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2. M5 Risk assessment of water management in Evrotas River Basin

1. INTRODUCTION

Water management practices in the Evrotas River Basin include intensive water abstraction from the river channel network and from the groundwater aquifers for irrigation, while severe morphological modifications of river channels, river banks and riparian vegetation, result from irrigation, land reclamation and flood protection activities. The watershed is crossed by an extended and dense irrigation channel network. Surface water is usually abstracted from springs, directly from the river or through weirs, while huge amounts of water are abstracted through wells which are currently estimated to be around 7,000. These practices result to the significant hydromorphological degradation of the river system, limiting habitat availability. The diminishing of the water volume may "concentrate" salts and pollutants and deplete oxygen, while the absence of water (e.g. Figure 1.1) may lead to mass extinction of certain organisms. These factors act cumulatively and deteriorate the chemical and biological status of the river.

Organisms have the ability historically to adapt to water scarcity conditions that occurs naturally. However, when a river dries out abruptly as a result of intense water abstractions, sudden environmental changes cause significant stress and the environmental risk becomes high. This phenomenon is particularly severe for the fish fauna in contrast to the macroinvertebrate fauna which has the ability to recolonise the dry area when conditions are appropriate. In the sense of the Water Framework Directive, the difference between a "naturally" and an "artificially" dry stream, as far as it concerns aquatic organisms is significant. If a river or a reach dries out from anthropogenic causes then its biological status based on fish assessment will score bad. However, if a reach dries out due to natural causes (i.e. long drought) then its biological quality based on fish fauna will be assessed with biological criteria and not with hydrological ones. Hence, one of the most important questions addressed when assessing the ecological quality of an intermittent river is to identify whether its intermittent character is attributed to natural or anthropogenic causes. However, the assessment and quantification of the causes that induce drought to aquatic systems is very complicated, it is carried out indirectly, and results can usually be inaccurate since climatic as well as human processes interact.

Water management, and particularly intense irrigation, causes soil salinisation. Salts that accumulate in the soils are then transferred into surface and groundwater and can raise water salinity. At high concentrations, salt can adversely affect aquatic species (e.g. Skoulikidis, 2008). Droughts additionally enhance this phenomenon (Skoulikidis et al., 2008).

Another major threat of river habitats and biota is the impact of hydromorphological alterations. Due to the flashy character of the Evrotas, flood events occur relatively often and thus several measures have been taken in order to avoid floods. These include river channel scouring and straightening, embankment and many more, which eliminate riparian and channel habitat diversity (e.g. Figure 1.2). This hydromorphological degradation results to habitat homogenisation that decreases species diversity and results to the formation of a relatively homogeneous macroinvertebrate community dominated by tolerant and generalist species with significant abundances (Karaouzas et al. 2007; Karaouzas & Gritzalis 2002). In addition, riparian habitat degradation may destroy macroinvertebrate species and their eggs and limit nutrient and food availability. Moreover, suspended solids and particulate nutrients may increase significantly due to bank soil erosion. Some macroinvertebrate species lay eggs that are dormant in order to withstand long droughts and when conditions are favourable they hatch. Furthermore, some species migrate deep into the substrate or into the hyporheic zone to avoid drought and emerge from it when the system recovers. River channel and riparian degradation through scouring and embankment may eliminate the species and their eggs and interrupt species emergence.

Drying is particularly significant for fish which are water-dependent organisms throughout their life. During drought periods, fish either die or retreat to pool refugia and small reaches maintaining flowing waters. In addition to causing death because of complete desiccation, droughts may raise water temperature and reduce dissolved oxygen, imposing adverse physical conditions on fish. Moreover, concentration of fish in reduced space can strengthen biotic interactions, by raising competition for food and increasing vulnerability to natural enemies. Extraction of water exacerbates the stresses, decreasing the resilience of fish populations to drought. Several species have evolved adaptive strategies against environmental harshness, but when the dry season becomes long and extreme, fish may face conditions to which they are evolutionary inexperienced. Successive and/or prolonged drought periods may be 'the straw that breaks the camel's back' for some of the most sensitive species, impeding their ability to persist. This may result in their potential replacement by more tolerant species and significant modifications to fish assemblage structure. Still another problem is the loss of habitat due to river straightening and other flood-defence measures, which not only it results in contraction of their living space, but may also disrupt connectivity among habitat patches or reduce the availability of refugia habitats. Problems such as toxic spills, eutrophication and the formation of algal blooms further increase the stress already experienced by fish during droughts and often result in severe fish kills.

After flow resumption, recolonisation of the desiccated areas from drought refugia begins allowing the fish community to recover. The recovery may be slow or rapid, depending on factors such as the amount and quality of refugia, their proximity to the dewatered areas, and the number, mobility and dispersal rates of survivors. When repeated droughts occur or where the quality of refugia is degraded due to human impacts, the speed of recovery is inhibited. For instance, river straightening reduces the availability of deep pools as drought refugia. Likewise, water abstraction may cause the desiccation of pools that would otherwise persist through the dry season.

Figure 1.1. The Evrotas River downstream from Pellana-Sellasia Bridge during May 2006 (**left**), September 2006 (**middle**) and during 2007 all year throughout (**right**)

Figure 1.2 Scouring, enlargement and straightening of Evrotas River bed near the river mouth (**left**). Removal of riparian forest and vegetation, enlargement and straightening of Evrotas River bed at Skoura (**right**).

2. METHODOLOGY

To present the current hydrological situation and the seasonal hydrological pattern of the Evrotas River system, several field trips were carried out in order to record the water abstraction points and the active river network was mapped in three periods in 2007. In addition, hydrograph analysis, using data from the automatic stage recorders, provide a figure on discharge variations for the period of one year (November 2006 – December 2007) (section 1).

To assess the effects of water management on the hydrological regime of Evrotas, a histrorical, a hydrological and a hydromorphological analysis were carried out (sections 2-4).

To assess the risk of water management on the abiotic and biotic characteristics of the river, hydrochemical and biotic data were utilised (sections 5 and 6).

2.1. Recording, mapping and hydrograph analysis

From the beginning of spring (April 2007) until the end of the summer (late September-early October 2007) several field expeditions were carried out in order to investigate hydromorphological modifications and record all the water abstraction points (including weirs and pump-stations) throughout the basin. In addition, the hydrologic condition of Evrotas River and most of its tributaries was monitored and recorded in detail. Thus, three hydrological maps were produced for the three investigated periods (April & May 2007, June & July 2007, August & September 2007) to illustrate the seasonal flow patterns and the areas that retain water and the areas that dry out. The information gathered during the field expeditions represent the hydrologic condition of Evrotas river system and it is especially important since it includes one of the worst drought periods of the last two decades (the other one being the 1990-1991 drought).

Moreover, data from the automatic stage recorders for the period November 2006 – December 2007 (converted to daily discharge) illustrate the droughts that occurred in summer 2007.

2.2. Historical analysis

Historical data have been assembled from libraries of the area, from local authorities, from local citizens (elders that know well the area) and from the literature. The historical analysis is in progress.

2.3. Hydrological analysis

Long-term monthly rainfall data, as well as, air temperature, water discharge, wells' water level and irrigated land areas, were assembled from the Prefecture of Laconia, Land Reclamation Service (LRS) to quantify the hydrological status of Evrotas water resources and assess temporal trends. In addition, data from stage-recorders that have been installed from the Institute of Inland Waters along the main course of Evrotas River, and water flow measurements carried out by LRS were collected to estimate discharge levels at daily basis and trace the temporal on an annual basis.

In order to estimate daily-hourly discharges, a rating curve between water stages and monthly discharge measurements was established. Data from 5 gauging stations were used (Vivari, Skortsinos, Skala, Sparti's bridge and Kelefina tributary) collected from November 2006 to December 2007.

2.4. Hydromorphological pressures and assessment

A hydromorphological analysis was performed with the use of the River Habitat Survey (RHS) method (Raven, et al., 1997). This method assesses the physical character of a sampling site at a 500 m length and involves the collection of numerous features recorded at 10 spot-checks in 50 m intervals. The habitat quality of each site (stream channel and riparian habitat) was evaluated with the use of the Habitat Quality Assessment Score (HQA) and Habitat Modification Score (HMS). HQA (Habitat Quality Assessment) assesses habitat diversity (in-stream and riparian), thus higher scores tend to mean higher quality. In contrast, higher HMS (Habitat Modification Score) scores mean more stream modifications and therefore poorer stream quality. Each site was classified into six categories according to HMS (0: Pristine; 0-2: Semi-natural; 3-8: Predominantly modified; 9-20: Obviously modified; 21-44: Significantly modified; 45 or more: Severely modified).

2.5. Hydrochemistry and pollution

Hydrochemical data from the hydrologic and biogeochemical monitoring network were used to assess a) possible impacts of irrigation on the salt balance of the river network and b) impacts of drought on the water quality. In addition, hydrochemical data from monthly monitoring campaigns (LRS) for the period February to November 2007 were evaluated.

2. 6. Biota

2.6.1. Fish

Results of the sampling expeditions carried out in 2006 have been presented in the first progress report (August 2006). In 2007, sampling trips to the area were made from April to the beginning of September. In 2008, a sampling trip was conducted in April and two more sampling rounds are scheduled for the summer period. Details of the fish sampling design and the methodology employed, and some of the results of the ichthyological investigations, are provided in section 3.6.

2.6.2. Macroinvertebrates

Benthic macroinvertebrate fauna was collected during the summer of 2006 with the STAR-AQEM methodology (AQEM Consortium 2002; STAR Consortium 2003). Analysis is expected to be completed by the end of June 2008. Since some macroinvertebrate species are relatively resistant to drought due to their adapted survival strategies and have the ability to recolonise former dry areas when conditions are appropriate, it is anticipated that their seasonal or spatial distribution may not assist the purposes of this task of the project. Hence, the use of macroinvertebrates as drought indices may be indicative and supplementary.

2.6.3. Riparian forests

This task was carried out by the University of Ioannina (Prof. P. Dimopoulos). The assessment of the impacts of hydromorphological modifications on the riparian forests of Evrotas, wa carried out in terms of literature research, field investigations, analysis of aerial photographs and GIS-mapping, and development of an appropriate protocol to describe and record the status of riparian vegetation with the use of QBR-index. According to this, the status of the riparian vegetation was classified into five categories. The respective report is attached at the end of this Appendix.

3. RESULTS

3.1. Recording, mapping and hydrograph analysis

The vast majority of Evrotas tributaries have intermittent or ephemeral character. Information collected from field expeditions and from personal communications with the LRO (V. Papadoulakis) and the Geotechnical Office of Skala (V. Lerikos) as well as from locals, it becomes apparent that there are an enormous number of water abstraction points for irrigational uses. Due to the immense water abstraction and long droughts, most streams that discharge into Evrotas River dry out during the summer at the mid and lower reaches and retain water only at their upstream reaches near the springs. It should be pointed out that during long droughts many reaches of the Evrotas River dry out for many kilometers thus having significant effects on aquatic life and on the economy of the area.

During late spring and summer many weirs are being temporarily installed for irrigational purposes, while there is a significant number of permanents ones (Fig. 3.1.1). Weirs have been established at Evrotas springs (Skortsinou) that supply the Municipalities of Skortsinou and Logkanikos, at Pellana (water is used from May) and Vivari springs, at Steno Vordonias (small weirs made from grit along Evrotas River), as well as along the main course of Evrotas river near Karavas (3 weirs north from Sparti, e.g. Afissos weir situated 300m upstream form Sparti Bridge), south from Sparti city near the area of Varika village. Near Vrodamas town there is a small irrigation dam made from concrete, while the weirs at Lefkochoma – Pyri near the Bridge of Skoura do not operate anymore. However, water abstraction in this area occurs through pump stations. There are also an unknown, yet large, number of weirs and water abstraction points throughout Evrotas river system from local citizens. Pump stations, both private and communal, and drillings are established throughout the length of Evrotas and particularly at the area of Karavas and downstream from Karavas. Irrigation from surface and groundwater is prohibited from Pellana - Sellasia Bridge (near Pellana village) until Skala at a distance of 300m from the river's banks. However, there are many private pump stations which are not being regulated or controlled by local authorities at the area of Skala.

During the summer period, the streams Vresiotiko (known also as Kastoras), Kardaris and Kastaniotiko dry out at their lower reaches due to irrigation and hence their waters never reach Evrotas. Along the course of Vresiotiko there are 2 weirs while one weir has been positioned at the confluence of Vresiotiko and Kastaniotiko that interrupt the water from reaching Evrotas during the summer. Oinous, the most important tributary of Evrotas used to retain water throughout the year; however during the last years it retains water only at its upper reaches. Two weirs have been recorded along Oinous River, the one being in the upstream part near Sellasia and the other one after its confluence with Sofroni stream (Figures 3.1.2 & 3.1.3). The three important streams (Gerakaris, Rasina and Kakaris) at south-western Taygetos, retain water only at their upper and middle reaches during the summer period, due to water abstraction. Xerias stream (near Sparti) was once an important tributary that used to supply Sparti. However, during our filed trips (2006-2008) it was complete dry. Magoulitsa is a small length stream but with significant water volume, supplied by the springs of Trypi. Again, due to irrigation and water supply of Sparti, during the summer its flow does not reach the Evrotas.

Vasilopotamos originates from the springs of Skala and from springs west of Skala. Few decades ago, the plain of Skala was a wetland (marsh) extending to the natural habitats of Evrotas Deltaic system. Today it has been straightened and channelized while sea water may intrude up to 700m into Vasilopotamos during drought periods. The Ω channel collects irrigatory waters and discharges into Laconikos Bay.

The three figures below (Figure 3.1.1, 3.1.2 & 3.1.3) illustrate the hydrological pattern of Evrotas River from the wet (April) until the end of the dry period (October). It was evident from the three figures that by the end of the summer most reaches along the main course of Evrotas have desiccated (Figures 3.1.2 & 3.1.3). By the end of the summer 2007, the only parts of Evrotas that had water were near the estuaries and near the springs. An important quantity of water was recorded upstream and downstream Karavas area, where several karstic springs and groundwater flow supply that particular reach. Furthermore, most tributaries of Evrotas River have dried out, while some maintained water only at their upper reaches.

Starting from Evrotas springs (Skortsinou) water flowed for about 12 km (Figure 3.1.1) during the wet period (April 2007) and disappeared few hundred meters before the bridge of Pellana – Sellasia (see Figure 1.1). However, during the mid-summer (August 2007) and late summer (beginning of October 2007) hydrologic conditions in the particular area changed significantly. Thus, during mid and late summer water flowed from the springs for about 1,421m, it was succeeded by several pools and then it disappeared for 700m. Water appeared again for 650m, disappeared for 800m and finally appeared again for 1,493m. Thus, for that particular distance, water flowed for about 5 km out of the initial 12 km that were recorded during the wet period. Water appears again after the confluence of Evrotas with Vathyrema stream (Vresiotiko, Kastaniotiko and Kardaris discharge into Vathirema) and flows until Vrodamas plain where it enters into the hyporheic zone. By the end of summer water occurred only for few hundred meters downstream from Karavas, downstream from Sparti's wastewater treatment plant and near Leukochoma. Finally, during spring, from Skala until the river mouth, Evrotas discharged for 7.6km while by the end of the summer this distance was limited to 1.8km, thus a decrease of 76.3%.

Figure 3.1.1. Hydrological mapping of Evrotas River Basin during the spring 2007. The green colour represents the reaches with water, while the red marks illustrate the weirs established throughout the watershed. Blue lines represent the ideal hydrologic network of the river basin.

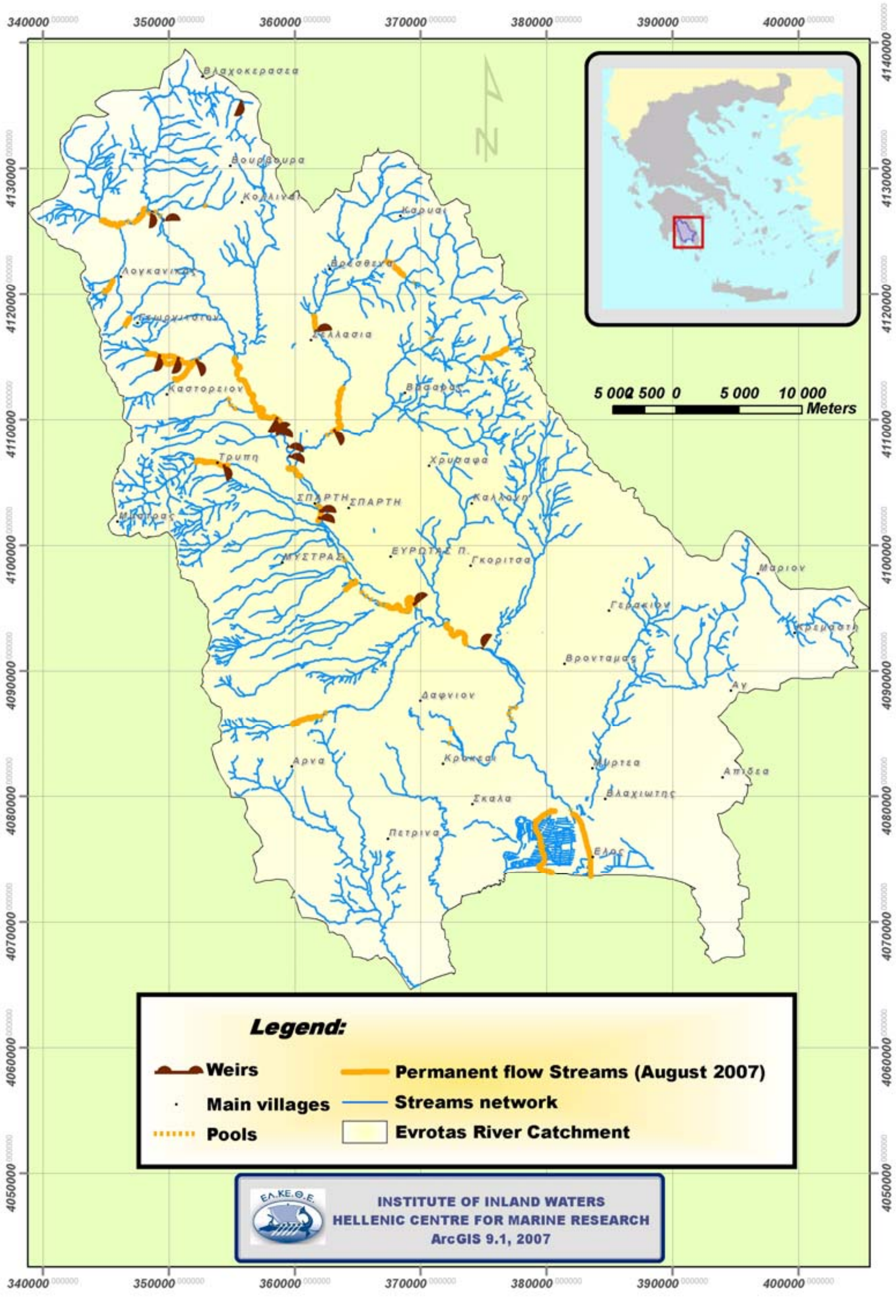


Figure 3.1.2. Hydrological mapping of Evrotas River Basin during mid-summer (August 2007). The yellow patterns represent the reaches with water, while the red marks illustrate the weirs established throughout the watershed. Blue lines represent the ideal hydrologic network of the river basin.

Figure 3.1.3. Hydrological mapping of Evrotas River Basin during the end of the summer (October 2007). The yellow patterns represent the reaches with water, while the red marks illustrate the weirs established throughout the watershed. Blue lines represent the ideal hydrologic network of the river basin.

Regarding the flow length of the streams that discharge into Evrotas, as recorded from through spring to late summer 2007, these can be summarised in the table below.

Table 3.1.1 Flow length of streams discharging into Evrotas in spring and late summer 2007.

