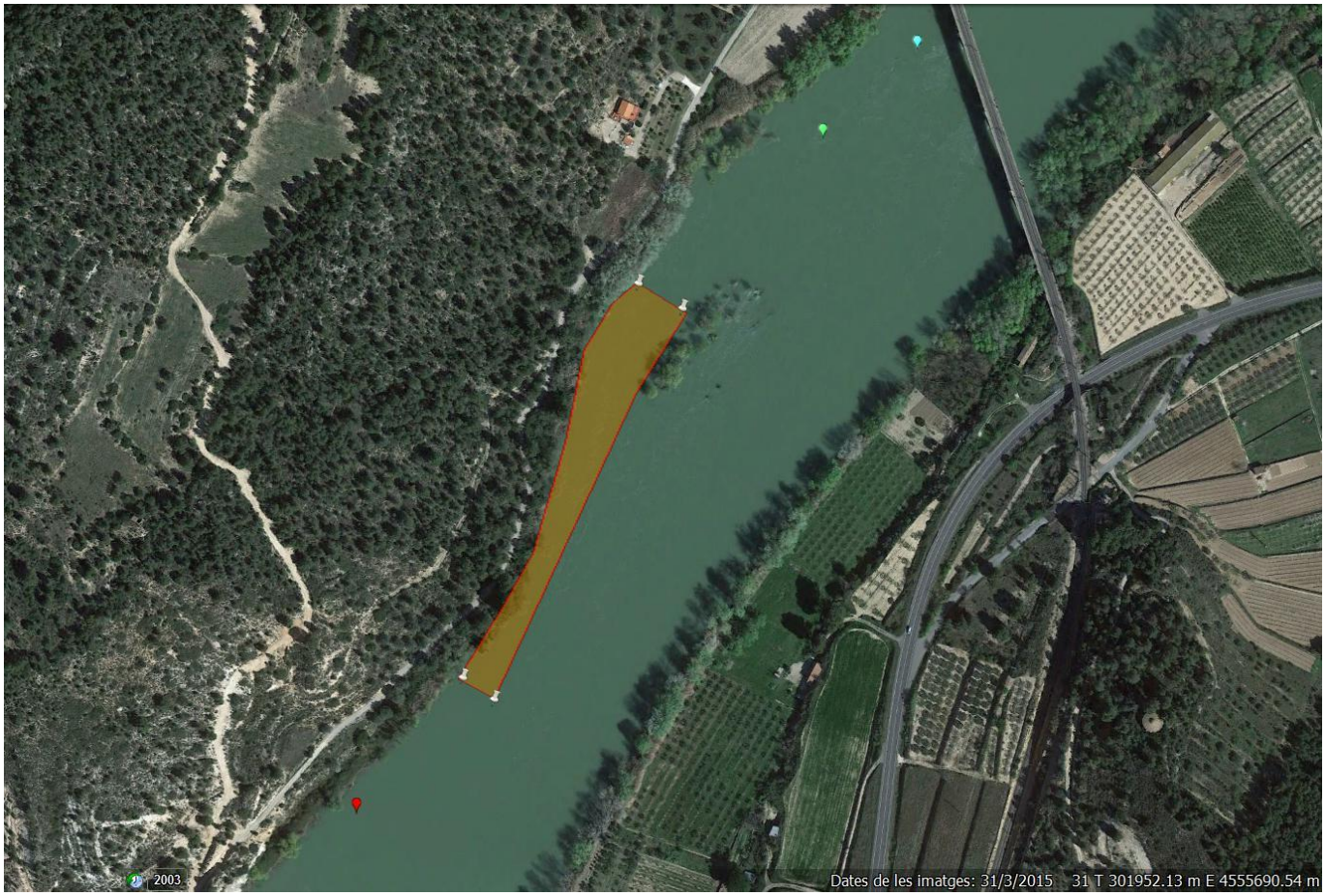


Figure 9: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the secondary river arm of the fluvial beach of Pont de Garcia (Garcia), see text for detail. An image of the site from the water surface is also included.

Nursery area (Figure 10). Name/location: Platja de Móra (secondary river arm); coordinates (midpoint): 31 T 301888 m E; 4552091 m N; average water depth: 0.5 -1.1 m; type of bottom substrate: gravel (coarse, 20 – 30 mm); average water current: < 0.1 m/s; macrophyte abundance: moderate + presence of filamentous green algae; macrophyte position: upright; area: 0.55 Ha.

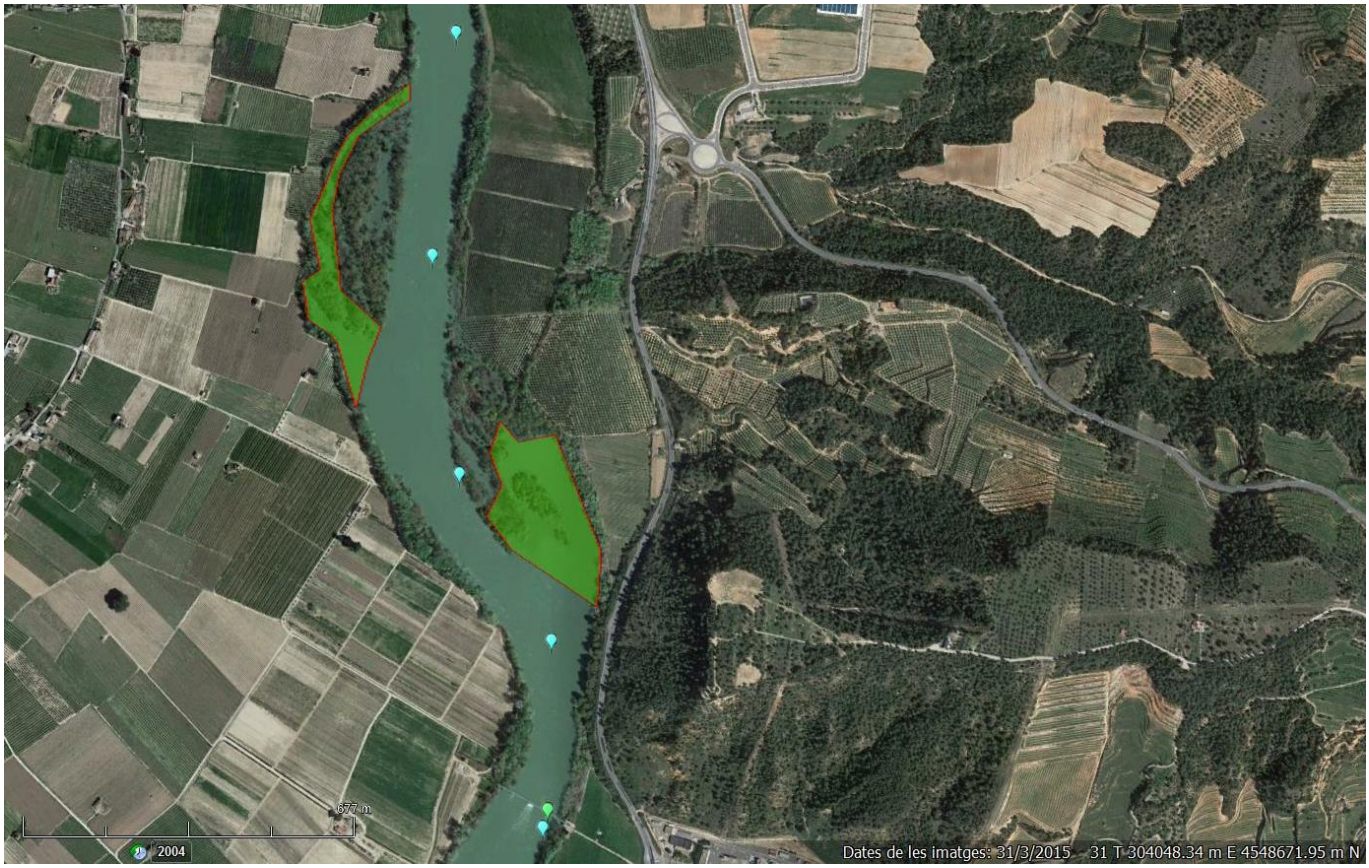
Figure 10: Aerial view (Google Earth) of the nursery area in Móra d'Ebre (Platja de Móra), see text for details. An image of the site from the water surface is also included.

❸ **<u>Section Móra d'Ebre – Miravet</u>** (average river water discharge: 151 m^3/s – value from the SAIH Tortosa station).

Nursery area (Figure 11). Name/location: downstream part of the Illa del Galatxo (secondary river arm) – Platja de Vista Móra (Municipality: Móra d'Ebre); coordinates (midpoint): 31 T 303069.4 m E; 4550613.5 m N (upstream limit) – 31 T 303277.9 m E, 4550340.3 m N (downstream limit); average water depth: 0.9 - 6.0 m; type of bottom substrate: gravel (coarse, 20 – 30 mm) with patchy areas of sand covered with green algae; average water current: < 0.5 m/s; macrophyte abundance: high (60 -75% bottom coverage); macrophyte position: upright; area: 20.9 Ha.

