Channels and ditches as the last shelter for freshwater mussels: the case of Margaritifera auricularia and other naiads inhabiting the mid Ebro River Basin, Spain

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ABSTRACT

1. Freshwater mussels or naiads are generally considered to thrive in river habitats, provided the ecological conditions are good. The presence of populations of these bivalves in artificial channels and ditches with natural bottoms has only scarcely been reported. The aim of this paper was to present the idea that these ‘channel’ and ‘ditch’ habitats could in fact be a sanctuary for naiads.

2. Approximately 80 km of several of these waterways fed by the mid Ebro River were sampled in Spain to monitor their naiad populations. Observations indicate that these habitats harbour substantial colonies of freshwater mussels (including two populations of adult specimens of the endangered species Margaritifera auricularia), much more so than the corresponding river.

3. The authors wish to alert conservation authorities and freshwater mussel experts to the extreme fragility and importance of this kind of habitat for the long-term conservation of these imperilled molluscs.

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Received 6 September 2006; Accepted 4 March 2007

KEY WORDS: conservation; endangered; bivalve molluscs; ecosystems; canals

INTRODUCTION

Freshwater bivalves (Unionoidea) or naiads are among the most endangered animals on the planet. Their reproductive cycle is highly specialized and relies upon a vertebrate host (mainly fish). On the gills or fins of this host, naiad larvae (glochidia) complete their metamorphosis giving rise to free juveniles that burrow into the bottom of the river or lake. Moreover, juvenile naiads are very demanding in terms of water and sediment quality. The human alterations suffered by water bodies in recent decades (water transfer, water...
abstraction, river channelization, dredging, impoundment, etc.) have had serious consequences on aquatic ecosystems (Dynesius and Nilsson, 1994; Harding et al., 1998), and the negative impact of these disturbances on the richness and density of naiad species has been demonstrated (Bogan, 1993; Vaughn, 1996; Arbuckle and Downing, 2002).

Freshwater mussels have generally been described in rivers, where they thrive under appropriate ecological conditions of substrate, water flow and fish abundance. However, the presence of populations of naiads in artificial channels and ditches with natural bottoms has only been reported in a few areas (Aldridge, 2000; Araujo and Ramos, 2000a; Araujo et al., 2000). This lack of information is remarkable since many rivers in Europe and some in North America have been extensively channelized to give rise to this type of waterway. However, based on the few reports available, it would appear that these waterways supplied by the rivers whose mollusc populations are in clear decline, are able to sustain the main reserve of the naiad populations (Holland-Bartels, 1990; Araujo et al., 2000). The most revealing case reported so far has been the finding of a population of Critically Endangered (IUCN) giant freshwater mussels, *Margaritifera auricularia*, in the Canal Imperial (Araujo and Ramos, 2000a), a channel fed by water from the mid Ebro River (Spain). The dramatic decline of *M. auricularia* across its classic distribution area (Araujo and Ramos, 2000b; Nienhuis, 2003) makes the Canal Imperial population the main stronghold of the species in the world. Other mussel species of conservation interest, such as *Unio mancus* (= *U. elongatulus*), have been reported also to inhabit this canal (Araujo et al., 2000).

This exciting finding is the subject of an ongoing project designed to improve our understanding of the richness and diversity of the naiads inhabiting the channels and ditches of the mid Ebro River, one of Spain’s largest rivers. Agricultural lands in this area are irrigated by buried waterways. Despite the fact that many of these have been filled in with concrete, several ditches and channels with natural bottoms remain undisturbed.

The aim of this paper is to introduce the idea of considering the ‘channel’ or ‘ditch’ habitat from a new perspective — as a sanctuary for naiads. With this in mind, several of these habitats were sampled to obtain data on their naiad populations. Our final goal is to alert conservation authorities and experts on freshwater mussels of the delicate nature and significance of this kind of habitat for the long-term conservation of these bivalves.