Stream name	**Spring**	***Late summer***
Length	*[meters]*	*[meters]*
Vathyrema	1,416	0 (only pools for 570m)
Voutikiotis	2,850	0
Gerakaris	7,247	800 (lentic waters)
Kakaris	4,665	N/A
Kakorema	1,014	0
Kastaniotis	2,518	2,518
Vresiotiko	2,682	2,641
Kerasiotiko	6,014	N/A
Kardaris	2,868	2,542 (flow)
Kotitsanis	4,185	600 (lentic waters)
Magoulitsa	11,780	2,795
Mylopotamos	3,011	600
Nikova	4,136	0
Kserilas	6,521	0
Oinous (Kelefina)	17,032	8,398
Paroritis	3,803	0
Verias	368	N/A
Skatias	7,468	0
Tzitziniotiko	2,731	N/A
Tyflo	2,005	700
Fteroti	2,942	200

Vathirema stream originates from the confluence of three streams namely Kardaris, Vresiotiko and Kastaniotis. During the wet period, all three streams ensure significant quantities of water into Vathirema and in turn into Evrotas River. By end of the summer, (as recorded at late September-early October 2007) Vathirema has been desiccated and only several mid and large-sized pools (for ca. 570m) remained near the confluence with the three aforementioned streams. Vresiotiko, Kardaris and Kastaniotis retained water few meters before their conjunction with Vathirema. Flow was mainly interrupted due to water abstraction and established weirs. Voutikiotis (flows through north Pellana plains) as well as Kserilas (flows through south Pellana plains) have dried out completely during the summer. Gerakaris joins Rasina stream and then their waters discharge into Evrotas. Rasina and the lower reaches of Gerakaris have been desiccated by mid-summer and by the end of the summer Gerakaris retained water (lentic waters) only at its upper reaches for approximately

800m. Streams Tyflo and Mylopotamos that would otherwise have dried early at the summer, maintain water at their lower reaches most of the dry period. This water is supplied by groundwater by the fruit juice processing units in order to wash away residual wastewaters. Nikova, Skatias, Kakorema and Paroritis also dry out completely, while Kakaris and Fteroti (located at the fringes of Taygetos Mt. highest point, Profitis Ilias) maintain water at their uppermost reaches. Magoulitsa retained water only at its upper reaches for almost 3 km during the dry period. The total discharge length of Oinous River as recorded during spring was 17 km. This distance was significantly reduced at mid summer (August 2007) to 5.2 km while due to rainfall towards the end of September its flow length increased temporarily to 8.4 km.

In several parts of Evrotas River and its tributaries, many pools are formed that are critically important for aquatic life, especially for fish. For example, within the gorge of Vrodama, there are several pools ranging from 5 to 10 m in diameter and sometimes they can even reach a depth of 3m. Water is reserved in these pools throughout the year (V. Lerikos) or at least most of the year. Many large pools were also formed at Evrotas River downstream from Vivari springs for about 400-600m.

Hydrograph analysis

Daily discharge data obtained from the automatic gauging stations illustrate the flashy regime of the river and the droughts that occurred in summer 2007.

Figure 3.1.4 presents the daily discharge at Sparta's bridge station. It is evident that the discharge decreases to the point of almost zero values, starting from the end of August 2007. Only some flash events supply Evrotas River with time-limited water discharges up to the end of November 2007. A similar water regime is apparent at upstream stations, such as the Vivari station. Here, the drought occurs earlier than at Sparta's bridge (Figure 3.1.5). A major tributary (Oinus), which joins the Evrotas upstream Sparta's bridge, also shows this type of intermittent regime (Figure 3.1.6).

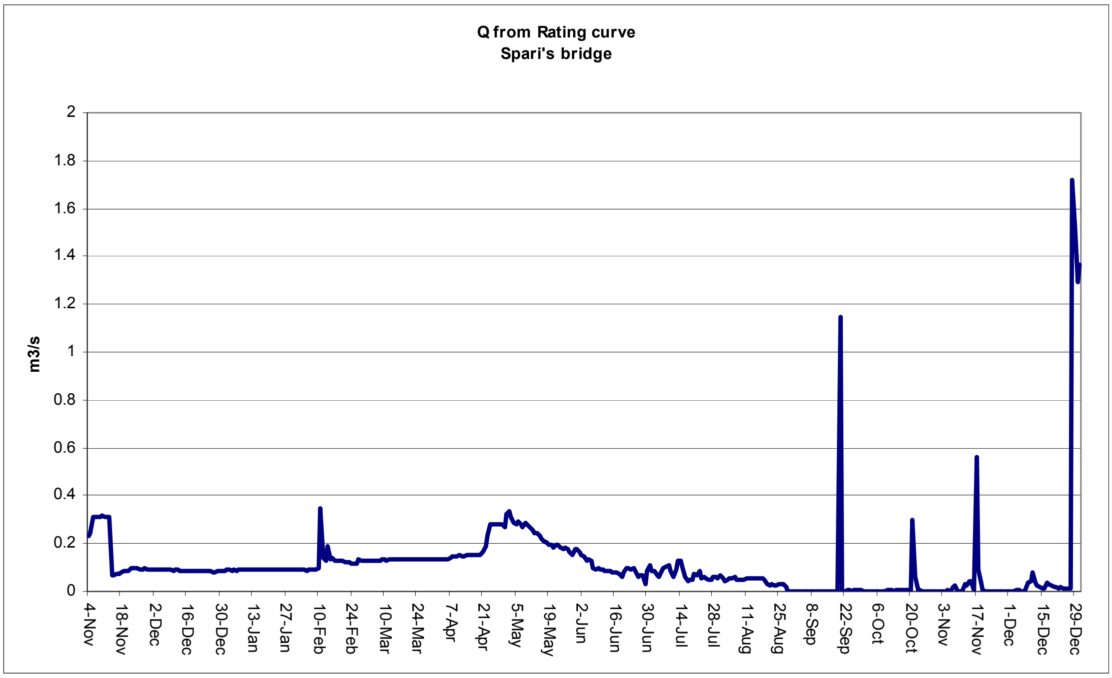


Figure 3.1.4. Daily hydrograph of Evrotas River at Sparta-bridge gauging station.

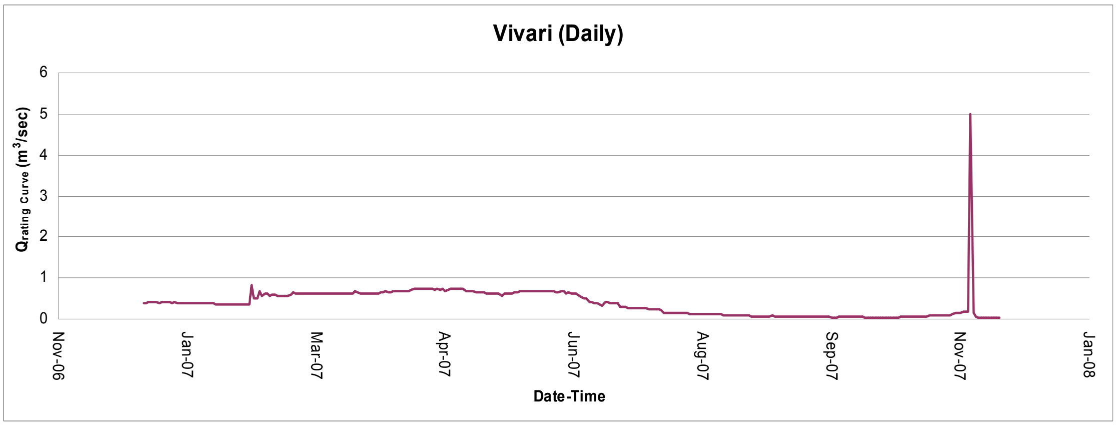


Figure 3.1.5. Daily hydrograph of Evrotas River at Vivari gauging station.

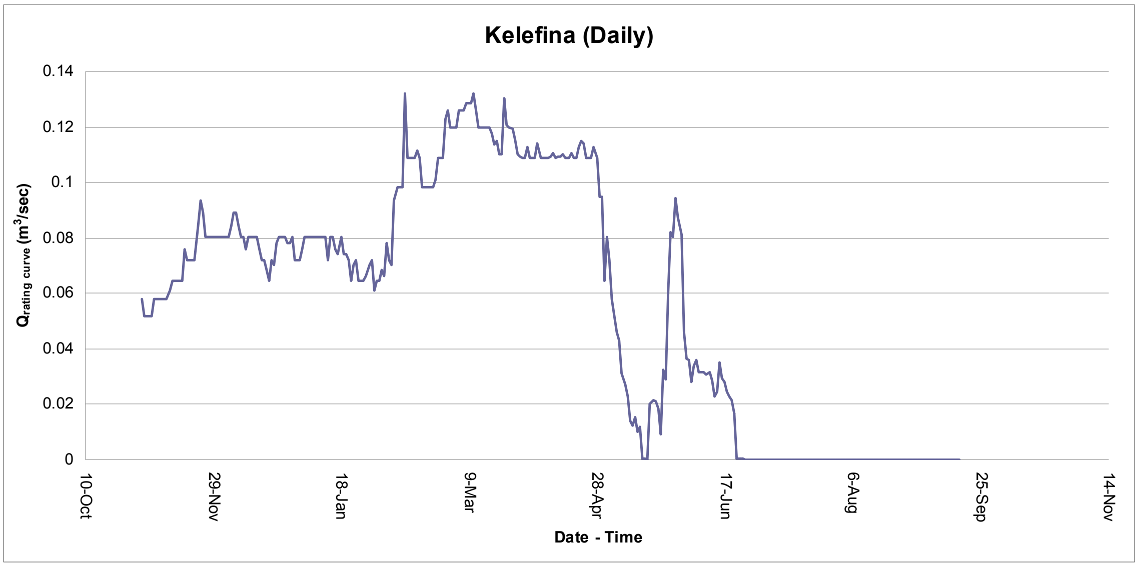


Figure 3.1.6. Daily hydrograph of Oinus Tributary at Kelefina-bridge gauging station.

The flashiness of the river is apparent from Figures 3.1.7 and 3.1.8. High values of discharge are observed in less than 3% of the year (measurements on daily basis). Regarding water flux, the Evrotas requires less than 20% of the time (on annual basis) to drain 50% of its water quantity (data from Sparta's bridge gauging station).

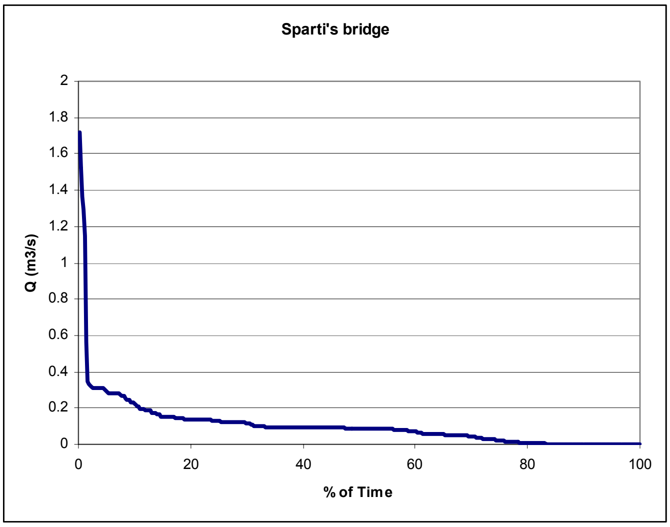


Figure 3.1.7. Flow duration curve at Sparta's bridge.

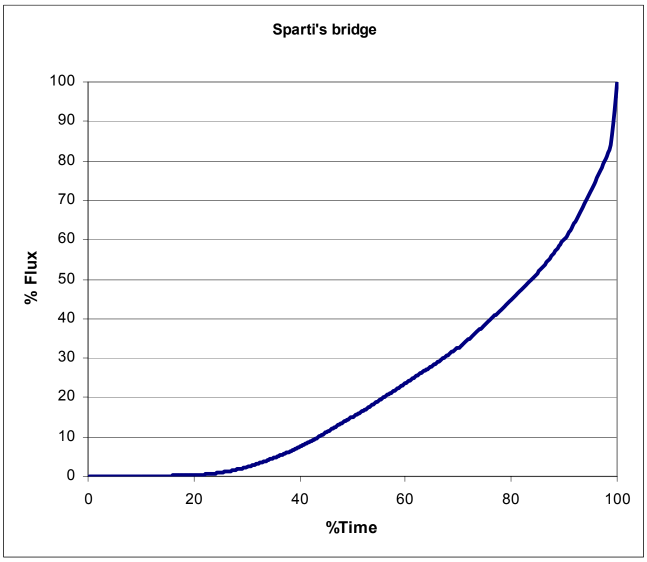


Figure 3.1.8. Flux duration curve at Sparta's bridge.

3.2. Historical Analysis

The name Evrotas derives from the ancient Greek words "evros" and "otos" which means mould, humidity resulting to decay and deterioration. In Greek mythology, according to Pausanias the river took its name after Evrotas, the legendary king of Lacedaemon. Until his days the Laconia valley was covered by a lake. King Evrotas created a canal near the mountain of Vrodamas conducting the water towards the Laconia bay. An artificial river outflow was developed in this way and in honor of the king, it was named after him.

Even in the case that this story is a myth, evidence from research boreholes in the area has proved the existence of a Pliocene lake that covered the greater part of Sparta valley. During the ancient days, although the Sparta valley was a very fertile the cultivated land, it occupied a small area due to the existence of the river, its tributaries and the swamps that created whenever it overflowed. There are some descriptions of the river in the scripts of Greek and Latin authors of that age. According to Euripides and Theogenis, there was a wetland full of reeds near the river. According to Polivios there were trees which produced great quantities of fruits, while Vergilios and Aineias mention the existence of laurels and myrtles respectively. Statios refers to the river as «ololifer», which means a shelter for swans, or «oliferi», which means full of olive trees.

Pausanias first, from who we derive the majority of information about the river, and Kikeronas later mention the periodic increase of the water level. Depicting the story of a girl who drawn in the waters of the Pellanitida spring, Pausanias also describes the communication between the waters of the Laconia springs through the aquifer. Another evidence that further supports the presence of a lake in the Laconia valley is that the suburbs of Sparta were almost always covered by standing waters and that is why they were called "The Lakes". The Temple of the Standing Artemis which called "The Laky" was also found in that area. Pausanias and other ancient Greek and Latin authors also mention that the springs of Evrotas in the Assea of Megalopolis, were the springs of the Alpheios River as well. They write that both rivers shared a common drainage for approximately twenty stadiums (1 stadium is 185 meters) and separate after entering into a land gap. Evrotas would appear again in the area of Veleminatida from the springs of Pellanitida and Lageia.

Finally, Pausanias refers to hydraulic projects that were conducted in the area and particularly to the irrigation of the Velemina area. The aim of these projects was the agricultural development of the greater part of the fertile Laconia land and the protection of communities. Vivid examples were the drainage of the Trinasos swamp, which overflowed again not being well maintained, and the construction of the Sparta aqueduct which pumped water from the Vivari springs.

During 19^{th} century the references of Greek and foreigner authors are similar to the previous ones, but they also provide information about the development of the area. In 1806, Chateaubriand travelled to Spartan land and describes the reeds and laurels that he saw on the river banks, as well as the abandonment of the area, where there were not any ancient monuments left, such as the ancient bridge of Vavika. He also mentions "Imeros" a forgotten ancient name of Evrotas and "Iris", another name used in the 19^{th} century. In Pouqueville's scripts, who visited Peloponnese in 1805, there is information about another name of the river, which was used during the Byzantine age. The name "Vasilopotamos" was given after the despots and the princes of Mystra. Flomber in 1851 speaks for the laurels, myrtles and mulberries which were growing on the banks of Evrotas, Ragkavis in 1853 writes about the Laconia land which was full of olive and fig trees and Mansolas describes the human, mainly agricultural, activity of those years.

During 19^{th} century there was an increase in agricultural production not only for self-consumption but also for trade reasons. According to 1861-1907 statistics, the two thirds of the active male population of Laconia were farmers. During the second half of the 19^{th} and the beginning of the 20^{th} century the basic agricultural products of Laconia were olive oil and olives, mulberry leaves, acorns and figs. During the same period, an expansion in the variety of cultivations was observed. Mansolas mentions that in 1875 intense land reclamation took place.

The majority of the created new land was used for the cultivation of wheat and other cereals – which had already started but was limited. Moreover, small cultivations of tobacco and vineyards were added. Finally, during that period citrus cultivations started to expand. At the beginning of the 20^{th} century and specifically in 1911, cotton cultivation was introduced in the agricultural production. Until then, the production of cereals and citrus had increased in such degree, that they were considered as the basic agricultural products of Laconia.

During the 21st century and specifically its second half, a dramatic change took place in Evrotas. From 1900 and for several decades the river had maintained its characteristic features. In October 1902, its precipitous waters drifted the Kopanos bridge, which was built in 1749.

During the decades 1930-1940 the image of Evrotas was almost idyllic. The same river which during the intense autumn and winter rainfalls overflowed and drifted stones, trees, bushes, animals and even humans on one hand, had developed lush vegetation and rich fauna along its length on the other. On the banks of the river there were willows, poplars, planes, laurels, reeds and other trees as well as a variety of wild flowers. In order to prevent the river water to move into their cultivations, the farmers used these trees and bushes as natural "green" barriers. In this way and as time went by, a scrub was created near the river, which became known as the Evrotas Scrub.

Many hydrophilous trees were growing there, converting it into an impermeable jungle during spring. The scrub sheltered a large number of animals: small mammals, amphibians, reptiles and mainly birds both endemic and emigrating species. Similarly to ancient years, Evrotas exhibited permanent flow along its whole length and throughout the year during the decades 1930-1940. Natural swimming pools also existed, which accommodated many swimmers during summer, for instance the natural swimming pool at Stefani. These pools that were found in hollows of the river were often dangerous due to their great depth and the swirls created by the fieriness of the water. Another evidence of Evrotas permanent flow was the existence of fish both in the main river and its tributaries. The inhabitants of the area used to fish fishes and eels in the night using several techniques.

During 1950, several studies and projects were carried out in the area in order to reduce the floods, increase the cultivated and irrigated land and limit the danger of malaria coming from the swamps. During the next decade, big hydrologic, irrigation, land reclamation and drainage projects such as the flow constraint of the streams entering Evrotas, the alignment of the river, the construction of boreholes and of an aqueduct for the water supply of Laconia, were materialised. In 1964, the erection of a 40 meters high terrene weir in the area of Kamares was decided. An area of approximately 90000 acres from Kamares to Xirokampi would be irrigated through two canals. The Ministry of Agriculture conducted the studies and was in charge of these projects. At the end of 1970 and beginning of 1980, a project for the drainage of Trinasos swamp was carried out. The project was completed by the "Hydraulic Trinasos Establishments", a company which drained the swamp and placed permanent hydraulic establishments such as a pumping station and ditches leading the ground water into the Laconia bay. As a result the Trinasos swamp converted into a particularly fertile area, where wheat, rice, cotton, olives, citrus, strawberries, peaches and apricots were cultivated.

3.3. Hydrological Analysis

In Evrotas, at Sparta bridge, and especially in Oinus, drying out occurs rapidly at the end of June 2007 (Figure 3.1.6). This sudden drop provides evidence for intense water abstractions. Figures 3.3.1 illustrate characteristic water abstraction practices in the Evrotas basin.

Figure 3.3.1. Water abstraction (up) and diversion (down, see pipe) in many locations in the main course of Evrotas River and tributaries.

Figure 3.3.2 presents the mean annual water discharge variation of Evrotas at Vrodamas station and the mean annual rainfall variation upstream from Vrodamas (average values from 5 rainfall stations) for 1974 – 2006. It becomes evident that both rainfall and water discharge decrease diachronically. However, while rainfall decreases about 1.52 mm/year, water discharge decreases about 2.34 mm/year which is 1.5 times larger than rainfall decrease. This difference (about 0.83 mm/year) is attributed to water abstractions.

During the period 1994-2006 (after the drought period of 1989-1993) there is a relatively increase in rainfall precipitation about 22.1 mm/year, while the corresponding increase in water discharge is only 2.7 mm/year (Figure 3.3.3). Therefore, the average surface water loss is estimated to be around 26,361,489 m^3/year. This amount corresponds to 24.5% of the Evrotas mean annual discharge.

During 1994-2006, evapotranspiration decreases at 6.04 mm/year. Thus, if the decreasing rates of evapotranspiration are taken into account, then surface water loss is estimated at 34,564,554 m^3/year that corresponds to 32.1% of the Evrotas mean annual discharge.

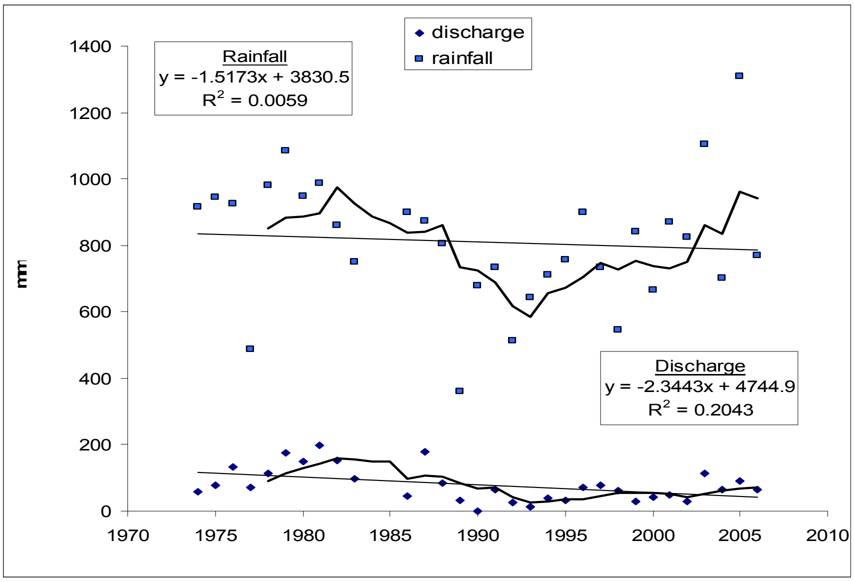


Figure 3.3.2. Mean annual water discharge variation at Vrodama station and mean annual rainfall data upstream from Vrodama (averages from 5 stations) (data from LRO) and 5-year moving averages.