Figure 11: Aerial view (Google Earth) of the nursery area located in the downstream part of the Illa del Galatxo (secondary river arm) – Platja de Vista Móra, see text for details. An image of the site from the water surface is also included.

Nursery area (Figure 12, upstream site**).** Name/location: secondary river arm of the Illa del Vado del Vapor (Municipality: Móra d'Ebre); coordinates (midpoint): 31 T 303204.1 m E; 4549397.6 m N (upstream limit) – 31 T 303090.0m E, 4548835.9 m N (downstream limit); average water depth: 1.1 – 1.8 m; type of bottom substrate: mixed area of gravel (coarse, 20 – 30 mm), sand and silt with large quantity of green algae; average water current: < 0.2 m/s; macrophyte abundance: low (10% macrophyte coverage); macrophyte position: upright; area: 0.73 Ha.



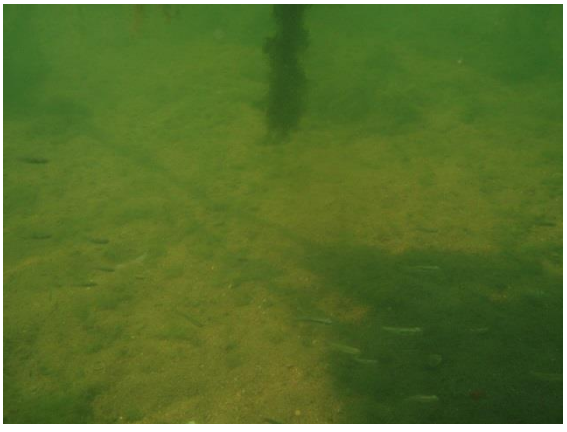


Figure 12: Aerial view (Google Earth) of the nursery area located in the secondary river arm of the Illa del Vado del Vapor – Platja de Vista Móra, see text for details. An image of the site from the water surface is also included (left image), as well as a detail of the bottom (underwater right image).

Nursery area (Figure 13, downstream site**).** Name/location: secondary river arm at the level of the Platja del Molló (Municipality: Móra la Nova); coordinates (midpoint): 31 T 303204.1 m E; 4549397.6 m N (upstream limit) – 31 T 303090.0m E, 4548835.9 m N (downstream limit); average water depth: 1.1 – 1.5 m; type of bottom substrate: mixed area of gravel (coarse, 20 – 30 mm), small cobbles (50 – 80 mm) and sand; average water current: < 0.2 m/s; macrophyte abundance: high (60 - 70% macrophyte coverage); macrophyte position: upright; area: 40.6 Ha.

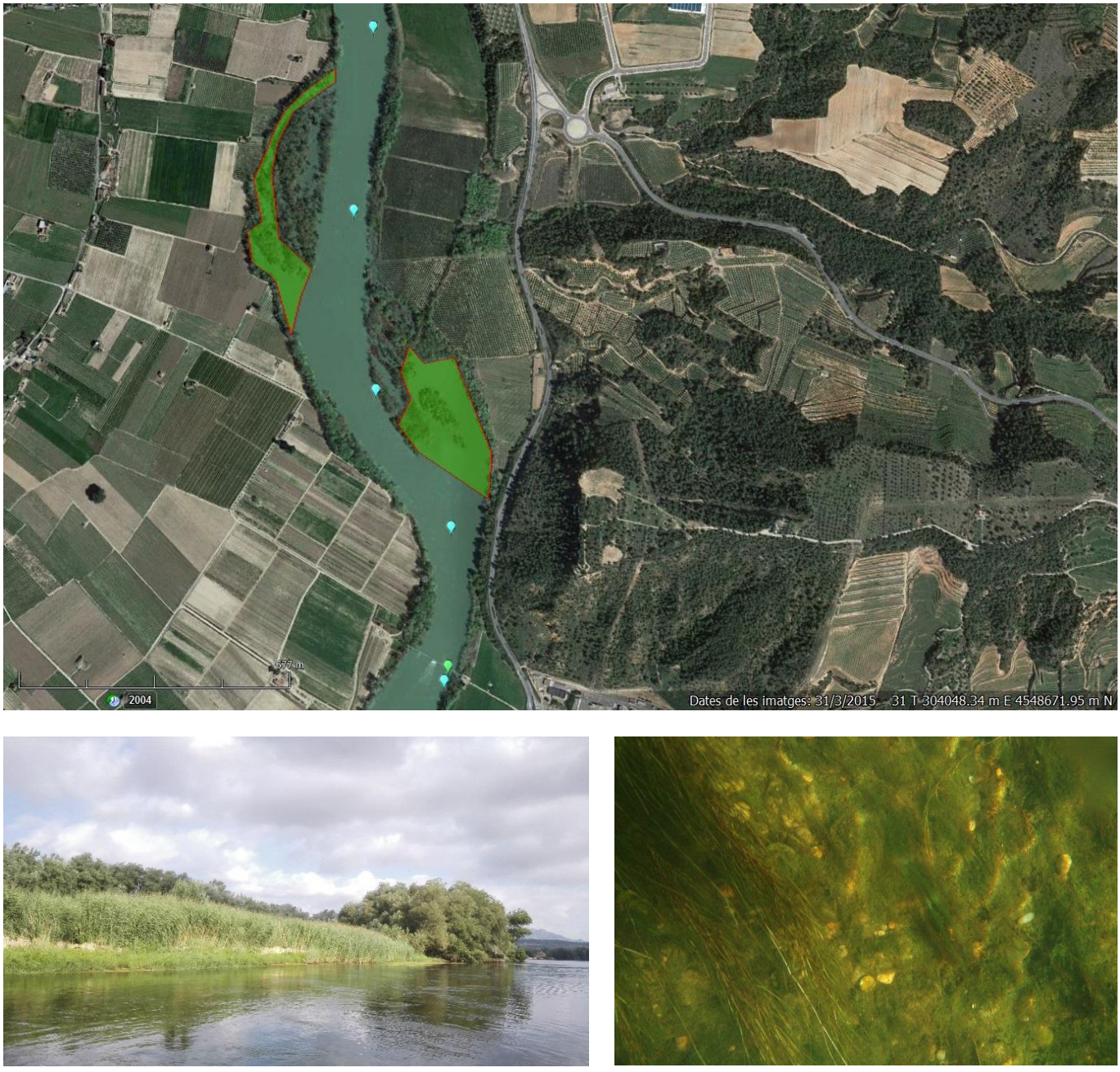


Figure 13: Aerial view (Google Earth) of the nursery area located in the secondary river arm at the level of the Platja del Molló, see text for details. An image of the site from the water surface is also included (left image), as well as a detail of the bottom (underwater right image).

Potential spawning ground (Figure 14). Name/location: opposite river bank to the Platja de la Barca de Benissanet (Municipality: Ginestar); coordinates (midpoint): 31 T m 305548.2 m E, 4546942.2 m N (upstream limit) – 302468.2 m E, 4546961.3 m N (downstream limit); average water depth: 1.1 – 1.5 m; type of bottom substrate: rocky river banks with scattered small boulders (>0.5 m) with small cobbles (50 -80 mm); average water current: 1.8 – 2.0 m/s (area with small whirlpools and turbulences next to the rocky river bank); macrophyte abundance: absent; area: 0. 11 Ha.

Figure 14: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the opposite river bank to the Platja de la Barca de Benissanet, see text for details. An image of the site from the water surface is also included.

Potential spawning ground (Figure 15). Name/location: Sénia de Rufín in front of km 15.5 route T-324 (Municipality: Benissanet); coordinates (midpoint): 31 T 300036.8 m E, 4547548.3 m N (upstream limit) – 31 T 299726.4 m E, 4547030.3 m N (downstream limit); average water depth: 6.0 – 7.7 m; type of bottom substrate small boulders (>0.5 m) with small cobbles (50 - 80 mm); average water current: 0.5 – 0.9 m/s; macrophyte abundance: moderate (20 - 60% macrophyte coverage); position: prostrate; area: 1.44 Ha.