**MATERIALS AND METHODS**

The Canal Imperial de Aragón was built in the eighteenth century and runs parallel to the Ebro River through the Spanish provinces of Navarra and Zaragoza. The last 25 km of its total length of 115 km constitute a narrow concrete ditch 1–2 m wide. The main part of the channel is 10 m wide and about 3.5 m deep when full. Its water flow rate is 0.6 m s\(^{-1}\). There is no shoreline vegetation or aquatic vegetation, with the exception of a few trees and scattered patches of *Typha* sp. The Canal de Tauste, which crosses the same provinces and runs parallel to the north-facing banks of the Ebro, was built in the thirteenth and completed in the sixteenth century. Although narrower than the Canal Imperial, it shares the same physico-chemical conditions. The other watercourses examined here were narrow (2 m) ditches of modern construction. These artificial channels and ditches, corresponding to the six sites sampled, form part of the main irrigation network of the mid Ebro River (Figure 1). Only waterways with large stretches of natural bottom were surveyed; small ditches of the secondary irrigation network were avoided.

Samples were obtained when the water level was low (some 40–100 cm deep), which is when channel maintenance procedures are normally undertaken (generally in February and November). The canals were waded and specimens searched for on the water surface, or identified from traces or shells appearing in the sediment. Owing to the turbidity of the water from the Ebro, a ‘viewing-glass’ was needed to identify specimens when the water was deeper than 50 cm.
Generally, several surveyors covered the whole breadth of the waterway. Areas with deep pools were avoided, or sampled using water pumps or by professional divers. Overall, 80 km were surveyed including: 34 km of the Canal de Tauste, 34 km of the Canal Imperial, 5 km of the Pina ditch, 8 km of the Canal de Lodosa, 200 m of the Lorés ditch and 250 m of the Cascajo ditch (Figure 1).

Mussel richness and density were evaluated by depleting a previously measured waterway stretch of all its naiads and calculating the number of specimens per square metre. To do this, the corresponding stretches were meticulously inspected. Collected specimens were measured with a calliper, classified to the species level and sometimes inspected for gravidity. These specimens were then returned to their original habitats. The data used to establish the structure of the *M. auricularia* populations (Figure 2) were derived from Table 1 and from previous measurements made on other specimens.

The sediment composition of the *M. auricularia* habitat had been determined to establish the channel beds preferred by this species. This analysis was based on 1071 random samples taken from a 40 km stretch of the Canal Imperial and 9 km of the Canal de Tauste. Samples were obtained from the top sediment layer inside 0.5 × 0.5 m wooden frames positioned in areas occupied by specimens of *M. auricularia* and analysed volumetrically, establishing the grain-size classes: boulders (>256 mm), pebbles (64–256 mm), gravels (2–64 mm), sand (0.06–2 mm) and lime (0.04–0.06 mm).
The results indicate the presence of the same four naiad species in the main river (Ebro) and in the artificial channels and ditches fed by this river: *M. auricularia* (Spengler, 1793), *Potomida litoralis* (Cuvier, 1798), *Unio mancus* Lamarck, 1819 (= *Unio elongatulus* C. Pfeiffer, 1825) and *Anodonta* sp. The species of *Anodonta* living in the Ebro was formerly described as *Anodonta cygnea* (Araujo and Ramos, 2000a) but preliminary results derived from an analysis of mitochondrial gene variability suggest that it might be *Anodonta anatina* or another species of the genus (Araujo, unpublished data).

The waterways were observed to harbour many colonies of freshwater mussels (Table 1). For instance, some sampled stretches 150 m in length showed densities of *P. littoralis* greater than 0.5 specimens per square metre and of *Unio mancus* and *Anodonta* sp. greater than two specimens per square metre.

Except in the case of the endangered *M. auricularia* (Figure 2), these naiads reproduced and underwent juvenile recruitment at all the sites sampled (Figure 3). Although the smaller size classes were always less abundant, recruitment in these three species was confirmed by the constant presence of juveniles in all yearly samples.

All the waterways examined had areas of their former natural bottoms (gravel, pebbles) affected by human activities (e.g. tipping rubbish, silting), such that the naiad microhabitats were often far from clean. Similarly, large amounts of clay and mud covered some areas of the bottom, more commonly near outflows and at the ends of the waterways. A few specimens, perhaps carried by the water or born in sediment patches, were sometimes found in the sediments covering the concrete-filled areas of the channels (Figure 3).

