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EFFECTS OF RIVER IMPOUNDMENT ON THE PRESENCE OF THE  
PYRENEAN DESMAN  
*(Galemys pyrenaicus)*

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## *Abstract*

The present work concerns the study of two lotic systems, one which is regulated (cascade scheme comprising three impoundments) and one that is free-flowing. This work was undertaken in order to evaluate the effects of the impoundments on the presence of the Pyrenean desman (*Galemys pyrenaicus*).

At each stream several variables were analysed, including morphological and hydrological variables together with benthic faunal communities, scat survey for determination of desman presence and the QBR Index (riparian habitat quality).

After the analysis of the results it is possible to say that there existed differences between regulated and unregulated sites, at the level of hydrological and morphological variables, together with desman presence and also of benthic faunal communities.

Desman presence seems to be related to variability in hydrological variables and to variability of benthic faunal communities.

Considerations of the implications of habitat fragmentation on desman populations are made.

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# I. INTRODUCTION

## 1. THE SPECIES UNDER STUDY – *GALEMYS PYRENAICUS*

### 1.1. Characteristics

#### 1.1.1. Systematics and morphology

The Pyrenean desman (*Galemys pyrenaicus*) (Fig. 1.1), also known as Iberian desman, is a semi-aquatic insectivorous mammal, belonging to the family Talpidae. It was first described by Etienne Geoffroy Saint-Hilaire in 1811, and is one of only two representatives of the sub-family Desmaninae, (the other one being the Russian desman, *Desmana moschata*, L.).



**Fig. 1.1** – The Pyrenean desman (*Galemys pyrenaicus*). From <http://www.naturlink.pt/canais/Artigo.asp?iArtigo=6802&iLingua=1>

It is a small animal, with a body length of about 15 cm, weighing around 70 g, the females being just slightly larger than the males (Queiroz *et al* 1996); it can live for at least three years Richard (1985*b*).

The desman is covered with a dense and glossy dark-brown coat, which is silvery-grey in the abdomen; the coat helps to retain a large quantity of air and provides both thermal isolation and buoyancy (Queiroz *et al* 1996). The feet, tail and snout are almost devoid of hairs. The tail is long and flattened at the tip; the feet are webbed and have stiff hairs to aid swimming, the hindfeet are equipped with large claws and are much larger than the forefeet (Palmeirim & Hoffmann 1983; Queiroz *et al* 1996). The eyes of the desman are very small and are hidden underneath its fur, as are the ears, which are devoid of auricles (Queiroz *et al* 1996).

The snout is long and mobile, and possesses highly innervated vibrissae. It is used for discrimination of surface textures, detection of obstacles, capture and handling of prey; detection of prey is made through chemoreception, using the Jacobson's organ located in the snout (Richard 1985*b*).

The Desmaninae possess musk glands at the base of the tail, and the faeces of *Galemys* have a characteristic musky scent when they are fresh, and it is thought that this might be involved in marking behaviour (Stone 1987*b*).

## **1.2. Fossil Record**

The desman is considered to be a relict species from the tertiary era; the first records amount to the Oligocene and Miocene in Europe, namely in the Oligocene of Germany, where signs of a desman-like insectivore – the *Dimyloides* – have occurred (Savage, cited in Ramalhinho & Boavida 1993). A fossil of the species *Mygalea antiqua*, which is considered by Richard (1976) close to the actual species, was found in the Upper Miocene of Sansan in Gers (France) and also in Norfolk (England) (Saint Girons, cited in Palmeirim & Hoffman 1983).

The fossil remains of another species (*Galemys kormosi*), which is considered to be the ancestor of *Galemys pyrenaicus*, have also been found in Norfolk, in deposits of the Lower Pleistocene (Harrison *et al* 1988) and in six other sites in continental Europe, mainly Spain, Poland, the Netherlands and Hungary, all in deposits of the Lower Pleistocene (Rumke, cited in Harrison *et al* 1988). However, since then, the geographical range of *Galemys* has contracted southwards (Corbet, cited in Harrison *et al* 1988) and nowadays, *G. pyrenaicus* is restricted to the Pyrenees and the north of the Iberian Peninsula (Fig. 1.2). Reasons for this historic reduction in geographic area are not clear; some authors argue that it might have been related to past climate changes, e.g. the end of the Ice Age (Almaça 1992), while others suggest that predation pressure played a part (Queiroz *et al* 1996). Competition with the water shrews of the genus *Neomys* has also been considered by some authors (Harrison *et al* 1988; Rumke, cited in Queiroz *et al* 1996) to be a factor in the displacement of *Galemys* from its previous range in western central Europe. It is interesting to note that today, the Eurasian water shrew (*Neomys fodiens*) and *Galemys pyrenaicus* have allopatric distributions, although their distributions overlap in rivers of the Pyrenees and Cantabria (Corbet, cited in Harrison *et al* 1988; Nores 1995). In a study conducted in the Spanish Pyrenees (Castián & Gosálbez 1999), it was found that the Eurasian water shrew *Neomys fodiens* had a high trophic overlap with *Galemys*, which was especially pronounced during springtime.

### **1.3. Geographic Distribution**

At present, the desman has a restricted geographic distribution and is limited to the French and Spanish slopes of the Pyrenees and to high altitude areas in the northern half of the Iberian Peninsula (Bertrand 1992, 1993). In Spain, the desman is present in

the provinces of Cantabria, Galicia, Asturias (*Cordillera Cantabrica*), Navarra, Aragón, la Rioja, Cataluña (Pyrenean slopes), the rivers of Gredos and Guadarrama Mountains belonging to the Central System (*Sistema Central*) and in the north of the Iberian System (*Sistema Ibérico*) (Castién & Gosálbez 1993; ICONA, cited in Hernández 1988; Nores 1998; Nores *et al* 1992, 1993*a,b*; Santamarina 1993). In Portugal, the desman occurs in the northern and central mountain ranges, its southernmost distribution coinciding with *Serra da Estrela* (central Portugal) (Queiroz *et al* 1996, 1998), an extension of the *Sistema Central*.

Some authors (Fernández-Salvador *et al* 1998; Nores 1998) declare that due to its habitat requirements, the desman's distribution is not continuous throughout its range, but is patchy and that there are some populations that are currently isolated. For example, Nores (1998) suggests that a disruption occurs in the Basque Country, where the desman has been recorded (Castién & Gosálbez 1993), separating the desman populations occupying the *Cordillera Cantabrica* from those occupying the Pyrenees and adjacent provinces of Navarra and La Rioja. It is also suggested that the populations occupying the northern Iberian System can be isolated from those occurring in the Pyrenees and in the *Sistema Central*, which in turn are isolated from the populations occupying the *Serra da Estrela* in Portugal (Fig. 1.2; Nores 1998; Queiroz *et al* 1998).



Fig. 1.2 – Assumed area of distribution of *Galemys pyrenaicus* in the Iberian Peninsula. From <http://www.naturink.pt/canaais/Artigo.asp?iArtigo=6802&iLingua=1> (adapted from Queiroz, 1996)

This geographic separation has led to some authors (Ellerman & Morrison-Scott, cited in Palmeirim & Hoffman 1983) to consider two subspecies, *Galemys pyrenaicus pyrenaicus* occurring in the Pyrenees and *Galemys pyrenaicus rufulus*, occurring west of the Ebro Valley (*Cordillera Cantabrica*, *Sistema Ibérico*, *Sistema Central* and Portugal) (Palmeirim & Hoffman 1983). The authors based their assumptions on morphological differences (skull, body size and fur coloration) between specimens caught at different locations, however González-Esteban and colleagues (1999) having examined specimens from different regions, have concluded that although there exists morphological variability of *Galemys pyrenaicus* across its distribution area, such variation is not enough to support a definite separation into two subspecies, and the authors further add that “the distribution of the population variations would be more complicated than the simple description of the two known subspecies”.

Richard (1976) considered altitude to be the major factor limiting the desman’s distribution, however, Bertrand (1993b) suggests that altitude is insufficient to characterise its distribution, since the desman has been found in a wide range of altitudes (50 m to 2200 m – Bertrand 1992; Castién & Gosálbez 1992, 1993) and that precipitation might also be a determining factor. Other authors also support this idea;

according to Fernández-Salvador *et al* (1998), rainfall and drought strength seem to be the climatic variables that restrict its distribution in the southern limits of its range. The aforementioned factors will affect water availability and flow regularity of streams, which in the opinion of Nores and colleagues (1993*b*; Nores & Alvarez 1995) are the main environmental constraints to the desman's distribution together with riverbed slope.

Thus, according to Fernández-Salvador and colleagues (1998) the desman appears to select Eurosiberian, high-mountain and humid Mediterranean climates and avoid semi-arid Mediterranean climates.

#### **1.4. Ecology**

##### **1.4.1. Habitat**

One of the first accounts of the desman's habitat was made by Peyre in 1956. According to this author, the desman inhabits the trout zone of streams which are characterised by cold, permanent flowing, highly oxygenated, turbulent water with abundant aquatic invertebrate fauna composed of insect larvae (Trichoptera, Plecoptera, etc.) and crustaceans (*Gammarus*). Provided these conditions are met, and that natural shelters are available, the desman can inhabit stream stretches ranging from small mountain streams to mid reaches, and even canals of water mills.

Richard (1976, 1985*b*) describes the desman as an animal exclusively adapted to aquatic habitats, especially the upper sections of rivers (the rithron) where the water has a low temperature and is highly oxygenised. According to this author, the ideal habitat for this species are fast flowing streams, flowing through meadows, bordered by stonewalls and trees such as ash and alder that allow light to penetrate through the canopies. He adds that the existence of exposed roots of the riparian vegetation and

stones in the stream banks make good shelters and grant access to crevices located under the banks, which the desman uses as nest. Thus, according to the authors mentioned, the species appears to prefer high-mountain unpolluted streams. However, in a later study undertaken by Bertrand (1992), he mentioned the presence of the species in high altitude lakes in the Pyrenees and Castián & Gosálbez (1992) found *Galemys* in moderately polluted sites suggesting that the desman has a certain tolerance to pollution.

#### 1.4.2. *Reproduction/Reproductive behaviour*

The desman's reproductive behaviour is largely unknown. It is thought that the reproductive period occurs between January and July (Richard & Vallette Viallard 1969). According to Peyre (1956) male spermatogenesis commences in November, and from January until May, the male is sexually active. Oestrus begins in January, the reproductive period lasting from February until May; the first pregnant females appear in February and the last in June (Peyre 1956). According to Richard & Vallette Viallard (1969), three annual peaks of pregnant females occur (February, end of March and May) suggesting that females are polyestrus, however, Queiroz *et al* (1996) argue against this hypothesis. The gestation period lasts for about 30 days (Peyre, cited in Palmeirim & Hoffman 1983), with the birth of the young occurring from March to July. The litter size ranges from 1 to 5 young, with 4 being the most frequent number; suckling lasts until August (Peyre 1956). Post-partum females were those found to be pregnant and lactating at the same time (Peyre, cited in Palmeirim & Hoffman 1983). Females are thought not to reach maturity until their second year, and immatures are described as weighing less than 50g (Peyre, cited in Richard & Vallette Viallard 1969).

### 1.4.3. *Social organisation*

Desmans appear to be sedentary, occupying fixed home ranges (Richard & Vallette Viallard 1969), which are essentially linear (along a stretch of river), since these animals never move from the stream (Stone & Gorman 1985). Richard and Vallette Viallard (1969) indicated home ranges of 100 m and 200 m for females and males respectively. In studies undertaken by Stone and Gorman (1985) and Stone (1987*a, b*) using radiotracked individuals, however, the desman's home ranges appeared to be much larger depending on the social status of the individual in the population. According to Stone & Gorman (1985) and Stone (1987*a*), desman populations are composed of sedentary and transient members.

The sedentary group is composed of paired adult desmans i.e. a female and its male partner, sharing the same stretch of stream, but being predominantly solitary, occupying separate and permanent nesting sites. For these resident males, the average home range is approximately 429 m ( $\pm 10$  m), while the resident female's home range is approximately 301 m ( $\pm 6.8$  m), being entirely contained within that of its partner (Stone 1987*a*). The territory of the sedentary group is largely exclusive to the pair, but there may be a slight overlap with the range of a neighbouring paired male, this does not, however, include the resident female's range (Stone 1987*a*).

Transient groups are composed of juveniles or solitary adult males or females, occupying home ranges of around 248 m ( $\pm 23$  m) and 584 m ( $\pm 97$  m) respectively (Stone 1987*a*). In contrast to the paired adults, neither solitary individuals nor juveniles are sedentary and their home ranges are of a temporary nature (Stone 1987*b*; Stone & Gorman 1985). Nores and colleagues (1998) studying desman densities in Spanish streams, found that the values range from 2.8 and 7.3 individuals per km, which he argues are consistent with the data provided Stone and Gorman (1985).

The desman is extremely aggressive towards conspecifics, especially between adults of both sexes and less so between adults and juveniles (Richard & Vallette Viallard 1969; Stone 1987a). Territorial defence through actively patrolling of marginal areas of territory is most apparent between resident adult male desmans. In contrast, such active behaviour is not apparent in transient members. Stone (1987a) also argues that this routine patrolling is accompanied by the deposition of scent marks alongside the boundaries.

According to Richard & Vallette Viallard (1969) it is the female that actively seeks a partner, although she shows more site fidelity than the male.

Desman's nests are subterranean; however, unlike the mole and the Russian desman, the Pyrenean desman does not burrow, and the shelters are natural crevices between rocks or tree roots located in the stream banks (Stone 1987b).

#### 1.4.4. *Patterns of activity*

It is widely referenced that the desman is a largely nocturnal species (Peyre 1956; Richard & Vallette Viallard 1969). It has a biphasic pattern of activity (Stone 1987b), a long period of activity during the night and a shorter one during the afternoon. Nocturnal activity usually commences just after 22:00 h and lasts for about 7 hours, the shorter diurnal activity period lasting between 2 to 4 hours (Stone 1987b). In an earlier study on captive desmans, Richard (1985a) also verified the biphasic period of activity of the species. His study comprised observations throughout the year and he observed that although for most of the year (from April to December) the activity patterns of the desman were similar to those described by Stone, during the remaining months, the usual pattern was altered and the desman's activity became mostly diurnal. Richard also observed that this change coincided with the start of reproductive activity – the

males were least active in March and most active in May. The activity of both sexes ceases in June for about 6 months (Richard 1985*b*). During the months of September, October and November, little activity was registered and according to Richard (1985*a*) this could be attributed to the scarcity of active females, but also to poor weather, since the desman's activity is known to be affected by rainfall, thunderstorms and temperature (Stone 1987*b*).

According to Stone (1985) these activity patterns seem to be shared by all animals independently of social status and are highly synchronised, and he suggests that this synchronisation might be a method of avoidance of conspecifics and that can also be useful against potential predators; further, he adds that prey availability may also be a factor since most invertebrate drift occurs during the night (Stone 1987*b*). However, this goes against the opinion that the desman searches for still prey and not for drifting prey (Richard 1976, 1985*b*; Queiroz & Almada 1993).

#### 1.4.5. *Feeding activity of the desman*

It is well established that *Galemys pyrenaicus* is an insectivore, feeding on aquatic invertebrates. The first accounts of its feeding regime were made by Trutat in 1891 (cited in Richard 1976) where he declared that the desman fed on fish fry and frogs. In 1935, Puisségur (cited in Peyre 1956) analysed stomach contents from specimens captured in France, and revealed that the desman fed mainly on larvae of insects (Trichoptera and Plecoptera), *Gammarus* and terrestrial insects that it captured in the stream banks. Later, Peyre (1956) confirmed this after analysing the stomach contents of specimens from France and added that *Gammarus* constituted the main prey of desmans. More recently, several authors (Bertrand 1993*a*; Bertrand & Clergue 1992; Castián & Gosálbez 1995, 1999; Santamarina 1993*a, b*; Santamarina & Guitián 1988)

have analysed stomach contents and faeces of desmans mainly from Galicia (NW Spain) and the Pyrenees. The findings are partly similar to those mentioned above, namely that the diet of *Galemys* is based essentially on Trichoptera, Ephemeroptera and Plecoptera, varying little throughout the year (Bertrand 1993a; Bertrand & Clergue 1992; Castián & Gosálbez 1995). Diptera can also be found in the desman's diet, although numbers vary seasonally and regionally (Castián & Gosálbez 1995; Santamarina 1993a).

Of the Trichoptera, the families that seem to occur more often in the desman's diet are the Hydropsychidae and Rhyacophilidae, with Sericostomastidae, Limnephilidae, Lepidostomastidae and Philipotamidae being consumed less often. Of the Ephemeroptera, the families Heptageniidae, Baetidae and Ephemeridae seem to be consumed most often but references to the family Ephemerellidae also occur. Of the Plecoptera, the most referenced families are the Nemouridae, the Perlodidae and the Leuctridae and of the Diptera, mainly the family Simuliidae; the majority being invertebrates that are characteristic of fast flowing, unpolluted waters (Tachet *et al* 1980).