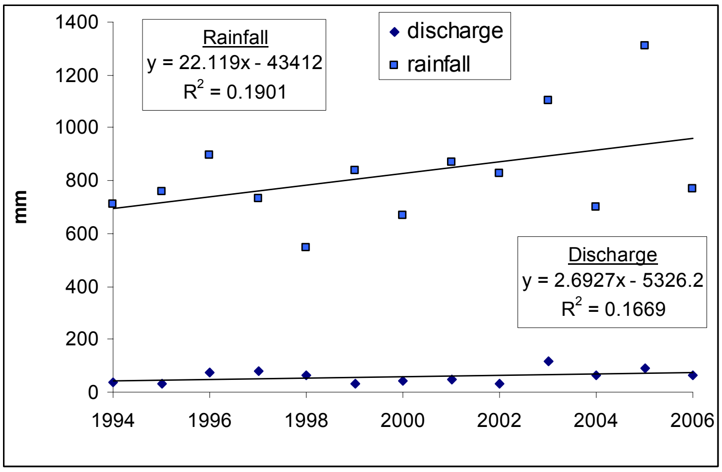


Figure 3.3.3. Mean monthly discharge variation as recorded at Vrodamas station and mean monthly rainfall variation upstream from Vrodamas station (averages from 5 stations) for 1994 – 2006 (Data from LRO).

Water level depths from several drillings were provided by LRO. Analysis of long-term water depth variations did not presented any significant trends. An example of water depth fluctuation that follows the general climatic variations is illustrated in Figure 3.3.4. After the dry period of 1990-93, with low groundwater table, followed an increase of water table level during 195-02, to drop again the recent years.

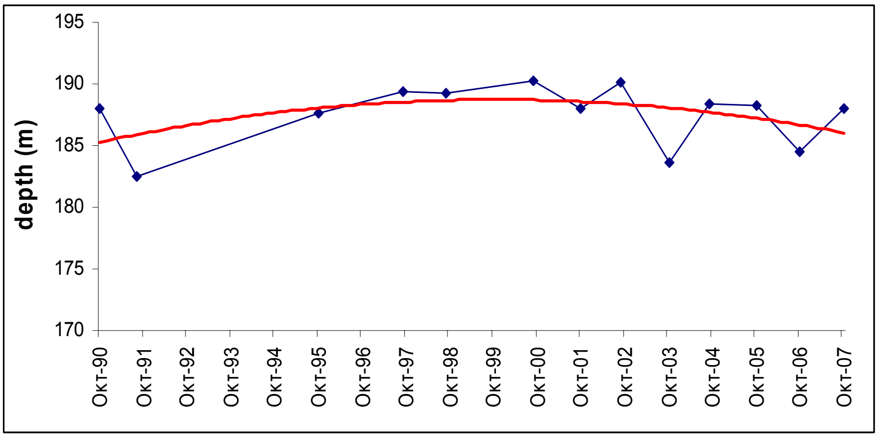


Figure 3.3.4. Long-term groundwater level variation Gouves drilling (G1) in October

3.4. Hydromorphological pressures and assessment

Over his long history, the Evrotas River has been significantly modified. Natural and semi-natural areas are very limited and these have been replaced by crops. In many parts of Evrotas River, crops end where the river water starts. For flood protection and to distribute the water into the agricultural land, the riparian zone of Evrotas has been shrunk, straightened, reinforced with grit or large stones or even with construction waste (Figure 3.4.1) while its natural vegetation has been removed. Every summer, about 80 meters prior the river mouth, an embankment is constructed to prohibit sea water intrusion (Figure 3.4.1). Moreover, the riverbed is being regularly cleared to control floods (Figure 3.4.2).

Water abstraction and distribution to croplands is performed either through irrigation channels or through pipelines or by stream diversion (Figures 3.3.1 and 3.4.3). All these hydromorphological modifications in Evrotas River and its tributaries result to the substantial decrease of freshwater, and to the desiccation of Evrotas river system.

Sand and gravel/pebble extraction occurs in the basin, particularly northern from Vivari springs and around and downstream Sparta. The intense sand extraction north and south of Sparta has vanished any kind of sand and gravel from the area and destroyed the natural habitats of the river.

Figure 3.4.1. Construction waste at Evrotas banks few meters downstream Sparta’s wastewater treatment plant (left). Dyke near Evrotas estuary (right).

Figure 3.4.2. Clearing and straightening of the Evrotas bed in the Skala region as a flood control measure (left). Grit weirs used to divert water into crops at Oinous River (right)

Regarding the results of HMS, the values ranged from 0 to 89. This indicates that the Evrotas river system in recorded HMS intersections presents great range regarding modifications and in several cases is strongly modified. Lower values appear in sites of medium and high altitude, as well as in distant areas of the river. In specific parts of the river, especially downstream from Sparta, some of these interventions are even from the age of ancient Sparta.

According to the HMS, several reaches along the Evrotas main stem (at the area of Sparta, at Skoura and downstream Skala) show severe modifications. Similarly, a number of tributaries are significantly (e.g. the downstream reaches of Gerakaris and

Kardaris, Kastaniotiko, Oinus, Skatias and Ag. Kyriaki) or severely modified (e.g. the confluence of Gerakaris and Rasina). In all these river reaches water abstractions occur, which partly contribute to the high HMS. However, there is a number of river reaches of pristine (Evrotas at Paleochora, Lagada-upstream) or semi-natural conditions (Kardaris, Vresiotiko, Kotitsanis, Oinus upstream and midway, Lagada at Trypi and Xerilas).

According to the values of HQA, there was a great variety of habitats in undisturbed and slightly modified parts, while in strongly modified the habitat quality could be characterized as satisfactory. Naturally, in strongly modified parts, the relatively high values were also due to the presence of vegetation not only in the riparian area but also in the river bed, which improved the HQA score. The presence of vegetation at these parts is due to the lowland character of the landscape. These small slopes however, presented limited number of flow types compared to the mountainous and semi- mountainous parts, where there were several flow types and increased flow. Lower habitat quality presented reaches along the Evrotas main stem (at the area of Sparti and at the downstream portion of the river), affected by excavations for flood control.

3.5. Hydrochemistry and pollution

Soil and water salinisation

The electrical conductivity of the examined stations was correlated with the percentage of agricultural areas in the respective subcatchments of the stations (Figure 3.5.1). The positive correlation between these two independed variables indicates a probable impact of agricultural practices (mainly irrigation) on the salt balance of a number of water courses. However, this correlation is not strong as observed elsewhere (Anapodaris River in Crete; Skoulikidis, 2008).

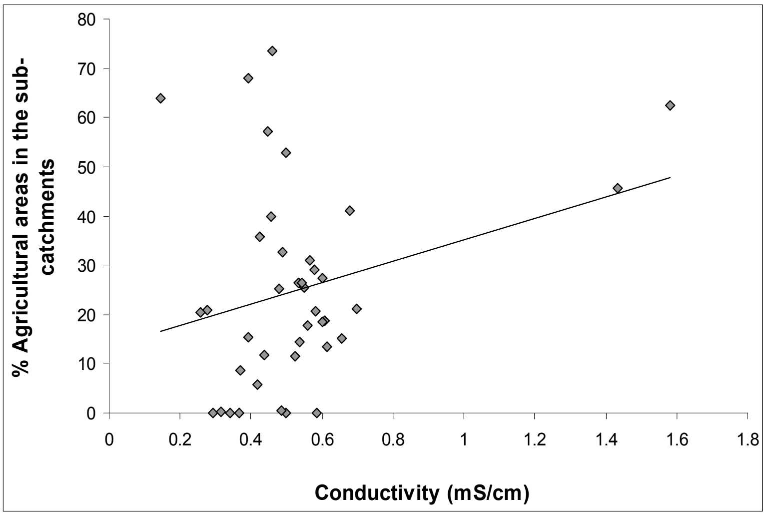


Figure 3.5.1. Correlation between conductivity measured at the different sampling sites of the monitoring network and the percentage of agricultural areas within the respective sub-basins.

Aquatic quality

Figure 3.5.2 is typical for Evrotas reaches that retain water during summer, when low flow, high transparency, appropriate water temperatures and nutrient availability give rise to eutrophic conditions that lead to explosive algae development.

Figure 3.5.2. Explosive development of algae during summer 2007 in Evrotas main stem.

The levels of physico-chemical and chemical parameters observed in September 2006, in a number of monitoring stations that retained water, were compared with levels observed during high water flow (May 2006 and March 2007). Waters in September showed increased temperature, conductivity, nitrate and ammonia, compared to the wet periods. Figure 3.5.3 present the seasonal conductivity variation for the Evrotas Basin. Almost all stations showed maximum mineralisation in summer, minimum in spring and intermediate levels in winter. Figure 3.5.4 present the seasonal variation of ammonium concentration. The majority of stations show maximum concentrations in summer. This is possibly due to organic matter (e.g. wastewaters) mineralisation. It is worth noting that the oxygen concentration in summer does not show any statistical differences compared to the wet periods, although water flow in a number of cases was minimal. This is most probably due to strong photosynthetic activity (e.g. through algae & macrophytes). It is expected that during the night respiration may cause significant drops in oxygen concentration.

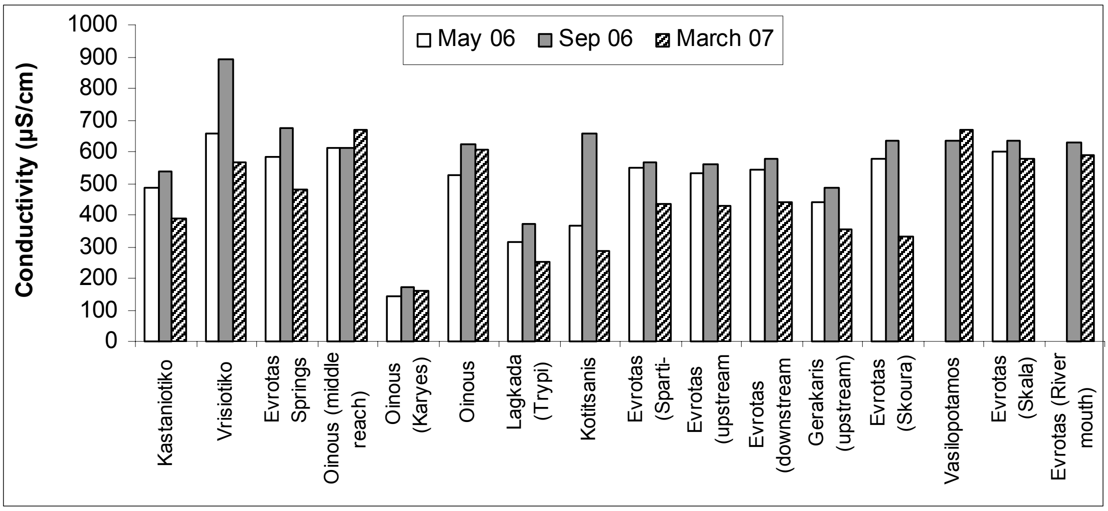


Figure 3.5.3. Seasonal variation of conductivity in Evrotas Basin

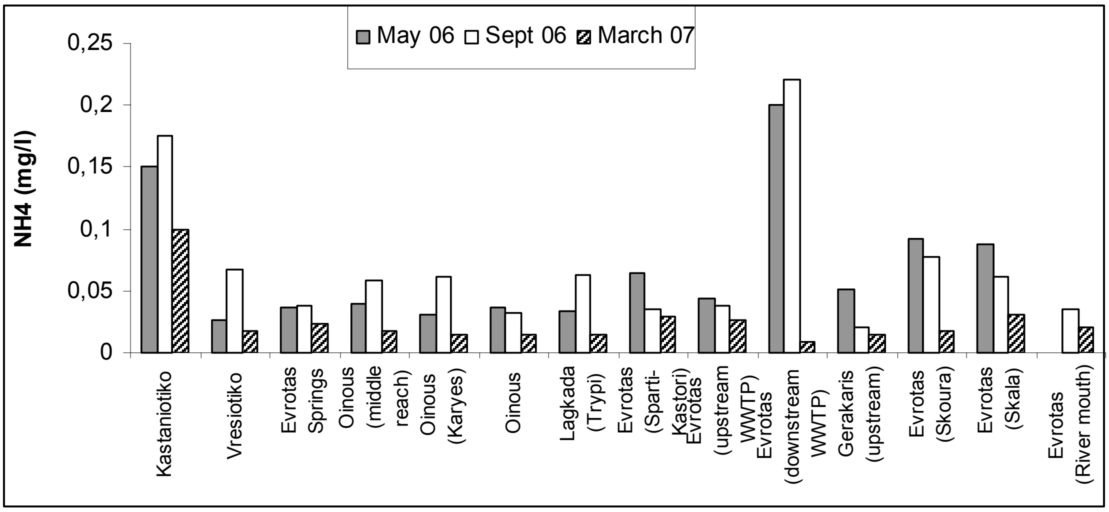


Figure 3.5.4. Seasonal variation of ammonium concentration in Evrotas Basin

Figure 3.5.5 presents monthly variations of total dissolved ion (TDI), calcium, magnesium, sodium and nitrate concentrations of Evrotas for 2007. Major cations, and hence TDI, follow the same seasonal pattern. Concentrations increase in the dry period (August-September) due to of high evapotranspiration and increased baseflow contribution in river flow. In contrast, nitrate concentration increases gradually during autumn and reaches maximum concentration in November as a result of arable land flashing.

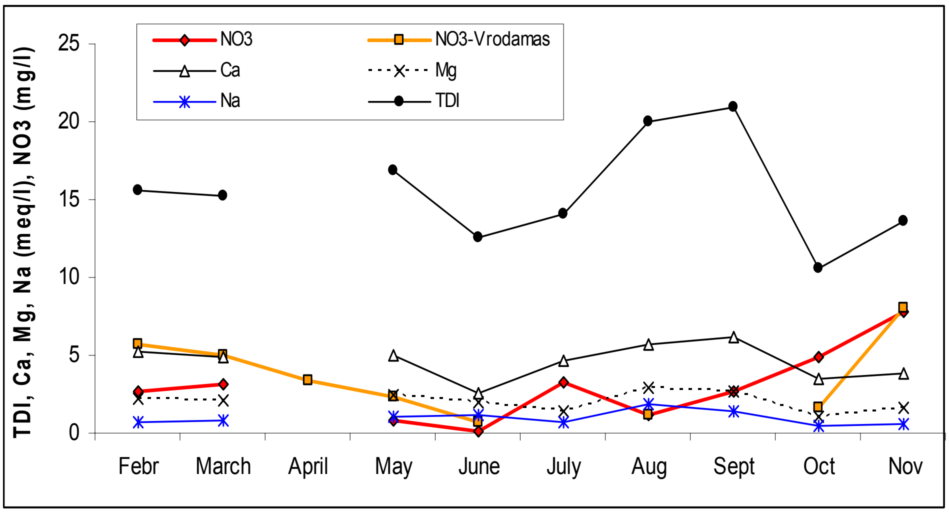


Figure 3.5.5. Monthly variation of TDI, major cations and nitrate of Evrotas at Skala (for nitrate also at Vrodamas) for 2007.

Consequently, river water mineralisation is governed by drought, nitrate levels mostly by arable land flashing and ammonia mainly by organic matter decay during the dry period. However, concentration differences obtained were not significant.

In order to examine in which extend river water quality is affected by drought, the chemical status of September was compared with the chemical status of the wet periods (Table 3.5.1). The results indicate that only three out of fifteen stations show worse nutrient status in September compared to the wet periods. Higher impact showed the station downstream the Waste Water Treatment Plant (WWTP). In this station the nutrient status degraded from high (March 2007) and good (May 2006) status to a poor status, since nitrate and ammonia presented elevated concentrations (6.4 mg/l and 113 μg/l, respectively) due to the WWTP-effluents.

Table 3.5.1. Nutrient status in Evrotas Basin stations that retain water in summer, in three different seasons

Site name	**Site number**	**May 06**	**Sept 06**	**March 07**
			Score	
Kastaniotiko	2	3.55	3.55	3.55
Vresiotiko	3	4.35	4.35	4.55
Evrotas Springs	4	3.95	3.75	4.35
Oinous (middle reach)	7	3.95	4.15	4.55
Oinous (Karyes)	9	4.35	3.75	4.55
Oinous	11	4.35	4.15	4.55
Lagkada (Trypi)	15	4.35	3.75	4.35
Evrotas (Sparti-Kastori)	37	3.75	3.75	3.95
Evrotas (upstream WWTP)	38	3.55	3.75	3.95
Evrotas (downstream WWTP)	39	3.35	2.95	4.15
Gerakaris (upstream)	46	4.15	4.35	4.35
Evrotas (Skoura)	48	2.55	3.55	3.15
Vasilopotamos	51		3.55	3.95
Evrotas (Skala)	52	2.95	3.75	3.55
Evrotas (River mouth)	53		3.55	3.75

Summarising, drought seems to affect aquatic quality in Evrotas basin. Nevertheless, according to the available data, changes in aquatic quality are not significant. In order to better assess the effects of drying out on the chemical quality of the river, specific monitoring in dense sampling intervals during the drying out process is needed. Diurnal variations should be also included in the monitoring scheme.

3.6. Fish - Results of the ichthyological investigations

3.6.1. Progress of work – modification of the initial research plan

In the framework of the EVROTAS-LIFE project an ichthyological investigation was undertaken with the three-fold objective to determine the fish species composition and abundance in the Evrotas R. and its tributaries, to assess the structure and quality of fish habitats and to develop a fish-based method for ecological quality assessments. Research initiated in May of 2006 and included the following tasks:

- Collection of information from the literature concerning the fish inhabiting the Evrotas basin.
- Identification of important pressures affecting fish populations and collection of information concerning the past hydrological and morphological conditions in the Evrotas basin.
- Distributional surveys aiming to map the distribution of fish in the basin and to assess the status of fish populations.
- Field research targeting to ecological status assessments (pre-classification of ecological status).

Some of the results of the 2006 research activities have been presented in the first progress report submitted in the 1st Progress Report (03-08-2006). Briefly, the Evrotas R. is a unique conservation hotspot in Greece, with a high biodiversity, including many local endemic plants and vertebrates. The river accommodates 5 native freshwater fish species plus two that have been introduced (typical estuarine species and marine migrants that occur in the lower part of the river are not included). Three of these species are range-restricted endemics of high conservation value: *Squalius keadicus* and *Pelasgus laconicus*, which are confined exclusively to this river, and *Tropidophoxinelus spartiaticus*, which also occurs in some rivers of southern Peloponnese. Historical records of occurrence and interviews with locals indicate that in the past, all fish species were widely distributed along the entire river and its tributaries. Due to human interventions (mainly severe water abstraction but also pollution and morphological alterations), fish populations are constantly declining. This is particularly true in the tributaries of the Evrotas R., where summer drying is now a seasonally predictable event and most fish populations are permanently extinct. Some preliminary results on the distribution of fish species and an initial characterisation of the ecological status of the visited sites are given in this report.

According to the work schedule, research for the year 2007 should focus in the development of a fish-based method of ecological status assessment, according to the demands of the Water Framework Directive 2000/60/EC (WFD). The following tasks were included in the original research scheme:

- Continuation of the distributional surveys in order to complete the mapping of fish distribution, to establish the ichthyological zonation pattern and to develop a biotic river typology.
- Habitat surveys aiming to obtain data on the ecological requirements of fish, with special attention to the local endemics.
- Selection of ichthyological metrics that respond predictably to anthropogenetic pressures.
- Identification and sampling of undisturbed sampling sites for the scope of establishing reference conditions.
- Identification and sampling of representative degraded sampling sites for the scope of metric calibration.
- Creation of multi-parametric index through which to measure ecological degradation due to human impacts.

This research scheme involved sampling of the selected sites on a monthly basis from spring to the end of summer. The first sampling trip was made in April 2007, which normally is a period of high flow due to snow melting. April was chosen for the start of the investigation because flow conditions were usually adequate to ensure fish were well distributed throughout the river. Research covered mainly the northern part of the Evrotas basin (main river course and tributaries upstream of the Bridge of Sparta) and aimed primarily to locating sampling sites representing the spectrum of landscape features, range of hydromorphological regimes and variety/intensity of human pressures. During the investigation it was observed that water flow was unnaturally low with most tributaries and some segments in the main river course being already dry or showing signs of future desiccation. Although droughts are predictable natural disturbances in the Evrotas R., 2007 was an exceptionally dry year that followed a generally wet year. In fact, the surveys in 2007 were in the most severe drought year on record since 1992, when almost the entire river dried out. As the season progressed, water discharge decreased rapidly and the surface waters were receding. When the area was revisited in May 2007 it was noted that some of the sampling sites selected for routine monitoring had dried up completely and many of the remaining sites of the sampling network were nearing to dry. In June and July the wetted area of the river continued to shrink and in August the largest portion of the Evrotas R. was completely DRY, with few only sections maintaining some flow or pools of remaining water.

