LIFE+ 2008

LIFE+ Programme (European Commission)
LIFE+ Environment Policy and Governance

Project INHABIT - LIFE08 ENV/IT/000413
Local hydro-morphology, habitat and RBMPs: new measures to improve ecological quality in South European rivers and lakes

ACTION GROUP D2: Demonstration actions in regions not directly covered by the project

- Action D2_IRSA (month 19-36) *Demonstration actions in regions not directly covered by the project* by IRSA
- Action D2_ISE (month 19-36) *Demonstration actions in regions not directly covered by the project by ISE*
- Action D2_PI (month 19-36) *Demonstration actions in regions not directly covered by the project by ARPA Piemonte*
- Action D2_SA (month 19-36) *Demonstration actions in regions not directly covered by the project by RAS*

Deliverable D2d2

Proceedings of INHABIT international workshops

The importance of habitat features and local hydro-morphology for the definition of ecological status in rivers

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The importance of habitat features and local hydro-morphology for the definition of ecological status in rivers

By: Buffagni A., S. Erba & M. Cazzola

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Brugherio, 30 November 2013

SUMMARY

Preface

INHABIT project 'Local hydro-morphology, habitat and RBMPs: new measures to improve ecological quality in South European rivers and lakes' is a Life+ co-funded European project for integrating information on local hydro-morphological and habitat features into practical measures to improve the reliability of implementation of WFD River Basin Management Plans (RBMPs) in South Europe.

In the context of INHABIT project, several national and international meetings and workshops were held as part of communication and dissemination action (DI) and demonstration actions in regions not directly covered by the project (D2). Outside Italian borders, particularly relevant have been three international workshops entitled 'The importance of habitat features and local hydro-morphology for the definition of ecological status in rivers', participated by Environment agencies, government officers, environmental NGOs, scientific consultants and water managers. The first international workshop was held in Barcelona (ES) on October, 17th 2012; the second was held in Vienna (AT) on February, 15th 2013 and the third in Nicosia (CY) on February, 28th 2013. Barcelona and Nicosia workshops had a defined focus on Mediterranean environments. During and after the dissemination activities a lively scientific debate on a range of issues addressed by INHABIT project has matured.

The subject of the two D2 deliverables, initially conceived in the project proposal as proceedings of the two national workshops, was modified afterwards in order to contain the many themes covered by both the national and international contexts. It has been eventually reckoned as more appropriate to specifically reserve one Deliverable (D2d1) to the results of the national workshops and focus the other one (D2d2) primarily on an international perspective.

As a result of this approach, the present D2d2 Deliverable includes a set of papers presenting some of the results of the three international workshops, plus some extra papers providing an overview of the outcomes of the discussion emerged on INHABIT issues, including main results from national workshops. Nonetheless, as more inherent in action D1 topics, results of two of the talks given during the workshops have been included in D1d5 Deliverable.

The Deliverable opens with an introductory paper by the Italian Ministry of Environment and Land and Marine Protection (MATTM) giving an overview on the normative framework for WFD implementation in Italy, basis of INHABIT project action. Single papers deal with the following issues: general presentation of the project actions, the adopted experimental approach, the activity of reference sites validation and critical aspects of typization, results of classification of investigated river sites, results of nutrient addition in river stretches, the analysis of stream flow regime in a temporary river, results of a study regarding sediment transport balance, river longitudinal continuity and riparian condition in selected Sardinian catchments. A significant part of the deliverable is dedicated to extra INHABIT Mediterranean countries issues, Cyprus and Greece.

A number of people have contributed in the organization of the workshops. We would particularly like to thank: Gerald Dörflinger (WDD - Water Development Department, Ministry of Agriculture, Natural Resources and Environment, Cyprus), Gisela Ofenböck (Lebensministerium, Austria) and Narcís Prat (Universitat de Barcelona, Spain) for hosting and co-organizing the three INHABIT workshops abroad. Additionally, we thank Wolfram Graf (University of Natural resources and Life Sciences, Vienna, Austria), Gabriele Weigelhofer (WCL, Lunz, Austria), Eugenia Martí (Centre d'Estudis Avancats de Blanes, Spain), Maria Rieradevall, Nuria Bonada (the two from FEM Research Group, Universitat de Barcelona, Spain), Francesc Gallart (IDAEA, CSIC Barcelona, Spain), Antoni Munné (Agència Catalana de l'Aigua, Spain), Charalampos Panayiotou and Iakovos Tziortzis (WDD, CY), Kostas Gritzalis, Nikos Skoulikidis and Stamatis Zogaris (HCMR-IMBRIW, Greece), S. Manolaki, (Uni Patras, Greece/Cyprus), D. Armanini and D. Demartini (Prothea, Italy), and all other researchers and delegates from Environment Agencies, private companies, NGOs, associations, etc. for actively participating to the workshops.