Although Peyre (1956) affirmed that *Gammarus* was the main prey item of the desman, since it is widely available in Pyrenean streams, this has not been supported by latter investigations, which have found *Gammarus* to be consumed only in very small amounts (Bertrand 1993a; Castián & Gosálbez 1995; Santamarina & Guitián 1988). Castián and Gosálbez (1995) suggest that the high level of chitin in relation to biomass might not make it a profitable prey item. In contrast, the energetic content of Trichoptera, Ephemeroptera and Plecoptera is much higher (Bertrand & Clergue 1992). This selection of Trichoptera has also been established for the dipper (*Cinclus cinclus*)

(Ormerod & Tyler, cited in Jenkins & Ormerod 1996), which during its breeding season has a very similar diet to the desman's (Bertrand & Clergue 1992).

Thus, in its natural environment, the desman appears to be highly specialised in its diet.

In captivity, however, the desman is less demanding and can eat items such as minced meat (Richard 1973) or other foodstuffs (Queiroz & Almada 1993; Richard & Vallette Viallard 1969) and can eat up to twice its body weight (Richard 1973).

According to various accounts (Hernández 1988; Richard & Vallette Viallard 1969), made in captivity and in the natural environment, the desman actively seeks its prey using its front hind paws to dislodge the submerged substrate. When it captures an item, it emerges and moves to a sheltered spot to ingest it. The desman does not detect the movements of the prey; this has also been argued by Richard (1976, 1985*b*) that states that the desman does not capture prey that is moving.

#### 1.4.6. *Predators*

The poor knowledge of the species and its role in the natural environment led to the idea that the desman had no natural predators. Only in the last two decades has it been shown that the desman is prey to several species, including fish, birds and mammals. Species mentioned as occasional predators of *Galemys* include the pike (*Esox lucius*) (Pena *et al*, cited in Bertrand 1992), the grey heron (*Ardea cinerea*), the little egret (*Egretta garzetta*), the white stork (*Ciconia ciconia*) (Hernández 1988), the barn owl (*Tyto alba*) (Brunet-Lecomte & Delibes 1984; Purroy *et al* 1988), the tawny owl (*Strix aluco*), the buzzard (*Buteo buteo*) (Díaz 1985), the stoat (*Mustela erminia*) (Bertrand 1992), the weasel (*Mustela nivalis*) and the beech marten (*Martes foina*) (Richard 1976). The otter (*Lutra lutra*) seems to be the major predator of *Galemys* (Adrián *et al* 1988; Callejo & Delibes 1987; Callejo *et al* 1979). Poduschka & Richard (1986)

declared that in some areas of Spain, following the escape of american mink (*Mustela vison*) from fur farms, desmans have disappeared, implying that this introduced mammal may be a predator. However, to date, conclusive evidence has not been presented (Queiroz *et al* 1996).

### **1.5. Status and Threats**

*Galemys pyrenaicus* is listed in the Spanish Red Data Book as “Rare” (Blanco & González 1991) and in the Portuguese Red Data Book as “Vulnerable” (Cabral *et al*, cited in Queiroz *et al* 1996), status that is also attributed by the IUCN (2002). The species is included in Annex II of the Bern Convention and Annexes II and IV of the Habitats Directive (European Directive 92/43/EEC). In France, it is considered “Rare” (Ministère de l’Écologie et du Développement Durable 2003).

There is consensus among scientists that the desman is becoming increasingly threatened across its range; the fact that the species is constrained to such a specific environment makes it most vulnerable to habitat reduction and/or alteration upon which river regulation and pollution are thought to play a fundamental part (Bertrand 1995; IUCN 2002; Nores 1998; Quaresma & Queiroz 1995; Queiroz *et al* 1993, 1996, 1998). Bertrand (1992) found that in rivers where impoundments are present, the desman is absent or present in a discontinuous manner, but in natural rivers, its presence is continuous. A similar pattern was found by Nores and colleagues (1998) investigating desman presence in Spanish streams; no catches or spraints were obtained in stretches downstream of dams where there were severe reductions in water flow.

The IUCN (2002) lists as major threats to the species, habitat loss and degradation due to infrastructure development, human disturbance, predation, persecution by fishermen, water pollution and intrinsic factors such as the species restricted range.

## 2. ECOLOGICAL EFFECTS OF RIVER IMPOUNDMENT ON RIVERINE ECOSYSTEMS

The physical, chemical and biological aspects of rivers are controlled upon by the river's hydrological characteristics, i.e. discharge patterns (Naiman *et al* 2000; Newbury 1984; Petts 1984; Statzner & Higler 1986); the insertion of a barrier in the riverbed creates an obstacle for free flowing waters and changes current and discharge patterns both upstream and downstream of the dam. The fine sediments that are transported by the current are deposited resulting in changes in substrate composition (Allan 1995; Baxter 1977; Hellowell 1988). Alterations in water quality and temperature regimes can also occur, especially in large reservoirs where thermal stratification occurs (Allan 1995; Petts 1984). These alterations in the physical and chemical parameters will induce changes in the benthic invertebrate community; the most common effect is the reduction in species diversity and community structure (Brittain & Saltveit 1989; Bunn & Arthington 2002; Fjellheim *et al* 1989; Petts 1984). Changes in riparian zones upstream of dams have also been reported and include reduced species diversity and sparser plant cover (Jansson *et al* 2000; Merritt & Cooper 2000; Nilsson & Berggren 2000). Riparian zones are widely recognised as essential components of the structure and function of river ecosystems (Décamps & Tabacchi 1992; Minshall 1988; Nilsson *et al* 1997; Vannote *et al* 1980), influencing the distribution and structure of benthic macroinvertebrate communities (Gregory *et al* 1991; Naiman & Décamps 1997; Rutt *et al* 1989).

Alterations of riverine ecosystems also occur below the dams. The sediments that become trapped in the reservoirs are lost to the downstream channel, causing degradation (Leopold *et al*, cited in Power *et al* 1996). Reduced flows can allow vegetation to encroach (Power *et al* 1996) and are the primary cause of the

modification of invertebrate communities below dams (Brittain & Saltveit 1989; Casado *et al* 1989; Cortes *et al* 1998; Cowx *et al* 1984; Englund & Malmqvist 1996; Hauer *et al* 1989; Hellowell 1988; Stanford & Ward 1989; Trotzky & Gregory 1974).

River impoundment can have several effects on vertebrates. Dam walls behave as barriers to movements of aquatic animals causing fragmentation of populations and in the long run, extinction of such populations (Couvet 2002; Hellowell 1988; Morita & Yamamoto 2001). Riparian zones provide better habitats compared to upland areas, and are extremely species rich (Doyle 1990). Thus, the loss of habitat through inundation of valley bottoms will affect animals that are exclusively dependent on this habitat, especially those that have restricted mobility such as small mammals, however, birds, which can easily disperse can also be affected (Nilsson & Dynesius 1994).

### 3. CHARACTERISATION OF THE STUDY AREA

The study area was located in the extreme northeast of Portugal, within the boundaries of Montesinho Natural Park (Fig. 3.1), a protected area of about 75 000 ha between latitudes 41° 47' N – 42° N and longitudes 6° 30' W – 7° 12' W, situated in the westernmost face of the Iberian Massif and which is bordered in the north, east and west by Spain (DSCN 1993).

Montesinho Natural Park is located in the North of the region of Trás-os-Montes. This region is characterised by an extensive plain, which is cut by deep gorges and where some formations emerge, the most important of which is the hill of Montesinho (1481 m) to the north; it is isolated from the western littoral by a mountainous range, which extends in a NE-SW direction – from Gerês-Larouco (1508 m and 1545 m, respectively) to Marão (1415 m) and to the north and northeast, the Cantabrian mountain range also isolate it from Atlantic influences (Aguiar 2001). Thus, due to its geography, the region has distinct climatic conditions, which are characterised by long, cold winters and short, extremely hot summers. The precipitation regime is typical of Mediterranean climates, the rains occurring during the winter (October to March), but varying immensely with altitude, from 2500 mm in the western mountain ranges to 1500 mm in Montesinho but less than 400 mm in the deep valleys; July and August are the driest months of the year. In terms of temperatures, the region has temperature oscillations that are typical of Continental climates, the highest temperatures being registered in July/August and the lowest in December/February (Azevedo *et al* 1995; Gonçalves 1981).

The geographic and climatic variations combine to produce a heterogeneous and diverse mosaic of vegetation, upon which agriculture has had an important impact.

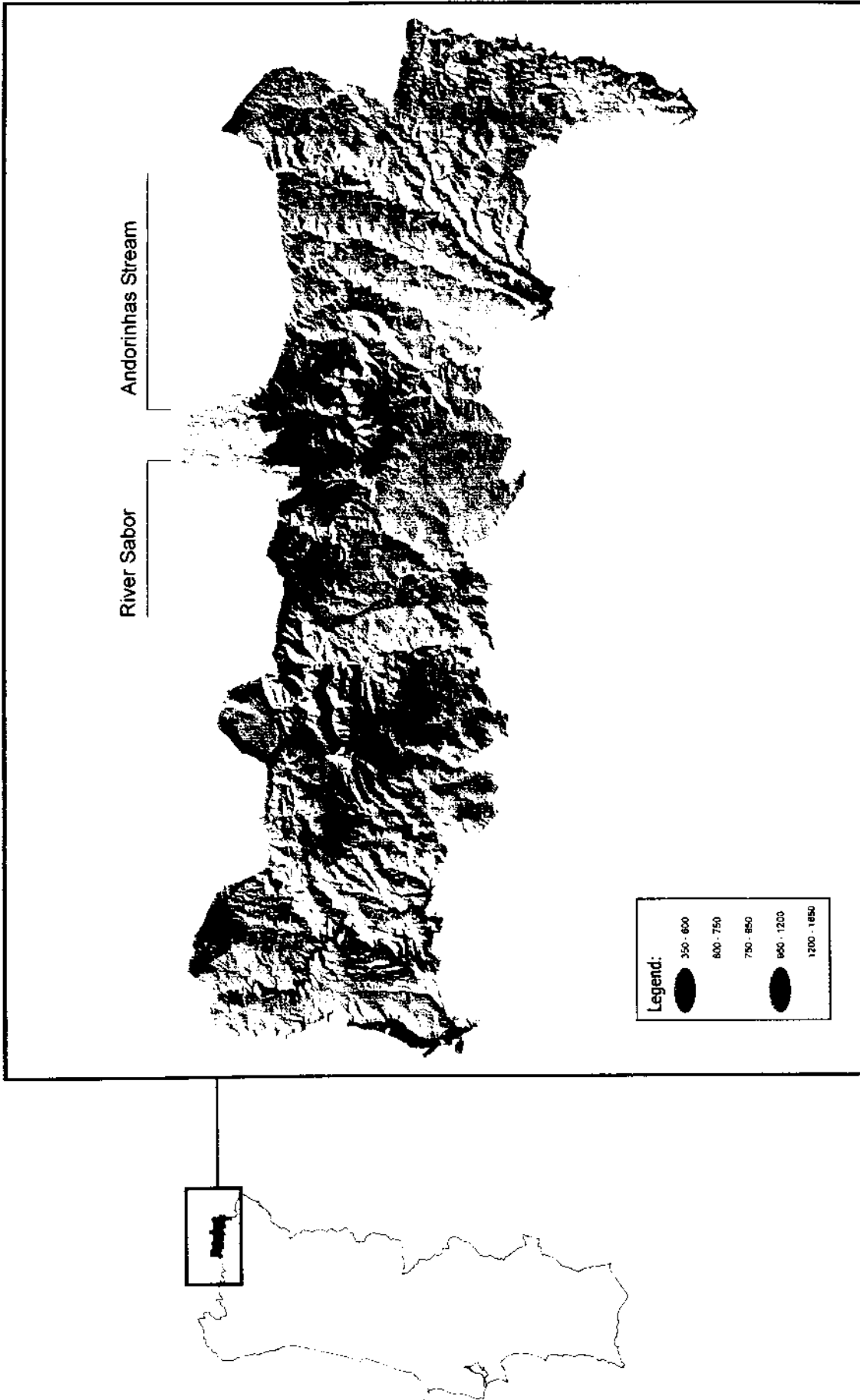


Fig 3.1- Localisation of Monteseinho Natural Park in Portugal, showing the watercourses studied. Legend represents altitudes in metres

Although agriculture and livestock raising are still an important and integral part of the Park (which has a human population of about 9000 inhabitants, distributed through 88 villages (Aguiar 2001), its importance has declined considerably in the last decades; now agriculture is practiced on a smaller scale, in a traditional way; essentially for self-sustenance. As a consequence, the less fertile areas away from the villages, generally at higher altitudes, where potato and rye was cultivated, have largely been abandoned, with the subsequent regeneration of the heath moorlands where *Erica arborea* and *Pterospartum tridentatum*, appear dominant.

Management through fire is still practised in these areas. In the terraced valley floors and alongside the watercourses are the pastures ('lameiros'), which are dominated by communities of *Molinio-Arrhenatheretea* (Aguiar 2001). With the decline of agriculture, many of these areas were abandoned and some are now being replanted with hybrid poplars (*Populus x canadensis*), ash (*Fraxinus angustifolia*) and chestnut trees (*Castanea sativa*) – this latter species is still important to the local economy, and the area it occupies is significant (Agroconsultores e Coba 1991).

Forests consist mainly of native trees such as oak (*Quercus ilex*, *Quercus rotundifolia*, *Quercus pyrenaica* and *Quercus robur* – ICN 2003); however a significant area is occupied with resinous trees (*Pinus sylvestris*, *Pinus nigra*). These areas are mainly privately owned, but some are also government owned; in the last few decades these areas have been decreasing mainly due to fires (Agroconsultores e Coba 1991).

#### **4. OBJECTIVES**

In view of the alterations in riverine habitats due to stream impoundment, and the high ecological requirements of this species, desman presence is suspected to be affected by river impoundment in three ways:

- decrease in food availability;
- habitat degradation;
- habitat fragmentation.

The objectives of this study were to verify whether such alterations had occurred in the headwaters of the Andorinhas stream, which is impounded by three reservoirs. Previous surveys at the Andorinhas stream had determined that the desman was present in the area (Ramalhinho & Tavares 1989), but later, desman presence was not detected at the impounded sites (Quaresma *unpublished*).

## II. METHODOLOGY

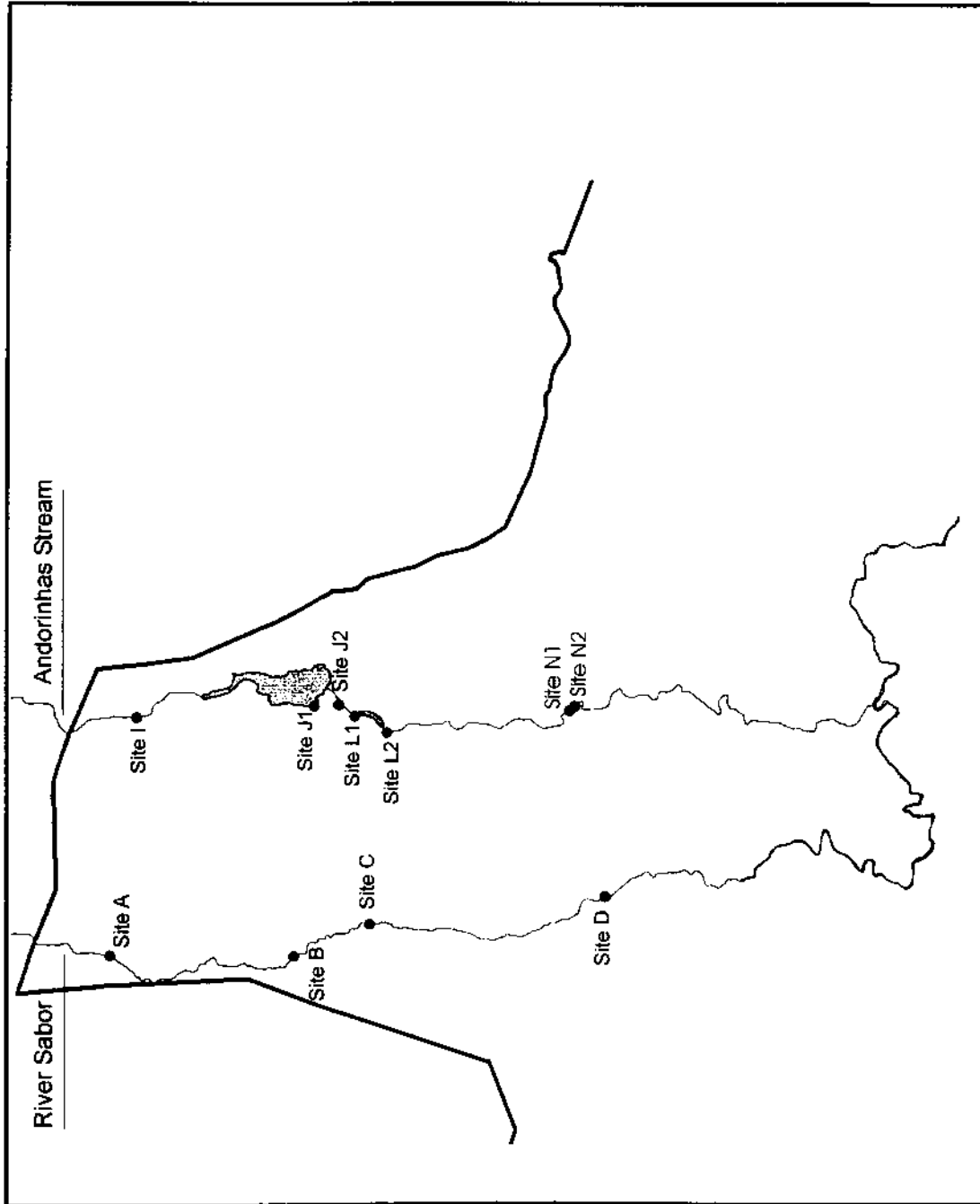
### 5. SAMPLING

#### 5.1. Selection of the Sampling Points

To study the influence of small river impoundments on the presence of the Pyrenean desman, several data were collected in Andorinhas stream and River Sabor concerning physical factors of the stream channels (water velocity, channel substrate and channel width and depth) and biotic factors (macroinvertebrate fauna, quality of riparian habitat, desman presence). Data were collected during July and the first week of August.