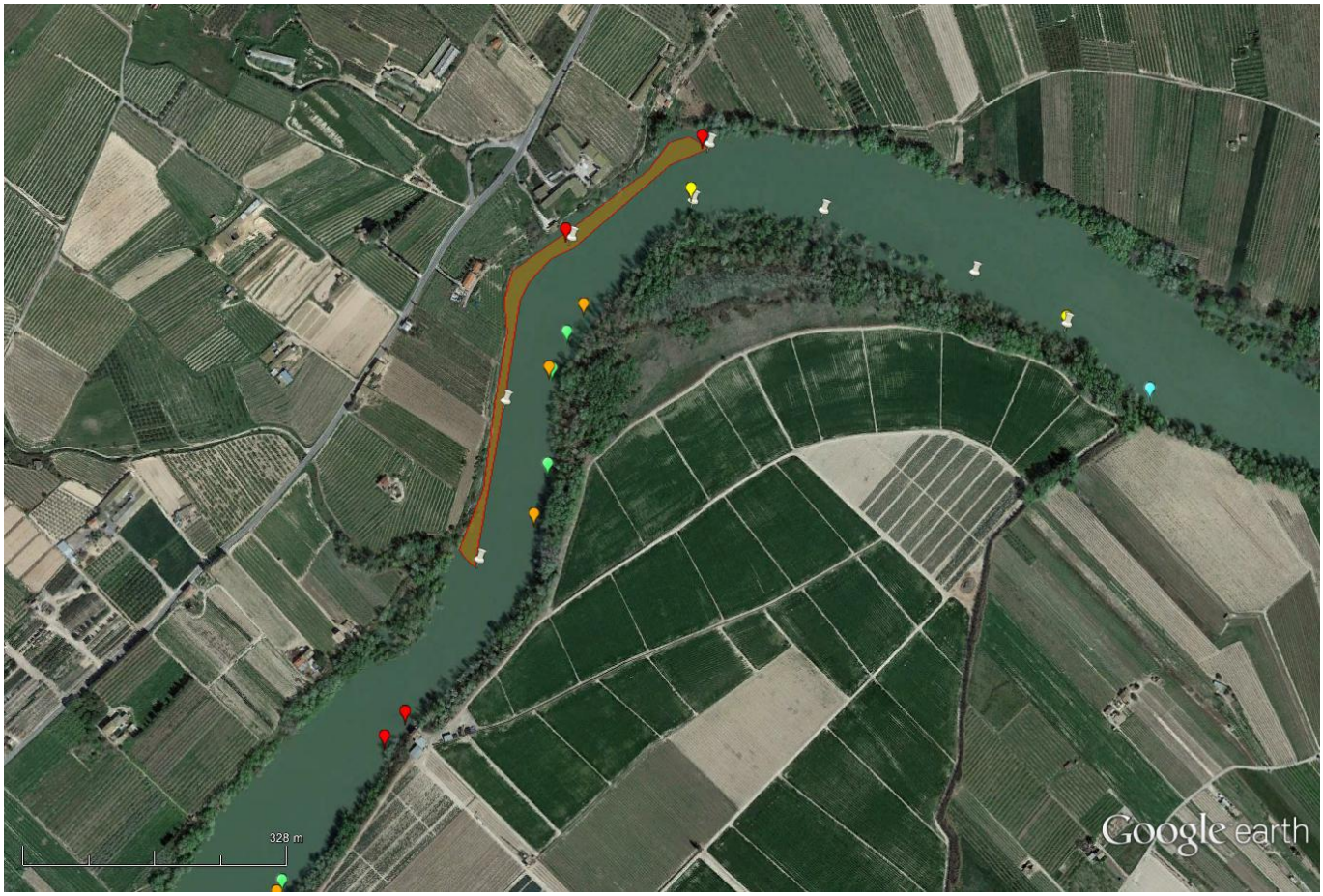


Figure 15: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located in the Sénia de Rufín in front of km 15.5 route T-324, see text for details. An image of the site from the water surface is also included.

Potential spawning ground (Figure 16). Name/location: Sénia de Gorreta – Sénia de Pau (Municipality: Miravet); coordinates (midpoint): 31 T 299303.5 m E, 4546521.8 m N (upstream limit) – 299341.7 m E, 4546211.1 m N (downstream limit); average water depth: 4.0 – 9.0 m; type of bottom substrate: rocky river banks with riparian vegetation, scattered small boulders (>0.5 m) with small cobbles (50 - 80 mm) and river pools; average water current: 0.3 – 0.9 m/s; macrophyte abundance: low (10-20% macrophyte coverage); position: prostrate; area: 0.67 Ha.

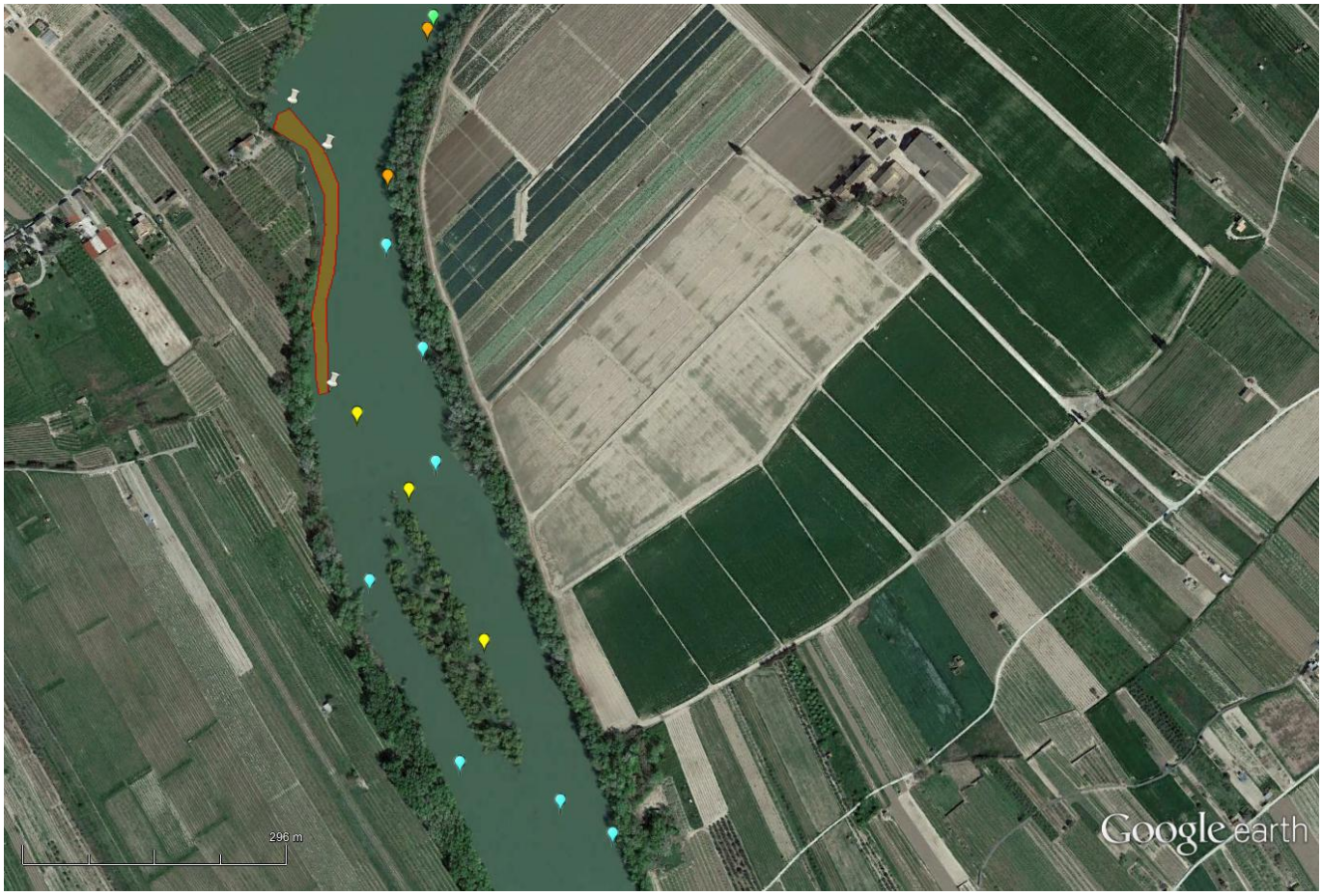


Figure 16: Aerial view (Google Earth) of the potential spawning ground for European sturgeon located next to the Sénia de Gorreta – Sénia de Pau, see text for details. An image of the site from the water surface is also included.

❹ **<u>Section Miravet – Benifallet</u>** (average river water discharge: 146 m^3/s – value from the SAIH Tortosa station).

Potential spawning ground (Figure 17). Name/location: Roques de Besaculs (Municipality: Miravet); coordinates (midpoint): 31 T 296368.3 m E, 4542414.6 m N (upstream limit) – 31 T 296409.2 m E, 4542368.4 m N (downstream limit); average water depth: 9.5 m; type of bottom substrate: rocky river banks with sandy bottom next to the bank, depth increases rapidly (river pools); average water current: 1.5 - 2.1 m/s; macrophyte abundance: absent; area: 0.20 Ha.