The endangered species *M. auricularia* was detected in only two of the channels surveyed, the Canal Imperial south of the Ebro and the Canal de Tauste towards the north. Both are old canals (eighteenth and

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Figure 2. Structure of the populations of *Margaritifera auricularia* in (A) the Canal Imperial (*n* = 660) and (B) Canal de Tauste (*n* = 149).

RESULTS

The results indicate the presence of the same four naiad species in the main river (Ebro) and in the artificial channels and ditches fed by this river: *M. auricularia* (Spengler, 1793), *Potomida litoralis* (Cuvier, 1798), *Unio mancus* Lamarck, 1819 (= *Unio elongatulus* C. Pfeiffer, 1825) and *Anodonta* sp. The species of *Anodonta* living in the Ebro was formerly described as *Anodonta cygnea* (Araujo and Ramos, 2000a) but preliminary results derived from an analysis of mitochondrial gene variability suggest that it might be *Anodonta anatina* or another species of the genus (Araujo, unpublished data).

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Table 1. Information on the waterway stretches (upstream to downstream) sampled including naiad species richness and density values

<table>
<thead>
<tr>
<th>Waterway</th>
<th>Date (day/month/year)</th>
<th>Stretch surveyed (m²)</th>
<th><em>Margaritifera auricularia</em></th>
<th><em>Unio mancus</em></th>
<th><em>Potomida littoralis</em></th>
<th><em>Anodonta sp.</em></th>
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<td>Potomida littoralis</td>
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sixteenth century, respectively) dug from the Ebro river terraces and both preserve extensive areas of natural bottoms. The sediment composition of these bottoms varies, but always includes large amounts of gravel (Figure 4).

In total, 2757 live specimens have been identified in the Canal Imperial, 1097 of which had been previously tagged. One hundred and forty-nine specimens found in the Canal de Tauste were all tagged. All these specimens were adult, the smallest being 120 mm in length (Figure 2). More than 100 dead specimens of *M. auricularia* were found in the different surveys performed in the two canals. Some of these valves were very old and others still preserved soft body parts. Although two of these older dead specimens were 85 mm
and 100 mm in length (Figure 5), we confirmed the lack of juvenile recruitment of this species across the entire study area (in addition to that of any of its known populations elsewhere (Araujo, personal observation)).

**DISCUSSION**

Besides the Canal Imperial being home to the largest population of *M. auricularia* in the world, it also harbours the main populations of naiads of the entire Ebro basin (see below). Nevertheless, caution is needed when drawing ecological conclusions from these data for two reasons. First, this waterway has been very disturbed by decades of human activities, and second, clear distinction should be made between the
Figure 4. Sediment composition of the habitat of *Margaritifera auricularia* (see ‘Materials and Methods’). Canal de Tauste: 68 specimens. Different zones of the Canal Imperial ordered upstream to downstream: CIA1 (18 specimens), CIA2 (52 specimens), CIA3 (78 specimens), CIA4 (482 specimens) and CIA5 (373 specimens). The distance between CIA1 and CIA5 is 40 km.

Figure 5. Juvenile specimens of *Margaritifera auricularia*. (A) Collected from the Canal de Tauste in 2003 and (B) Collected from the Canal Imperial by Haas (1916).
presence of adult naiads and the existence of a reproductive population undergoing juvenile recruitment. This last issue is difficult to determine and varies for each naiad species.