The choice of the sampling sites was determined taking into account the localization of the impoundments in the Andorinhas stream. Control points were then chosen upstream and downstream of the impoundments. However, due to the difficulty in accessing points below the impoundments in the Andorinhas stream, it was decided that a further watercourse would be sampled so as to be able to determine any effects of impoundment on the presence of the desman. The River Sabor was thus chosen to function as a control; both watercourses are located relatively near to each other, drain similar geomorphologic areas, flow in the same direction (N-S), and have similar macroinvertebrate communities (Teixeira, *pers. comm.*). Thus the points in the Sabor River were chosen so as to be roughly parallel to those in the Andorinhas Stream (Fig. 5.1 - overleaf), so as to control for longitudinal variability as much as possible (Cummins, cited in Petts 1984; Vannote *et al* 1980).

A total of 11 sites were sampled, 4 located in the Sabor River (A, B, C and D) and 7 in Andorinhas stream (I, J1, J2, L1, L2, N1 and N2). Sites J1, L1 and N1 were located in



**Fig. 5.1** - Sampling sites at Andorinhas Stream and River Sabor.

the reservoirs (Serra Serrada, Graíhas and Montesinho, respectively); sites J2, L2, N2 were located below the dams, between 2-20 m below the dam wall where water depth was enough to allow sampling.

## **5.2. Benthic Invertebrates**

Samples of invertebrates were collected during July using a 150 x 250 mm frame hand net with a 0.5 mm mesh. In each of the sampling sites, one 5-minute sample was taken, with the collector moving about while kick-sampling, so as to sample all the different substrata found at the sites. Pools and riffles were also sampled together. Thus the various microhabitats available to the desman's prey and the desman itself were sampled. In shallower sites, samples were obtained near the margins as well as in the middle of the streambed; in reservoirs, sampling only took place nearer the margins, taking into account the predominant substrate.

The contents of the hand net were poured into labelled 0.5 l bottles which were filled with stream water and transported to the laboratory. In the laboratory, the samples were washed into a sieve (mesh diameter 0.5 mm), coarse organic matter was washed and removed and the remaining contents transferred to a white tray where they were sorted under bright illumination. Invertebrates were placed in small, labelled containers with 70% alcohol for posterior identification. Identification consisted of emptying the containers into a petri dish and examining the contents under a binocular microscope. Invertebrate identification was made to Family, with the aid of keys (Tachet *et al* 1980).

### 5.3. Scat Survey

Determination of *Galemys* presence was made by scat survey. This methodology has already been used in several other studies in Portugal (Quaresma & Queiroz 1995; Queiroz *et al* 1998), Spain (Nores *et al* 1992) and France (Bertrand 1992). The use of scats has also been used successfully to determine evidence of otter presence (MacDonald & Mason 1983).

Desman scats have a cylindrical and grainy form, with a length of about 1.5 to 2.5 cm and have a distinctive musky smell (*pers. obs.*). Scats can appear isolated or in groups of 2 or more scats, which are then designated as latrines. These latrines can be constituted by individual scats or by an indistinct mass of excreted material which, according to Queiroz *et al* (1998) suggests the regular utilisation of these sites.

The scat survey essentially involves walking along a stretch of river examining with a lantern emergent stones and exposed roots of riparian vegetation in both margins and streambed, taking particular care in examining sheltered stones since the desman especially uses these places to deposit its faeces (Quaresma, *pers. comm.*).

According to Nores and colleagues (1992), a 600 m transect is necessary to guarantee a 95% probability of finding desman evidence when it occurs at the site; thus to each surveyed site corresponded a stretch of 600 m, except for the reservoirs where the whole perimeter was surveyed. The search was abandoned when positive and unmistakable signs of the desman were found or when the 600 m were completed without finding any evidence.

When found, scats were individually stored in plastic tubes, labelled and frozen for posterior laboratory confirmation. In the laboratory, scats were defrosted and placed in small petri dishes and observed under the binocular microscope for hairs. Although desman excrements are characteristic and easy to differentiate, some which are smaller

than usual may be confounded with those of shrews which also occur in the prospected sites, namely, *Neomys anomalus*, *Sorex granaries* or *Crocidura russula* (Quresma, *pers. comm.*). Laboratory confirmation was done through hair examination (Queiroz *et al* 1998; Poduschka & Richard 1985), and comparison was made with prepared samples (Carvalho, *unpublished*). Desman signs were used exclusively as indicators of desman presence, independently of the number of scats found.

#### **5.4. Physical Parameters**

Physical parameters were determined in the same area where desman signs had been found. The physical parameters determined were channel width and depth, water velocity, channel substrate and shading.

##### *5.4.1. Width and depth*

The streambed width and depth of each of the sampling sites was measured from the margins at three consecutive points, each separated by 5 m. The site where desman scats were found was used a reference point from where 5 m were measured upstream and downstream; at these points width was determined using a tape measure and depth was determined using a ruler. Values obtained were then averaged to give a single value for width and another for depth. Width and depth of reservoirs were estimated from maps.

#### 5.4.2. *Water velocity*

Water velocity was measured using a ping-pong ball dropped at the upstream point where width and depth were measured and counting the time it took to complete 10 m. If there was no perceptible change in movement for 1 minute, water velocity was recorded as nil.

#### 5.4.3. *Channel substrate*

The substrate present at the sampling site was estimated as percentages using a scale for substrate sizes, adapted from the Wentworth scale (Allan 1995, pp. 60).

Substrate was estimated from the 10 m stretch used for width, depth and water velocity measurement.

#### 5.4.4. *Shading*

Shading was estimated as a percentage of the area of the stream channel shaded by overhanging canopy in the 10 m stream stretch.

### **5.5. QBR Index**

The QBR Index (in English, Riparian Forest Quality), developed by Munné and colleagues (2003) is a quantitative index, designed to assess the stream bank habitat quality by measuring four components of the riparian habitat, i.e. total riparian vegetation cover, cover structure, cover quality and channel alterations. The index is based on structural complexity and naturalness of riparian vegetation community and takes into consideration geomorphologic differences between the different stream sections (e.g. headwaters, mid reaches, floodplains). There is no need for expert knowledge on vegetation; however, the observer has to be able to differentiate between

native and exotic tree species. Each component of the riparian habitat is measured by a section, each section scoring between 0 and 25 points; the final QBR index being between 0 and 100. There are five quality classes of riparian habitat (Table 5.1).

**Table 5.1** – Quality classes according to the QBR Index (Munné *et al*, 2003).

<i>Riparian Habitat Quality Class</i>	<i>QBR</i>
Riparian habitat in natural condition	≥ 95
Some disturbance, good quality	75-90
Disturbance important, fair quality	55-70
Strong alteration, poor quality	30-50
Extreme degradation, bad quality	≤ 25

The index incorporates a section on river channel alterations, which assesses the existence of man-made structures such as weirs; these structures can affect riparian vegetation in several aspects, e.g. by affecting biogeochemical cycles, altering plant communities and reducing their growth, sometimes leading to invasion by exotic species (DiSalvo & Hart 2002; Jansson *et al* 2000; Nilsson & Berggren 2000; Nilsson *et al* 1997; Nilsson & Svedmark 2002; Pinay *et al* 2002).

This index has been successfully tested in Spanish rivers (Munné *et al* 2003), and has been applied to Portuguese rivers with success (Oliveira, *pers. comm.*).

The index was calculated in 50 m stretches at all sites. At sites where desman presence was detected, the stretch was determined so as to include the point where desman signs were present. In sites where desman presence was not detected, the stretch consisted of the last 50 m of the length surveyed for desman signs.

## **6. DATA ANALYSIS**

### **6.1. Pre-treatment of Data**

Analysis of macroinvertebrates was restricted to families of Trichoptera, Ephemeroptera, Plecoptera and Chironomidae since these are considered to be the main prey of the desman (*cf.* Section 1.4.5) and because available data suggest that these orders are particularly sensitive to abiotic and biotic changes induced by river regulation (Brittain & Saltveit 1989; Cowx *et al* 1984; Hauer *et al* 1989; Stanford & Ward 1989). Families that were only represented by one individual in the totality of the samples or that were present in only one of the samples were discarded.

A *Type* variable was created by grouping the sampled sites into three categories; the category “natural” contained Sites A, B, C, D and I, the category “reservoir” contained Sites J1, L1 and N1 and the category “below dam” contained the remaining sites (J2, L2 and N2). This separation would allow comparisons to be made between the three categories (and thus sites) to determine whether there were any differences in substrata, benthic fauna and the QBR index.

### **6.2. Statistical Analysis**

Before any statistical tests were undertaken, all data were subjected to the Kolmogorov-Smirnov goodness of fit test to determine whether it was normally distributed (Green *et al* 1997). The test revealed that the data were not normally distributed and so nonparametric tests were used to analyse the data. Nonparametric tests are usually more conservative, thus decreasing the chance of occurring a Type I error (Dytham 1999).

Differences between the variables *Flow* and *Type* were determined using the Mann-Whitney U test, except for the categories “reservoir” vs “below dam”, for which the

Wilcoxon's signed rank test was used since these sites are located in the same stream and thus related.

To determine if there existed any relationship between desman presence and other factors (benthic invertebrates, physical parameters and QBR index) the Spearman's rank correlation was applied.

### III. RESULTS

#### 7. CHARACTERISTICS OF THE SAMPLING POINTS

The area where the study was undertaken included the headwaters of the River Sabor and the Andorinhas Stream, which flow through the hill of Montesinho (Fig. 3.1). Both watercourses flow parallel from north to south with the summit of Montesinho between them. The uppermost part of the watercourses drain a large valley with a low gradient, where granite dominates as bedrock, which encroaches further downstream to form deep gorges; here, granite is replaced by schist which then dominates throughout the remaining of the courses. Moorland, rocky outcrops, assemblages of oak (*Quercus* spp.) and pine occupy the hillsides that surround both watercourses. Pasture areas bordering the watercourses also appeared regularly, especially where the hillsides had a low gradient; many showed no signs of activity and the invasion of coarse vegetation and scrub in some of these areas led me to think that these might be abandoned.

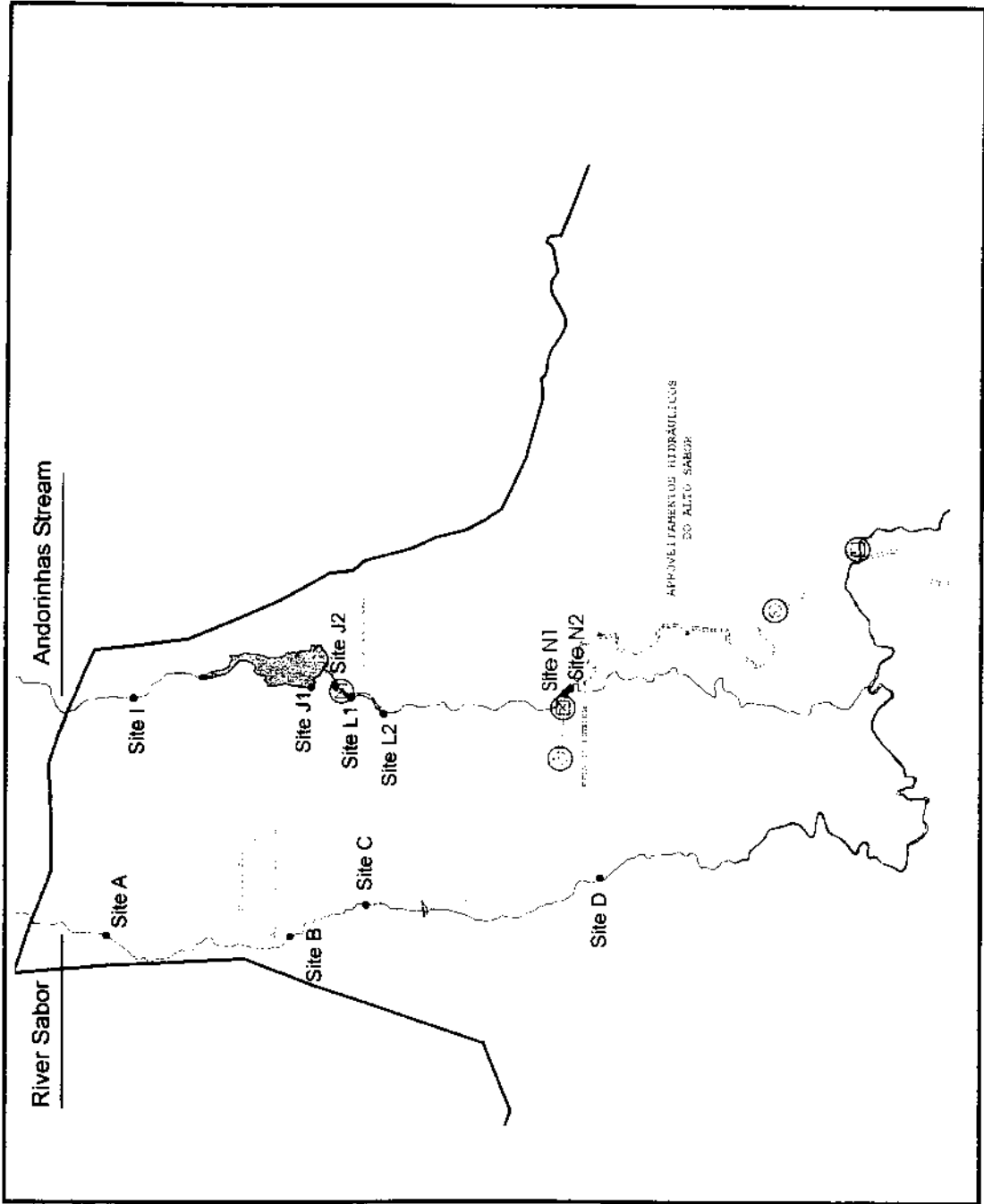
The margins of both watercourses appeared to be well preserved throughout the distance studied (except for the Serra Serrada dam – see below). In the headwater sections (1 to 4 km from the source), where the gradient is low, the margin vegetation is composed of grasses, heather (*Erica* spp.), gorse (*Ulex* spp.) and broom (*Cystisus* and *Genista* spp.) alternating with rocky outcrops and boulders; here the channels are narrow and shallow with rapids and small waterfalls. Further downstream, the channel becomes wider and slightly deeper, the rapids alternating with slow flowing stretches corresponding to areas where small traditional weirs are located; the shrub vegetation is replaced by trees typical of riparian areas; first with willow (*Salix alba*) and then with alder (*Alnus glutinosa*) (dominant type), alder buckthorn (*Frangula alnus*), poplars

(*Populus* spp.) and ash (*Fraxinus angustifolia*), frequently forming gallery structures; the undergrowth in this area is composed of mosses, herbaceous and shrub species such as blackberry (*Rubus ulmifolius*), water mint (*Mentha aquatica*) and ivy (*Hedera helix*) among others and seedlings of the above mentioned trees.