Due to these unanticipated circumstances the initial work schedule could not be followed. Reasons are:

- Most sites of the established sampling network dried up quickly and were unavailable for sampling, especially in July and August. Note that late summer is the best period of the year for obtaining fish data for the purpose of developing an ecological status assessment index.

- During drought periods fishes responded to stress by altering their normal habitat use patterns (e.g. in their struggle to breathe they tended to segregate in riffles); this was an obstacle in the efforts to assess their biological and ecological requirements needed in metric selection.
- Hydrological deterioration and the associated fish habitat degradation resulted to catastrophic mortalities in desiccated areas and severe reductions of abundance and/or dramatic alterations in fish community structure in areas where desiccation was not complete. These conditions did not enable the development of a biotic river typology using spatially-based approaches. Also, they prevented the characterisation of biological reference conditions according to methodologies promoted by the WFD. Finally, the extensive summer kill and severe habitat degradation did not permit the calibration of metrics against pressure types and ranges of impacts.

Overall, the sampling results obtained in 2007 are inappropriate for the development of an ecological status index based on fish using spatially-based methodologies. Despite these difficulties, the research group is attempting to develop such an index using an alternative methodology that relies on expert judgment for the characterisation of reference conditions. This approach is not incompatible with the WFD. Some data obtained in 2006 and 2007 will be utilised and, additionally, (a) fish data from the Evrotas R. obtained in the 1990's through the cooperation of the scientists involved in the present project, and (b) fish data to be obtained through sampling to be performed in 2008.

But whereas the atypical hydrological situation in 2007 impeded works towards the development of an ecological status index, it offered a unique scientific opportunity to study the effects of drought on fish populations, particularly with respect to (a) impacts on habitat conditions and survival, (b) influences on fish abundance and percentage species composition, and (c) changes in the habitat use patterns of fish species. Such a study was not the initial concern, neither it was included in the initial work schedule. However, faced with an extreme in severity drought event (that may become a normal feature for the Evrotas R. in the future due to the combined effects of climate change and escalating water abstraction), we undertook an investigation aiming:

- To examine how desiccation and the altered flow regimes modified the distribution of fish species and affected fish abundance, species richness and fish community structure.
- To consider the role of water refugia (reaches retaining some flow and pools with remaining water) on fish population dynamics during drought.
- To study the re-colonisation processes from drought refugia and the rate of re-establishment of the depleted populations after a severe hydrological disturbance.

In the present report we present data on fish distribution and abundance obtained during the surveys carried out in 2007 and we perform comparisons with past distributional records. We attempt an assessment of the effects of droughts and other anthropogenic disturbances (e.g. flood control operations) on fish populations and we examine the resilience of the fish community to the effects of the 2007 droughts through comparisons of distributional and abundance data in 2008 (i.e. the year following the drought) with data of previous years. Finally, we discuss the implications of the results of this study for water and habitat management. The report includes some preliminary results of the analysis of data used for the development of an ecological status assessment index. Final results of this analysis will be presented in the next report.

3.6.2. Sampling design and methodology

In 2007, five visits to the area were made from April to the beginning of September on approximately monthly intervals. Fish sampling was conducted during the April, July and August-September trips (during the May trip the electrofishing apparatus failed to work properly and the sites could not be sampled quantitatively). During the April survey a visual inspection of the survey area was made a network of sampling stations was established based on the principles of landscape and macro-habitat representativeness and prevailing human pressures (reference sites were included). In addition, fish sampling was conducted using standardized electrofishing methods in the portion of the Evrotas basin upstream of the bridge of Sparta. Unfortunately, the river desiccated rapidly through the summer, as previously discussed. In view of this unexpected situation, the field work schedule was modified, with the emphasis shifted from ecological status assessments to the study of the effects of drought on fish populations, as explained in section 3.6.1. The new work schedule necessitates the continuation of ichthyological sampling in 2008 in order to assess the impact of the 2007 summer drought on fish populations, to ascertain post-drought dispersal routes from refuge areas, and document rates and spatio-temporal patterns of re-colonization. This work schedule involves three sampling rounds, from April to August-September. The April sampling round has already been completed. Below a description is given of the tasks performed and the methodology employed:

(a) A hydrological investigation of surface waters distribution was undertaken in order to monitor the recession of waters and to map the wetted area in each sampling period. For this purpose, the survey area or parts of it was inspected four times (April, May, July, and August-September) and the boundaries of the wetted areas or the areas with remaining pools of water were recorded through the use of GPS coordinates. Additional information on surface waters distribution was obtained from members of the scientific groups working on invertebrates and riparian forests. In the last sampling round (end of August – beginning of September 2007) a complete hydrological survey covering the entire river and all tributaries was undertaken. The product of this investigation is a series of maps showing the wetted segments of the river in different time periods from April to the beginning of rains in autumn (see section 3.1).

(b) During each survey trip fish sampling was carried out through the use of CEN electrofishing sampling standards and a modified version of the FAME[1] project protocols. Because most of the initially established sampling sites desiccated through summer, new sites in areas retaining water were added to the sampling scheme. Effort was devoted to include sites in hydrologically adverse segments of the river (i.e. suffering substantial reduction of flow and water level) in order to examine the effects of drought on fish populations. Throughout the surveys, a Hans-Grassl GmbH battery-powered backpack electrofisher (Model IG200-2, DC pulsed, 1,5 KW output power, 35-100 Hz, max. 850) was routinely used to sample fish in running waters. In marshy areas and shallow pools with stagnant water sampling was done with scoop nets and/or fry nets. Larvae and juveniles were sampled with beakers and small-meshed dip-nets. The fish caught were identified to species, measured, counted and released to the system to avoid depleting the populations. Sub-samples of larvae and adults were taken from some sites and preserved in a formalin solution for subsequent examination in the laboratory. Fish were grouped in 5 cm class intervals and a relevant fish abundance-length class protocol was completed (Protocol 1). Following fish sampling, photographs were taken and common landscape and habitat features were measured and recorded in a field protocol (Protocol 2). This protocol accommodates fields for sampling details, hydrological characteristics, habitat variables, substrate composition and physicochemical parameters. Habitats where divided in five types (pools, glides, runs, riffles and rapids). The physicochemical parameters were recorded through the use of a Horiba W-2010 multiparametric instrument measuring water temperature, conductivity, turbidity, dissolved oxygen and pH. During the April 2008 sampling expedition some additional parameters were recorded (TDS, NO^3, Cl^-). Important anthropogenic pressures were assessed at the sampling site and river segment.

(c) The fish data obtained during the 2007 sampling were analysed to estimate the abundance and fish species composition at each site and to assess seasonal trends. Fish species presence/absence data from all years (2006, 2007 and 2008), sampling seasons and sampling stations were combined to assess the species spatial distribution and the longitudinal zonation pattern in the structure of fish assemblages. The extent of population losses were evaluated and the most probable causes of population declines, both direct (death due to loss of water, hypoxia or hyperthermia) and indirect (degradation of water quality, habitat deterioration, disruption of longitudinal connectivity, alteration of food

[1] EU FAME (2005). Fish-based Assessment Method for the Ecological Status of European Rivers – A Contribution to the Water Framework Directive. Final Report; Manual for the application of the European Fish Index – EFI. http://fame.boku.ac.at.

resources, intense competition due to crowding and increased predation risk in shrinking pools) were speculated. Special attention is paid to assess the role of pool refugia in influencing fish persistence through the dry season.

(d) The biology and ecology of the species inhabiting the Evrotas basin is being studied particularly with respect to life-history attributes that affect persistence under drought conditions (habitat requirements, migratory behaviour, water demands, thermal tolerance and reproductive style). Scope is to assess the capacity of species or their different life stages to tolerate environmental extremes or to avoid environmental harshness by mechanisms such as migration, early reproduction and high reproductive effort. This study is based on a review of the available literature and treatment of the present fish occurrence data to reveal possible relations with key environmental features.

(e) Work for the year 2008, already started, involves electrofishing surveys and focuses in the evaluation of the effects of the 2007 drought on populations through comparisons of estimated fish densities in 2007 and 2008 in a number of sites representing homogeneous river segments. The capacity of the biota to recover, the rate of recovery and the re-colonization routes from drought refugia (e.g. upstream migration of adults or downstream transport of larvae) will be examined through monitoring changes of fish densities in a number of stations. Hopefully the data will enable to assess the colonization potential of different species and their differential ability to re-establish self-sustained populations.

(f) An artificial fertilisation and rearing experiment of *Squalius keadicus* that has high relevance to conservation efforts was conducted in April 2008 as following: Ova of two ripe females caught by electrofishing in the station Voskos were stripped by gently pressing their abdomen into a glass dish that contained a small quantity of water. The ova were adhesive and negative buoyant and stuck immediately to the dish. Milt from five males was then stripped and mixed with the eggs. Some water was added and the mixture was stirred by gentle movements of the dish for 5 minutes. Following, the water containing unfertilised eggs and debris was poured off, and the eggs were carefully washed with river water several times. The dish was placed in a plastic bag containing water. A pump supplying air was used to aerate the water. The bag was transported to the laboratory where hatching started four days after fertilisation. As the larvae hatched, they were collected with beakers and pipettes and transferred to the rearing tanks, where they were fed with special food for larval fish. Samples of larvae were taken on a daily basis, examined under an image analyser, photographed alive and preserved in a 4% formalin solution for subsequent morphological descriptions. At the time of the writing of the present report the larvae are about 10 days old (from the time of hatching) and are reared with almost no mortalities. A description of the morphological development of the *S. keadicus* larvae will be provided in the final report.

Protocol 3.6.2.1. Fish abundance and length class recording sheet.

River ______________________ Total No fishes ______________________

Site name ______________________ Time of sampling ______________________

Date ______________________ Length ______________________

Species	**Length Class [cm]**									
	0+	**< 5**	**5 - 10**	**>10 - 15**	**>15 - 20**	**>20 - 25**	**>25 - 30**	**>30 - 35**	**>35 - 40**	**> 40**

Protocol 3.6.2.2. Landscape characteristics and habitat features recorded in the sampling sites (two pages).

HCMR-IIW //Rapid Ichtyo-Assessment Protocol

1. Researcher		**2.Fisher:**	**3.Completed by:**		
4.Sampling Site	Code	Name	**5.Date**		
6.Hydrographic Basin		**7. Course**			
8. Location Descriptions (nearest village; distance from bridges...).				**9. Reference site** Yes ☐ No ☐	**10. Status site** ------------
11. GPS Coordinates				**12. Altitude**	
				13. Slope	
14. Time	Start		Finish		
15.Sampling Instruments			**16.Sampling Effort**: A B C D		
17. Fished length (m)			**18.Fished area (m^2)**		
19. Sampling details	☐ Whole ☐ other:				

20. Flow regime	Permanent		Summer dry		Winter dry		Episodic	

21. SITE DIMENSIONS

LENGTH m:		
Width (m)	Left bank up to water	
	Wetted width	
	Right bank up to water	

22.WIDTH (m) **23. DEPTH** (m)

<1	%	<0.25	%		
1≤L<5	%	0.25≤P<0.5	%		
5≤L<10	%	0.5≤P<1	%		
10≤L<20	%	≥1	%		
≥20	%	Mean		Max	

24. SUBSTRATE (%)

Rock continuous		Sand <2mm	
Boulder >256mm		Silt	
		Clay	
Cobble 64-256mm		Organic	
Pebble 16-64mm		Artificial	
Gravel 2-16mm			

25. SHADEDNESS

Approximate % :	

26. WEATHER

27.VELOCITY (estim.)

< 0,1 m/s	
0,1-0,25 m/s	
0,25-0,5 m/s	
0,5-0,75 m/s	
0,75-1 m/s	
> 1 m/s	

28. PHYSICOCHEMICAL MEASUREMENTS

Conductivity (mS/m)		T° of air (° C)	
D.O.		T° of water (° C)	
PH		Turbidity	
Salinity			

29. HELOPHYTES **30. BOTTOM VEGETATION** **31. HABITAT TYPE %**

Missing		Missing		Pool (deep/still)	
Isolated Rare		Algae/moss only		Glide (shallow/move)	
Sparce		Sparce		Run (deep/move)	
Intermidiate		Intermidiate		Riffle (shallow/rough)	
Rich		Rich		Rapid (steps/fast)	
Dominating sp.:		Dominating:		Other....................	

32.Important Pressures:

33.Fish habitat Details:

Cover types sampled: logs/large woody debris, deep pools, overhanging vegetation, boulders/ cobble, riffles, undercut banks, thick root mats, dense macrophytes beds, isolated/backwater pools, marshy fringes, other natural cover types

34.Other Notes/ Interviews:(hydrology, modifications, pollution, introductions, historical fish presence, fishing methods&activities)

35. Site drawing:

Upstream

Downstream

3.6.3. Results and discussion

3.6.3.1. The paleogeographical setting

Greece hosts the most diverse freshwater ichthyofauna of Europe. More than 160 species (including diadromous and euryhaline) have documented occurrence records in Greek freshwaters of which 139 species are exclusively freshwater. A great proportion of these species (47 species or 35% of the native fish fauna) are found exclusively in Greece and another 28 species have a wider distribution in the Balkan Peninsula south of the Danube (Economou et al., 2007). This high proportion of endemicity is attributed to the complex geological and climatic history of the area which, combined with geographical isolation and environmental diversification, have provided conditions conducive to speciation (Skoulikidis et al., 2008).

Various hypotheses have been proposed to explain the origin and diversity of endemic freshwater fishes in Greece (and the Balkan peninsula in general). One hypothesis postulates that fish invaded twice the area through river captures and have remained isolated ever since. The first wave occurred during Oligocene and Miocene times when Euro-Siberian and Palaearctic species colonised the area through aquatic bridges that occurred at that time. This was followed by a second wave of arrivals of Danube and the Black Sea fishes that reached the north Aegean drainages during Pliocene or Pleistocene times through a river capture involving the Axios R. (Economidis & Bănărescu, 1991). An alternative hypothesis holds that significant colonisation of Peri-Mediterranean areas by fish occurred in the late Miocene, immediately after the Messinian salinity crisis, when the Mediterranean sea dried up, and freshwater from the Paratethys Sea drained into the Mediterranean basin (Bianco, 1990). During the Pleistocene glaciations most of Greece remained free of ice and therefore served as a refugium for the preservation of freshwater fish species, which were eradicated in other parts of Europe. After the end of the glacial period the Greek rivers did not contribute to the recolonization of the European rivers with freshwater fishes, which took place from the Black Sea mainly through the Danubian hydrographic network. Thus, the Greek rivers and lakes have retained ancestral elements of the European ichthyofauna, which have experienced a long period of isolation and have speciated to the present-day forms.

Due to mountain barriers and deep seas that were not drained during marine regressions, southern Greek ichthyofauna contains the most ancient freshwater endemisms. This holds particularly true for the Evrotas R. basin, which represents one of the most isolated parts of the Greek peninsula. This river harbours three unique endemic species of special conservation concern: *Squalius keadicus*, *Tropidophoxinellus spartiaticus* and *Pelasgus laconicus*. Of these species, *S. keadicus* represents a relic cyprinid species, with remarkable interest for its evolutionary history. In fact, in molecular reconstructions of the phylogeny of Leuciscins, *S. keadicus* holds one of the two basal branches in the phylogenetic tree. According to Tsigenopoulos & Karakousis (1996), the genetic divergence of *S. keadicus* started in the late Miocene, 5.5 years ago, however, another view maintains that the divergence started 10.6 years ago and coincided with the splitting up of the Aegean Arc (Doadrio & Carmona, 1998; Zardoya & Doadrio, 1999). Whatever the case, *S. keadicus* is one of the most ancient European fish species anincluded in phylogenetic comparisons attempting to elucidate the evolutionary history and taxonomic relations of European cyprinidis (e.g. Sanjur et al., 2003). Its present-day distribution is restricted to Laconia (Evrotas and Vassilopotamos Rivers) where it usually inhabits sites with fast-flowing waters. However, there is evidence from genetic studies that the historic range of this species was wider and included rivers of south-west Peloponnese from which it was extirpated by introgression with new Squalius invaders (Durand et al., 2000).

T. spartiaticus belongs to the Greek endemic genus *Tropidophoxinellus*. Its distribution is confined to southern Peloponnese (rivers Evrotas, Vassilopotamos, Pamissos, Peristeras and Neda). Its sister species, *T. hellenicus*, inhabits the Acheloos R. of western Greece and the Pinios R. of Peloponnese. Both species are fluvio-lacustrine showing preference for riverine segments with slow-flowing waters (*T. hellenicus* also occurs in lakes of the Acheloos R. system, where it is a dominant species). It is very likely that the ancestral habitats of *T. spartiaticus* included lacustrine environments, since there is geological evidence that a large lake existed in the middle and lower portion of the Evrotas R. in Pliocene times (see also section 3.2). Finally, the species *P. laconicus* is a stagnophilic species that inhabits quiet sections of the Evrotas R. and the Vassilopotamos R. This species has also been found in Kato Assea, where the Alfios R. springs (the rest of the Alfios R. is inhabited by the related species *P. stymphalicus*). Interestingly, ancient writers mention that the Kato Assea springs of the Alfios R. and the Skortsinou springs of the Evrotas R. were hydrologically connected through surface flow (see section 3.2). This past connection of the two spring areas may explain the common occurrence of *P. laconicus* in the Evrotas R. and the upper portion of the Alfios R.

3.6.3.2. The ecological setting

Evrotas is a medium-sized, mid altitude river which drains a total area of 2017 km^2. The river originates from Taygetos Mountain (2407 m), flows southwards through the Laconia basin and discharges into the Laconikos Gulf, where it creates a small (53 km^2) delta. The mountainous area of the basin is formed by Mesozoic-Palaeogene limestones (42% of the basin) and flysch (29% of the basin), while the lower parts are covered by Pliocene and alluvial sediments. As a result of high infiltration, drought and intensive water abstractions, Evrotas river system has temporary flow characteristics.

A characteristic of the Evrotas R. is the presence of springs along the river channel route, especially in the upper half of the river. One of the river's main features is that some portions have no surface-water flows during the dry period of the year. This was not a normal feature of the river in historical times, but it tends to become a characteristic of the present-day environment. For example, as soon as the river reaches the Vrodama plains, water is lost through the porous riverbed to the underlying aquifer. Eventually, the river disappears entirely for several km and re-appears in the Skala area, where it becomes a permanent river again (however, residual pools of water normally remain in the Vrodama gorge). Some of the groundwater water reemerges in springs located in the Skala area and feed the Vassilopotamos R. This type of intermittent flow is now characteristic of several portions of the Evrotas R., which remain dry during the summer. The length of the desiccated portions and the duration of the desiccation period vary among years, depending on the groundwater level, which is a function of precipitation levels and extent of water abstraction. In years of exceptionally low precipitation, low groundwater levels combined with increased water abstraction lead to the desiccation of a substantial portion of the Evrotas R. However, isolated pools of water may remain in some portions. These pools are important for the maintenance of biodiversity, acting as refugia for fish and other biota elements (e.g. birds, amphibians and invertebrates).

Nowadays, few only of the Evrotas R. tributaries maintain perennial flow. During the rainy season, some tributaries maintain constant flow, whereas others have flow only during and after substantial rains. During the dry season, the water of the tributaries is heavily exploited for irrigation. Eventually, all tributaries dry up completely except few which maintain water in spring areas or in residual pools.

The lower portion of the river has been largely embanked to prevent flooding and expand agricultural land. Land uses in the basin are typical dry Mediterranean, dominated by olive groves and orange orchards. Point sources of pollution comprise untreated and treated municipal wastes and agro-industrial units, olive oil presses, orange juice factories, slaughterhouses, food industries and a plastic industrial plant. Small tributaries were excluded, because they either dry up completely in summer, or the persistence of residual surface waters is uncertain over the years.

In the middle and lower parts of the Evrotas R., particularly in segments with perennial flow, there is rich submerged and emerged vegetation which includes a great number of aquatic plants (*Potamogeton* sp. etc.) and helophytes (*Nasturdium officinale*, *Lycopus europaeus*, *Mentha aquatica*, *Typha domingensis*, *Phragmites australis* etc.) (Koumpli-Sovantzi et al., 1997). In the past, the Evrotas R. was characterized by rich riparian forest vegetation. Today, relicts of the former riparian forests are present at the upper portion of the river, were *Platanus orientalis* dominates. At the river's midway, relicts of mixed forests with *P. orientalis*, *Salix* spp, and *S. alba* are found. The riparian forests once provided effective protection against bank erosion, protection from flooding episodes, cover for wildlife and many other ecosystem services. These forests are now often felled or cleared illegally for agricultural expansion within the river's riparian zone or near floodplain areas. The river's delta is dominated by extended bush lands with *Tamarix* spp. Along temporal tributaries *Nerium oleander* and *Vitex agnus-castus* tufts dominate.