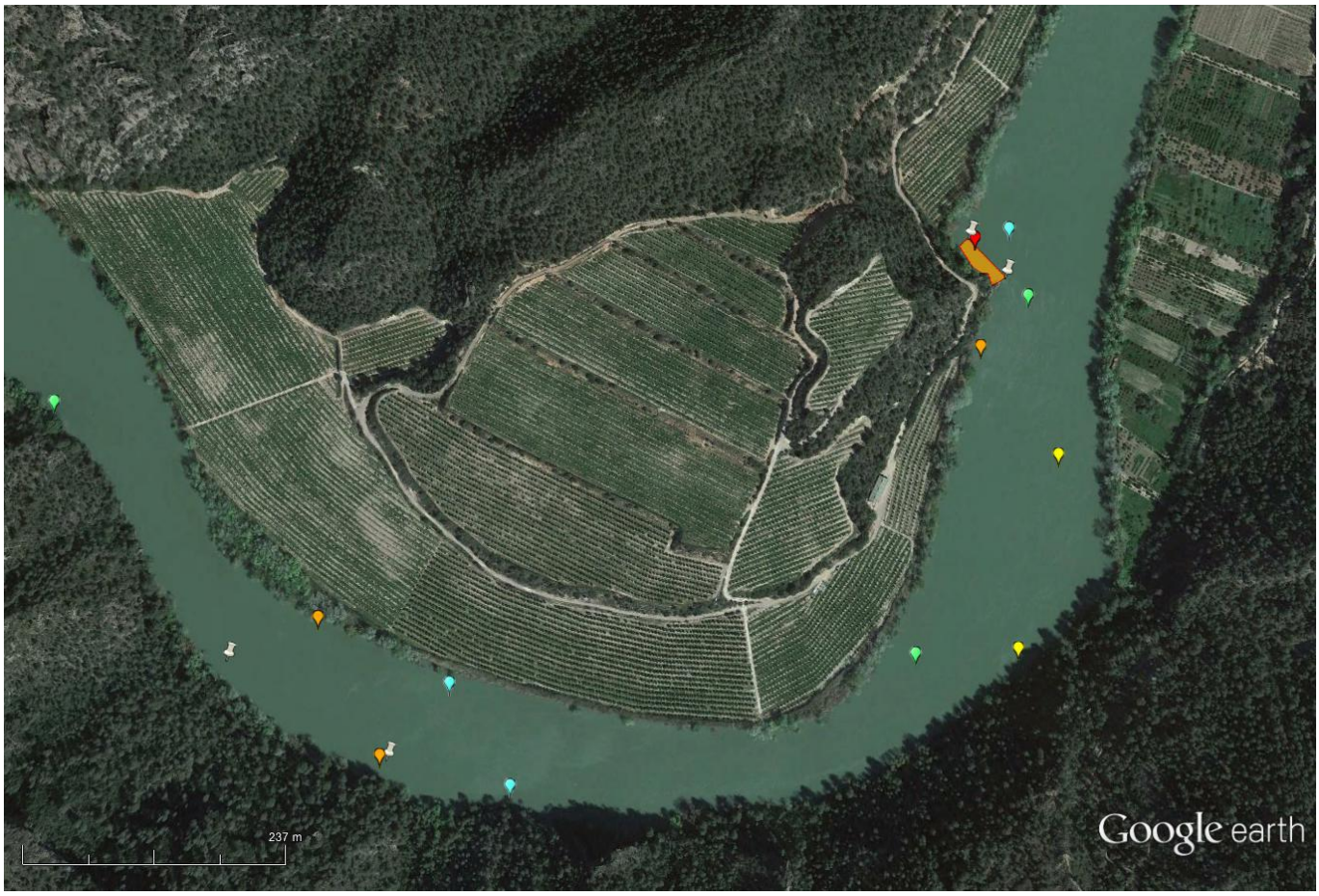


Figure 17: Aerial view (Google Earth) of the potential spawning ground for European sturgeon in the Roques de Besaculs, see text for details. An image of the site from the water surface is also included.

Nursery area (Figure 18, upstream site**).** Name/location: secondary river arm at the Illa del Nap (Municipality: Benifallet); coordinates (midpoint): 31 T 292071.8 m E; 4540395.9 m N (upstream limit) – 31 T 291908.5 m E, 4540127.3 m N (downstream limit); average water depth: 0.5 - 1.5 m; type of bottom substrate: mixed area of gravel (coarse, 20 – 30 mm), small cobbles (50 – 80 mm) and sand with filamentous green algae ; average water current: 0.2 – 0.7 m/s; macrophyte abundance: high (60 - 70% macrophyte coverage); macrophyte position: semi-erect; area: 0.79 Ha.

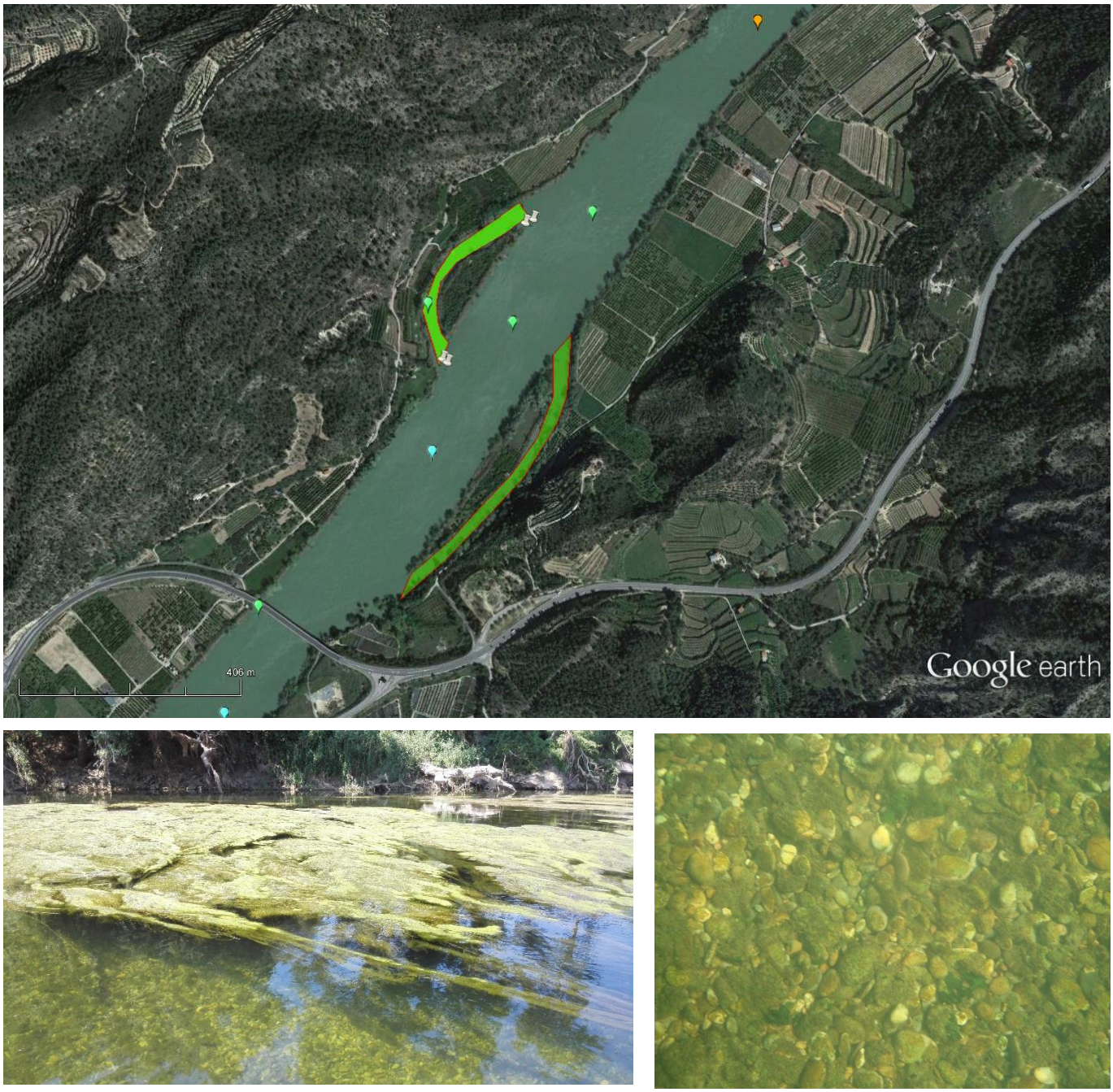


Figure 18: Aerial view (Google Earth) of the nursery area located in the secondary river arm at the Illa del Nap, see text for details. An image of the site from the water surface (lower left), together with an underwater image of the site showing the type of substrate (lower right).

Nursery area (Figure 19, downstream site**).** Name/location: secondary river arm at the Illa de Cateura (Municipality: Benifallet); coordinates (midpoint): 31 T 292127.6 m E; 4540136.7 m N (upstream limit) – 31 T 291830.6 m E, 4539705.1 m N (downstream limit); average water depth: 0.5 - 1.0 m; type of bottom substrate: mixed area of gravel (coarse, 20 – 30 mm), small cobbles (50 – 80 mm) and sand with filamentous green algae ; average water current: 0.2 m/s; macrophyte abundance: high (70 – 80 % macrophyte coverage); macrophyte position: upright and semi-erect; area: 1.31 Ha.