In the case of the endangered *M. auricularia*, there are very few data on its presence in the Ebro River. According to Haas (1916), the only author who has studied living populations of the species in the river, in the year 1900 craftsmen who used the pearly shell of *M. auricularia* to make knife handles fished 40 kg of naiads per day from the meanders of the Ebro. If these 40 kg mentioned by Haas comprised empty shells, this would mean some 1900 specimens, while if the craftsmen weighed complete specimens including soft parts this would indicate around 1000 individuals. However, these data from Haas (1916) are a little unclear since he described captures of several species of naiads rather than specifying numbers of specimens of *M. auricularia*. Nevertheless, some years later in 1916, fishermen needed one month to capture 0.3 kg of specimens in the same zone. Unfortunately, Haas (1916) failed to provide information on the size of the area surveyed by the fishermen, although he did mention that *M. auricularia* in this meander area of the Ebro lived in turbid waters at depths of 5–7 m. In recent surveys conducted in selected zones of this same area by scuba divers, only one live specimen of *M. auricularia* was found, yet using the same sampling technique in different reaches of the river several kilometres upstream from the meander area (more than 25,000 m were surveyed), 40 living specimens in three separate colonies were recorded (Araujo, personal observation). There have also been reports of some live adult specimens in the lower Ebro (MIMAM, 2001). All these data suggest that *M. auricularia* is practically extinct in this river, and that the Canal Imperial and Canal de Tauste are the sites that will be important for restoring this species.

Unfortunately, the Canal Imperial population of *M. auricularia* is not free from danger. These results indicate that adult specimens can survive in different types of sediments of the Canal Imperial (and Canal de Tauste), including mud layers with anoxic bottoms. The largest colony of the species (approximately 1000 specimens) living in the muddy stretch of the last reach of the Canal Imperial, is becoming progressively buried, although in the past it probably lived on a clean bed of gravel (where the mussels were born). Given that mud deposition increases both over time and along the channel and that naiads have scarce mobility, these mud-dwelling specimens are likely to suffocate in the years to come. This lethal silting effect, which also blocks communication with groundwater, will be aggravated when lock gates are installed. Locks retain fine sediments and divide the channel into unconnected segments (Figure 6). Although a less urgent threat, other colonies living in cleaner gravel bottoms will have the same conservation problems. Notwithstanding, these modifications to their habitat are not the main threat for the populations of *M. auricularia*, which suffer from the old age of specimens, lack of host fish and consequent lack of juvenile recruitment.

In summary, the future of *M. auricularia* is very bleak if immediate conservation measures (habitat protection and artificial breeding and restocking) are not implemented. The recent recovery plan for the species in Aragón (Boletín Oficial de Aragón, 2005) may help preserve these last specimens, but unless the
large-scale modifications (installing lock gates, covering bottoms and slopes with concrete) that the Canal Imperial is currently suffering (Figure 6) are stopped, the recovery of the species will be jeopardized. The impacts of these hydraulic structures will probably be as harmful for channel naiad populations (owing to sediment deposition, barriers to water flow and fish migration, etc.) as the effects of dams on river populations of these molluscs (Watters, 1996; Vaughn and Taylor, 1999; Hardison and Layzer, 2000).

The main difference between the status of the other three naiad species and that of *M. auricularia* is that their populations in the waterways examined are more or less structured and juveniles are present, even thriving in muddy areas. This difference can be explained first by the absence of a sufficiently large population of the host fish to *M. auricularia* (Araujo et al., 2000), and second by the longevity of this species. The following are the native host fish to *M. auricularia*: *Acipenser sturio* (extinct) and *Salaria fluviatilis* (endangered) (Araujo et al., 2001); *U. mancus*: *Barbus graellsi*, *Barbus haasi*, *Squalius pyrenaicus*, *Squalius cephalus*, *Chondrostoma migii*, *Phoxinus phoxinus* and *S. fluviatilis* (Araujo et al., 2005); and *Anodonta sp.: B. graellsi, C. migii, S. fluviatilis, Gobio gobio, S. pyrenaicus and S. cephalus* (Gómez, personal observation). In the Canal Imperial, *M. auricularia*, whose lifespan is more than 50 years (Araujo, personal observation), takes 8–10 yr to reach sexual maturity and its host fish are practically absent. Without good host fish populations, reproduction cannot take place, despite the adult naiad population being fertile and probably sufficiently large. In contrast, the remaining species, whose lifespan is shorter, who reach sexual maturity quicker and have a wider, more available, host fish range, are capable of maintaining large populations in the waterways examined. The fish hosts of *P. littoralis* are as yet unknown, but given that it is the most abundant naiad (both in the canals and in the Ebro) and its recruitment was confirmed, it may be assumed that, like *U. mancus* and *Anodonta sp.*, it has a wide host fish range or its hosts include common fish species.