3.6.3.3. The fish species inhabiting the Evrotas basin

Table 3.6.3.3.1 presents the freshwater fish species recorded in the Evrotas R. system during the surveys carried out in 2006, 2007 and 2008. Nomenclature follows Kottelat & Freyhof (2007). Authority and previous species names according to Economidis (1991), if a species renaming has occurred, are also given in order to facilitate comparisons with data of earlier surveys. For each species information is provided on the provenance status (native or introduced) and the conservation status. The endemicity level of the native species is indicated.

In addition, species of the marine family Mugilidae were found in the lower reaches of the Evrotas R. (downstream of the Skala bridge) and in the Vassilopotamos R. One unidentified gobiid species (family Gobiidae) was caught in the estuary of the latter river.

Fig. 3.6.3.3.1. presents photographs of the freshwater fishes occurring in the Evrotas R. Table 3.6.3.3.2 summarises relevant literature concerning the native fishes occurring in the Evrotas R.

Table 3.6.3.3.1. The fish fauna of the Evrotas R. basin (Vassilopotamos R. is included)

Name	Authority	Previous name	Provenance	Endemicity	Conservation status			
					IUCN (2007 update)	Habitats Directive	Bern Convention	Red book
Cyprinidae								
Squalius keadicus	(Stephanidis, 1971)	*Leuciscus keadicus*	Native	Evrotas	Endangered	App. II	App. III	
Tropidophoxinellus spartiaticus	(Schmidt-Ries, 1943)	NO CHANGE	Native	Southern Peloponnese	Vulnerable			
Pelasgus laconicus	(Kottelat & Barbieri, 2004)	*Pelasgus stymphalicus*	Native	Evrotas, Assea (Alfeios)	Critically endangered		App. III	
Salmonidae								
Oncorhynchus mykiss	(Walbaum, 1792)	NO CHANGE	Introduced					
Blenniidae								
Salaria fluviatilis	(Asso, 1801)	NO CHANGE	Native	Mediterranean	Least concern		App. III	
Anguillidae								
Anguilla anguilla	(Linnaeus, 1758)	NO CHANGE	Native	Widespread				
Poeciliidae								
Gambusia holbrooki [2]	Girard, 1859	*Gambusia affinis*	Introduced	Widespread				

[2] *Gambusia holbrooki* has replaced former claims of *Gambusia affinis* in Greece.

Figure 3.6.3.3.1. Photographs of the fish species inhabiting the Evrotas R.

A. NATIVE SPECIES

Squalius keadicus (Stephanidis, 1971)

Adult individual at site An_GefKollinon 2

Adult individual at site Giakoumeika

Close-up photo of an individual *S.keadicus*.

Anal fin of *S.keadicus*

Caudal fin of *S.keadicus*

Dorsal fin of *S.keadicus*

Figure 3.6.3.3.1. (continued)

Tropidophoxinellus spartiaticus (Schmidt-Ries, 1943)

Adult individual at site An_GefKollinon 2

Close-up photo of an individual *T.spartiaticus*

o

Anal fin of an individual of *T. spartiaticus* (a diagnostic morphological character enabling distinction from of *S. keadicus*

Figure 3.6.3.3.1. (continued)

Pelasgus laconicus Kottelat & Barbieri, 2004

Adult individual at site An_GefKollinon 2.

Adult individual at site Skortsinou Springs.

Figure 3.6.3.3.1. (continued)

Anguilla anguilla (Linnaeus, 1758)

Individual at site Us_Karavas.

Eel straggling to breathe due to anoxic conditions near site Voltari 2.

Figure 3.6.3.3.1. (continued)

Salaria fluviatilis (Asso, 1801)

Two freshwater blennies at Vassilopotamos site.

The same two blennies.

Figure 3.6.3.3.1. (continued)

B. ALIEN SPECIES

Onchorhynchus mykiss (Walbaum, 1792)

Rainbow trout caught at site BioXios.

Gambusia holbrooki Girard, 1859

Tiny mosquitofish caught at site Vassilopotamos.

Table 3.6.3.3.2. Published works referring to the native fishes occurring in the Evrotas R.

Reference	*S. keadicus*	*T. spartaticus*	*P. laconicus*	*S. fluviatilis*
Almaça (1976).		X		
Barbieri et al. (2000)	X	X	X	X
Barbieri et al. (2000)	X	X	X	X
Bianco (1986)		X	X	
Bobori & Economidis (2006)	X	X	X	X
Bobori et al. (2001)	X	X	X	X
Bogutskaya (2000)		X		
Bogutskaya (2002)	X			
Carmona (1997)		X		
Daget & Economidis (1975).				X
Daoulas et al. (1995)			X	
Doadrio & Carmona (1998).	X			
Doadrio & Carmona (2003).	X			
Doadrio & Carmona (2006).	X			
Durand et al. (2000)	X			
Durand et al. (2006)	X			
Economidis & Voyadjis (1981)				X
Economidis & Sinis (1982)				X
Economidis (1991)	X	X	X	X
Economidis (1996)	X			
Economidis (1995)	X	X	X	X
Economidis et al. (1981)				X
Economidis et al. (1996)	X	X	X	
Economou et al. (1994)				X
Economou et al. (1999)	X	X	X	X
Economou et al. (2003)		X	X	X
Economou et al. (2005)	X			
Economou et al. (2007)	X	X	X	X
Iliopoulou-Georgudaki et al. (2003)				X
Kottelat & Barbieri (2004)			X	
Kottelat & Freyhof (2007a)	X	X	X	X
Kottelat & Freyhof (2007b)			X	
Kottelat (1997)	X	X	X	X
Maurakis & Grimes (2003)	X	X		X
Maurakis et al. (2001)	X	X	X	
Moosleitner (1988).				X
Perdices et al. (2000)				X
Reynolds et al. (2005)	X	X		
Sanjur et al. (2003)	X			
Smith & Darwall (2006)	X	X	X	X
Stephanidis (1971)	X	X	X	X
Stephanidis (1974)		X	X	X
Tsigenopoulos & Karakousis (1996)	X			
Tsigenopoulos et al. (1999)	X			
Zardoya & Doadrio (1999)	X	X		
Zardoya et al. (1999)	X	X		
Ηλιοπούλου– Γεωργουδάκη κ.α. (2000)				X
Κοκκινάκης κ.α. (1999)				X
Κοκκινάκης κ.α. (2000)				X
Μπαρμπιέρι (2000)	X	X	X	

Μπαρμπιέρι κ.α. (2003)		X		
Νταουλάς κ.α. (1993)				X
Οικονομίδης (1973)	X		X	X
Οικονομίδης (1974)				X
Οικονομίδης (1979).		X		
Οικονόμου (2000)			X	
Οικονόμου κ.α. (1999)	X	X	X	X
Οικονόμου κ.α. (2000)	X			
Οικονόμου κ.α. (2001)				X
Παπακωνσταντίνου (2005)			X	X
Στεφανίδης (1939)			X	X
Στεφανίδης (1950)			X	
Τίγκιλης (2000)				X
Τίγκιλης (2003)				X
Τίγκιλης κ.α. (2001)				X
Ψαρράς κ.α. (1997)				X

3.6.3.4. The ecology and biology of species

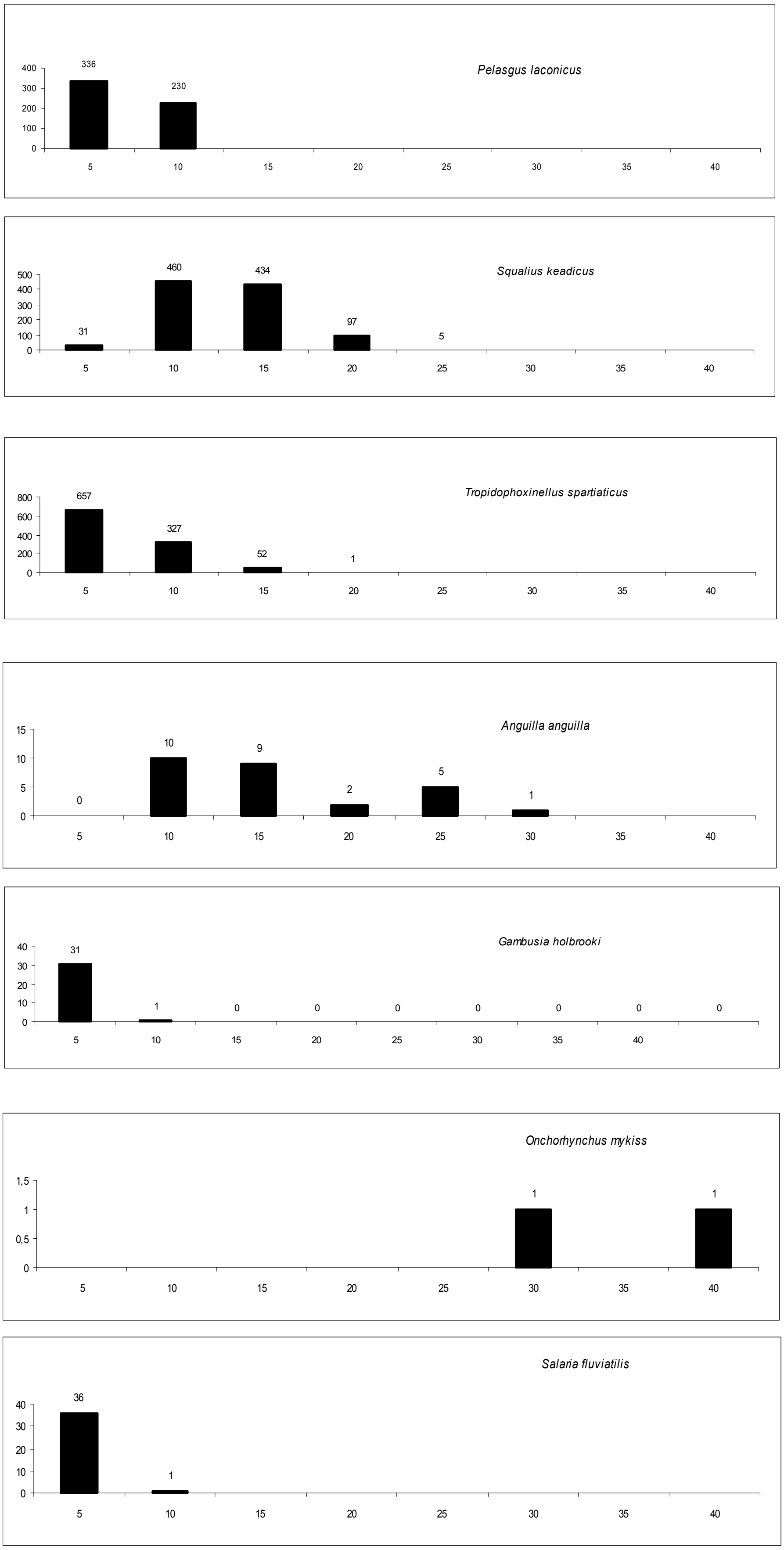
The Evrotas R. system is coming under increasing pressure from water resource development schemes, pollution and engineering works related to flood control. As a result, there is growing concern about conservation of the native freshwater fish and the ecological integrity of the ecosystem. Unfortunately, there is little information on the biology of these species upon which conservation actions could be based. There is also paucity of information about their habitat requirements and the ecological factors that regulate fish distribution and abundance. This information is crucial if the fish communities are to be managed from a catchment-wide perspective. Here we synthesise current knowledge on the biology and ecology of the Evrotas R. fish species focusing on conservation-relevant attributes that explain their distribution and physiological response to stressful environmental agents.

Fig. 3.6.3.4.1 shows the length distribution of the species sampled during the 2007 surveys, arranged in class intervals.

Squalius keadicus is rheophilic species, requiring permanently flowing waters, an aquatic habitat type which is being severely impacted by water abstraction. According to our data, *S. keadicus* reaches a maximum size 25 cm but most sampled individuals were below 20 cm in length. Reproduction takes place in the second half of April and the beginning of May. The food consists of insects and various invertebrates. It was caught mainly in the upper portion of the Evrotas R., where the water is cooler than in the lower portion due to the existence of cold-water springs along the river course. This evidence may suggest that *S. keadicus* is a cool-water species. Normally, it is found in deep runs in the main river channel. It is a very energetic fish, able to resist fast flow, and it is intolerant to low oxygen conditions. In the summer, when the river recedes, *S. keadicus* is forced to occupy unfavourable habitats with little or zero flow. Indeed, we often observed this species to be stranded in remaining pools where it existed under suboptimum conditions. In shallow pools, where surface water temperature follows ambient air temperatures closely and oxygen concentration is low, dead or dying fish were frequently observed, because they were already living near the threshold of oxygen and temperature tolerance. When there was some flow of water between pools, fish tended to concentrate in the shallow water corridor connecting the pools presumably for respiratory reasons.

Tropidophoxinellus spartiaticus is a less rheophilic species that shows preference for waters with slow flow. It is a strongly phytophilic species that depends on vegetation for reproduction, foraging and protection from natural enemies. It is often found in backwaters hidden among aquatic plants. It reaches about 15 cm in length but most individuals were around or below 10 cm. It breeds in April and May and feeds on insect larvae, invertebrates, mollusks and algae. It was caught exclusively in the middle and lower portion of the Evrotas R. were aquatic vegetation is abundant. Interestingly, its abundance in the middle portion was much lower than expected on the basis of results of previous investigations conducted in the late 1990s (Economou et al. 1999). We speculate that repeated drying episodes have generated adverse ecological conditions for this species, perhaps because of the reduction of aquatic vegetation. *T. spartiaticus* was never caught in the upper portion of the Evrotas R. where aquatic vegetation is lacking or sparse.

Figure 3.6.3.4.1. Length frequency distribution of the fish species during the 2007 surveys



Salaria fluviatilis is a peri-mediterranean freshwater species of marine ancestry. It is cryptobenthic, spending most of its time in crevices, under stones or among plants. Its food consists of young stages of fish and amphibians, insects and other small animals. It grows to a maximum size of 10 cm. The female lays down small elliptical eggs in holes or under stones. The eggs are guarded by the male until they hatch. The tiny larvae are planktonic and require for their survival limnetic conditions where rotifers and other microplanktonic organisms utilized as food abound. This species was found only in the lower portion of the Evrotas R. where lentic conditions enabling the survival of the early life-stages can still be found. In the past, *S. fluviatilis* had a wider distribution in the Evrotas basin. However, human interventions, particularly hydro-morphological alterations, have caused the destruction of the specialized habitats needed for the survival of its larvae, causing the disappearance of this species from the middle and upper parts of the basin.

Pelasgus laconicus is a local endemic, previously considered conspecific with *Pseudophoxinus stymphalicus,* which is widely distributed in western Greece. It is reaches a size of about to cm but most individuals are smaller than 7 cm in length. *P. laconicus* is a helophytic species showing little mobility and lives in protected sites with stagnant waters or sluggish flow. The presence of aquatic vegetation is an important habitat requirement for this species. During the reproductive period it lays down adhesive eggs on aquatic plants. Its food consists of algae and a great variety of small organisms. This species has wide environmental tolerances. Its capacity to tolerate a wide range of thermal regimes and to live in poorly oxygenated waters confers a survival advantage under stressful conditions. However, it is vulnerable to wide flow regime fluctuations that cause damage of the aquatic vegetation and/or destruction of protected embayments and pools utilized as habitats.

3.6.3.5. Fish zonation pattern

Overall patterns of fish distributions within basins provide interesting insights into habitat requirements and also assist in the establishment of biotic river typology schemes needed for the development of ecological quality classification systems compatible with the WFD. Unfortunately, disturbed hydrological conditions in 2007 prevented to establish a zonation pattern based on site-based quantitative fish data obtained through electrofishing sampling (which is the most efficient method for obtaining quantitative data). Indeed, the rapid desiccation of the Evrotas R. resulted to the extirpation of fish populations in sites visited in late spring and summer. In addition, differential mortality in the remaining sites due to the dramatic flow regime alteration resulted in major changes to the fish community structure, which was thus not representative of the natural (undisturbed) conditions. Because of these difficulties, the zonation pattern was established using both quantitative and qualitative data collected with all sampling instruments (electrofishing apparatus, scoop nets, fry nets, larval sampling equipment) in the three years of the study (2006, 2007 and 2008). Some of these data were obtained during preliminary visits to the study area and their intended use was different than the one we now place on them (e.g. assessments of breeding seasons and spawning grounds through larval sampling).

Occurrence records of all fish species in all sampling localities and years/seasons of sampling were used to construct a species occurrence matrix (Table 3.6.3.5.1). We need to clarify that only data from sites in which sampling was performed are included in the matrix. However, supplementary data from earlier surveys (1990s) and visual observations during preliminary visits to the study area were utilised for the interpretation of the pattern of fish distribution.

The position of the sampling localities is shown in the map of Fig. 3.6.3.5.1 (colours indicate the year of sampling: Purple 2006, Yellow 2007, Red 2008). Presence/absence data of individual species in the sampling localities are shown in Fig. 3.6.3.5.2.

We acknowledge that some bias is introduced to this ichthyological zonation scheme. On the one hand, the use of non-quantitative sampling techniques in several sampling occasions prevented the detection of species presences in some sites. On the other hand, harsh hydrological conditions caused complete desiccation or severe reduction in stream flow that resulted in local population extinctions and a temporally variable fish community structure. For example, only *T. spartiaticus* was caught in the area extending from Voltari to the bridge of Vrodama (site names Voltari1, Voltari2, Voltari3 and G._Vrontama). This area was sampled only once, in May 2006, with non-quantitative techniques, which are ineffective for the very energetic species *S. keadicus*. In 2007, the area was always dry when visited, and no quantitative sampling with electrofishing equipment was ever conducted. Therefore, the historical presence of *S. keadicus* in this area cannot be excluded. Nonetheless, the data allow, at least, inferences of confirmed species presences and provide a rough approximation of their distribution in the basin.

Cluster analysis was performed to elucidate the spatial pattern of fish distribution (Fig. 3.6.3.5.3). Although the data reveal various instances of ichthyological homogeneity, a clear ichthyological zonation pattern does not become immediately apparent. This is due, at least partly, to confusion arising from the occurrence of fishless stations (particularly in tributaries which experience frequent drying episodes) and the lack of quantitative samples from some riverine portions. Despite these methodological shortcomings, a longitudinal zonation pattern is derived from the analysis of joint species presences and persistent species absences in river segments sampled repeatedly with different instruments. The general trend is an increase of overall abundance and species richness downstream. A schematic representation of the ichthyological zonation appears in Fig. 3.6.3.5.4. Five ichthyological zones, characterized by distinct fish assemblages, are delineated. Fish assemblage structure correlated with environmental gradients of habitat characteristics, particularly flow regimes, channel morphologies, substrate composition and physical-chemical attributes.

<u>Zone A</u> comprises a small section of the Evrotas R. headwaters, just below the Skortsinou springs. This area is an adverse environment for fish due to that a substantial portion of the spring water is diverted to agricultural fields during the warm period of the year, which results to poor flow in the main channel. Only one species, the highly tolerant to water level reduction *P. laconicus*, was caught in this section.

<u>Zone B</u> comprises rather restricted and comparatively undisturbed section of the river that runs through a hilly area characterized by the presence of karstic springs along the main channel. The water is well oxygenated and generally cool. During the summer of 2007 some segments retained water, despite reduced flow from springs; this enabled the maintenance of fish populations in relatively healthy condition. The channel is narrow and, due to the relatively high slope, water movement is swift, which prevents the development of aquatic vegetation. In normal hydrological years, this part of the river is characterised by fast and turbulent flow over a riverbed consisting of rocks, boulders and cobbles, and contains a variety of habitats (deep runs, glides, riffles and pools). In drought years a portion of zone C dries out but deep pools remain at places. There is lack of floodplain habitats in this area. The fish community is species-poor and structurally simple. Repeated electrofishing sampling revealed that only two species participated in the catches: *S. keadicus* and *P. laconicus*. On the basis of abundance

and frequency of occurrence, *P. laconicus* was the dominant species. However, *S. keadicus* was locally abundant and its populations contained a wide range of age classes. We suspect that the prosperity of *S. keadicus* in this area is linked with environmental stability and hydrological, morphological and physicochemical attributes such as high current velocity, low water temperature, high oxygen concentration and substrata of large dimension, i.e. rocks, cobbles and occasionally pebbles. *T. spartiaticus* was never caught, despite considerable sampling effort. It is notable in this context that the characterization of this area as a distinct zone is based primarily on the absence of *T. spartiaticus*. There are two possible explanations for the reasons of this absence: *T. spartiaticus* was present in the past but was extirpated during a drying occasion, and has not managed to re-colonise the area since then; alternatively, the area does not satisfy the ecological requirements of this species because it does not contain calm vegetated habitats. The latter explanation is ecologically more meaningful, however distributional surveys conducted in April 2008 yielded results that weaken this explanation. The surveys revealed the presence of *T. spartiaticus* in sites downstream of zone B. These sites are contained in a large segment of the river several km long that dried up completely during the summer 2007. Considering the long length of the dried segment and the poor migratory capacity of *T. spartiaticus*, we consider highly unlikely that colonisation occurred by upward migration from downstream localities. Hence, we are left with the possibility that *T. spartiaticus* does exist in zone B, albeit at very low densities. If this is the case, the absence of this species from the samples taken from zone B must be attributed to poor electrofishing sampling efficiency in some of the larger deeper habitats. Future work should focus on efforts to ascertain the presence of this species in the area under consideration through the use of powerful electrofishing equipment in deep runs and pools. Such equipment was not available at the time of our investigations.