D2D2.1 - GENERAL INTRODUCTION TO INHABIT PROJECT AND STRUCTURE OF ACTIVITIES

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SUMMARY

INHABIT Project 'Local hydro-morphology, habitat and RBMPs: new measures to improve ecological quality in South European rivers and lakes' is a LIFE+ project supported by the European Union under the LIFE + Environment Policy and Governance 2008 programme. The aim of the project to a wider extent is to integrate information on habitat and local hydromorphological features into practical measures for WFD River Basin Management Plans (RBMPs) in South Europe. The project has a strong linkage with Water Framework Directive implementation, with regard to some of the most innovatory aspects.
Detail objectives are dealing with a series of features: inclusion of innovative measures related to habitat into RBMPs, quantification of natural variability for local hydromorphological, habitat and chemico-physical variables known to have an influence on biological communities and evaluation of importance of water quantity in the definition of ecological status and related uncertainty.
INHABIT project is organized into a set of activities developing at different time scales: i) Preparatory project phase (P); dealing with the review of approaches and methods, selection of methods, protocols and study sites; ii) assessment of environmental and biological condition and variability (I1); iii) relationship between nutrients, community and environmental conditions (I2); iv) Proposal of innovative measures for river basin management plans (I3); v) Demonstration actions on classification and uncertainty (D1); vi) Demonstration actions in regions not directly covered by the project (D2); vii) Communication and dissemination of results (DI).
The project has a highly innovative approach in particular for what water resources in South Europe is concerned. INHABIT takes into account some crucial aspects of lakes and river management, both extremely important and generally overlooked during RBMPs drafting and WFD implementation.

1. INTRODUCTION

The project INHABIT is part of LIFE+ programme, EU's funding instrument for the environment. The general objective of LIFE is to contribute to the implementation, updating and development of EU environmental policy and legislation by co-financing pilot or demonstration projects with European added value. LIFE+ programme is divided into three components: LIFE+ Nature and Biodiversity, LIFE+ Information and Communication and Environment Policy and Governance. Within this latter module, INHABIT project is part of the 'Water' section that covers a wide range of themes, monitoring and management of river basins among others.
The project aims at integrating information on local hydro-morphological features into practical measures linked to the possible implementation of WFD River Basin Management Plans (RBMPs) and the

effectiveness of ecological status assessment methods in South Europe. INHABIT is focused on the study of rivers and lakes in two Italian areas, Piedmont and Sardinia, covering a wide range of environmental characteristics and water body types. Project results aim at providing a sound scientific basis for RBMPs implementation in Italy and, to a lesser extent, in Europe. The project has several objectives, among these:

- Suggestions for RBMPs implementation related to a set of water bodies representative of a relevant part of Italian streams and lakes, through the introduction of innovative measures taking into account information on local hydromorphology and habitat;
- To quantify natural variability of habitat and chemico-physical parameters influencing biotic communities and the definition of biological responses;
- The definition of some elements useful to RBMPs implementation, in particular: a) the influence of habitat discharge-related features on the assessment of rivers ecological status; b) the influence of variation in water level on natural and artificial banks on the evaluation of lakes ecological status; c) the interaction between habitat features and nutrient concentration, including their removal, as a tool for improving water quality in rivers; d) large scale and trans-basin transport of nutrients and possible consequences for the implementation of RBMPs and programs of measures (PoMs).
- The evaluation of the role of the above mentioned aspects on ecological status definition and its related uncertainty.

2. INHABIT PROJECT GENERAL STRUCTURE

INHABIT project is divided into phases, or activities, following a time schedule.