The success of these waterways for naiad proliferation and/or conservation can be understood if these habitats are considered as funnels, where fish enter from the river and probably spend most of their life. For instance, the presence of the *M. auricularia* population in the Canal Imperial is probably the result of historical colonization events by fish no longer present in the area, as proposed for other disturbed systems (Vaughn and Taylor, 2000). A positive relationship between mussel species richness and the abundance of fish has been demonstrated (Watters, 1992; Vaughn and Taylor, 2000). Hence, if the populations of naiads and fish living in these channels are sufficiently large and fertile, the fish will be infected by glochidia and the mussel reproductive cycle will continue. We consider this the main argument for taking immediate measures to preserve these habitats.

The following data clearly reflect the decline of naiads in their natural habitat (i.e. the Ebro River) and may also help understand the current interest in these waterways for the conservation of freshwater mussels. In surveys of the Ebro river undertaken in the early twentieth century, it was reported that hundreds of *P. littoralis* and about 40 *U. mancus* specimens were collected in a river stretch 60 m long and 8 m wide in 2.5 h by a single person (Haas, 1917). In contrast, in the recent survey performed by scuba divers in the best zone of the same river area, 15 and 16 specimens respectively were collected of each species (Araujo, personal observation). In further surveys carried out in 2005 in a 300 000 m² area of the river in the city of Zaragoza, 825 live naiads (619 *P. littoralis*, 179 *U. mancus* and 27 *Anodonta sp.*) were sighted by a team of eight people in 10 working days (unpublished data). These observations vary tremendously from the data quoted by Haas (1917) and those of the present paper (Table 1).

The environmental quality of the waterways examined in this report (and of others to be surveyed) is not ideal. Besides constant silt deposition and the installing of lock gates affecting the conservation of naiads, activities such as water regulation and replacement of natural bottoms with concrete are also responsible for the massive death of naiads. For example, in 2002 around 300 naiads were found recently dead along a 300 m stretch of the Lores ditch in response to maintenance works performed several kilometres upstream. This, and the high number of *M. auricularia* valves found in the surveys performed in the Canal Imperial...
and Canal de Tauste, reflect the habitat and specimen destruction suffered by these waterways over the last few years.

In conclusion, if new concrete waterways are constructed to regulate the water supply and avoid water losses, this measure should not be applied to the ancient channels and ditches that have worked well for centuries. The costs of investment and modernization, today’s social pressures and this recently identified need to preserve naiads, should prompt more natural solutions. Channels such as the Canal Imperial, Canal de Tauste and other natural ditches in the Community of Aragón and other areas of the Ebro basin house colonies of thousands of naiads that must be preserved, especially since their survival in the Ebro river is highly jeopardized.

The sustainable restoration of these waterways including interventions designed to improve slope stability and preserve their natural bottoms, and the inspection and rescue of their naiad populations, along with prohibiting lock gate installations, must be endorsed by the corresponding environmental authorities. Measures such as restocking with native fish (mainly *S. fluviatilis*, host to *M. auricularia* glochidia) and eradicating exotic species, could help recover populations of this vanishing mollusc. Some of these measures were proposed in the Action Plan for *M. auricularia* entrusted to the European Council (Araujo and Ramos, 2001) and by Aldridge (2000). It is important to recognize that some of these naiads are protected by laws such as the Habitats Directive and that *M. auricularia* is classed by the IUCN and Spanish catalogue of endangered species as Critically Endangered.

ACKNOWLEDGEMENTS

The authors thank the Departamento de Medio Ambiente de la Diputación General de Aragón (DGA) and Departamento de Medio Ambiente, Ordenación del Territorio y Vivienda del Gobierno de Navarra for their support with the projects ‘Conservación de especies amenazadas de moluscos acuáticos de Aragón’ and ‘Estudios preliminares de la población de *M. auricularia* y otras náyades en Navarra’. Also thanked are the ranger teams of Aragón and Navarra for their assistance in the field and the authorities of the Canal Imperial de Aragón and Canal de Tauste for their help with our surveys. The English version of the manuscript was revised by Ana Burton (BSc). The authors are also indebted to two anonymous referees for their constructive comments.

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