Zone C runs through the upper Laconia plain and constitutes a large and morphologically heterogeneous segment of the Evrotas R. It includes braided channels with alluvial gravel and sand beds, remnants of floodplains, narrow passages and wide riffle and pool structures at places. Gradient slope ranges from low to moderate and there is presence of backwater habitats at several locations. There are several karstic springs along the river's route of which only one extensive spring system (the Vivari spring) did not dry during the late summer 2007 desiccation. This spring supported water flow for about 2 km. At about the bridge of Sparti shallow groundwater reemerged at the surface allowing the maintenance of flow and pool conditions for about 1 km. The two areas, along with a short segment fed by waste water discharged from the Waste Purification Station of Sparta, were the only parts of zone C that remained wet in summer 2007. At places, vegetation cover (emergent and submergent) and deep pools (>1.0 m) frequently shaded by riparian canopy, generated suitable habitat conditions for *T. spartiaticus*. Two more species were encountered at high densities in this zone: *P. laconicus*, which occurred in backwaters and in vegetated areas with low current velocity, and *S. keadicus*, which was mostly present in runs. With the progress of the dry season, the latter species tended to be associated with riffles where more favourable flow conditions were maintained. The occurrence of healthy populations of these three species is the ichthyological characteristic of zone C. *Anguilla anguilla*, once very abundant in this area, was rarely caught. *Salaria fluviatilis*, also known to occur in this area in the past, was not present in our samples. Few individuals of the introduced trout, *Onchorhynchous mykiss*, were found in deep runs. A remarkable characteristic of the vegetated areas of this zone was the occurrence of enormous concentrations of larvae in spring and fry in summer, mainly of *T. spartiaticus* and *P. laconicus*, which indicates substantial spawning activity.

Zone D comprises two segments of the Evrotas R. in which the assemblage structure could not be established with reasonable certainty. The first segment, immediately below zone C, dried out completely in 2007, except in the area Pyri where deep pools remained. Unfortunately, the drying occurred early in the season and no samples were taken. Some data were obtained during a preliminary extensive survey in 2006 but these data are not adequate to infer the fish species composition. On the other hand, the remaining pools at Pyri were far too deep to be sampled with the sampling instruments available. The second segment is located in the estuary of the river where great depth prevented sampling operations.

Zone E is a relatively short segment that starts from the bridge of Skala and extends to near the estuary. From the physicochemical point of view, water is warm and slightly saline due to elevated concentrations of groundwater salinity. The lower part of the zone is characterised by slowly flowing water and a sandy or muddy riverbed in the form deep runs alternating with deep pools that were maintained throughout the summer of 2007. Pool-development increased downstream, thus enhancing the probability of fish finding adequate water refugia over the dry season. Because of great depths, this part was insufficiently and non-quantitatively sampled. In the upper part, around the Skala bridge, the bathymetry is more in the form of riffles, glides and runs. In 2007 this part dried early in the season but samples taken before complete drying combined with electrofishing data obtained during the 2006 surveys indicate the presence of *T. spartiaticus* (very abundant), *S. keadicus* (very rare), *S. fluviatilis* (moderately abundant) and *A. anguilla* (common). As previously mentioned, *S. fluviatilis* was once widely distributed in the middle and lower portion of the Evrotas R. According to the results of the present investigation, *S. fluviatilis* is now restricted to this lower portion of the river. Some mugilid specimens were also caught. Overall, fish diversity was generally greater than in upstream parts of the Evrotas R. The numerical dominance of *T. spartiaticus* is attributed to the existence of large, deep pools and runs with sluggish waters and abundant hydrophilous vegetation, which seems to have an overriding effect in the distribution of this species. Large concentrations of larvae and fry of these fishes were observed during spring and early summer. *P. laconicus* and *G. holbrooki* were absent from our samples, which is peculiar, since surveys conducted by us in the 1990s indicated high densities of the former species and occasional records of the latter species in this same area. The absence of *P. laconicus* and *G. holbrooki* in the Skala region was probably a result of floods in the previous year (winter 2005-2006) that washed away all individuals of these two species, which are stagnophilic, and thus unable to persist under flash flood conditions.

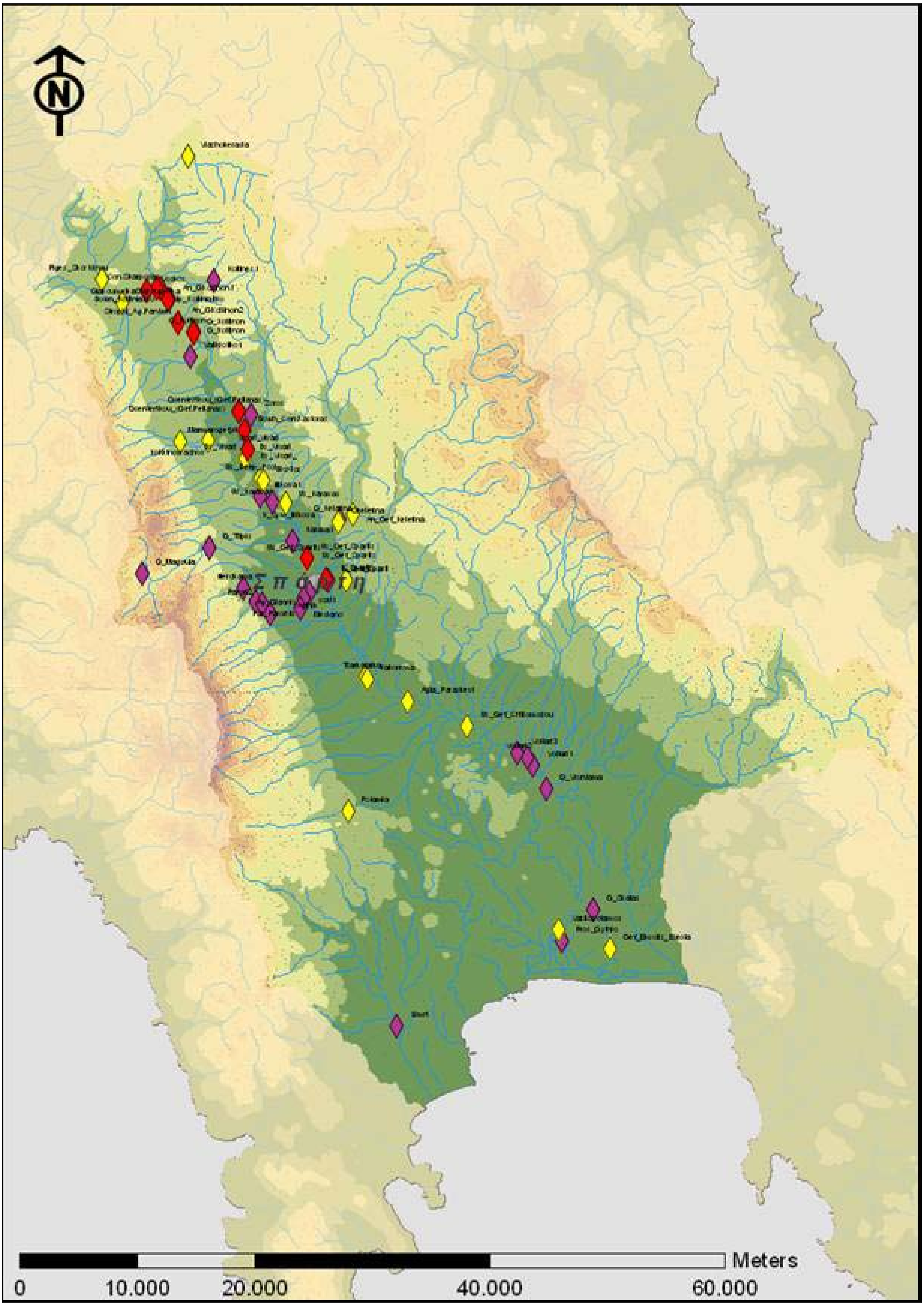
Zone F encompasses the northeastern stretch of the northern-most tributary of the Evrotas R. (the Kerassea headwaters) and associated tributaries. These are largely fishless areas because they are subject to frequent drying, even in hydrologically and climatologically "normal" years. Historical information (old sampling records and interviews with local villagers) indicate the presence of fish in many tributaries of the upper Evrotas R. Nowadays fish are absent because of complete and almost permanent desiccation that prevents the colonisation and re-establishment of fish populations. Overall, fish occurrences in the Evortas' tributaries were extremely rare and spotty as a whole. During the 2006 surveys, fish were found in few remnant pools of the Paroritis, Magoulitsa and Skatias streams, and in a small spring-fed section of the Oinous stream. In August-September 2007, when a compete ichthyological investigation covering the entire Evrotas R. basin was undertaken, fish were encountered only in isolated pools of the streams Gerakaris, Chiliomodou and Ag. Mammas, and also in a short flowing section of the Oinous stream. Three species were caught: *S. keadicus*, *P. laconicus* and, in a single instance, *Onchorhynchous mykiss*.

Table 3.6.3.5.1. The geographical position of the sampling sites (2006-2008) and the recorded fish species.

Site Name	Stream	Basin	Date	Coordinates		*S. keadicus*	*T.spartaiticus*	*P.laconicus*	*S.fluviatilis*	*O.mykiss*	*A.anguilla*	*G.holbrooki*	Mugilidae
Aginik	Magoulitsa str.	Evrotas	29/5/2006	360142	4103295	-	-	-	-	-	-	-	-
scat1	Skatias	Evrotas	29/5/2006	359731	4102856	+	-	-	-	-	-	-	-
Mesiano	Paroritis	Evrotas	29/5/2006	359486	4102095	-	-	+	-	-	-	-	-
Ag_Giannis	Kefalari Ag.Ioanni	Evrotas	29/5/2006	357126	4101687	-	-	-	-	-	-	-	-
Far_Paroritis	Paroritis	Evrotas	29/5/2006	356029	4102665	-	-	-	-	-	-	-	-
Parori2	Paroritis	Evrotas	29/5/2006	356543	4102508	-	-	-	-	-	-	-	-
Nerokarya	Nerokarya	Evrotas	29/5/2006	355114	4103634	-	-	-	-	-	-	-	-
G_Tripis	Magoulitsa str.	Evrotas	29/5/2006	352531	4106715	-	-	-	-	-	-	-	-
G_Magoula	Magoulitsa str.	Evrotas	29/5/2006	347484	4104734	-	-	+	-	-	-	-	-
Karava1	Lekani Str.	Evrotas	29/5/2006	358891	4107210	-	-	-	-	-	-	-	-
Nikova1	Nikova Str.	Evrotas	29/5/2006	356355	4110635	-	-	+	-	-	-	-	-
K_Sym_Nikova	Evrotas R.	Evrotas	29/5/2006	357349	4110214	+	+	+	-	-	-	-	-
K_Sparti	Evrotas R.	Evrotas	29/5/2006	361589	4104269	+	+	+	-	-	-	-	-
G_Skalas	Evrotas R.	Evrotas	30/5/2006	381724	4079208	+	+	-	+	-	+	-	+
Limni	Sminous	Sminous	30/5/2006	366807	4070403	-	-	+	-	-	-	-	-
Pros_Gythio	Vasilopotamos	Vasilopotamos	30/5/2006	379356	4076850	+	+	-	-	-	+	+	+
G_Vrontama	Evrotas R.	Evrotas	30/5/2006	378127	4088467	-	+	-	-	-	-	-	-
Voltari1	Evrotas R.	Evrotas	30/5/2006	377156	4090187	-	+	-	-	-	-	-	-
Voltari2	Evrotas R.	Evrotas	30/5/2006	376734	4090824	-	+	-	-	-	-	-	-
Voltari3	Evrotas R.	Evrotas	30/5/2006	375961	4091158	-	+	-	-	-	-	-	-
G_Kelafina	Kelefina str. (or Oinous)	Evrotas	31/5/2006	362444	4108825	+	-	+	-	-	-	-	-
Zoros	Zoros Springs	Evrotas	31/5/2006	355742	4116887	-	-	-	-	-	-	-	-
Gsentenikou (Gef.Pellanas)	Evrotas R.	Evrotas	31/5/2006	354787	4117072	+	+	+	-	-	-	-	-
Vatikiotiko1	Vatikiotiko Str.	Evrotas	31/5/2006	351109	4121308	-	-	-	-	-	-	-	-
G_Kollinon	Evrotas R.	Evrotas	31/5/2006	351397	4123240	+	+	-	-	-	-	-	-
An_GKollinon 1	Evrotas R.	Evrotas	31/5/2006	349472	4125605	+	+	+	-	-	-	-	-
Kollines1	Kolliniatiko Str.	Evrotas	31/5/2006	352904	4127054	-	-	-	-	-	-	-	-
Vlachokerasia	Papadesi str.	Evrotas	28/4/2007	350923	4136477	-	-	-	-	-	-	-	-
Piges_Skortsinou	Evrotas R.	Evrotas	28/4/2007	344386	4127149	-	-	+	-	-	-	-	-
Giakoumeika	Evrotas R.	Evrotas	28/4/2007	345950	4125403	+	-	+	-	-	-	-	-
Giakoumeika	Evrotas R.	Evrotas	31/8/2007	345950	4125403	+	-	+	-	-	-	-	-
An_GKollinon 2	Evrotas R.	Evrotas	29/4/2007	350167	4123943	+	-	+	-	-	-	-	-
G_Kollinon	Evrotas R.	Evrotas	29/4/2007	351307	4123181	+	+	-	-	-	-	-	-
Vivari	Evrotas R.	Evrotas	29/4/2007	355407	4114179	+	+	+	-	-	-	-	-
Ds_Vivari	Evrotas R.	Evrotas	24/7/2007	355292	4113550	+	+	+	-	+	+	-	-
Ds_Vivari	Evrotas R.	Evrotas	28/8/2007	355292	4113550	+	+	+	-	+	-	-	-
Us_Deep_Pool	Evrotas R.	Evrotas	24/7/2007	356342	4112006	+	+	+	-	+	-	-	-
BioXios	Evrotas R.	Evrotas	24/7/2007	356620	4111837	+	+	+	-	+	+	-	-
Us_Karavas	Evrotas R.	Evrotas	24/7/2007	358302	4110157	+	+	+	-	-	-	-	-
Us_Karavas	Evrotas R.	Evrotas	29/8/2007	358302	4110157	+	+	+	-	-	+	-	-
Us_Gef_Spartis	Evrotas R.	Evrotas	25/7/2007	359977	4105897	+	+	+	-	-	-	-	-
Us_Gef_Spartis	Evrotas R.	Evrotas	29/8/2007	359977	4105897	+	+	+	-	-	+	-	-
K_Sparti	Evrotas R.	Evrotas	30/4/2007	362902	4104290	+	+	+	-	-	-	-	-
K_Sparti	Evrotas R.	Evrotas	25/7/2007	362902	4104290	+	+	+	-	-	-	-	-
Agia_Paraskevi	Evrotas R.	Evrotas	1/9/2007	367644	4095077	+	+	+	-	-	+	-	-
Us_Gef Chiliomodou	Evrotas R.	Evrotas	30/8/2007	372157	4093194	+	+	+	-	-	-	-	-
Gef_Ekvolis Evrota	Evrotas R.	Evrotas	2/9/2007	383022	4076283	+	+	-	+	-	+	+	+

Tsarkalaika	Tsarkalaika	Evrotas	1/9/2007	364362	4096925	-	+	+	-	-	-	-	-
Kakorema	Kakorema	Evrotas	1/9/2007	364527	4096737	-	+	+	-	-	-	-	-
Potamia	Gerakaris	Evrotas	1/9/2007	363082	4086690	-	-	+	-	-	-	-	-
Vasilopotamos	Vasilopotamos	Vasilopotamos	30/8/2007	379073	4077742	+	+	+	+	-	+	+	+
Kokkinovrachos	Ag.Mamas & Kardaris	Evrotas	31/8/2007	352430	4114939	+	-	+	-	-	-	-	-
Marmarogefyri	Kastoras	Evrotas	31/8/2007	350335	4114787	-	-	-	-	-	-	-	-
G_Kelefina	Kelefina str. (or Oinous)	Evrotas	30/4/2007	362373	4108674	+	-	+	-	+	-	-	-
An_Gef_Kelefina	Kelefina str. (or Oinous)	Evrotas	3/9/2007	363467	4109297	+	-	+	-	-	+	-	-
Down Kolliniatiko	Evrotas R.	Evrotas	11/4/2008	349445	4125586	+	+	+	-	-	-	-	-
Up_Kolliniatiko	Evrotas R.	Evrotas	11/4/2008	348847	4126458	+	-	+	-	-	-	-	-
Strophi Ag.Pantwn	Evrotas R.	Evrotas	11/4/2008	350210	4123833	+	+	+	-	-	-	-	-
Gsentenikou (Gef.Pellanas)	Evrotas R.	Evrotas	12/4/2008	354787	4117072	+	-	+	-	-	-	-	-
G_Kollinon	Evrotas R.	Evrotas	12/4/2008	351347	4123062	+	-	-	-	-	-	-	-
Con_Skarpovas	Evrotas R.	Evrotas	12/4/2008	348577	4126498	+	-	+	-	-	-	-	-
Down Con_Kastoras	Evrotas R.	Evrotas	12/4/2008	355192	4115646	+	-	+	-	+	-	-	-
Vivari	Evrotas R.	Evrotas	13/4/2008	355407	4114179	+	+	+	-	-	-	-	-
Us_Vivari	Evrotas R.	Evrotas	13/4/2008	355407	4114179	+	-	+	-	-	+	-	-
Voskos	Evrotas R.	Evrotas	14/4/2008	347823	4126331	+	-	+	-	-	-	-	-
K_Sparti	Evrotas R.	Evrotas	14/4/2008	361435	4104317	+	+	+	-	-	-	-	-
Us_Gef_Spartis	Evrotas R.	Evrotas	14/4/2008	359963	4105939	-	-	-	+	-	-	-	-

Figure 3.6.3.5.1. Sampling localities in the three years of study.