Figure 19: Aerial view (Google Earth) of the nursery area located in the secondary river arm at the Illa de Cateura, see text for details. An image of the site from the water surface (lower left), together with an underwater image of the site showing the type of substrate (lower right).

Section Benifallet – Xerta's weir (average river water discharge: 130 m^3/s – value from the SAIH Tortosa station).

Nursery area (Figure 20). Name/location: Mas de Mollet (Municipality: Benifallet); coordinates (midpoint): 31 T 290276.4 m E, 4537105.6 m N (upstream limit) – 31 T 290223.5 m E, 4537089.4 m N (downstream limit); average water depth: 0.2 – 0.5 m; type of bottom substrate: sand with very fine gravel covered with large masses of filamentous green algae; average water current: <0.1 m/s; macrophyte abundance: low (10-20% bottom coverage); macrophyte position: semi-erect; area: 0.09 Ha.

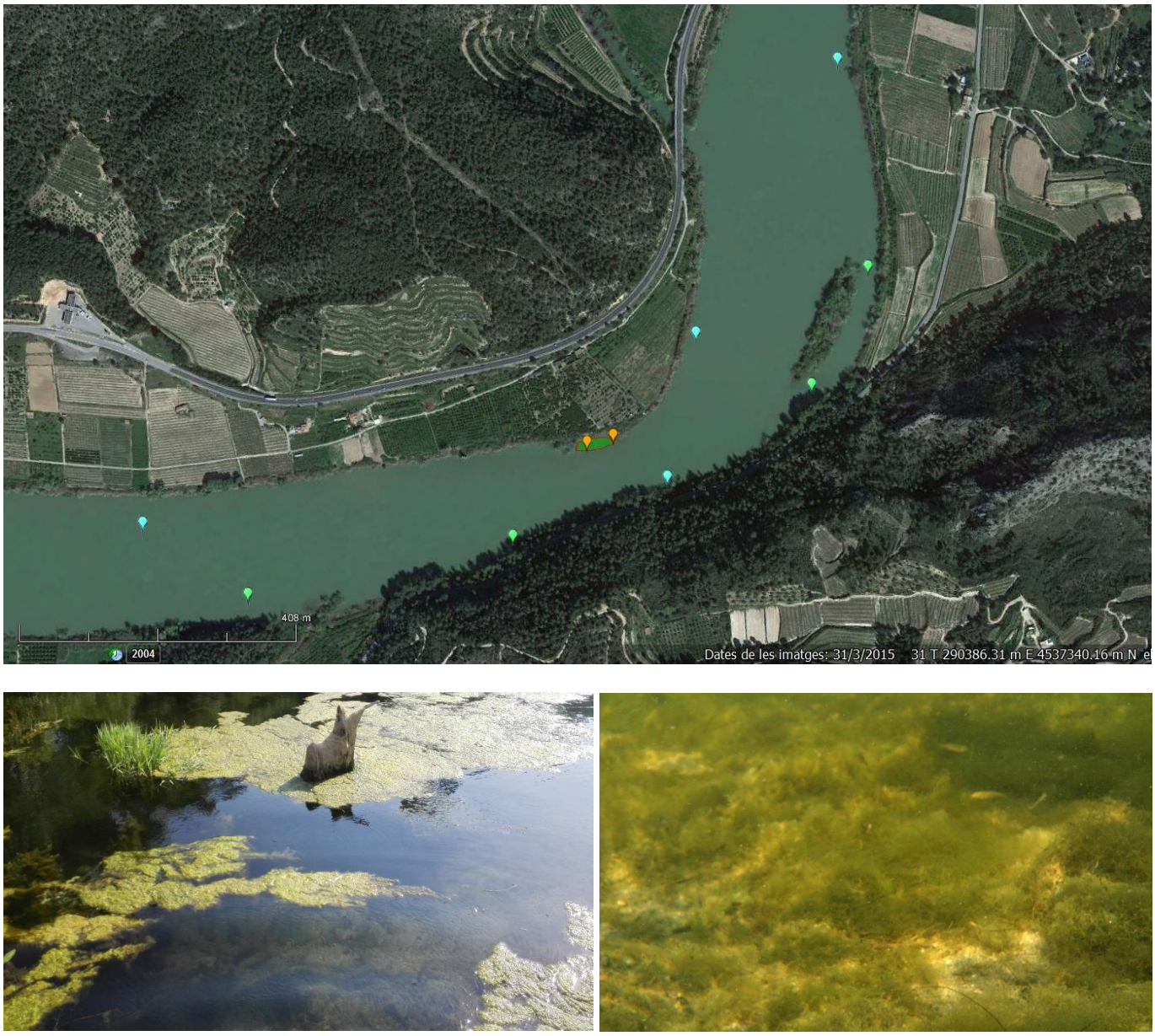


Figure 20: Aerial view (Google Earth) of the nursery area located Mas de Mollet (Benifallet), see text for details. An image of the site from the water surface is included, as well as a detail of the bottom (underwater image) showing masses of green algae covering the sandy bottom of this nursery area.

Potential spawning grounds (Figure 21). Name/location: Roca de l'Hombro (Municipality: Benifallet); coordinates (midpoints for both locations): location 1: (upstream site) 31 T 288237.6 m E, 4536307.9 m N (upstream limit) – 31 T 288278.6 m E, 4536295.0 m N (downstream limit); location 2 (downstream site): 31 T 288326.8 m E, 4536170.2 m N (upstream limit) – 288402.6 m E, 4536107.7 m N (downstream limit); average water depth: 5.6 – 8.5 m; type of bottom substrate: rocky river banks with scattered large boulders (>1.5 m) with small cobbles (50 -80 mm) within river pools; average water current: 1.5 – 1.8 m/s (location 1), 0.7 m/s (location 2); macrophyte abundance: absent; area: 0.06 Ha (location 1), 0.14 Ha (location 2).

Figure 21: Aerial view (Google Earth) of the potential spawning grounds of the Roca de l'Hombro (Benifallet), see text for details. Images of both sites from the water surface (location 1: left image, location 2: right image) are also included.

Potential spawning grounds (Figure 22, upstream site**).** Name/location: opposite river bank in front of the Mas de Xalamera (Municipality: Benifallet); coordinates (midpoints): 31 T 288874.2 m E, 45.5587.6 m N (upstream limit) - 31 T 288848.8 m E, 4535374.6 m N (downstream limit); average water depth: 5.5 – 8.6 m; type of bottom substrate: rocky river banks with scattered large boulders (>1.5 m) with small (50 - 80 mm) and large (120 -150 mm) cobbles within river pools; average water current: 1.1 – 1.5 m/s; macrophyte abundance: low (<10%); macrophyte position: semi-erect and prostate; area: 0.26 Ha.