### **7.1. Andorinhas Stream**

The Andorinhas stream (that arises in Spain) is the first main affluent to join the River Sabor (see below) on its left side. The Andorinhas stream is regulated by three impoundments (Serra Serrada dam, Gralhas weir and Montesinho weir – Fig. 7.1), forming a cascade. This regulatory scheme was designed for water storage to supply the city of Bragança and also to generate hydroelectric power; its building was phased, with the Serra Serrada being the first to be completed, in 1988, followed by Gralhas weir in 1991 and Montesinho weir in 1993 (Pinheiro *et al*, 1991). The Serra Serrada dam is the largest, with a 23.35 m high concrete wall, with a reservoir capacity of 1.5 hm<sup>3</sup> and is located roughly 3 km downstream of the spring source. It possesses a gated outlet with a diameter of 600 mm. Both the Gralhas and Montesinho weirs are smaller in relation to wall height and capacity and do not possess gated outlets (Pinheiro *et al*, 1991).

The basic functioning of this scheme is as follows. The water contained in the Serra Serrada dam feeds the Gralhas powerhouse (turbine output of 170 kW for a maximum rated flow of 0.4 m<sup>3</sup>/s) through a 450 m long penstock. The water is then discharged in the Gralhas reservoir. From there, the water is driven through 1850 m headrace canal to a pressure chamber and a 760 m penstock, which feeds the Montesinho powerhouse (1150 kW turbine output for a maximum rated flow of 0.65 m<sup>3</sup>/s), with the water being discharged in the reservoir. Finally, from the Montesinho weir, the water travels



**Fig. 7.1** - Location of sampling points in relation to impoundments in Andorinhas Stream. Veiguiñas dam in the River Sabor is currently undergoing an Environmental Impact Assessment.

through a 4250 m headrace canal and pressure chamber to two penstocks, one (1135 m), connected to Prado Novo powerhouse (2270 kW turbine output for a maximum rated flow of  $1\text{m}^3/\text{s}$ ), which is located in the River Sabor below the its confluence with the stream, and where the water is returned to the River Sabor, and another penstock (about 4 km) connected to a water treatment station which delivers water to Bragança (Pinheiro *et al*, 1991). During the summer, from June onwards, electricity is only generated in the Gralhas and Montesinho powerhouses since water delivery to the city of Bragança is the main priority.

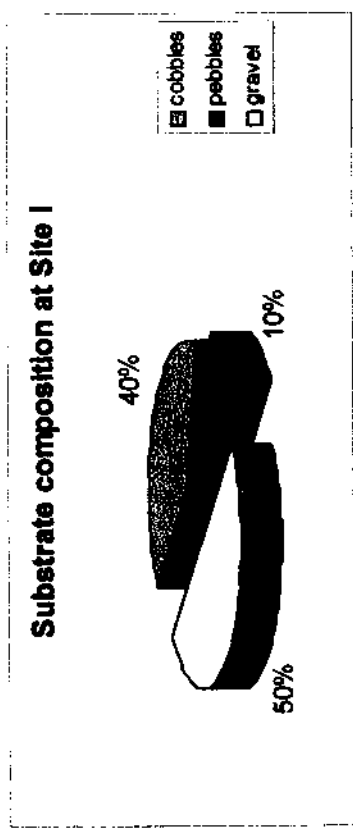
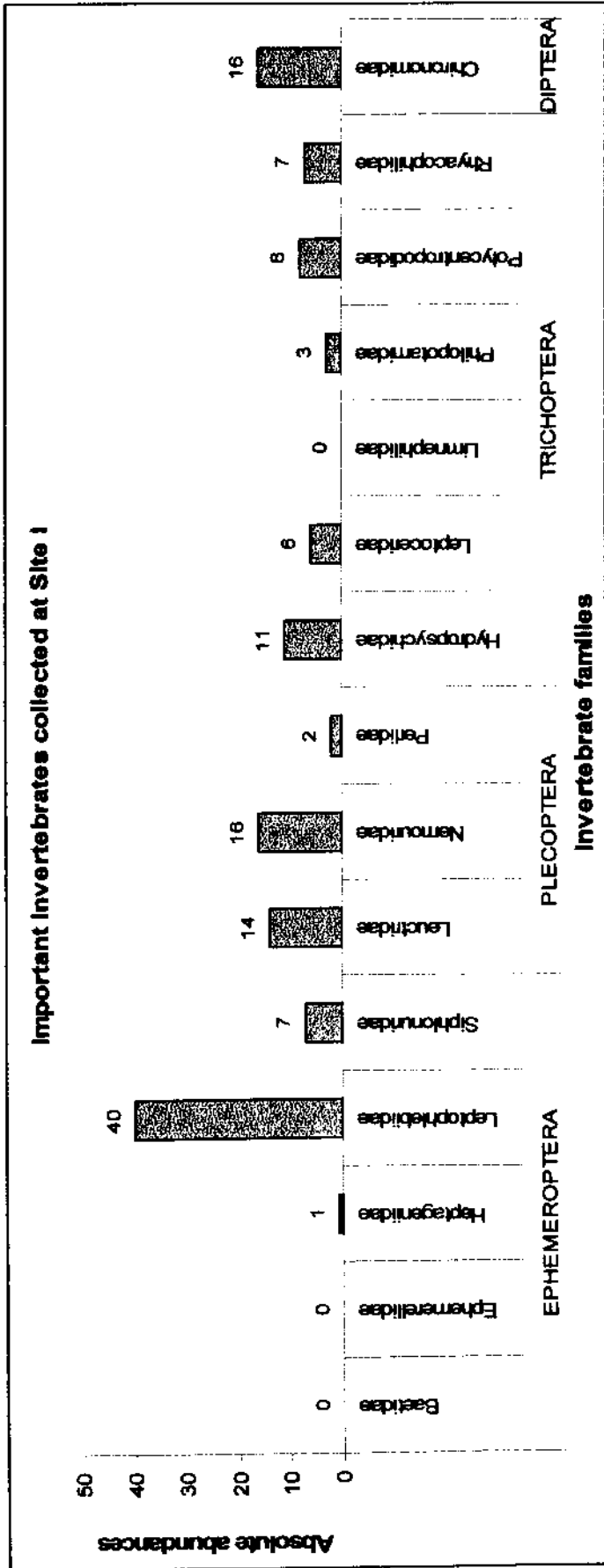
During the time the study took place (June and July), which was exceptionally hot and dry, no flow was recorded below any of the dams, and no water was released from the Serra Serrada dam outlet. As a response to enquiries made about minimum flow releases from the dams, the staff at Bragança's City Hall revealed that no provisions for minimum flow releases were in place from any of the dams during the summer. The Serra Serrada reservoir shows the largest difference in fluctuating water levels; in the Gralhas and Montesinho reservoirs, on the contrary, the water level was kept relatively constant (*pers. obs.*). ✓

#### 7.1.1. *Characterisation of the sampling points in the Andorinhas stream*

Seven points were sampled in the Andorinhas stream, located along the stream, the first point (I) being situated roughly 2 km downstream of the spring source and the last (N2), roughly 6 km downstream of the stream source (Fig. 7.1). The data obtained from benthic invertebrate sampling, values obtained for physical parameters and QBR Index and desman scat survey results for each sampling point is presented below:

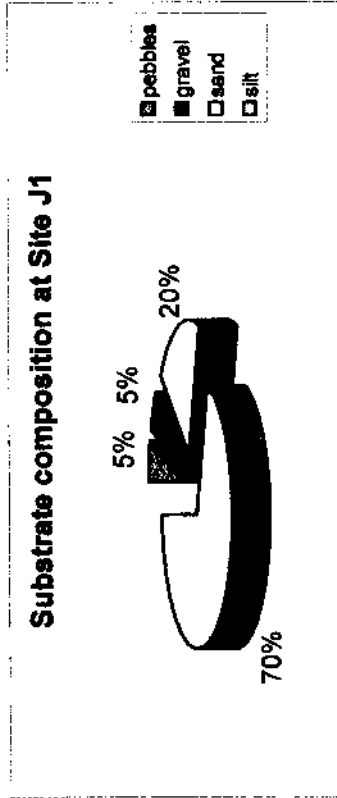
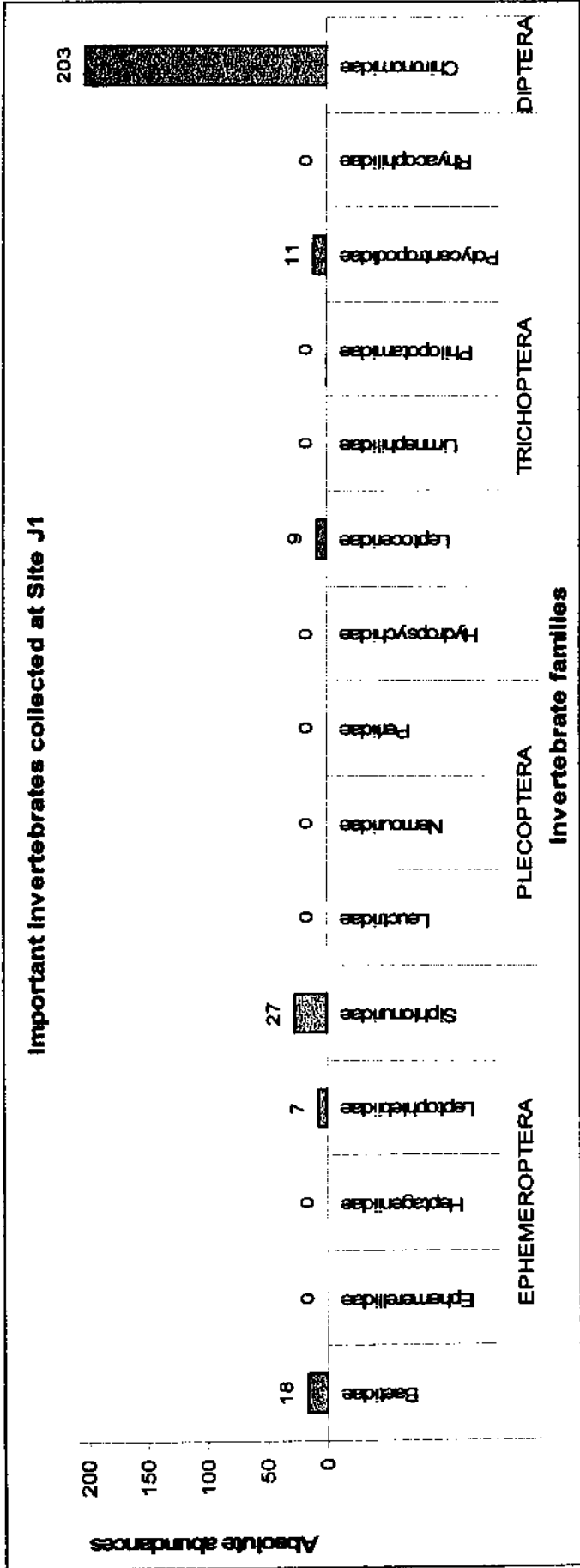
- Point I (Fig. 7.2) – situated roughly 2 km downstream of the stream source, and 1 km upstream of the Serra Serrada dam where there was no noticeable effect from the impoundment, thus being used as a control point. Desman presence was detected;
- Point J1 (Fig. 7.3) – situated in the reservoir of the Serra Serrada dam (~ 1500 m long), roughly 3 km from the stream source. Desman presence was not detected;
- Point J2 (Fig. 7.4) – situated below the Serra Serrada dam wall. No flow was recorded at this site. The stream channel was almost dry, except for localised pools of stagnant water. Desman presence was not detected;
- Point L1 (Fig. 7.5) – situated in the reservoir of the Gralhas weir (~ 400 m long), roughly 3.5 km away from the stream source. Desman presence was not detected;
- Point L2 (Fig. 7.6) – situated below the weir wall. No flow was recorded at this site. The stream channel was almost dry, except for the existence of some pools of stagnant water. Desman present was not detected;
- Point N1 (Fig. 7.7) – situated in the reservoir of the Montesinho weir, roughly 6 km away from the stream source. This reservoir is the smallest of those sampled (~ 50 m long). Desman presence was not detected.
- Point N2 (Fig. 7.8) – situated below the weir wall. As occurred with points J2 and L2, there was no flow recorded at the site. Stagnant water pools were detected.

Only further downstream (roughly 200 m) was some flow detected. Desman presence was not detected.



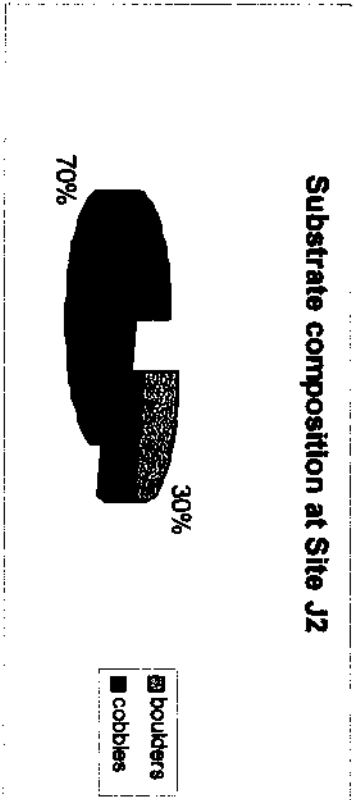
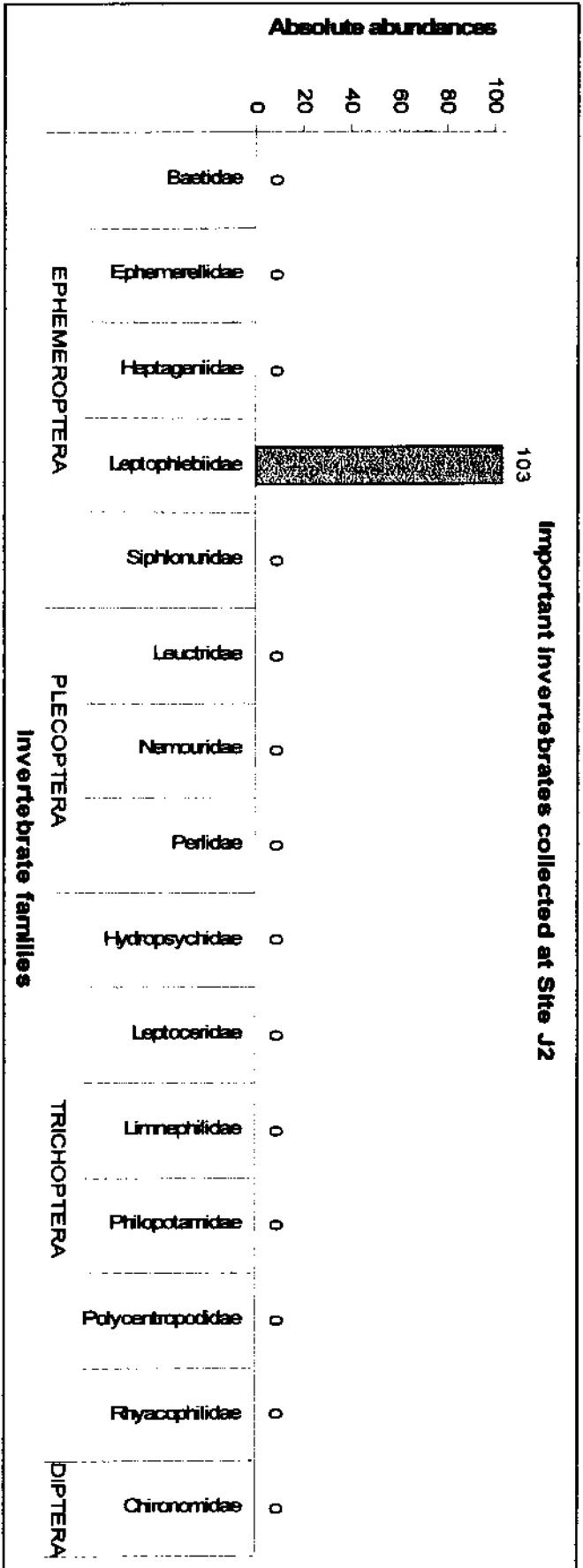
Desman presence	Detected
Distance surveyed	250 m
Channel depth	0.01 m
Channel width	0.07 m
Water velocity	0.09 m/s
Shading	75
QBR Index value	80