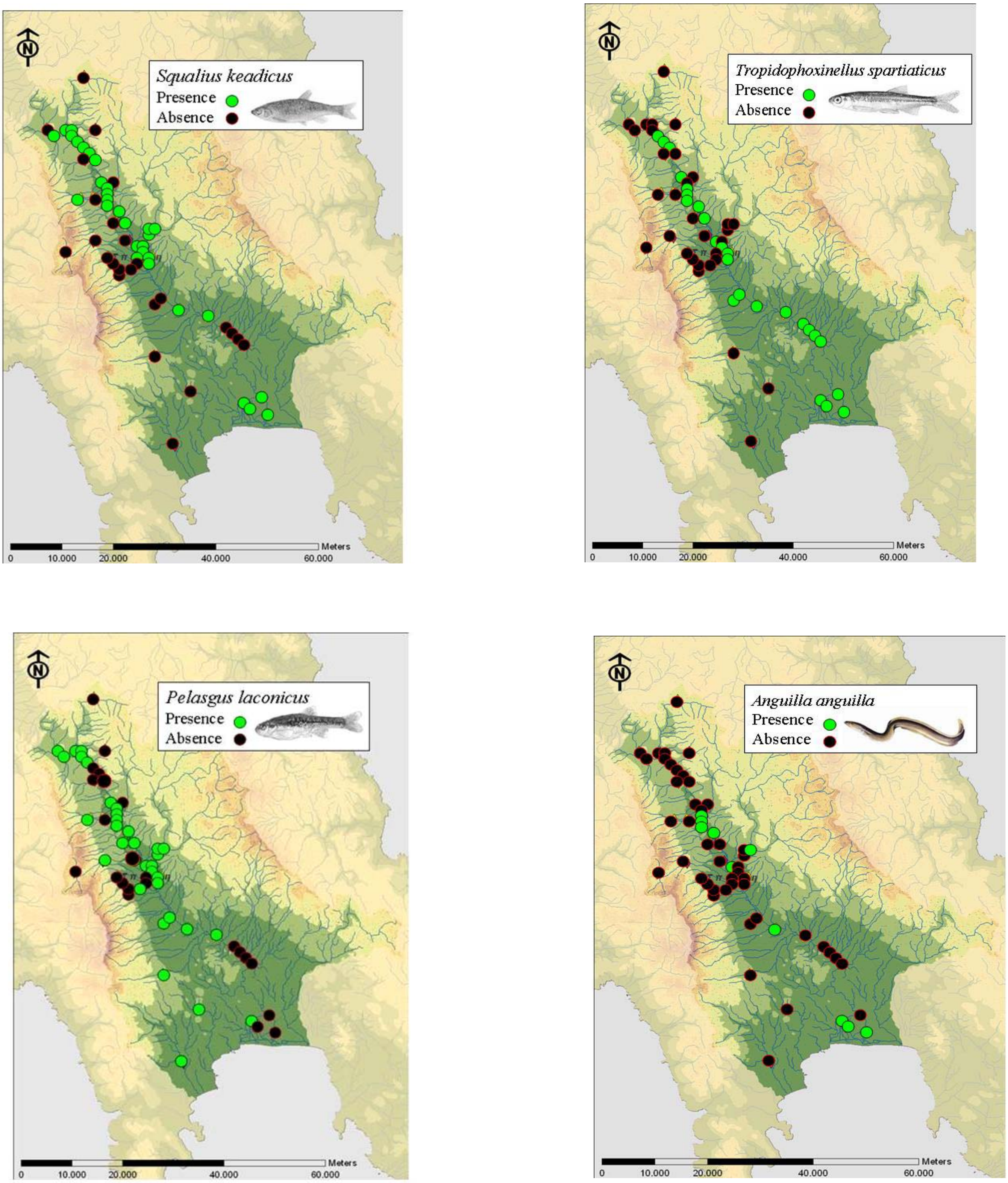
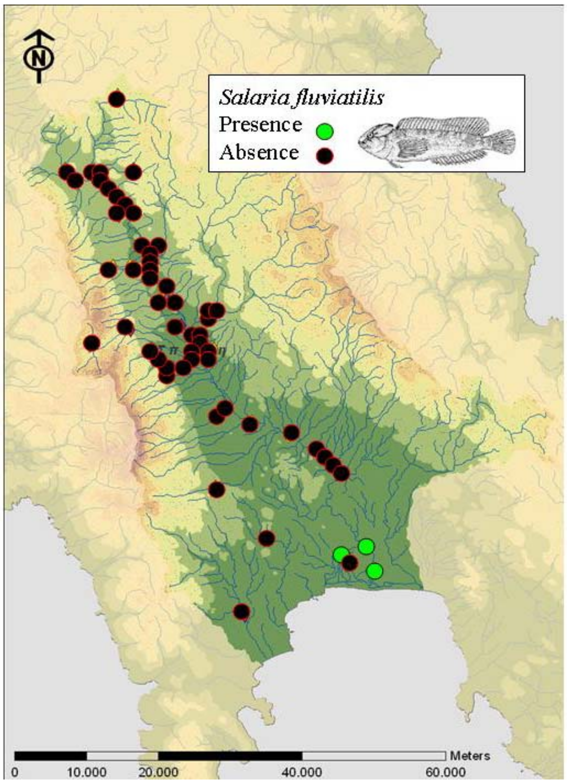
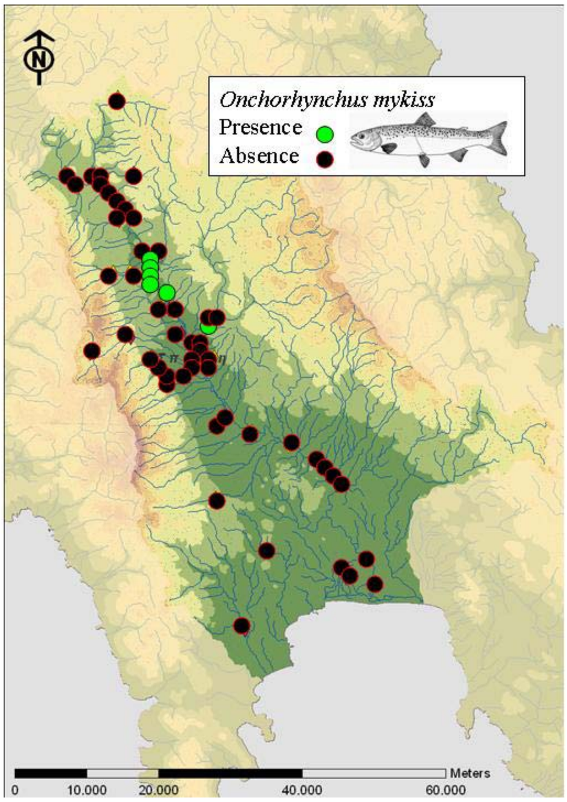


Figure 3.6.3.5.2. Occurrence records (presence/absence data) of the freshwater fish species in the Evrotas basin (all years, sampling seasons and sampling sites combined).





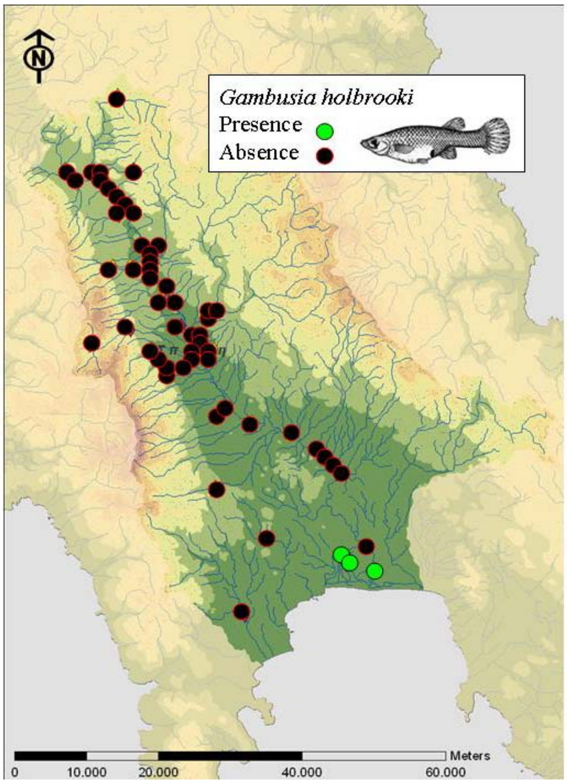


Figure 3.6.3.5.2. (continued)

Figure 3.6.3.5.3. Fish community **c**luster analysis (presence/absence data) to reveal areas of ichthyological homogeneity.

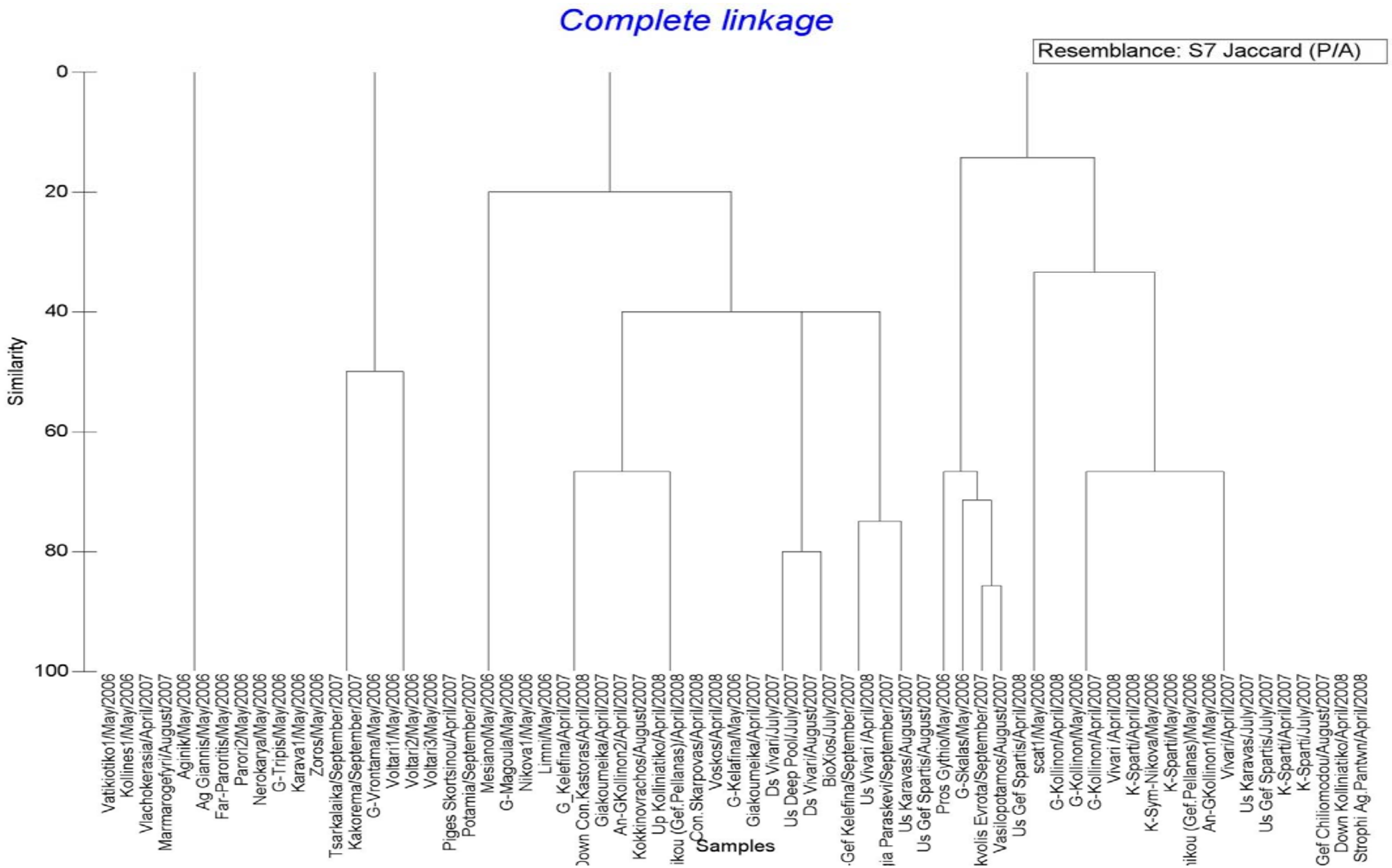
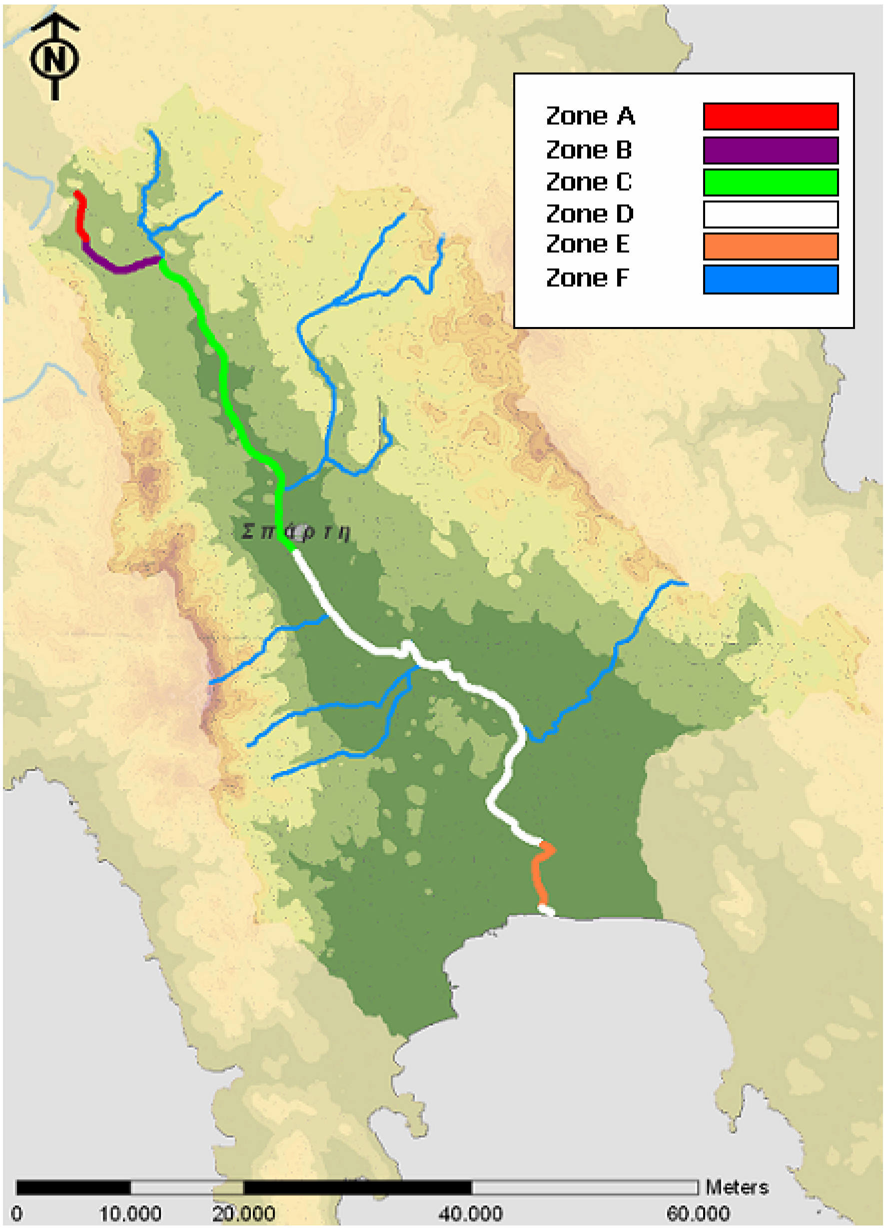


Figure 3.6.3.5.4. Longitudinal ichthyological zonation in the Evrotas basin.



3.6.3.6. Species distribution and abundance in 2007

The surveys conducted in 2007 clearly demonstrated adverse drought effects on fish communities. When the surveys initiated, fish were encountered in almost all sampling localities of the main river channel, even in localities that dried out in the previous summer (e.g. around the bridge that connects the villages Pellana and Kolynes). However, fish were not found in the upper right reaches of the Evrotas R. (areas around the villages Kerasea and Vlachokerasia) that experience frequent drying episodes and do not seem to accommodate fish, at least in the recent years. This distribution pattern indicates that in normal years, local droughts leave little persistent signal in the existing fish fauna, and that the recovery of fish populations can be rapid. This is not the case with streams, where re-colonisation is slow due to obstacles impeding upward fish migration (e.g. bridges and irrigation dams) and frequent drying episodes.

Fish densities at sampling sites were used to build a species composition and abundance and matrix, presented in Table 3.6.3.6.1. Only data from sites where electrofishing was conducted are accommodated in the matrix. Some characteristics of the sampled localities are shown in Table 3.6.3.6.2. Fig. 3.6.3.6.1 shows a map of the study area with pies in the sampling stations denoting the species composition and abundance in the sampling sites. The data reveal a longitudinal distribution pattern characterized by a generally decreasing percentage contribution of *S. keadicus* and increasing percentage contribution of *T. spartiaticus* downstream, already described in the preceding section. In total, three species appeared regularly n the catches (*L. keadicus, P. laconicus and T. spartiaticus*). *O. mykiss* and *A. anguilla* were infrequently caught. S*. fluviatilis* and *G. holbrooki* appeared only in the lower reaches of the river near the estuary, and also in the Vassilopotamos R.

As the season progressed the wetted area of the river was shrinking. Inevitably, sampling was restricted to positions with remaining water. In the drying areas fish either died or assemble at residual pools where hyperthermia, anoxia and increased predation from birds and otters led to significant mortality. Because in such habitats fish experience high mortality, ichthyological parameters such as overall abundance, species richness, assemblage structure and habitat use patterns are not representative of an undisturbed fish community.

An interesting comparison is between samples taken around the Sparta bridge (which was one of the non-desiccated areas) in different time periods, namely spring and summer. In April 2007 this area had substantial flow and maintained connections with upstream and downstream segments of the Evrotas R. At sites, the wetted river width exceeded 40 m (e.g. downstream of the Sparta bridge). Flow reduction through the season resulted to the decrease of the wetted width and the overall surface area. In July the river channel downstream of the Sparta bridge was less than 3 m wide. Thereafter this riverine section continued to shrink and in August almost all sites downstream of the Sparta bridge were completely dry. At the same time, hydrological connectivity was disrupted because all upstream and downstream river segments were dry. In the beginning of September the remaining wetted area was an isolated narrow channel about 1 km long. This area became a refuge for fish (and other aquatic organisms) during the dry season. Fish previously dispersed over a wider wetted area retreated and survived during the drought event, albeit at suboptimum conditions.

As expected, we observed generally high abundances of fishes at this permanently flowing area. However, fish abundances and the composition of the community was very different in spring and summer. On the one hand, we observed that population densities of all species area increased during the dry season, which was apparently the result of fish aggregating in greatly reduced areas/volumes of water as the river dried up. Therefore, inferences of the effects of drought events on fish population dynamics based on population densities may be misleading, because concentration of fish in reduced space (e.g. narrow channels or few remaining pools) leads to increases in "apparent" fish densities, even though the overall population size has declined severely. On the other hand, the fish community structure in the Sparta bridge area changed through the dry season, with *S. keadicus* dominating downstream of the Sparta bridge in April but becoming the dominant species upstream of the Sparta bridge in July and August. Our interpretation of this changing distribution pattern is that *S. keadicus*, being a cold-water and strongly rheophilic species with high oxygen demands, tended to migrate to the upstream limits of the wetted area, where there was some influx of groundwater, and thereby to reduce the risk of death from hypoxia and hyperthermia.

The survey design, the time and means available do not allow to assess the magnitude of fish population losses due to the drought event. However, considering that about 80% of the main river course and almost all of its tributaries dried up during the 2007 desiccation, we assert that fish mortalities were enormous. Indeed, large sections of the river were left for 40 to 120 days without flow in late spring – autumn 2007. Effectively, all or nearly all fish in these areas died. Although freshwater fish are generally mobile, able to escape harsh conditions by migrating upstream or downstream to find more favourable areas, fish movements were prevented by progressive habitat isolation. Shallow areas were the first to dry with the reduction of flow. Surface flow sometimes ceased across riffles, setting barriers to dispersal. Fish were thus trapped in deeper sites, which progressively shrank, and finally dried out. We witnessed several instances of drying and recently dried pools with dead or dying fish within them. These dead fish provided an abundant food source for terrestrial predators and scavengers, such as birds, which tended to concentrate in large numbers in dried up habitats.

The sections which remained wet during the dry season provided refugia from harsh physical conditions and were also a source of fish for recolonization after flows re-established in the rainy season. Dry-season refugia were of different types (small or longer reaches maintaining flowing waters, shallow or deeper pools) and varied in suitability and functional importance for different fish species and life stages. Deep run and pool refugia seem to play a key role in the maintenance of the Evrotas R. fish species, first because they usually show a higher probability of persisting through the dry season and second because large water bodies are less affected by ambient air temperatures and other physical extremes than smaller water bodies. In shallow runs and pools, by contrast, the habitat conditions tended progressively to deteriorate for a variety of reasons, including elevated temperature, low concentration of dissolved oxygen, substrate habitat degradation and eutorophication from pollution or the decomposition of plant and animal remains. Moreover, crowding of fish in reduced space strengthened biotic interactions, leading to reduced food availability and increased vulnerability to aquatic and terrestrial predators. Generally, large-bodied *S. keadicus* individuals appeared to be more sensitive to hyperthermia and oxygen deprivation than smaller-bodied ones and individuals of other species.

Most probably, large-bodied *S. keadicus* is also highly vulnerable to predation by otter, which was the main fish predator in the study area (other fish predators such as eel, trout and aquatic snakes did not occur at densities high enough to justify a significant predatory impact). Otter activity was most heavily concentrated in deep pools, as indicated by the high incidence of occurrence of otter feces containing fish scales and bones around pools.