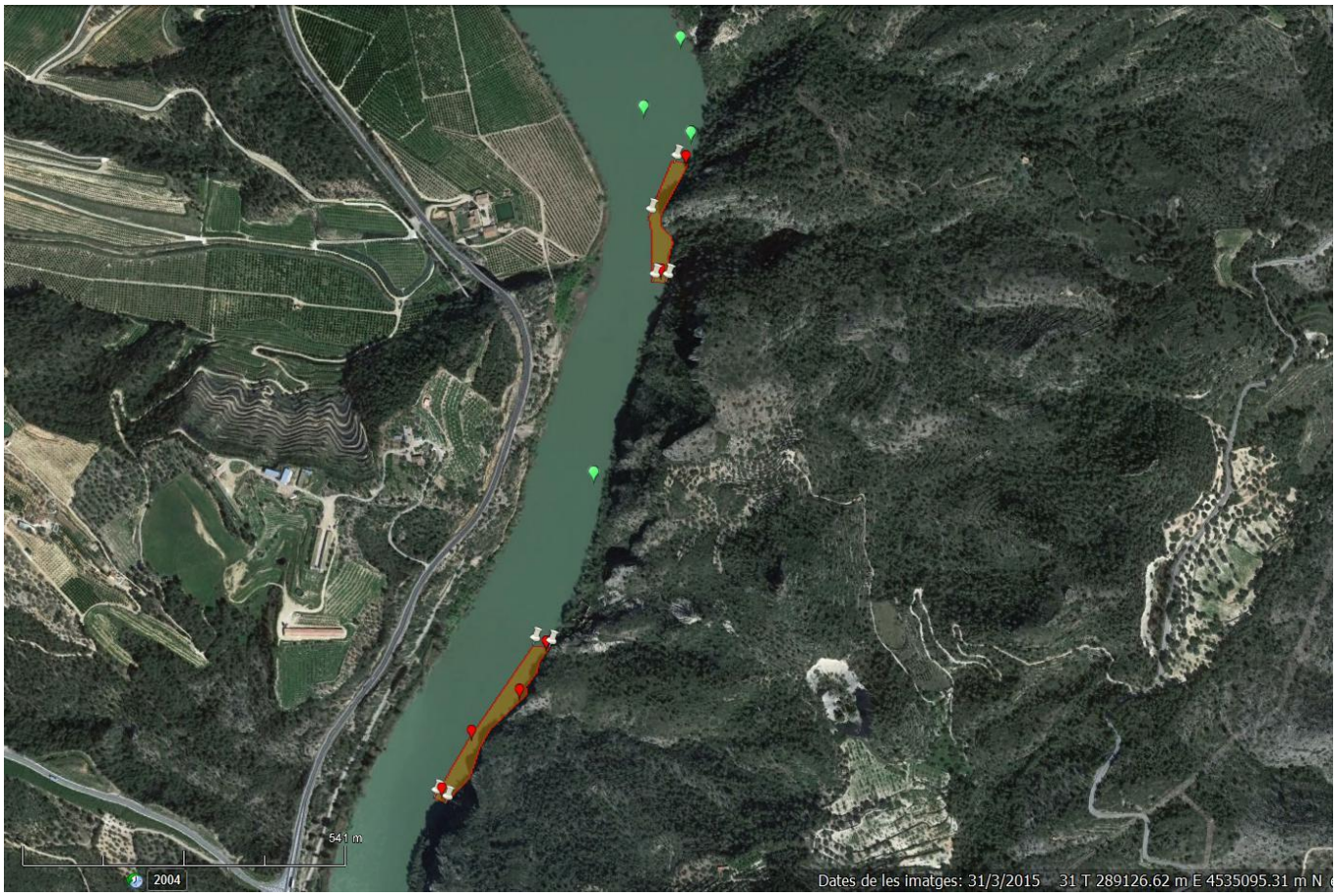


Figure 22: Aerial view (Google Earth) of the potential spawning ground in the site situated in the opposite river bank in front of the Mas de Xalamera (Municipality: Benifallet), see text for details. An image of the site from the water surface is also included.

Potential spawning grounds (Figure 23, downstream site**).** Name/location: site close to El Clot de la Pedrera, kilometric point 34 C-12 in the opposite river bank (Municipality: Benifallet); coordinates (midpoints): 31 T 288663.8 m E, 4534729.5 m N (upstream limit) - 288501.7 m E, 4534450.8 m N (downstream limit); average water depth: 3.1 – 8.3 m; type of bottom substrate: rocky river banks with scattered large boulders (>1.5 m) with small (50 - 80 mm) and large (120 -150 mm) cobbles within river pools; average water current: 1.1 – 1.5 m/s; macrophyte abundance: low (<20%); macrophyte position: semi-erect and prostate; area: 0.78 Ha.

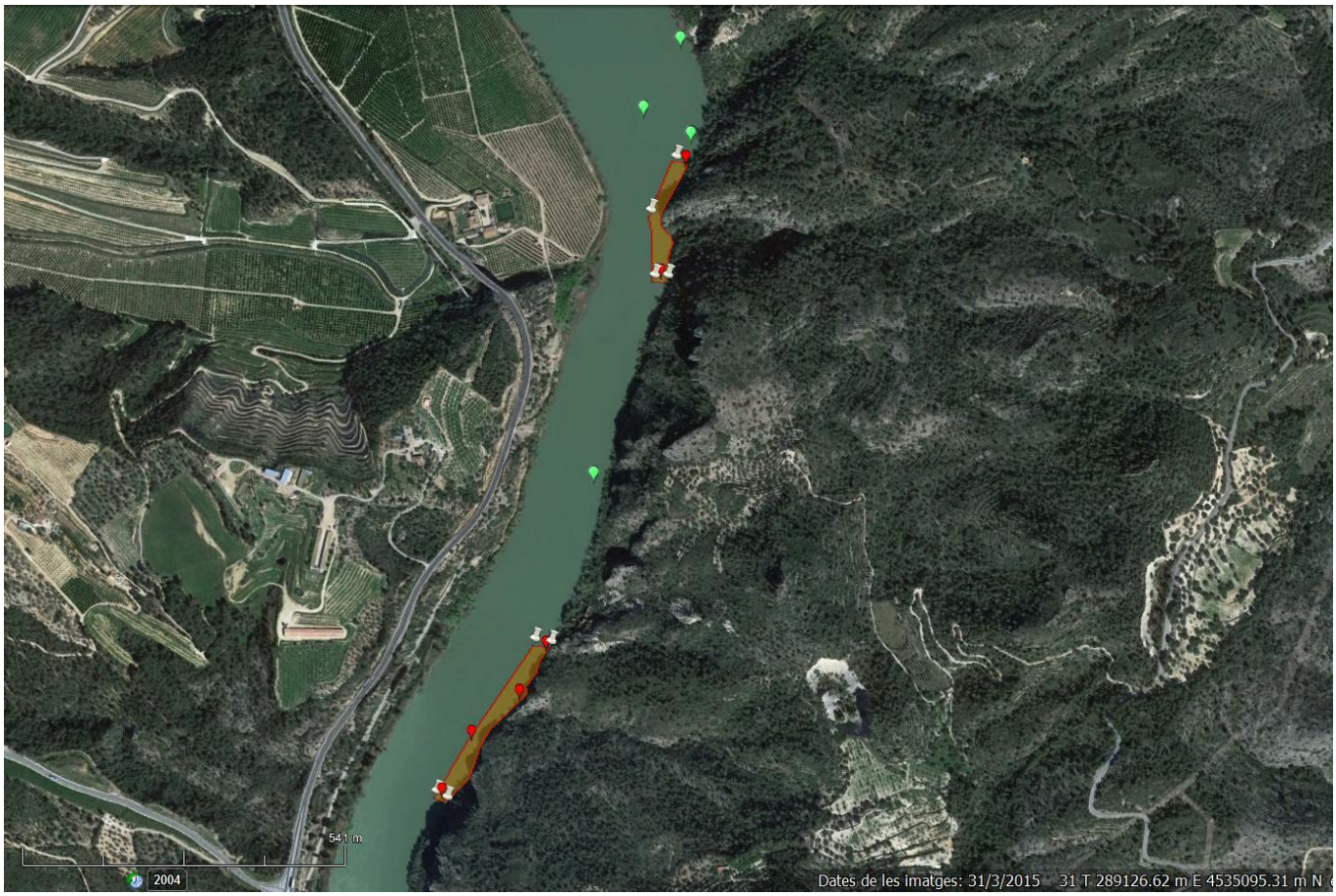


Figure 23: Aerial view (Google Earth) of the potential spawning ground close to the El Clot de la Pedrera, see text for details. An image of the site from the water surface is also included.

Potential spawning grounds (Figure 24). Name/location: Caldera de l'Arram (Municipality: Xerta); coordinates (midpoints): 31 T 288320.9 m E, 4534009.5 m N (upstream limit) - 288371.0 m E, 4534004.2 m N (downstream limit); average water depth: 5.6 -6.2 m; type of bottom substrate: rocky river banks with scattered large boulders (>1.0 m) with large (120 -150 mm) cobbles within river pools; average water current: 1.5 – 1.8 m/s; macrophyte abundance: absent; area: 0.09 Ha.