Fig. 7.2 – Sampling and survey data results from Point 1



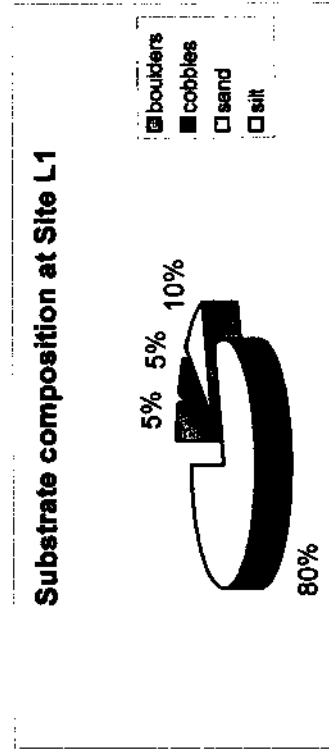
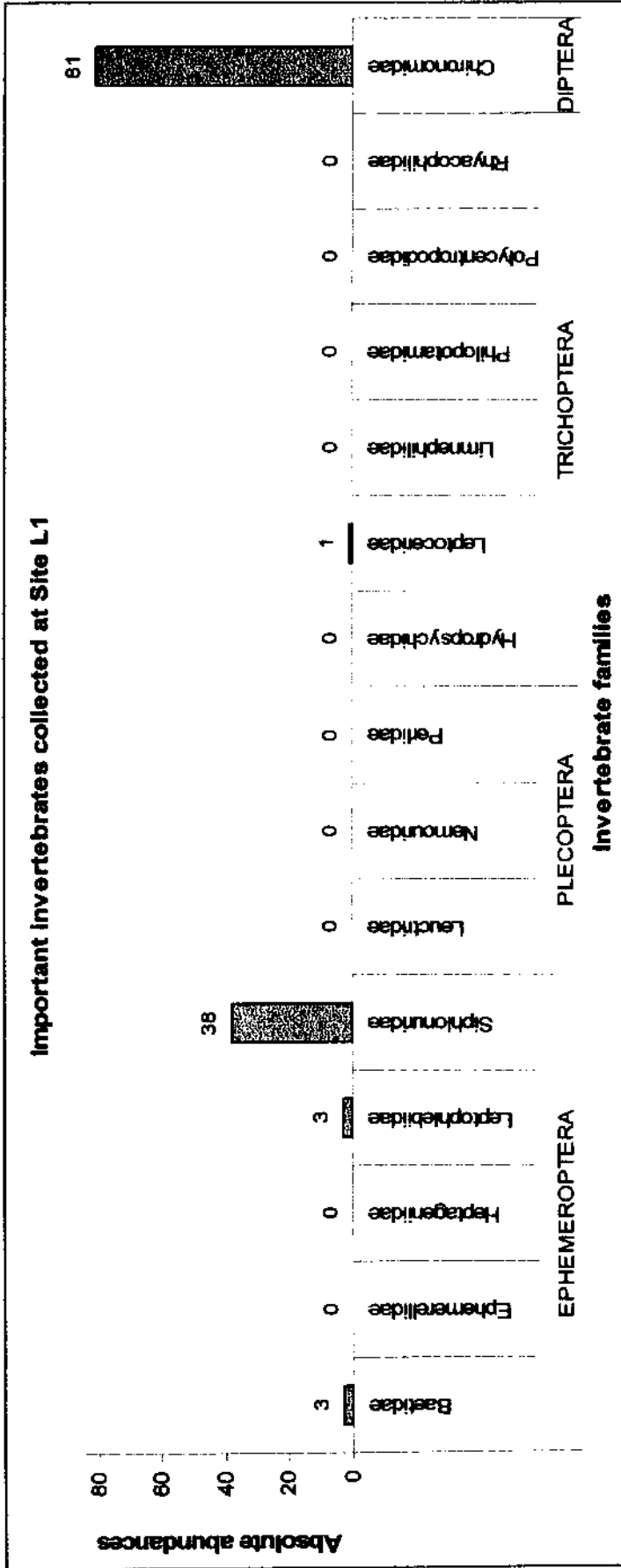
Desman presence	Not detected
Distance surveyed	Total length of reservoir
Channel depth	15.00 m
Channel width	200.00 m
Water velocity	0.00 m/s
Shading	0
QBR Index value	10

Fig. 7.3 -- Sampling and survey data results from Site J1



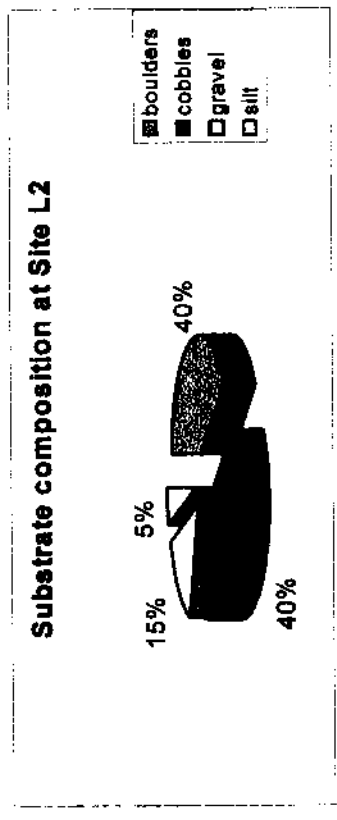
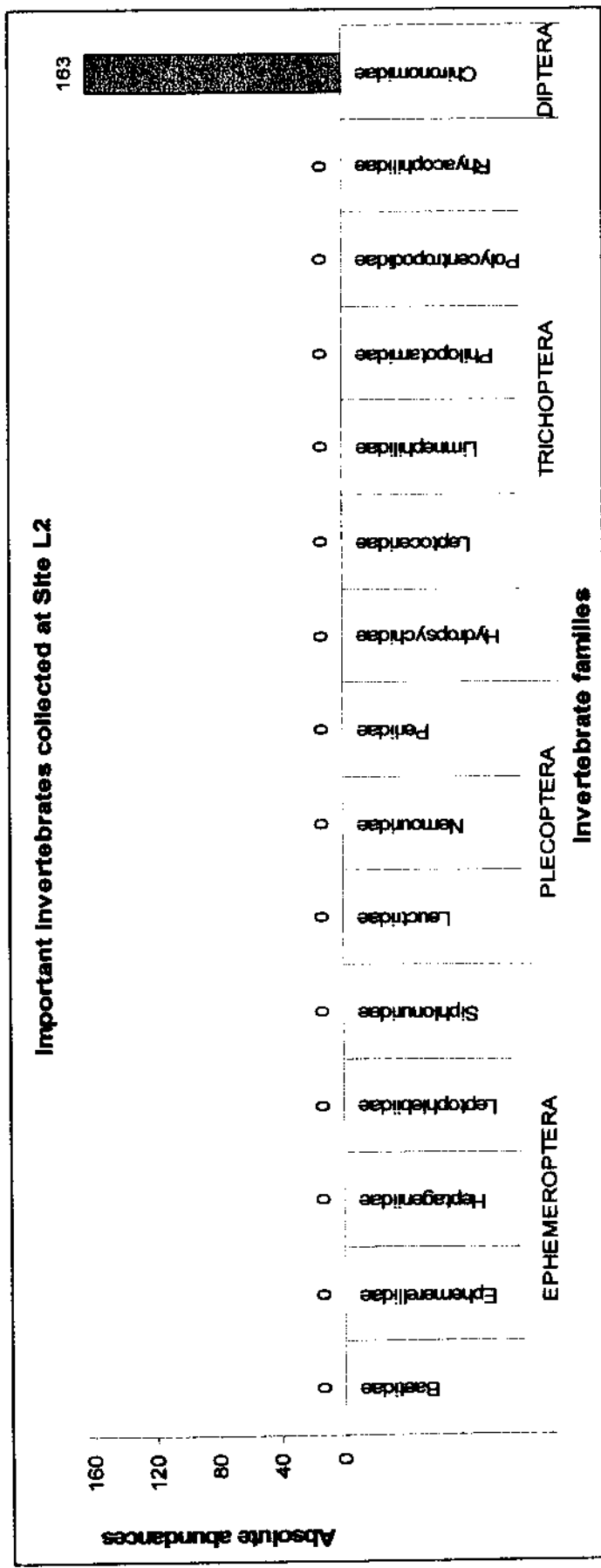
Desman presence	Not detected
Distance surveyed	450 m
Channel depth	0.50 m
Channel width	1.50 m
Water velocity	0.00 m/s
Shading	70
QBR Index value	75

Fig. 7.4 – Sampling and survey data results from Site J2



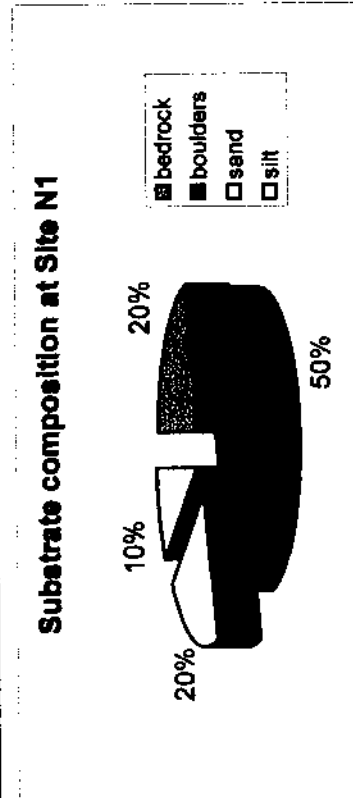
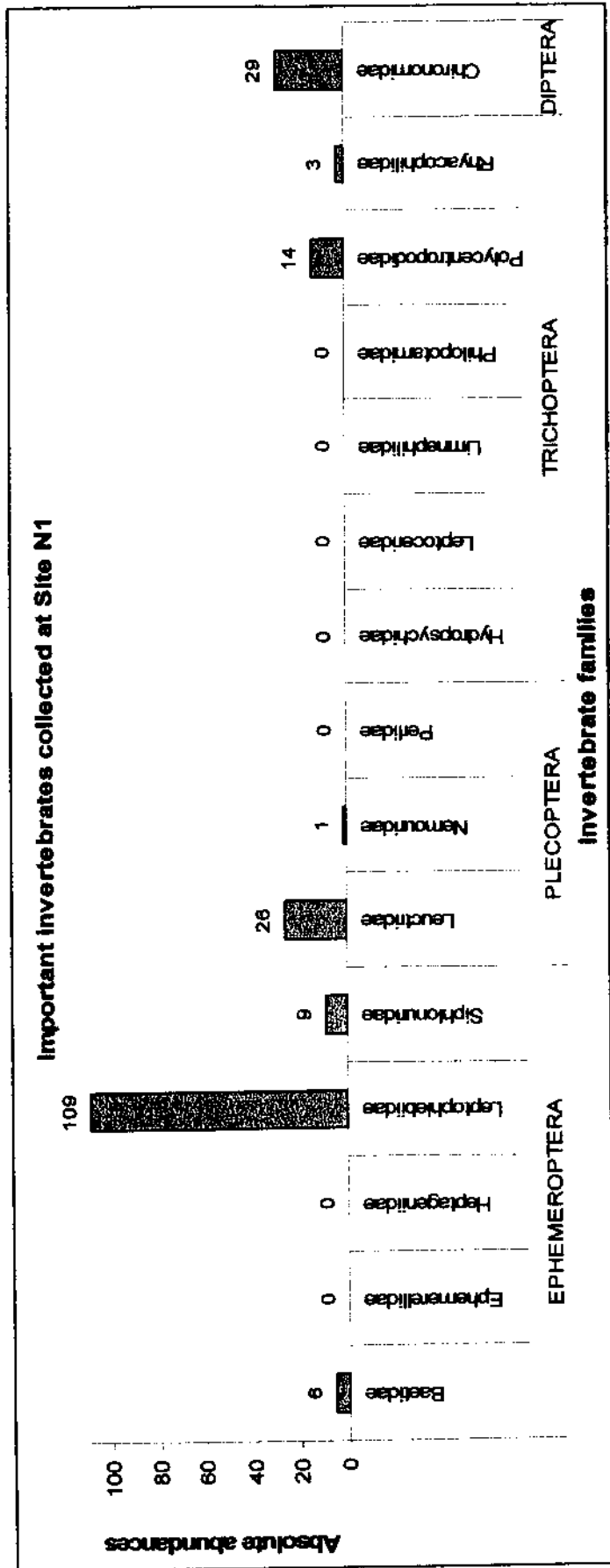
Desman presence	Not detected
Distance surveyed	Total length of reservoir
Channel depth	5.00 m
Channel width	30.00 m
Water velocity	0.00 m/s
Shading	0
QBR Index value	50

Fig. 7.5 -- Sampling and survey data results from Site L1



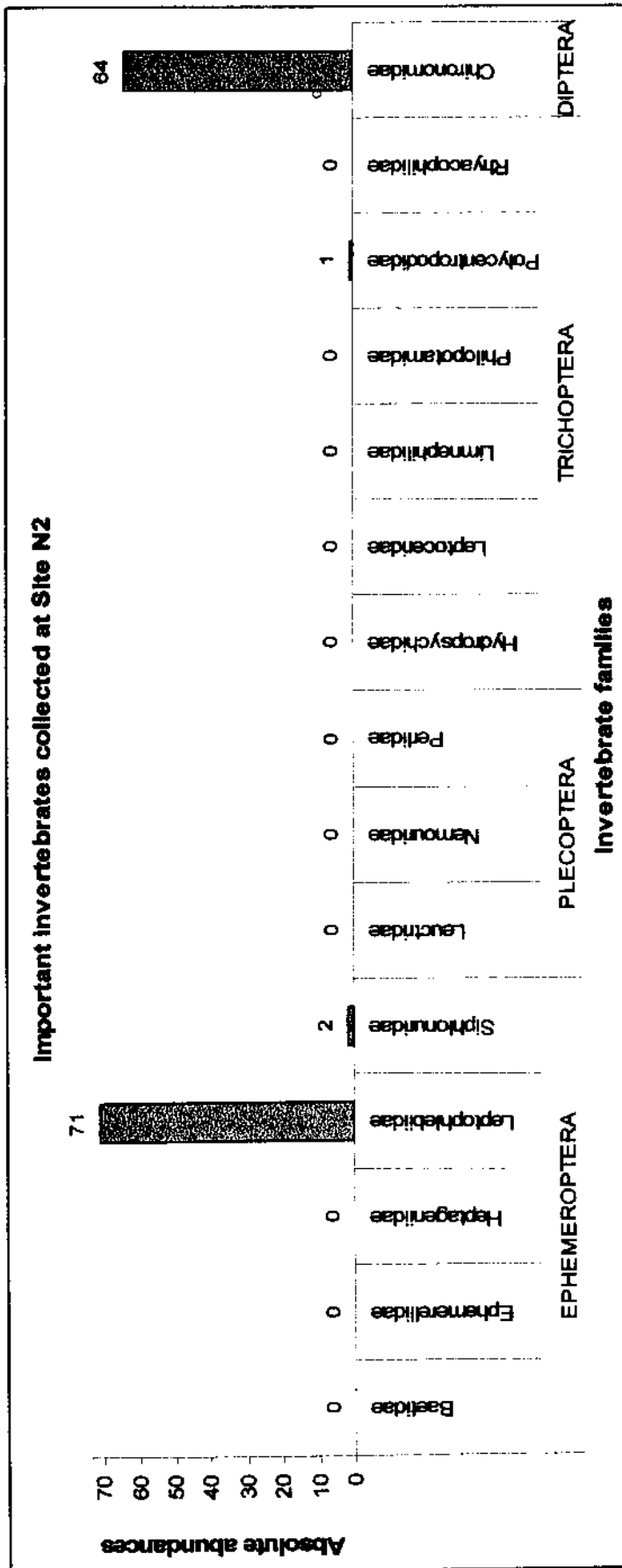
Desman presence	Not detected
Distance surveyed	600 m
Channel depth	0.80 m
Channel width	2.10 m
Water velocity	0.00 m/s
Shading	50
QBR Index value	95

Fig. 7.6 -- Sampling and survey data results from Site L2



Desman presence	Not detected
Distance surveyed	Total length of reservoir
Channel depth	1.20 m
Channel width	15.00 m
Water velocity	0.00 m/s
Shading	50
QBR index value	50

Fig. 7.7 – Sampling and survey data results from Site N1



### Substrate composition at Site N2

Substrate Type	Percentage
silt	50%
gravel	30%
cobbles	5%
pebbles	5%
boulders	5%
bedrock	5%

Desman presence	Not detected
Distance surveyed	500 m
Channel depth	0.30 m
Channel width	2.00 m
Water velocity	0.00 m/s
Shading	50
QBR index value	95

Fig. 7.8 – Sampling and survey data results from Site N2

## 7.2. River Sabor

The River Sabor has its source in Montesinho hill in Spanish territory, about 2 km from the Portuguese border and is part of the River Douro catchment. It is about 152 km long and its catchment is the largest sub-catchment of the River Douro in Portuguese territory (3453 km<sup>2</sup>) (Queiroz *et al.*, 1998).