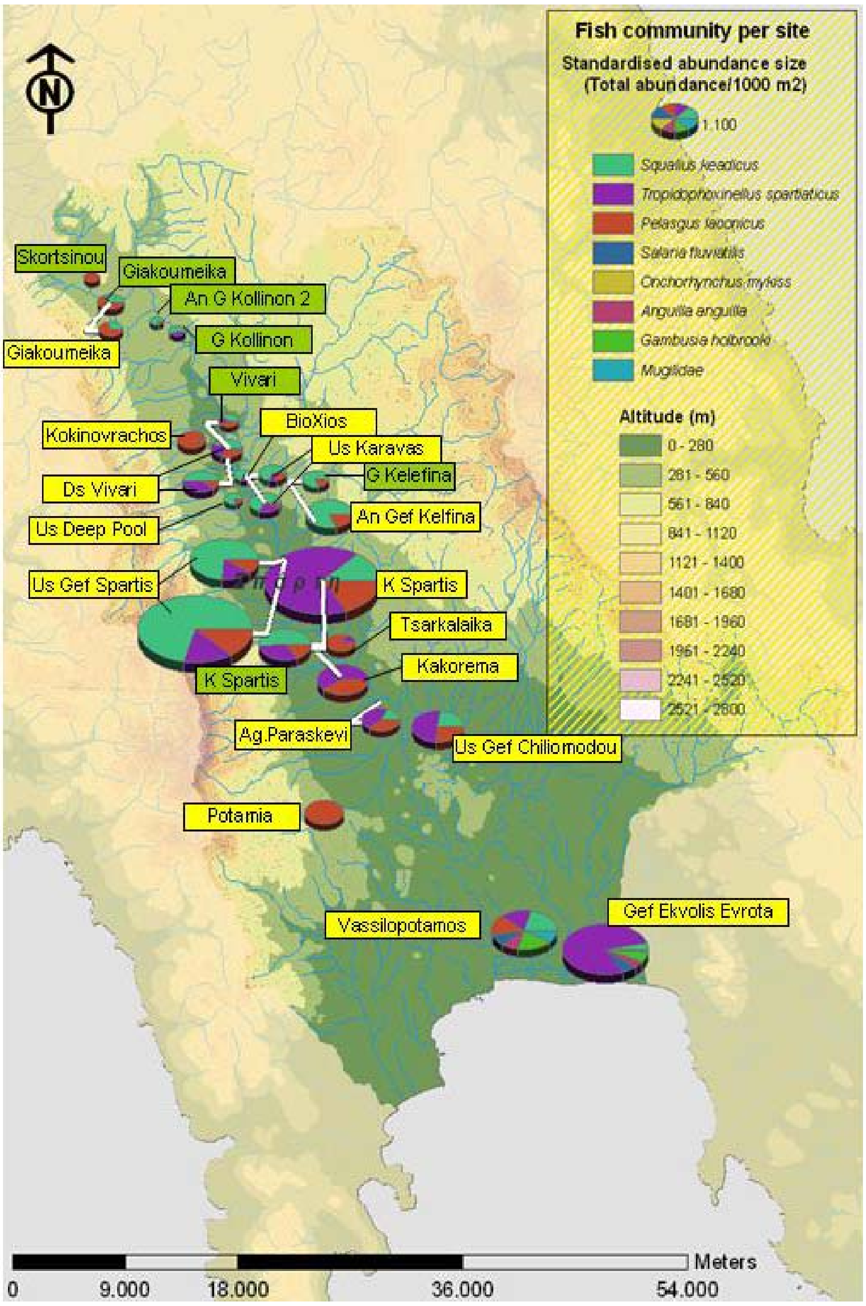
Table 3.6.3.6.1. Fish species composition and abundance in the sites sampled in 2007.

Site Name	Date	*S.keadicus*	*T.sparticus*	*P.laconicus*	*S.fluviatilis*	*O.mykiss*	*A.anguilla*	*G.holbrooki*	Mugilidae
Vlachokerasia	28/4/2007				No fish				
Piges Skortsinou	28/4/2007			20					
Giakoumeika	28/4/2007	21		50					
An_GKollinon2	29/4/2007	15		3					
G_Kollinon	29/4/2007	35	27						
Vivari	29/4/2007	38	14	44					
G_Kelefina	30/4/2007	31		7		1			
K_Spartis	30/4/2007	183	123	53					
Ds_Vivari	24/7/2007	45	22	31		2	2		
Us_Deep_Pool	24/7/2007	106	11	14		1			
BioXios	24/7/2007	102	23	28		1	1		
Us_Karavas	24/7/2007	147	27	41					
Us_Gef_Spartis	25/7/2007	265	66	44					
K_Spartis	25/7/2007	29	174	39					
Ds_Vivari	28/8/2007	50	40	10		1			
Us Karavas	29/8/2007	168	70	15			1		
Us Gef Spartis	29/8/2007	98	23	13			1		
Us Gef Chiliomodou	30/8/2007	32	73	37					
Vasilopotamos	30/8/2007	23	21	16	9		11	24	9
Giakoumeika	31/8/2007	22		35					
Kokkinovrachos	31/8/2007	1		70					
Marmarogefyri	31/8/2007				No fish				
Tsarkalaika	1/9/2007		1	6					
Kakorema	1/9/2007		33	23					
Agia Paraskevi	1/9/2007	27	66	59			1		
Potamia	1/9/2007			40					
Gef Ekvolis Evrota	2/9/2007	17	499		37		22	32	8
An-Gef Kelefina	3/9/2007	116		27			1		

Table 3.6.3.6.2. Dimension characteristics of the sampled sites in 2007.

Sites	Date	Fished Length (m)	Fished Area (m^2)	Width L_bank (m)	Wetted width (m)	Width R_bank (m)	Mean width (m)	Mean Depth (m)	Max Depth (m)	Shadedness %
Vlachokerasia	28/4/2007	25	75	10	3	2	2.5	0.15	1.5	40
Piges Skortsinou	28/4/2007	70	150	1	2.5	1	2.5	0.2	0.5	80
Giakoumeika	28/4/2007	80	240	1	3	1	3	0.25	1	85
An_GKollinon2	29/4/2007	100	200	10	11	50	9	0.3	2	0
G_Kollinon	29/4/2007	150	400	15	5.5	30	5.5	0.4	1	0
Vivari	29/4/2007	100	450	5	12	-	5	0.3	1.5	80
K_Sparti	30/4/2007	80	250	0	50	0	50	-	-	0
G_Kelefina	30/4/2007	50	100	2	2	5	2	0.25	1	10
Ds _Vivari	24/7/2007	120	200	0	20	0	18	0.5	0.8	30
Us_Deep_Pool	24/7/2007	120	700	0	7	3	5.6	0.3	1	65
BioXios	24/7/2007	100	800	3	9.5	3	9.5	0.4	1.1	60
Us_Karavas	24/7/2007	110	550	3	5.5	3	5.3	0.35	1.8	45
Us_Gef_Spartis	25/7/2007	100	54	0	5	40	3.4	0.4	0.9	20
K_Sparti	25/7/2007	50	35	-	2.5	-	-	1	1.4	2
Ds_Vivari	28/8/2007	60	150	0	11	0	11.5	0.35	0.5	30
Us_Karavas	29/8/2007	90	475	3	5	3	5.3	0.25	1.2	45
Us_Gef_Spartis	29/8/2007	100	54	0	4.5	40	3	0.35	0.8	20
Us_Gef Chiliomodou	30/8/2007	35	100	5	5	0	5	0.35	0.5	80
Vasilopotamos	30/8/2007	25	50	2	9	2	9	0.7	1.2	0
Giakoumeika	31/8/2007	80	160	0	2	0	2	0.15	0.4	85
Kokkinovrachos	31/8/2007	75	170	0	2.5	0	2	0.15	1	100
Marmarogefyri	31/8/2007	-	-	-	1.7	-	-	0.1	-	-
Agia_Paraskevi	1/9/2007	55	200	1	7.5	3	-	0.25	1	90
Tsarkalaika	1/9/2007	5	15	1.5	2	1.5	-	0.28	0.65	100
Kakorema	1/9/2007	28	42	2	2	3	2.8	0.15	0.25	90
Potamia	1/9/2007	20	50	8	1.5	2	-	0.8	0.3	100
Gef_Ekvolis Evrota	2/9/2007	90	160	2.5	3	35	3	0.25	0.9	20
An_Gef_Kelefina	3/9/2007	50	120	5	3	0	2.8	0.25	0.6	90

Figure 3.6.3.6.1. Abundance (pie radius) and species composition (slices) in sampling stations visited in 2007 (spring trips: green labels); summer trips: yellow labels).



3.6.3.7. Resilience of the system – recolonisation following a seasonal drought

What happens following severe drought conditions that affect extensive portions of the river? To what extent do the rates of recovery vary with the intensity of dry spell? To what extent does the spatial scale of drying affect recovery? Perhaps, effects of drought in one year could be more evident in the next year, i.e. allowing a time lag for effective dispersal from refugia where the fish were confined during the dry period.

The surveys initiated in 2008 are designed to answer whether, to which extent and how quickly a fish community will recover from the perturbation induced by extreme drought in summer 2007. In April 2008 we surveyed quantitatively upper portions of the Evrotas R. with an electrofishing machine. In the following months we shall conduct more sampling trips to the area in order to continue observations on post-desiccation dispersal. We shall also attempt to assess effects of reproductive activity on the recovery process.

Table 3.6.3.7.1 shows the sampling sites in April 2008. The sampling network includes sites in areas which remained wet in summer 2007 (e.g. Vivari, Us Vivari, Voskos, K_Sparti, Us Gef Spartis) and sites in areas which dried up completely (e.g. Strophi Ag.Pantwn, G Sentenikou, G_Kollinon, Down Con.Kastoras, Down Kolliniatiko).

Table 3.6.3.7.1. Fish species composition and abundance in the sites sampled in April 2008.

		Species							
Site Name	**Date**	***S.keadicus***	***T.spartiaticus***	***P.laconicus***	***S.fluviatilis***	***O.mykiss***	***A.anguilla***	***G.holbrooki***	**Mugilidae**
Strophi Ag.Pantwn	11/4/2008	5	4	1					
Gsentenikou (Gef.Pellanas)	12/4/2008	1		4					
G_Kollinon	12/4/2008	6							
Con.Skarpovas	12/4/2008	7		8					
Down Con.Kastoras	12/4/2008	3		27		1			
Vivari	13/4/2008	29	6	83					
Us Vivari	13/4/2008	1		34			1		
Voskos	14/4/2008	28		64					
K_Sparti	14/4/2008	1	2	6					
Us Gef Spartis	14/4/2008			1					
Down Kolliniatiko	11/4/2008	15	8	3					
Up Kolliniatiko	11/4/2008	7		12					

Two dominant patterns emerge from these data:

First, there were great declines in population abundance in comparison to spring 2007. Such declines are evident mainly in sites which experienced the effects of drought. However, much reduced population abundance was also observed in some sites that did not dry. For example, we caught very few fish in sites around the bridge of Sparta (sites K_Sparti and Us Gef Spartis) where, from April to August 2007, enormous fish concentrations were observed. To some extent, this low fish density in April 2008 may be the result of poor electrofishing sampling efficiency due to wide and deep habitats at this site. However, we are confident that the main reason of poor catches was low fish density, as considerable effort was devoted to sample different stretches and a variety of habitats. Moreover, we noticed that reproductive activity in this site was extremely low. In fact, we detected only one small shoal of *P. laconicus* larvae, whereas in the equivalent period of 2007 this same area was found to be swarming with larvae and fry. Therefore, poor catches seems to be a true reflection of scarcity of fish in this area in 2008. There are two probable explanations for this phenomenon:

- It is possible that the "Sparti bridge" refugium did not persist long enough and dried up sometime after our last sampling trip to this area (end of August 2007). If this is the case, the local fish populations vanished little before the beginning of the autumn rains; then the individuals we caught in this area in April 2008 were migrants from other drought refugia.

- River regulation for flood control may have generated deleterious effects on fish populations through eliminating fish habitats. In the winter 2005-2006 destructive flooding episodes occurred in the Evrotas basin, which led to the decision for defense measures against floods to be taken in order to protect agricultural property. During our sampling trips in 2007 we witnessed intense engineering work in large portions of the river (river straightening and embankment, bed leveling). Bulldozers were used to flatten and wide the river bed and to remove gravel for the construction of protective levees. Regardless of whether these constructions were correct or necessary, the effects on fish populations were catastrophic: there was a substantial loss of fish habitats in large portions of the river (including the estuarine reaches downstream the Skala bridge). Eventually, there was a significant reduction of the diversity of fish habitats (pools, runs, riffles, etc.) and concomitantly a destruction of specialised niches used by fishes (protected embayments, caves in the roots of riparian trees, rooted vegetation, large rocks, etc.). In addition, these engineering works generated negative impacts on the size and quality of persisting refugia, e.g. through silt deposition, shallowing of the river and damaging the aquatic vegetation. According to this explanation, the scarcity of fish around the Sparta bridge is the consequence of the elimination of habitat refugia that enable fish to resist extreme flows, in the absence of which they are swept away during winter sluices.

Second, fish populations had already started to re-colonise, albeit slowly, the areas affected by the drought. Our evidence suggests that re-colonisation occurred mainly through downstream dispersion from drought refugia. Undoubtedly, such refugia play a critical role in promoting population re-establishment processes and thereby the persistence of native fish populations. In normal years, the Evrotas R. fish populations appear resilient to the occurrence of droughts, and they tend to recover shortly after the cessation of the dry period. The 2007 drought, however, was very severe, and the rate of re-colonisation was extremely slow. At least until April 2008, the fish communities in the affected areas did not show signs of significant recovery. The rate of recovery can vary from area to area and is a function of various factors, such as: number and quality of the drought refugia that will provide the colonists, number of remaining fish in the refugia, distance of the area from the refugia, features affecting longitudinal connectivity, current habitat conditions, and availability of suitable microniches in the affected areas. Various human constructions in the Evrotas R., such as the high pedal of the Pelana bridge and many small irrigation dams along the river's route, bare fish reinvasions from downstream refugia. Finally, recovery rates may differ among species, depending on migratory patterns, habitat preferences and life-history traits such as body size, timing and duration of the breeding season, reproductive age and reproductive effort.

According to out data, *T. spartiaticus* was the species which was mostly adversely affected by the drought. Indeed, the extremely small number of individuals of this species sampled in April 2008 indicates that the populations are near to the limits of collapse. This fact, coupled with evidence of poor reproductive success of *T. spartiaticus*, at least in April 2008, may suggest that the re-establishment of the populations may be very slow. However, we did not sample the lower portion of the Evrotas R., e.g. the area downstream of the bridge of Skala, which seems to be a stronghold for this species. A significant factor that may slow down the rate of recovery of this species is that the flood defense engineering works caused a substantial damage to backwaters, pools and vegetated habitats that are mostly used by this species. On the contrary, *P. laconicus* appeared to be less sensitive to the drought effects, as significant concentrations of these species were recorded at places with suitable habitat conditions. This species possesses life-history traits such as small body size, early maturation and protracted spawning season, which reflects resistance to low water levels and rapid colonisation efficiency. Furthermore, spawning activity (presence of larvae and fry) of this species was observed in various places.

For the above reasons, it may take long, perhaps years, for the fish communities to recover fully. However, a sequence of harsh events such as a series of hydrologically adverse summers or flash flooding events in winter may delay recovery and/or result in significant modifications to community structure. Local extinctions during years of severe drought are not unlikely. This has already happened in several streams which were once perennial and historically harboured fish, and now have temporary flow characteristics. The anticipated climate change may act additively to the already elevated water abstraction, turning the Evrotas R. to an intermittent river that may not be able to support fish.

3.6.3.8. Synthesis – assessment of effects of drought on fish communities

Summer droughts, arising from a combination of natural causes and water abstraction, are becoming an increasingly more frequent phenomenon in the Evrotas R. Droughts generate major impacts on the survival of fish, and also influence growth and reproductive activities; thereby, they affect densities and size- or age-structure of populations. The effects of droughts on the Evrotas R. fish populations are of two kinds: direct and indirect. Direct effects include death from hypoxia or hyperthermia, habitat contraction or deterioration, loss of connectivity among river segments and poor reproductive success. Indirect effects include changes in food web structure that may result to food limitation, competition due to confinement in small living space, elevated predation, increased parasite load, evolutionary changes in life-history traits and changes in gene frequency because of 'bottleneck' effects. The impacts of human-induced droughts (through water abstraction) exacerbate the stresses already experienced by fish populations by other causes, such as flood control engineering, introduction of exotic species and deterioration of water quality due to organic pollution. Fig. 3.6.3.8.1 shows photographs depicting characteristic pressures impacting the fish populations.

It is not easy to determine the specific mechanisms underlying population declines or the exact reason of death of individuals, because several stressful agents can have interactive effects on individuals or populations (for example, individuals stressed by food limitation or oxygen depletion are more vulnerable to predation by otter and birds). However, we can see the overall effect of droughts on fish populations through estimations of mortality rates and assessments of re-colonisation and recovery rates. A specially designed study should be launched to address these issues in a quantitative way.

It might be argued that the Evrotas R. fishes are adapted to harsh and highly variable ecological conditions, because they have been subject to consistent selective pressure for droughts during the course of their evolutionary history. However, our historical hydrological data indicate that, at least until the 1950s, drought events were rare and locally restricted. It may therefore happen that the Evrotas R. fishes have not evolved specific adaptive strategies to face drought. In extreme years as during the prolonged drought during the years 1988-1992, fish nearly reached the edge of their tolerance limits to drought effects. Therefore, they may be are evolutionarily unprepared to tolerate further stressors in a future period of prolonged and extreme drought. This again reiterates the need for studies examining (a) the status of native fishes especially during and after drought periods, (b) the species' resistance mechanisms for drought, and (c) the resilience of the fish communities to drought, especially with regard to reproductive efficiency and dispersal abilities after droughts.

3.6.4. Risk assessment - Management considerations

The hydrological data presented in this report reveal general trends towards reduced precipitation and increased inter-annual variability, which is likely the consequence of ongoing climate change (section 3.3). In the future, the magnitude and frequency of summer droughts is likely to increase due to the combined effect of climate change and growing demands for water by agricultural.

The ichthyological surveys yielded results demonstrating that the summer 2007 drought has caused substantial mortality that may produce long-term effects on fish assemblages. More severe droughts expected under altered future climates and elevated water consumption may result in severe declines or extinctions of sensitive species. Concurrently, floods during the wet season are becoming more common, partly as a result of (a) loss of the floodplains that were important for buffering extreme water fluctuations in river flow during flooding episodes, and (b) the clearing of riparian forests, which provided protection against bank erosion. The occurrence of such floods generates further stress to fish populations, exacerbating the stresses already experienced due to the drought events. Changing drought and flood regimes thus need to be duly considered in the development of conservation strategies for the Evrotas fish species.

Better management of the Evrotas R. during and following droughts and floods is of critical importance for the protection and persistence of the native fish community. Reducing unnecessary water consumption is probably the most viable conservation strategy for protecting the water resource and the water-dependent organisms. Some additional actions in the direction of alleviating the adverse impacts of human-induced disturbances are considered below.

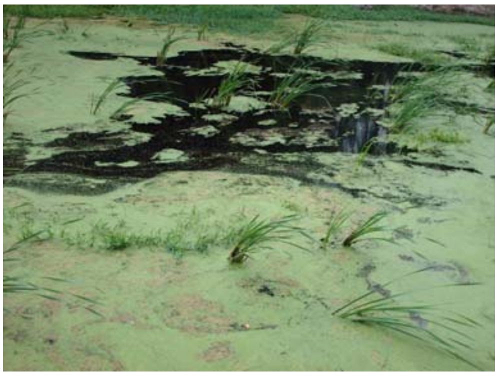
- Both the survival of fish during droughts and the rate of recovery following droughts depend strongly on the existence of suitable microhabitats and deep pool refugia, as well as on the existence of sufficient connectivity among habitat patches. Gravel abstraction and engineering works associated with flood control operations (e.g. river straightening, levelling and flanking) generate substantial damage to fish habitats and they also reduce the availability of drought refugia. Therefore, it is important to include the issue of fish habitats and fish refugia (e.g. deep pools) in future water management projects. Morphological disturbances affecting fish habitats (gravel abstraction, embankment) or fragmenting populations through impeding fish movements (dams and bridges preventing fish passage) should be minimised to the degree possible Environmental impacts assessments through the cooperation of competent scientists should be undertaken when river regulation or agricultural projects are implemented.

- Water abstraction represents the greatest threat to the Evrotas R. fish and other elements of the biota. Maintenance of ecological flows until the end of the dry season, in at least some reaches, is a critical issue. It is suggested that some spring-fed reaches should be set aside and protected from overpumping. Possible areas to be included in the protection scheme are spring-fed sections of the Evrotas R. at Vivari and at confluence of the river with the Kollyniatiko stream. Another possible refugial area is at a middle portion of the Oinous stream, where a thriving *S. keadicus* population still persists. To support human activities which depend on water and are socially advantageous, alternative sources of water should be considered where possible.
- Because isolated large pools play an important role in fish survival and the recovery process, some areas known to maintain large pools should be included in the protection scheme. In this context, care should be taken for the maintenance of pool water throughout the dry period (e.g. these pools should not be pumped in particularly dry years). Because of the hydraulic connection between surface water and groundwater, restrictive measures for groundwater pumping in the designated protected areas should also be considered.
- Native fishes should be watched closely, especially following periods of drought. Long-term monitoring of the water resources (water quantity and quality) and the fish living in the Evrotas R. should be established with the two-fold objective to constantly assess the conservation status of fish populations and to evaluate the influence of anthropogenic disturbances on the ecosystem.

Figure 3.6.3.8.1. Some anthropogenic disturbances affecting the Evrotas R. and its biota

Gravel extraction and flanking by levees (upstream of Sparti Bridge).

Extensive deforestation for the creation of a pumping station at site Us_Karavas.



Algal blooms near the Waste Treatment Plant.

Water abstraction in various locations in the main course of Evrotas R.

Clearing and straightening of the Evrotas bed in the Skala region as a flood control measure.

Disrupting longitudinal connectivity and imposing barriers to fish dispersal.

Predators Tracks

Otter feces containing fish scales.

Bird tracks near a shrinking water pool.


Dead or dying fish due to desiccation

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