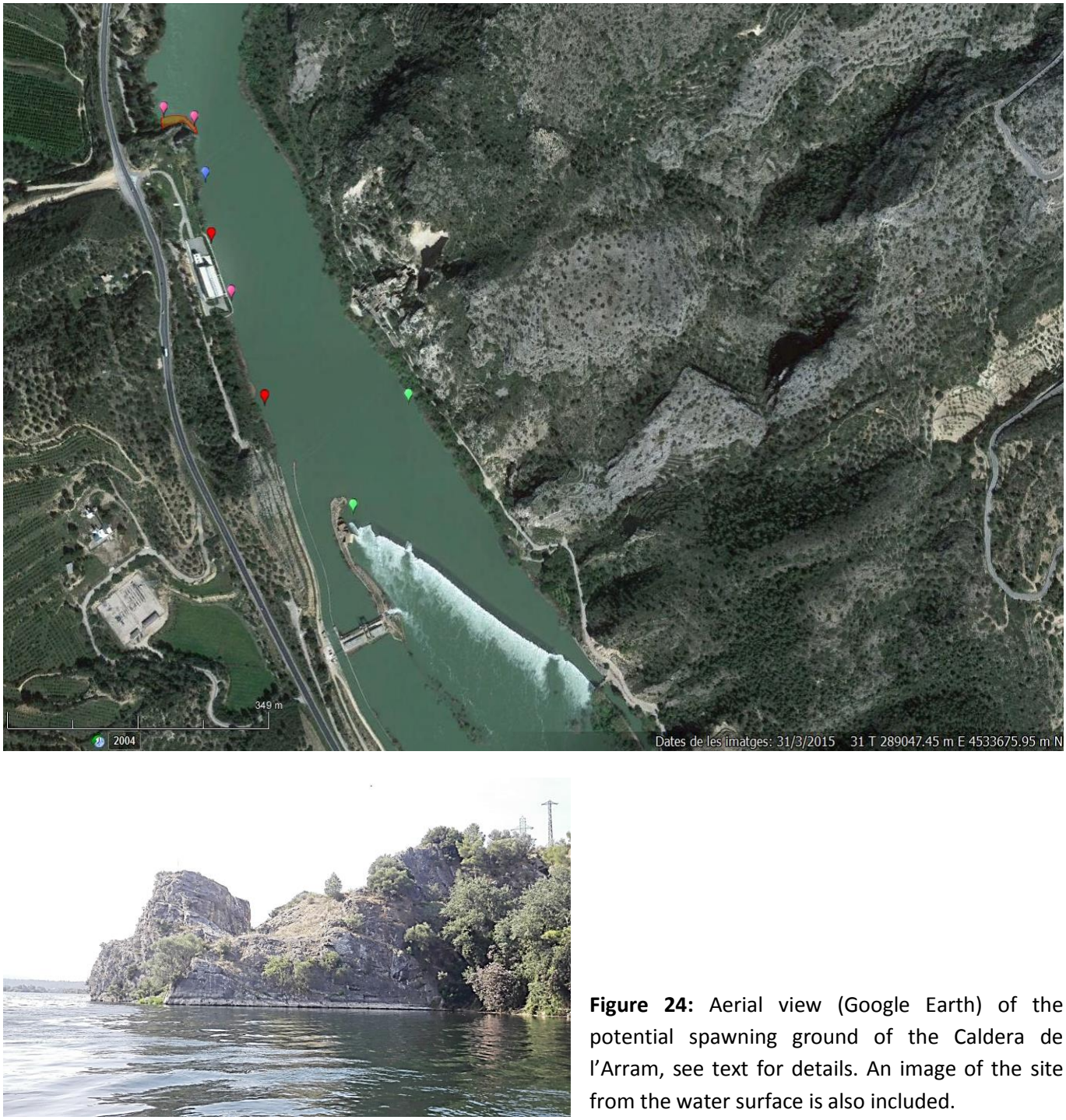


Figure 24: Aerial view (Google Earth) of the potential spawning ground of the Caldera de l'Arram, see text for details. An image of the site from the water surface is also included.

A1.1.3. Conclusions

Along the 58 km of the Ebro River monitored (river stretch comprised between Flix and Xerta's weir), we have recorded a total surface of 8.2 Ha of **potential new spawning grounds** for European sturgeon. In terms of importance, the river sector with the highest abundance of these sites is the river stretch comprised between the Ascó weir and the village of Móra d'Ebre, comprising half of the potential spawning grounds located for European sturgeon, whereas other significant stretches of the river are those comprised between the villages of Móra d'Ebre and Miravet (24.4%) and that between the village of Benifallet and the Xerta's weir (23.9%). In contrast, the river sections comprised between the Flix's dam and Ascó's weir and comprised between the villages of Miravet and Benifallet did not have significant potential spawning grounds for European sturgeon (Table 3).

Table 3. Relevance of potential spawning grounds for European sturgeon along the Ebro River stretch comprised between the Flix's dam and the Xerta's weir. Data is expressed area (Ha) and the percentage of the total area covered by these sites per river section.

	Spawning grounds (Total area= 8.2 Ha)	**Nursery areas (Total area = 46.8 Ha)**
Flix's dam – Ascó's weir	-	64.8 %
Ascó's weir – Móra d'Ebre	4.65 Ha / 56.7 %	7.9 %
Móra d'Ebre – Miravet	2.22 Ha / 27.1 %	25.5%
Miravet – Benifallet	0.2 Ha / 2.4 %	1.7%
Benifallet – Xerta's weir	1.13 Ha /13.8 %	0.2%

Although surface area of individual sites varies considerably, data on the surface area of potential spawning grounds for European sturgeon was in correlation and agreement with the number of spawning sites found along the Ebro River stretch comprised between the Flix dam and Xerta's weir, with the river section with the highest number of potential spawning grounds being that comprised between Asco's weir and the village of Móra d'Ebre, followed by the section comprised between the village of Benifallet and Xerta's weir (Table 4).

Table 4. Number of potential spawning grounds (sites) for European sturgeon along the Ebro River stretch comprised between the Flix dam and Xerta's weir.

	Spawning grounds (number of sites)	**Nursery areas (number of sites)**
Flix's dam – Ascó's weir	0	1
Ascó's weir – Móra d'Ebre	6	3
Móra d'Ebre – Miravet	3	3
Miravet – Benifallet	1	1
Benifallet – Xerta's weir	5	1

Regarding the presence of **nursery habitats** and their total surface area, we have recorded a total of 46.8 Ha (Table 3), among which 64.8% of them were found in the river section comprised between the dam of Flix and the Asco's weir (Flix meander). The second river section in order of importance with regards to the number and area of nursery habitats is that comprised between the villages of Miravet and Móra d'Ebre (25.5%), whereas the rest of the river sections monitored showed a lower abundance of areas for nursery grounds.

Summarizing, if the construction of a fish lift at the Xerta's weir and a fish ramp at the level of the Ascó Nuclear Power station is accomplished within the duration of the Migratoebre project, there would be 58 km more of accessible river for the European sturgeon. Thus, this diadromous species would find a total 15 new potential spawning grounds occupying a total area of 8.2 Ha. This would represent for this species an increase in spawning grounds of 4.1 fold, as compared to the current spawning area located under the Xerta's weir (2.0 vs 8.2 Ha), if river connectivity is achieved. It is noteworthy to mention, that the river section with the highest abundance and area of spawning grounds for European sturgeon is that comprised between the village of Móra d'Ebre and the Ascó's weir (ca. 51% of the total area and 40% of sites). It should be mentioned that the above-mentioned spawning sites for European sturgeon would be shared with the twaite shad, although competence for them may low due to the different reproductive calendar of both species, twaite shad matting from late April until early June (López et al., 2011) and European sturgeon between May and June (Acolas et al., 2011), as well as their different reproductive behavior, since twaite shad reproduce at night hours (23:00 to 04:00 h; López et al., 2011) and sturgeons during day hours (Buckley and Kynard, 1985; Bouckaert et al., 2014). In case of potential overlapping and competence for the same spawning sites (June), it may be expected that European sturgeon may occupy the downstream spawning sites comprised between Xerta's weir and Miravet, and twaite shad those located upstream Miravet. However, this hypothesis would need fieldwork validation whenever in the future both species coexisted in the lower stretches of the Ebro River.

The abundance in number and surface area of nursery sites along the river stretch, comprised between the Flix's dam and Xerta's weir, guarantees that if reproduction of European sturgeon takes place there will be enough areas where the larvae and fry of this species can grow-up during their juvenile stage and before returning to the sea during the first two years of life of juveniles.

References Action A.1 (European sturgeon)

Acolas ML, Castelnaud G, Lepage M, Rochard E, 2011. Biological cycles and migrations of Acipenser sturio. In: Biology and Conservation of the European Sturgeon Acipenser sturio L. 1758. Pages 147-152. P Williot, E Rochard N Desse-Berset, F Kirschbaum, J Gessner (Editors). London, Springer.

Arndt GM, Gessner J, Bartel R, 2006. Characteristics and variability of spawning habitat for Baltic sturgeon in the Odra River and its tributaries. *Journal of Applied Ichthyology* 22, 172-181.

Baumgartner G, Nakatani K, Gomes LC, Bialetzki A, Sanches PV, Makrakis MC, 2004. Identification of spawning sites an natural nurseries in the upper Paraná river. *Environmental Biology of Fishes* 71, 115-125.

Boisneau P, Mennesson-Boisneau C and Baglinière JL (1990). Description d'une frayère et comportement de réproduction de la grande alose (*Alosa alosa* L.) dans le cours superieur de la Loire (France). *Bulletin Français de*

Bouckaert E K, Auer NA, Roseman EF, Boase J, 2014. Verifying success of artificial spawning reefs in the St. Clair–Detroit River System for lake sturgeon (*Acipenser fulvescens* Rafinesque, 1817). *Journal of Applied Ichthyology* 30, 1393-1401.

Brosse L, Berrebi P, Desse-Berset N, Lepage M, 2009. Sturgeon Recovery Plan in the Rhône River (France): Preliminary Results on Species Determination and Habitat Suitability. Pages 403-421. In: Carmona R, Domezain A, García Gallego M, Hernando JA, Rodríguez F, Ruiz-Rejón M (Editors), Biology, Conservation and Sustainable Development of Sturgeons (Springer), Fish & Fisheries Series Volume 29.

Buckley J, Kynard B, 1985. Habitat use and behavior of pre-spawning and spawning shortnose sturgeon, *Acipenser brevirostrum*, in the Connecticut River. Pages 111–117 in FP Binkowski, SI Doroshov (Editors). North American sturgeons: biology and aquaculture potential. Dr. W. Junk. Dordrecht, The Netherlands.