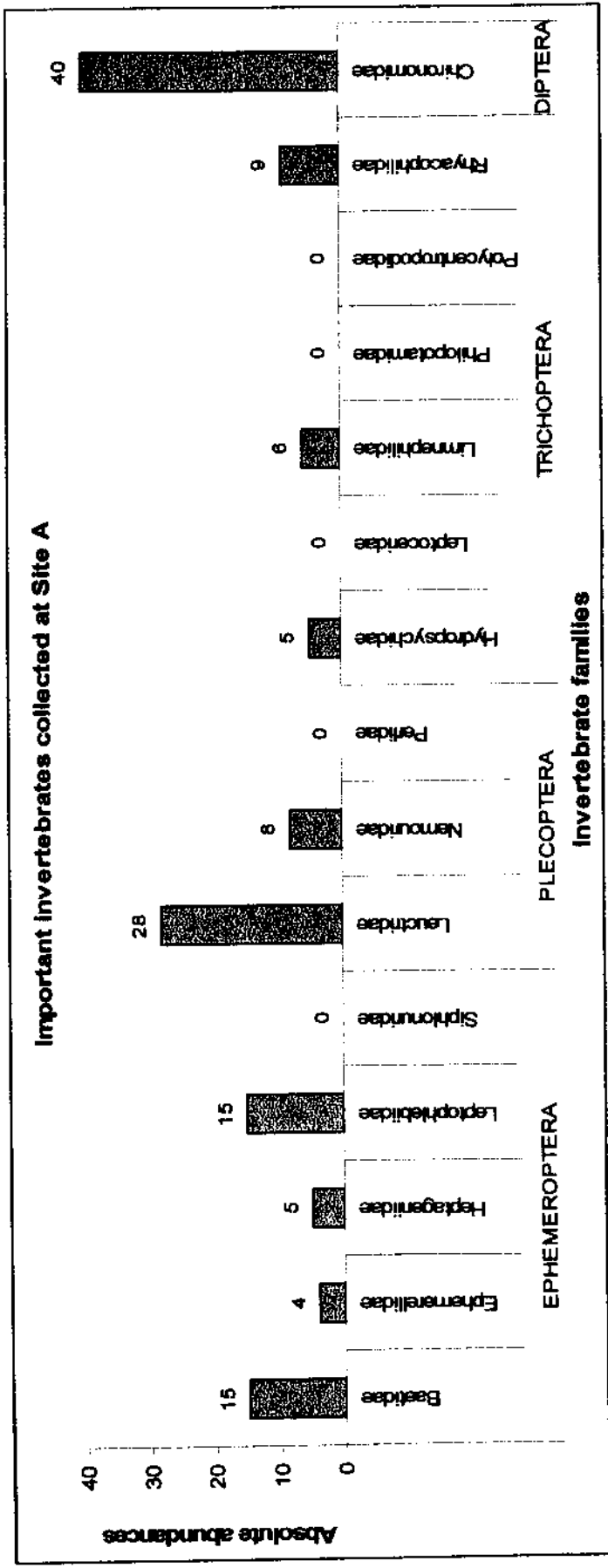
At the moment, the Sabor is not impounded but an Environmental Impact Assessment is currently under way for the follow-up of the hydroelectric development built in the Andorinhas Stream. A 35 m high dam with a capacity for 4.21 hm<sup>3</sup> of water is projected (Fig. 7.1), which is to be connected to Montesinho weir to generate hydroelectricity (Pinheiro *et al.*, 1991; Quaresma, *pers. comm.*). Thus the River Sabor is considered to be in its natural condition.

### 7.2.1. Characterisation of the sampling points in the River Sabor

Five points were sampled in the River Sabor, located along the stream, the first point (A) being situated roughly 2 km downstream of the spring source and the last (D), roughly 4.5 km downstream of the stream source (Fig. 4.1). The data obtained for benthic invertebrate sampling, values obtained for physical parameters and QBR Index and desman scat survey results for each sampling point is presented below:

- Point A (Fig. 7.9) – situated roughly 2 km downstream of the stream source.  
Desman presence was detected;
- Point B (Fig. 7.10) – situated roughly 3 km downstream of the stream source.  
Desman presence was detected;

- **Point C (Fig. 7.11) – situated roughly 3.5 km downstream of the stream source.  
Desman presence was detected;**
- **Point D (Fig. 7.12) – situated roughly 4.5 km downstream of the stream source.  
Desman presence was detected;**



#### Invertebrate families

Desman presence	Detected
Distance surveyed	50 m
Channel depth	0.20 m
Channel width	1.00 m
Water velocity	0.14 m/s
Shading	80
QBR Index value	90

#### Substrate composition at Site A

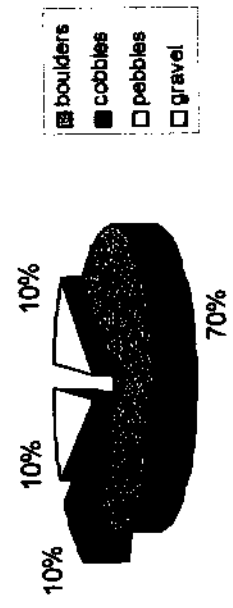


Fig. 7.9 – Sampling and survey data results from Site A

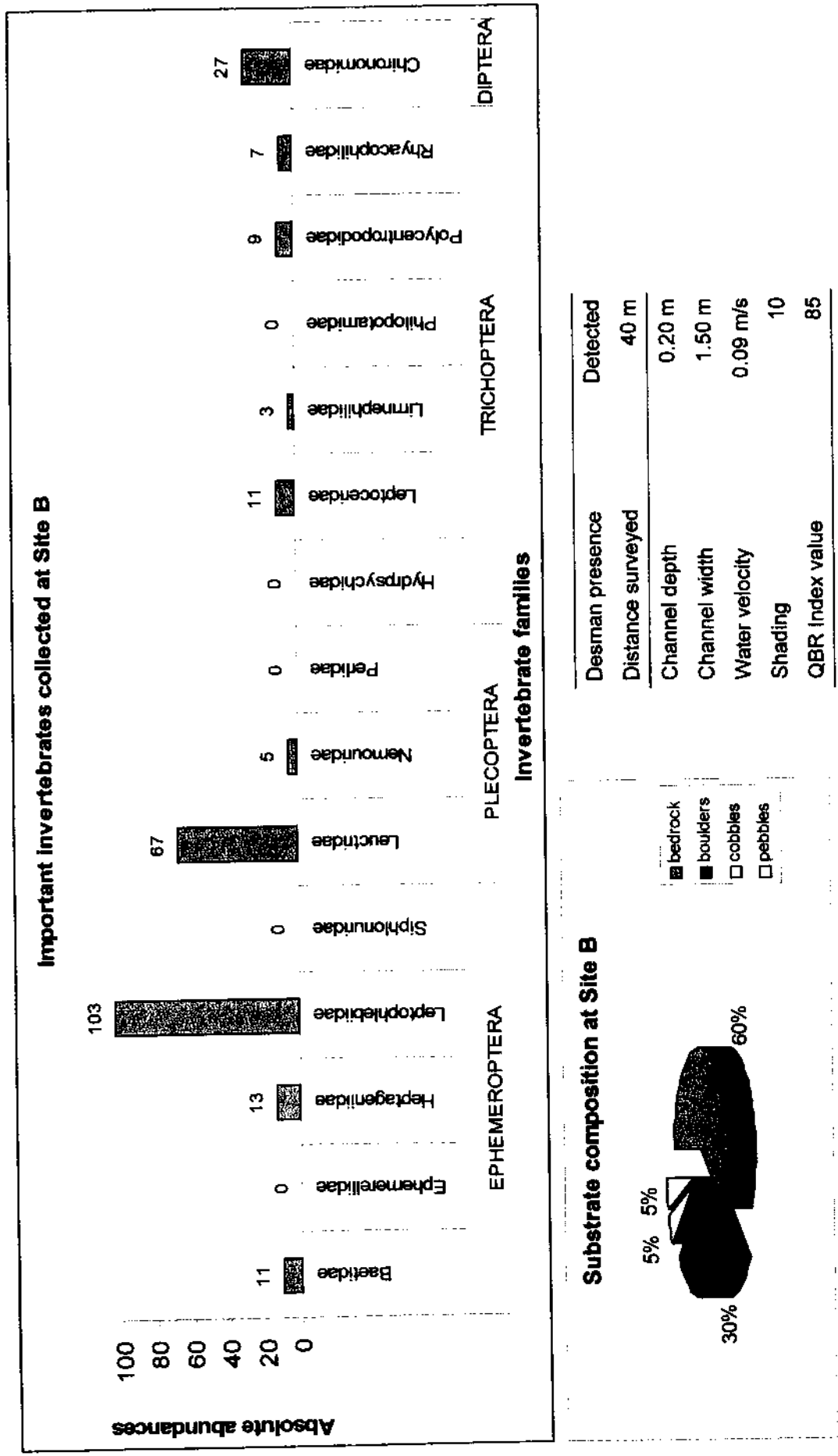
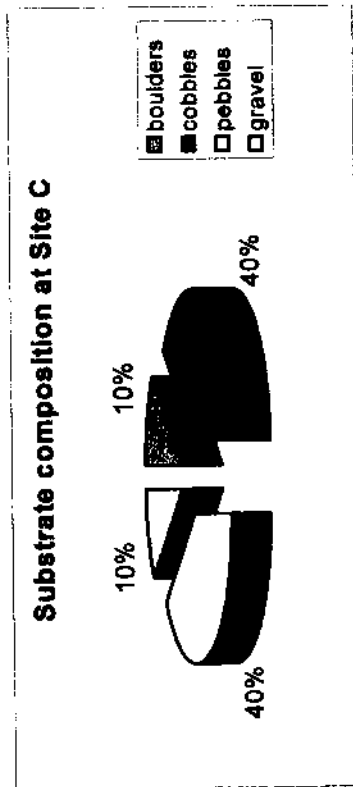
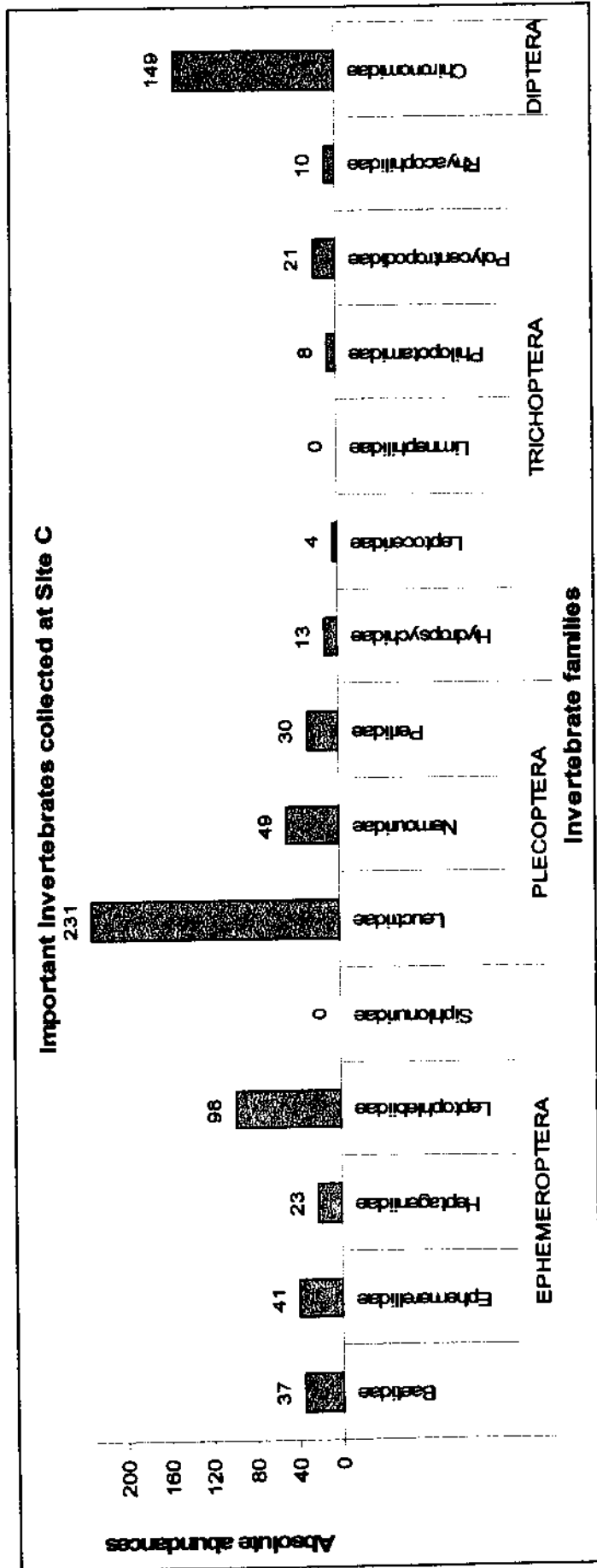
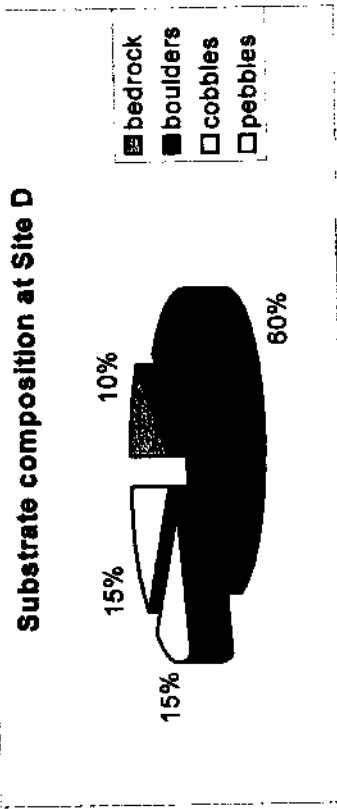
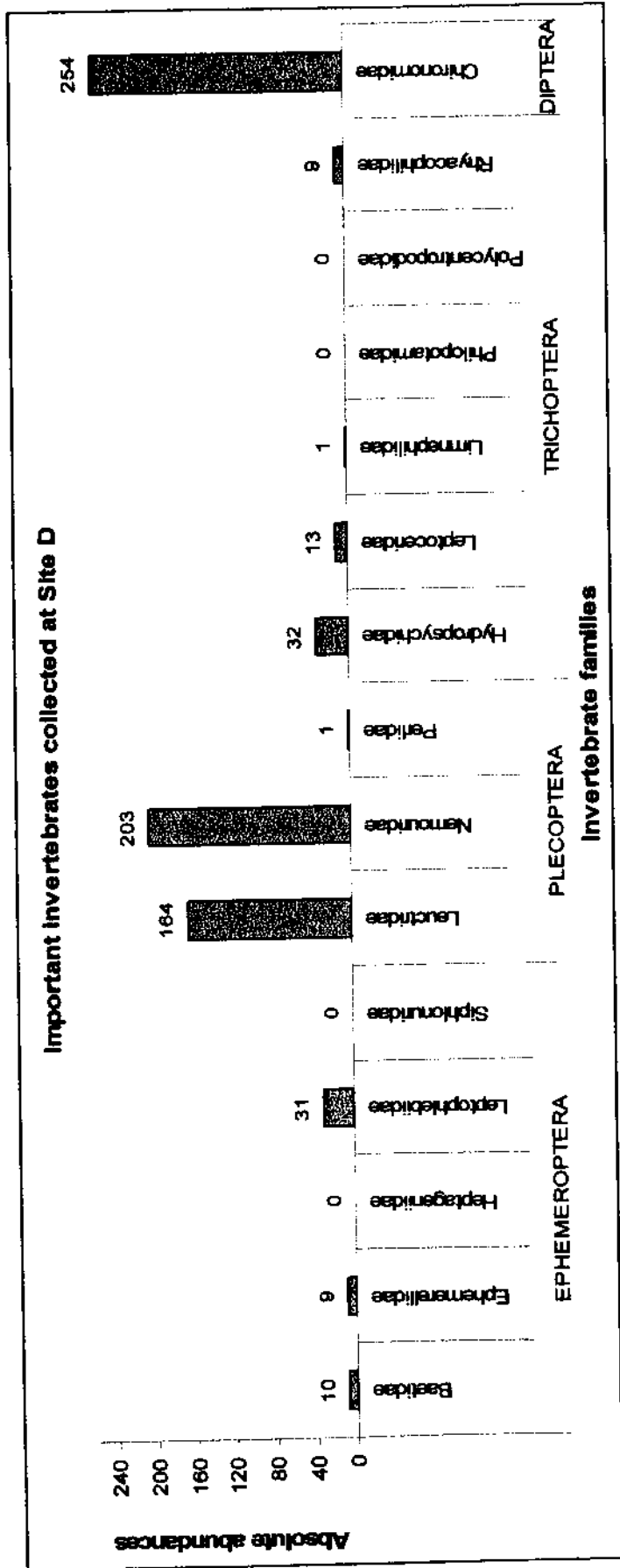


Fig. 7.10 – Sampling and survey data results from Site B



Desman presence	Detected
Distance surveyed	0 m
Channel depth	0.10 m
Channel width	1.50 m
Water velocity	0.26 m/s
Shading	50
QBR Index value	90

Fig. 7.11 – Sampling and survey data results from Site C



Desman presence	Detected
Distance surveyed	35 m
Channel depth	0.30 m
Channel width	1.70 m
Water velocity	0.17 m/s
Shading	10
QBR Index value	95

Fig. 7.12 – Sampling and survey data results from Site D

## 8. EFFECTS OF IMPOUNDMENT IN THE ANDORINHAS STREAM

### 8.1. Physical Characteristics

Observation of figure 8.1 shows that substrate composition at regulated and unregulated sites is very variable. At reservoir sites, finer substrate material (silt) dominates, whereas at the unregulated sites this material is absent, the substrate being dominated by larger material; at sites below dams cobbles and boulders are the dominant substrate (Figs. 7.2 – 7.12).