Du H, Yang DG, Chen XH, 2011. Spatial structure and bottom characteristics of the only remaining spawning area of Chinese sturgeon in the Yangtze River. *Journal of Applied Ichthyology* 27, 251-256.

Dumont P, D'Amours J, Thibodeau S, Dubuc N, Verdon R, Garceau S, Fortin R, 2011. Effects of the development of a newly created spawning ground in the Des Prairies River (Quebec, Canada) on the reproductive success of lake sturgeon (*Acipenser fulvescens*). *Journal of Applied Ichthyology* 27, 394-404.

Fox D A, Hightower JE, Parauka FM, 2000. Gulf sturgeon spawning migration and habitat in the Choctawhatchee River system, Alabama-Florida. *Transactions of the American Fisheries Society*. 129: 811-826.

Gao X, Li MZ, Lin PC, Duan ZH, Liu HZ, 2013. Environmental cures for natural reproduction of Chinese sturgeon, *Acipenser sinensis* Gray, 1835, in the Yangtze River, China. *Journal of Applied Ichthyology* 29, 1389-1394.

Hall JW, Smith TI, Lamprecht SD, 1991. Movements and habitats of shortnose sturgeon, *Acipenser brevirostrum* in the Savannah River. *Copeia* 1991, 695-702.

Jego S, Gazeau C, Jatteau P, Elie P, Rochard E, 2002. Spawning grounds available for the European sturgeon *Acipenser sturio* L. 1758 in the Garonne-Dordogne basin. Methods used, present status and prospects. *Bulletin Français de la Pêche et de la Pisciculture 365-366*, 487-505.

Kieffer MC, Kynard B, 1996. Spawning of shortnose sturgeon in the Merrimack River, Massachusetts. *Transactions of the American Fisheries Society* 125, 179–186.

Kieffer MC, Kynard B, 2012. Pre-spawning and non-spawning spring migrations, spawning, and effects of river regulation and hydroelectric dam operation on spawning of Connecticut River shortnose sturgeon. In Life History and Behaviour of Connecticut River Shortnose and Other Sturgeons. Pages 73-113 in Kynard B, Bronzi P, Rosenthal H (Editors), Norderstedt: Demand GmbH.

LaHaye M, Branchaud A, Gendron M, Verdon R, Fortin R, 1992. Reproduction, early life history, and characteristics of the spawning grounds of the lake sturgeon (*Acipenser fulvescens*) in Des Prairies and L'Assomption rivers, near Montrkal, Quebec. *Canadian Journal of Zoology* 70, 1681-1689.

López MA, Andree KB, Sánchez R, Queral JM, Franch N, Schneider P, Gisbert E, 2011. First characterization of the spawning habitat and mating behaviour of twaite shad in the Ebro River (Western Mediterranean) *Journal of Ichthyology* 27, 53-55.

Manny BA, Kennedy GW, 2002. Known lake sturgeon (*Acipenser fulvescens*) spawning habitat in the channel between lakes Huron and Erie in the Laurentian Great Lakes. *Journal of Applied Ichthyology* 18, 486-490.

McCabe Jr. GT, Tracy CA, 1994. Spawning and early life history of white sturgeon, *Acipenser transmontanus*, in the lower Columbia River. *Fishery Bulletin* 92, 760-772.

Paragamian VL, Kruse G, Wakkinen VD, 2001. Spawning habitat of Kootenai River white sturgeon, post-Libby Dam. *North American Journal of Fisheries Management* 21, 10–21.

Paragamian VL, Wakkinen VD, 2002. Temporal distribution of Kootenai River white sturgeon spawning events and the effect of flow and temperature. *Journal of Applied Ichthyology* 18, 542-549.

Parsley M J, BeckmanLG, McCabe G Jr, 1993. White sturgeon spawning and rearing habitat in the Columbia River downstream of McNary Dam. *Transactions of the American Fisheries Society* 122, 217–228.

Rovira A, Alcaraz C, Trobajo R, 2016. Effects of plant architecture and water velocity on sediment retention by submerged macrophytes. *Freshwater Biology* 61, 758-768.

Silva PA, Reynalte-Tataje DA, Zaniboni-Filho E, 2012. Identification of fish nursery areas in a free tributary of an impoundment region, upper Uruguay River, Brazil. *Neotropical Ichthyology* 10, 425-438.

Veschev PV, 2009. The state of natural reproduction of stellate sturgeon *Acipenser stellatus* in the Lower Volga. *Journal of Ichthyology* 49, 662-667.

Williot P, Rouault T, Brun R, Gessner J, 2011. Characteristics of the reproductive cycle of wild *Acipenser sturio*. Pages 165- 176. In: Biology and Conservation of the European Sturgeon *Acipenser sturio* L. 1758. 152. P Williot, E Rochard N Desse-Berset, F Kirschbaum, J Gessner (Editors). London, Springer.

Yang D, Kynard N, Wei Q, Chen X, Zheng W, Du H, 2006. Distribution and movement of Chinese sturgeon , *Acipenser sinensis*, on the spawning ground located below the Gezhouba Dam during spawning seasons. *Journal of Applied Ichthyology* 22, 145-151.

Zhang H, Wei QW, Kyanrd BE, Du H, Yang DG, Chen XH, 2011. Spatial structure and bottom characteristics of the only remaining spawning area of Chinese sturgeon in the Yangtze River. *Journal of Applied Ichthyology* 27, 251-256.

Zhang H, Yang DG, Wei QW, Du H, Wang CY, 2013. Spatial distribution and spawning stock estimates for adult Chinese sturgeon (*Acipenser sinensis* Gray, 1835) around the only remaining spawning ground during the trial operation of the newly constructed Three Gorges Project in the Yangtze River, China. *Journal of Applied Ichthyology* 29, 1436-1440.

References Action A.1 (European sturgeon)

Acolas ML, Véron V, Jourdan H, Bégout ML, Sabatié MR, Baglinière JL 2006. Upstream migration and reproductive patterns of a population of allis shad in a small river (L'Aulne, Brittany, France). *ICES Journal of Marine Science* 63, 476-484.

Baumgartner G, Nakatani K, Gomes LC, Bialetzki A, Sanches PV, Makrakis MC, 2004. Identification of spawning sites an natural nurseries in the upper Paraná river. *Environmental Biology of Fishes* 71, 115-125.

Beasley CA, Hightower JE, 2000. Effects of a low-head dam on the discrimination and characteristics of spawning habitats used by striped bass and American shad. *Transactions of the American Fisheries Society* 129, 1316-1320.

Boisneau P, Mennesson-Boisneau C and Baglinière JL (1990). Description d'une frayère et comportement de réproduction de la grande alose (*Alosa alosa* L.) dans le cours superieur de la Loire (France). *Bulletin Français de la Pêche et de la Pisciculture* 316, 15–23.

Cassou-Leins F, Cassou-Leins JJ, 1981. Recherches sur la biologie et l'halieutique des migrateurs de la Garonne et principalement de l'alose, *Alosa alosa* L. Doctorate 3 Séries Thesis, Institute National Polytechnique de Toulouse, Toulouse, France.

Caswell PA, Aprahamian, MW, 2001. Use of river habiat survey to determine the spawning habitat characteristics of twaite shad (*Alosa fallas fallax*). *Bulletin Français de la Pêche et de la Pisciculture* 362-363, 919-929.

Harris JE, Hightower JE, 2011. Identification of American shad spawning sites and habitat use in the Pee Dee River, North Carolina. *North American Journal of Fisheries Management* 31, 1019-1033.

Hightower JE, Sparks KL, 2003. Migration and spawning habitat of American shad in the Roanoke River, North Carolina. *American Fisheries Society Symposium* 35, 193-199.

Hightower JE, Harris JE, Raabe JK, Brownell P, Drew CA, 2012. A Bayesian spawning habitat suitability model for American shad in Southeastern United State Rivers. *Journal of Fish and Wildlife Management* 3, 184-198.

López MA, Andree KB, Sánchez R, Queral JM, Franch N, Schneider P, Gisbert E, 2011. First characterization of the spawning habitat and mating behaviour of Twaite shad in the Ebro River (Western Mediterranean) *Journal of Ichthyology* 27, 53-55.

Maitland, PS, Hatton-Ellis TW, 2003. Ecology of the Allis and Twaite Shad. Conserving Natura 2000 Rivers Monitoring Series 3 (Peterborough), 32 p.

Massmann, WH, 1952. Characteristics of spawning areas of shad *Alosa sapidissima* (Wilsom) in some Virginia streams. *Contributions from the Virginia Fisheries Laboratory* 39, 78-93.

Rovira A, Alcaraz C, Trobajo R, 2016. Effects of plant architecture and water velocity on sediment retention by submerged macrophytes. *Freshwater Biology* 61, 758-768.

Silva PA, Reynalte-Tataje DA, Zaniboni-Filho E, 2012. Identification of fish nursery areas in a free tributary of an impoundment region, upper Uruguay River, Brazil. *Neotropical Ichthyology* 10, 425-438.