Results from the Mann-Whitney U test<sup>1</sup> show that there is a significant difference for several substrate classes between natural sites and reservoir sites, namely cobbles ( $P = 0.036$ ), pebbles ( $P = 0.036$ ), sand ( $P = 0.036$ ) and silt ( $P = 0.036$ ).

Between natural sites and sites below dams significant differences were found for pebbles ( $P = 0.036$ ). Significant differences were also found between reservoir sites and below dam sites for certain classes of substrata, specifically for boulders ( $P = 0.045$ ) and silt ( $P = 0.045$ ).

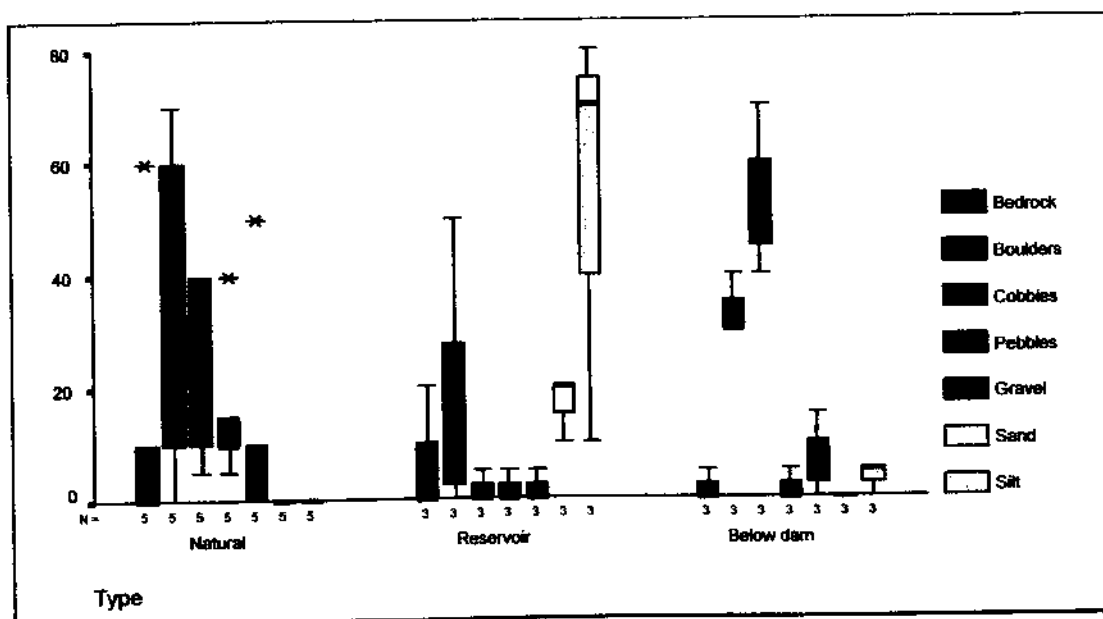


Fig. 8.1 – % Substrate composition at unregulated and regulated sites.

<sup>1</sup> An adapted version of the data output from the Mann-Whitney U tests can be found in Annex I (Table A).

Water velocity ( $P = 0.036$ ), channel depth ( $P = 0.036$ ) and width ( $P = 0.036$ ) were also found to be significantly different between reservoir sites and natural sites. Differences in channel depth ( $P = 0.036$ ) and water velocity ( $P = 0.038$ ) between natural and below dam sites were also found to be significant.

## 8.2. Invertebrate Fauna

Figure 8.2 presents the composition of Ephemeroptera communities between regulated and unregulated sites. At regulated sites, Ephemeroptera communities seem to be impoverished as compared to unregulated sites. Fewer families were collected at these sites, especially at the tail water sites where only two families of Ephemeroptera were collected. Ephemerellids and Heptagenids were not found at any of the regulated sites (Figs. 7.2 – 7.12).

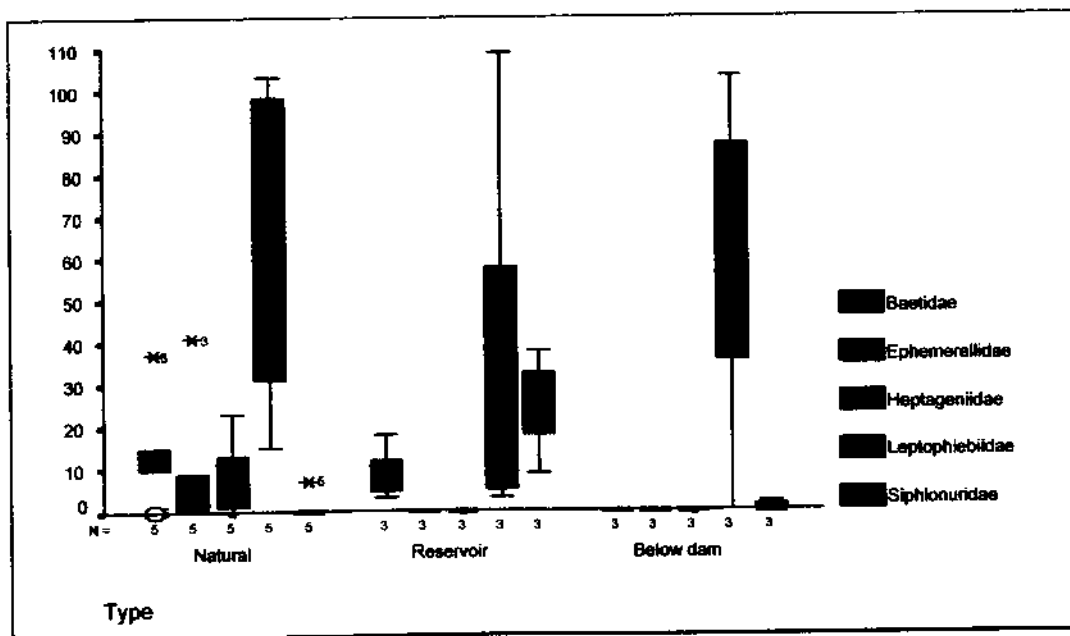


Fig. 8.2 – Composition of Ephemeroptera communities at unregulated and regulated sites.

Results from the Mann-Whitney U tests comparing natural and reservoir sites, showed significant differences for only one Ephemeroptera family, i.e, Siphonuridae ( $P =$

0.036). No significant differences were found between natural and below dam sites for any of the Ephemeroptera families. No differences were found between reservoir and below dam sites (Wilcoxon's signed rank test<sup>2</sup>).

Figure 8.3 shows the variation in Plecoptera fauna at regulated and unregulated sites. At unregulated sites, three families were collected, the higher numbers of individuals belonging to the Leuctridae family. At reservoir sites few or no individuals were collected. No Plecoptera were collected at any of the below dam reservoirs (Figs. 7.4, 7.6, 7.8).

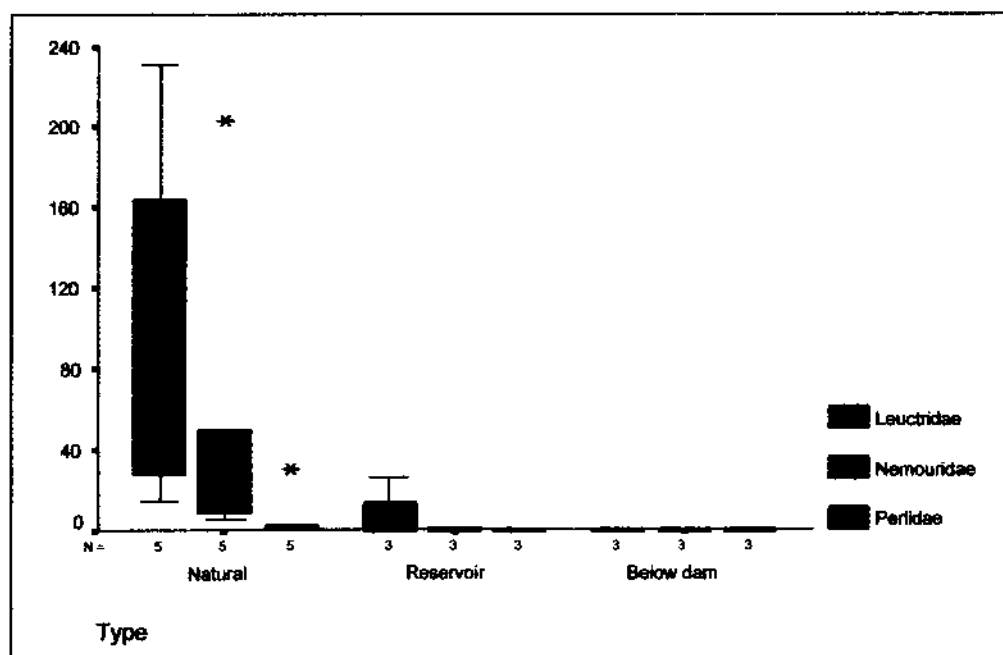


Fig. 8.3 – Composition of Plecoptera communities at unregulated and regulated sites.

Results from the Mann-Whitney U tests show significant differences for Nemouridae abundances between natural and reservoir sites ( $P = 0.036$ ). Abundances of Leuctridae ( $P = 0.036$ ), and Nemouridae ( $P = 0.036$ ) were also significantly different between natural and below dam sites.

<sup>2</sup> An adapted version of the data output from the Wilcoxon's signed rank test can be found in Annex I (Table B)

Abundance of Nemouridae ( $P = 0.038$ ) was also found to be significantly different between reservoir and below dam sites (Wilcoxon's signed rank test).

Figure 8.4 shows the variation in Trichoptera fauna at regulated and unregulated sites.

The abundance and diversity of Trichoptera communities at below dam sites is very poor compared to natural and reservoir sites (Figs. 7.2 – 7.12).

Natural sites seem to have a more diverse community than regulated sites, however, results of Mann-Whitney U tests only show significant differences for Rhyacophilidae abundances ( $P = 0.036$ ), between natural and reservoir sites and also between natural and below dam sites.

No differences between reservoir and below dam sites were found for any of the Trichoptera families.

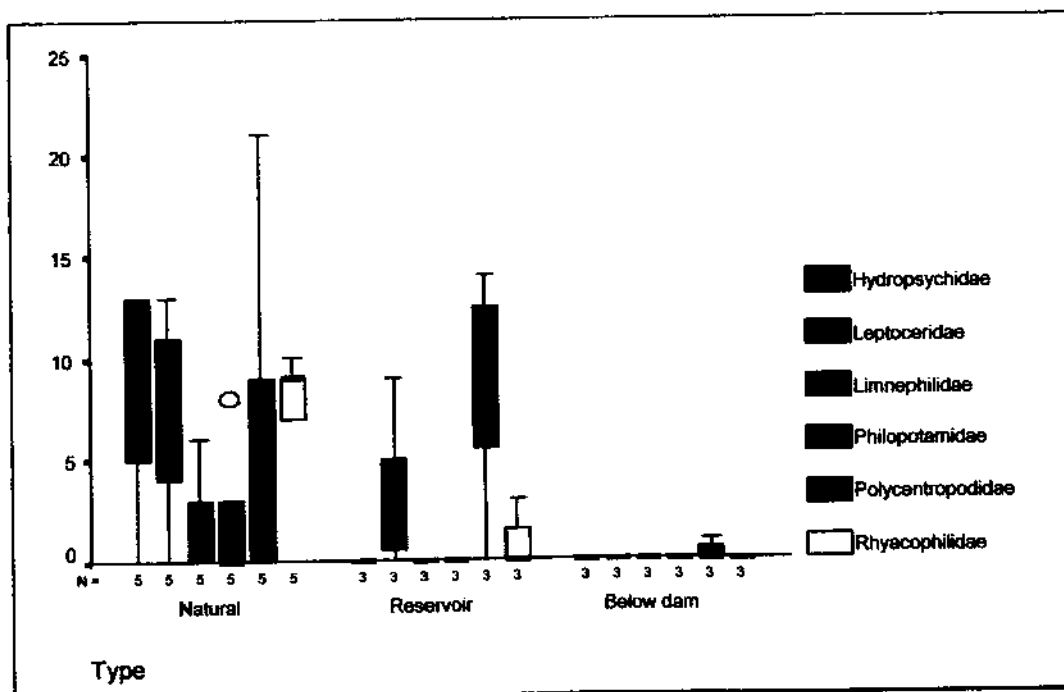


Fig. 8.4 – Composition of Trichoptera communities at unregulated and regulated sites.

### 8.3. Riparian Habitat

Values of the QBR Index (riparian habitat quality) (as shown in Fig. 8.5) at natural and below dam sites appear very similar. On the contrary, QBR values from reservoir sites appear to be very different from those measured both in unregulated sites and below dam sites. Results from the Mann-Whitney U test support this; riparian habitat quality differs significantly between reservoir and natural sites ( $P = 0.036$ ), but not between natural and below dam sites ( $P = 0.786$ ). Riparian habitat quality is also differs significantly between reservoirs and dam tail waters ( $P = 0.027$ ; Wilcoxon's rank test). Shading by riparian vegetation shows a somewhat similar pattern to that of the QBR index, being significantly different between natural and reservoir sites ( $P = 0.036$ , Mann-Whitney U), but not differing between reservoirs and below dam sites.

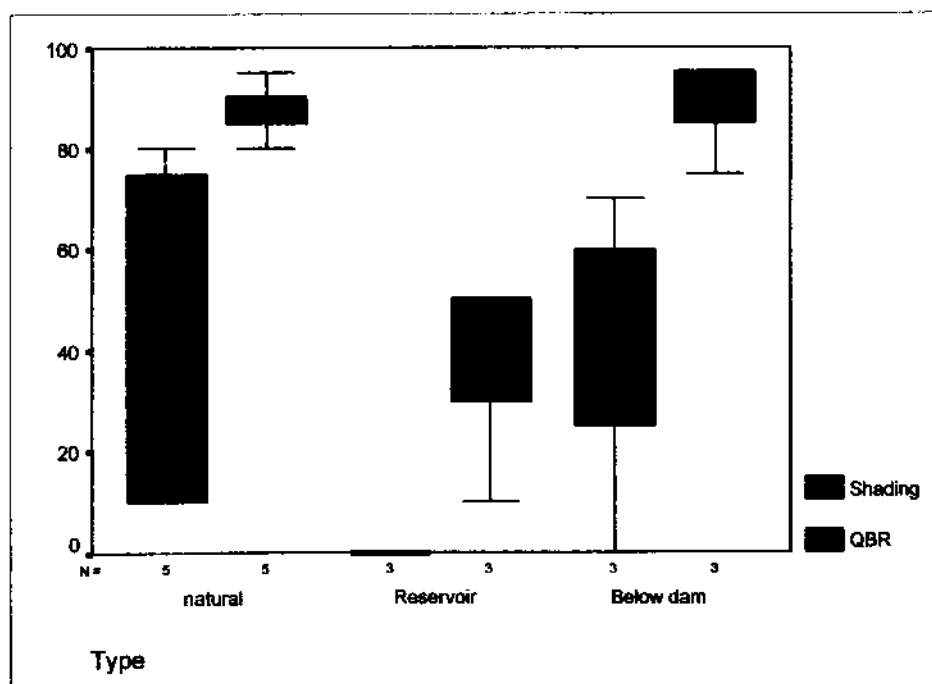


Fig. 8.5 – Measures of riparian habitat features at regulated and unregulated sites.

#### 8.4. Desman Presence

Desman presence was not detected in any of the reservoirs surveyed or in the tailwaters below the reservoirs, and was found to differ significantly between natural and regulated sites (reservoirs and dam tailwaters) ( $P = 0.036$ ).

Desman presence was not detected at the Serra Serrada reservoir, even though a high survey effort was put into place (the total perimeter of the reservoir was surveyed, roughly 3 km – the reservoir is about 1500 m long), when 1200 m (a 600 m stretch, covering both margins) are usually considered sufficient to detect desman presence (Nores *et al*, 1992). A complete stretch of about 2950 m was surveyed uninterruptedly, comprising the totality of the Serra Serrada reservoir, the downstream section of the Serra Serrada dam up to the Gralhas reservoir, at which the full perimeter was also surveyed, and a further 600 m downstream of the Gralhas weir wall without finding any desman evidence. At both below the Montesinho reservoir and in the reservoir itself, no desman signs were found. However, the distances surveyed at these sites were below the 600 m required.

The opposite trend occurred at the River Sabor, where at all the sites surveyed, desman signs were found sometimes immediately, the longest stretch surveyed were 50 m at Site A.

Spearman's correlation tests (Annex II – Table C) were performed to determine relationships between desman presence and the variables measured.

Significant positive correlations were found between desman and the following variables: water velocity ( $r_s = 0.947$ ,  $P < 0.001$ ), pebbles ( $r_s = 0.837$ ,  $P = 0.001$ ), shading of stream channel ( $r_s = 0.616$ ,  $P = 0.033$ ), benthic macroinvertebrates such as Ephemerelellidae ( $r_s = 0.661$ ,  $P = 0.027$ ), Heptageniidae ( $r_s = 0.802$ ,  $P = 0.003$ ),

Leuctridae ( $r_s = 0.848$ ,  $P = 0.001$ ), Nemouridae ( $r_s = 0.908$ ,  $P < 0.001$ ), Perlidae ( $r_s = 0.661$ ,  $P = 0.027$ ), Hydropsychidae ( $r_s = 0.802$ ,  $P = 0.003$ ), Rhyacophilidae ( $r_s = 0.913$ ,  $P < 0.001$ ) and Limnephilidae ( $r_s = 0.661$ ,  $P = 0.027$ ).

Significant negative correlations were found between desman and the following variables: channel depth ( $r_s = -0.843$ ,  $P = 0.001$ ), channel width ( $r_s = -0.757$ ,  $P = 0.007$ ) and silt ( $r_s = -0.789$ ,  $P = 0.004$ ).

No significant correlation was found between desman presence and QBR Index values.

## IV. DISCUSSION

### 9. EFFECTS OF REGULATION IN THE ANDORINHAS STREAM AND THE PRESENCE OF THE PYRENEAN DESMAN

After the analysis of results, it is possible to say that the impoundments located in the Andorinhas stream have induced several changes in the physical habitat of the stream, especially at the reservoir sites. The most noticeable modification is the obstruction of free-flowing waters and consequent alteration of current velocity, flooding of margins and adjacent terrain, leading to a deeper and wider channel. The creation of a barrier to flow causes trapping of river sediment (Allan, 1995; Baxter, 1977; Merritt & Cooper, 2000); this was observable at the reservoir sites where substrate composition was severely modified as compared to dam tail waters and free-flowing sites. Substrate was predominantly composed of fine sediment (silt), dominating over the larger substrata e.g. boulders, cobbles and pebbles found at the River Sabor and also at dam's tail water sites. The modification of discharge regimes in the Andorinhas, together with substrate modification through siltation has led to modifications of benthic invertebrate species composition and richness, with the replacement of lotic species by burrowing organisms predominantly adapted to lentic habitats (Allan, 1995; Brittain & Saltveit, 1989; Fjellheim *et al*, 1989; Petts, 1984; Pozo *et al*, 1997; Stanzner & Higler, 1986).

Decline in abundance was especially noticeable for the Nemouridae stoneflies, which are mostly rheophilic and sensitive to alterations caused by river regulation (Baxter, 1977; Petts, 1984; Stanford & Ward, 1989; Tachet *et al*, 1980). This pattern was visible in the Serra Serrada and Gralhas reservoirs where the Nemouridae (and indeed all the Plecoptera found at Site I) were absent.

The Ephemeroptera and Trichoptera show a varied response to river impoundment depending on the species habitat preferences (Petts, 1984). Certain Trichoptera families (e.g. Hydropsychidae, Philopotamidae and Rhyacophilidae) are affected by low current velocities (Trotzky & Gregory, 1974), while others (e.g. Leptoceridae), are predominantly limnophilous (Tachet *et al*, 1980). A number of Ephemeroptera families are also typical of slow-flowing and lentic habitats, e.g. Siphonuridae, certain Leptophlebiids and Baetids (*Cloeon* spp.), while others, such as certain Baetidae (*Baetis* spp.), Heptageniidae, Ephemerellidae and Ephemeridae, are found in lotic habitats (Allan, 1995; Brittain & Saltveit, 1989; Fjellheim *et al*, 1989; Tachet *et al*, 1980).

The numbers of Ephemeroptera found at the reservoirs were very reduced compared to free-flowing sites in the River Sabor and were principally represented by Siphonuridae and Leptophlebiidae, with smaller numbers of Baetidae.

The numbers of Trichoptera found at the reservoirs were also very reduced compared to free-flowing sites in the River Sabor and were principally represented by Leptoceridae and Polycentropodidae, i.e. families predominantly adapted to lentic habitats that benefit from the slow-flowing conditions found at the reservoirs (Tachet *et al*, 1980).

Decline in abundance was especially noticeable for the Rhyacophilidae caddis flies, which are mostly rheophilic and very sensitive to alterations caused by river regulation (Baxter, 1977; Petts, 1984; Stanford & Ward, 1989; Tachet *et al*, 1980). This pattern was visible in the Serra Serrada and Gralhas reservoirs where the Rhyacophilidae were absent.

The quality of riparian habitat (as measured by the QBR Index) was also affected in reservoirs, especially in the Serra Serrada reservoir, which had the lowest QBR value.

The large variation of water levels in reservoirs has been pointed by some authors as a

determinant factor in the alteration of shorelines, with the decline of plant species diversity and reduction in vegetation cover having been recorded at several reservoirs (Hellawell, 1988; Jansson et al, 2000; Merritt & Cooper, 2000; Nilsson & Berggren, 2000).

At the dam tail waters, alterations at the level of benthic faunal communities as compared to unregulated sites were even more impressive. These sites were characterised by a complete cessation of flow; the water retained at these sites having a fowl smell and a yellowish coloration. Leptophlebiidae and Chironomidae dominated at these sites.

Stoneflies (Plecoptera) were completely absent at dam tail waters; regulation and drought have been found to seriously impact stonefly communities, which are sometimes eliminated from regulated areas (Cowx *et al*, 1984; Stanford & Ward, 1989); Leuctridae and Nemouridae seem to be particularly affected by drought conditions (Cowx *et al*, 1984).

Caddisflies (Trichoptera) were also completely absent at tail water sites. In general, Trichoptera species abundance and diversity decreases at dam tail waters (Hauer *et al*, 1989); this is especially true for those species that are adapted to swift water currents such as Rhyacophilidae, upon which a reduction in current has a negative impact (Trotzky & Gregory, 1974).

The quality of riparian habitat (as measured by the QBR Index) was not affected at tail waters.

Investigations undertaken in the Andorinhas stream prior to the construction of the Serra Serrada dam, revealed that desman individuals were present at the site where the reservoir is now located (captures were obtained in 1988) (Ramalhinho & Boavida,

1993; Ramalhinho & Tavares, 1989); in their paper, Ramalhinho & Boavida (1993) refer to the 'complete change in habitat after dam construction'.

In subsequent investigations at the Serra Serrada dam (Quaresma & Queiroz, 1995), desman presence was not detected, although it was found to be present upstream the dam, roughly at the site where this study's Site I was located (Quaresma, *pers. comm.*).

In this study, desman presence was also not detected at the Serra Serrada reservoir (even though a high survey effort was put into place) nor at any other reservoir. Several reasons can be put forward to justify why this occurred.

A first consequence of reservoir creation will be the inundation of the riparian habitat leading to loss of sheltering and nesting sites available to the desman. Individuals are forced out of their territories and must search for new ones; this can be problematic, especially for such a territorial species as the desman (Nilsson & Dynesius, 1994).

At the reservoirs, new marginal vegetation will eventually develop, but several studies have demonstrated that this new vegetation can be permanently different from the original community (Jansson et al, 2000; Nilsson *et al*, 1997), and can probably be insufficient to accommodate the desman's needs – the margins of the Serra Serrada dam were virtually barren (*pers. obs.*).

Channel substrate composition at the reservoirs is modified by reduced current velocity leading to sedimentation, which has a major effect on benthic invertebrate communities. These alterations are especially evident for the Plecoptera and some families of Trichoptera which constitute the desman's main prey e.g. Nemouridae, Leuctridae and Rhyacophilidae (Bertrand, 1993a), some of which have been found to significantly decrease in abundance at the reservoir sites studied.

Thus, at the impoundments present in the Andorinhas stream, significant changes in riverine habitat could be detected that can justify the disappearance of desman:

- at the reservoirs the quality of riparian habitat is poor, comparing to free-flowing stretches;
- benthic invertebrate communities are altered, both at reservoirs and dam tail waters; some important families significantly decreasing in abundance, or disappearing altogether.

The building of a barrier also obstructs the dispersion of animals up and downstream.

The stream, in addition to being the desman's habitat, also functions as an essential and the only corridor for dispersion since the desman never moves from the stream (Stone & Gorman, 1985), therefore, any permanent structures placed transversally on this corridor will lead to individuals at either side of the barrier losing contact with the other side. At the Andorinhas stream such barriers have been introduced, permanently altering certain habitat features as discussed above.

Thus, the presence of impoundments at the Andorinhas stream has affected the desman population in three ways:

- decrease or even absence of food availability, both quantitatively and qualitatively;
- decrease in physical habitat availability;
- creation of physical barriers between desman populations (by the dam itself and by the creation of a hostile environment through which the desman is not able to disperse).

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## **ANNEX I**

**Table A – Data output from the Mann-Whitney U Tests between *Type* categories**

	N	Mean ± SD	Natural / reservoir	Natural / below dam
			<i>P</i>	<i>P</i>
Desman	11	0.45 ± 0.52	0.036*	0.036*
Depth	11	2.15 ± 4.49	0.036*	0.036*
Width	11	23.36 ± 59.28	0.036*	0.143
Velocity	11	0.07 ± 0.09	0.036*	0.038*
Bedrock	11	8.64 ± 18.18	1	0.786
Boulders	11	29.55 ± 24.13	0.393	1
Cobbles	11	25.00 ± 23.87	0.036*	0.071
Pebbles	11	8.18 ± 11.68	0.036*	0.036*
Gravel	11	8.64 ± 14.68	0.392	1
Sand	11	4.55 ± 8.20	0.036*	1
Silt	11	15.45 ± 29.70	0.036*	0.143
Shading	11	31.36 ± 33.62	0.036*	0.571
QBR	11	74.09 ± 26.91	0.036*	0.786
Baetidae	11	9.09 ± 11.29	0.786	0.071
Ephemerellidae	11	4.91 ± 12.30	0.250	0.250
Heptageniidae	11	3.82 ± 7.51	0.071	0.071
Leptophlebiidae	11	52.73 ± 44.73	0.571	1
Siphonuridae	11	7.55 ± 12.96	0.036*	1
Leuctridae	11	48.18 ± 78.02	0.071	0.036*
Nemouridae	11	25.64 ± 60.60	0.036*	0.036*
Perlidae	11	3.00 ± 8.98	0.250	0.250
Hydropsychidae	11	5.55 ± 10.00	0.071	0.071
Leptoceridae	11	4.00 ± 4.98	0.393	0.071
Limnephilidae	11	0.91 ± 1.92	0.250	0.250
Philopotamidae	11	1 ± 2.49	0.392	0.393
Polycentropodidae	11	5.82 ± 7.29	0.786	0.393
Rhyacophilidae	11	4.09 ± 4.30	0.036*	0.036*
Chironomidae	11	93.27 ± 85.37	0.786	1

\* Significant difference at the .05 level (2-tailed)

\*\* Significant difference at the .01 level (2-tailed)

**Table B** – Data output from the Wilcoxon’s signed rank test between Type categories Reservoir and Below dam

	N	Mean ± SD	P
Depth	6	3.80 ± 5.76	0.753
Width	6	41.77 ± 78.32	0.138
Bedrock	6	4.17 ± 8.01	0.916
Boulders	6	25.83 ± 19.60	0.046*
Cobbles	6	27.50 ± 29.96	0.115
Pebbles	6	1.67 ± 2.58	0.916
Gravel	6	4.17 ± 5.85	0.344
Sands	6	8.33 ± 9.83	0.339
Silt	6	28.33 ± 36.42	0.046*
Shading	6	20.00 ± 31.62	0.916
QBR	6	62.50 ± 32.67	0.027*
Baetidae	6	4.50 ± 7.04	0.518
Leptophlebiidae	6	48.83 ± 51.54	0.058
Siphonuridae	6	12.67 ± 16.10	0.223
Leuctridae	6	4.33 ± 10.61	0.339
Nemouridae	6	0.17 ± 0.41	0.038*
Leptoceridae	6	1.67 ± 3.61	0.492
Polycentropodidae	6	4.33 ± 6.41	0.916
Rhyacophilidae	6	0.50 ± 1.22	0.194
Chironomidae	6	90.00 ± 78.33	0.046*

\* Significant difference at the .05 level (2-tailed)

**Table C – Data output from Spearman's rank correlation test**

	Type		Desman	
	$r_s$	$P$	$r_s$	$P$
Flow	<b>0.927</b>	<b>0.000**</b>	<b>-1</b>	<b>0.000**</b>
Type	<b>N/A</b>	<b>N/A</b>	<b>-0.927</b>	<b>0.000**</b>
Desman	<b>-0.927</b>	<b>0.000**</b>	<b>N/A</b>	<b>N/A</b>
Depth	<b>0.642</b>	<b>0.033*</b>	<b>-0.843</b>	<b>0.001**</b>
Width	<b>0.540</b>	<b>0.086</b>	<b>-0.757</b>	<b>0.007*</b>
Velocity	<b>-0.878</b>	<b>0.000**</b>	<b>0.947</b>	<b>0.000**</b>
Bedrock	<b>-0.158</b>	<b>0.643</b>	<b>0.134</b>	<b>0.695</b>
Boulders	<b>-0.039</b>	<b>0.908</b>	<b>0.146</b>	<b>0.668</b>
Cobbles	<b>0.306</b>	<b>0.360</b>	<b>0.029</b>	<b>0.932</b>
Pebbles	<b>-0.776</b>	<b>0.005**</b>	<b>0.837</b>	<b>0.001**</b>
Gravel	<b>-0.118</b>	<b>0.730</b>	<b>0.243</b>	<b>0.471</b>
Sand	<b>0.205</b>	<b>0.545</b>	<b>-0.553</b>	<b>0.078</b>
Silt	<b>0.547</b>	<b>0.081</b>	<b>-0.789</b>	<b>0.004**</b>
Shading	<b>-0.350</b>	<b>0.291</b>	<b>0.564</b>	<b>0.071</b>
QBR	<b>-0.059</b>	<b>0.863</b>	<b>0.351</b>	<b>0.289</b>
Baetidae	<b>-0.612</b>	<b>0.045*</b>	<b>0.443</b>	<b>0.172</b>
EphemereIIDae	<b>-0.613</b>	<b>0.045*</b>	<b>0.661</b>	<b>0.027*</b>
Heptageniidae	<b>-0.744</b>	<b>0.009**</b>	<b>0.802</b>	<b>0.003**</b>
Leptophlebiidae	<b>-0.112</b>	<b>0.743</b>	<b>0.145</b>	<b>0.671</b>
Siphonuridae	<b>0.212</b>	<b>0.531</b>	<b>-0.504</b>	<b>0.114</b>
Leuctridae	<b>-0.847</b>	<b>0.001**</b>	<b>0.848</b>	<b>0.001**</b>
Nemouridae	<b>-0.888</b>	<b>0.000**</b>	<b>0.908</b>	<b>0.000**</b>
Periidae	<b>-0.613</b>	<b>0.045*</b>	<b>0.661</b>	<b>0.027*</b>
Hydropsychidae	<b>-0.744</b>	<b>0.009**</b>	<b>0.802</b>	<b>0.003**</b>
Leptoceridae	<b>-0.643</b>	<b>0.033*</b>	<b>0.545</b>	<b>0.083</b>
Limnephilidae	<b>-0.613</b>	<b>0.045*</b>	<b>0.661</b>	<b>0.027*</b>
Philopotamidae	<b>-0.476</b>	<b>0.138</b>	<b>0.514</b>	<b>0.106</b>
Polycentropodidae	<b>-0.265</b>	<b>0.430</b>	<b>0.121</b>	<b>0.723</b>
Rhyacophilidae	<b>-0.892</b>	<b>0.000**</b>	<b>0.913</b>	<b>0.000**</b>
Chironomidae	<b>-0.019</b>	<b>0.955</b>	<b>0.346</b>	<b>0.297</b>

\* Significant correlation at the .05 level (2-tailed)

\*\* Significant correlation at the .01 level (2-tailed)