Preparatory project phase (P) – Review of approaches and methods, selection of methods, protocols and study sites. This action group includes two clusters of themes, the first of which has dealt with a summary analysis of approaches and methods used in the preparation of river basin plans in the study areas. The second cluster of issues mainly deals with the selection of methods and protocols to be used during the project. Special focus has been placed to the selection of suitable methods for deriving habitat information. Within Italian RBMPs, such aspects are at the moment the less studied and in depth analyses and methodological setting are still needed. Results of the two phases are presented (in Italian) in deliverables Pd1 (Marziali et al., 2010) Pd4 (balestrini et al., 2010) and Pd3 (Buffagni et al., 2010) or in the results page on INHABIT website (www.life-inhabit.it).

Assessment of environmental and biological condition and variability (I1). On the basis of the results achieved from the group of action P, sampling campaigns have been performed on the field for the collection of biological, chemical and hydro-morphological both for rivers and lakes. Samples have been collected in reference (i.e. nearly-natural sites) and degraded sites, in different seasons. Alterations are mainly related to habitat aspects, while alteration in chemico-physical features have not been considered. Part of I1 activity has been dedicated to the validation of the selected river reference sites, through the compilation of dedicated check tables (WFD criteria verification tables for reference sites in rivers, Buffagni et al., 2008). Such verification tables allows the validation of the reference status of a site based on abiotic features. Selection of reference sites are carried out by identifying sites (or reaches) presenting minimum (i.e. not significant) anthropic disturbance. After the pre-selection, sites characteristics are checked against a set of criteria (listed in Buffagni et al., op. cit.). Such criteria, to a different level of importance (essential, important and ancillary), quantify the extent of possible pressures on candidate sites and on their surrounding areas at different spatial scale (i.e. basin, reach, site). For each of the listed criteria a set of answers (e.g. numeric, %, yes/no, no/few/many) and

two boundaries (reference and refusal) are possible.
Validation of river reference sites for Piedmont and Sardinia are presented in deliverable I1d1 (Erba et al., 2011) and I1d4 (Erba et al., 2012) respectively. Other than with these themes, deliverable I1d1 deals with the description of study areas and sites. Deliverables I1d4 (Erba et al., 2012) e I1d5 (Morabito et al., 2012) are dedicated to the presentation of aspects of sites variability related to natural and anthropic features, for rivers and lakes respectively.
Relationship between nutrients, community and environmental conditions (I2). Interactions among nutrients, local hydromorphology, habitat conditions and biotic communities have been investigated in both rivers and lakes. On the basis of the results obtained in P group of action, impact of source and non-source nitrogen and phosphorous pollution has been investigated in each considered basin. Relationship among basin characteristics (land use, topography, landscape structure etc.), reach features and nutrient loads have also been analyzed. Among the deliverables dedicated to I2 action, deliverable I2d1 (Balestrini et al., 2012) describes sites habitat and physical-chemical characterization. Both habitat and physical-chemical characteristics play a crucial role in the interpretation of nutrient retention mechanisms, by describing chemico-physical water composition and defining important aspects influencing water residence time and water-sediment interactions. Results related to retention metrics in investigated sites are presented and discussed in deliverable I2d2 (Balestrini & Biazzi, 2012).
Proposal of innovative measures for river basin management plans (I3). Biological communities (Biological Quality Elements, *sensu* WFD) present a preferential response to local-scale, habitat-mediated factors and only in a minor extent to large-scale, geo-morphological features. Habitat and local hydro-morphological scale is highly pertinent for the correct interpretation of biotic response to restoration actions. Although basin scale processes are unmistakably crucial in long term planning, relations between biological and hydromorphological large scale variables are difficult to detect. The relationships between hydromorphological and biological parameters are usually not clearly established and their link to the quality of the water bodies is often merely hypothetical. On the other hand it appears clear how large-scale (basin) investigation should be coupled with local-scale (habitat) analysis, more relevant for biological data interpretation. The main aim of I3 group of action is to suggest possible integrative measures for RBMPs to be easily implemented after a detailed analysis of water bodies habitat conditions. Figure 1 diagram shows the relative importance of different spatial scales in the response to management practices and in use for research purposes.

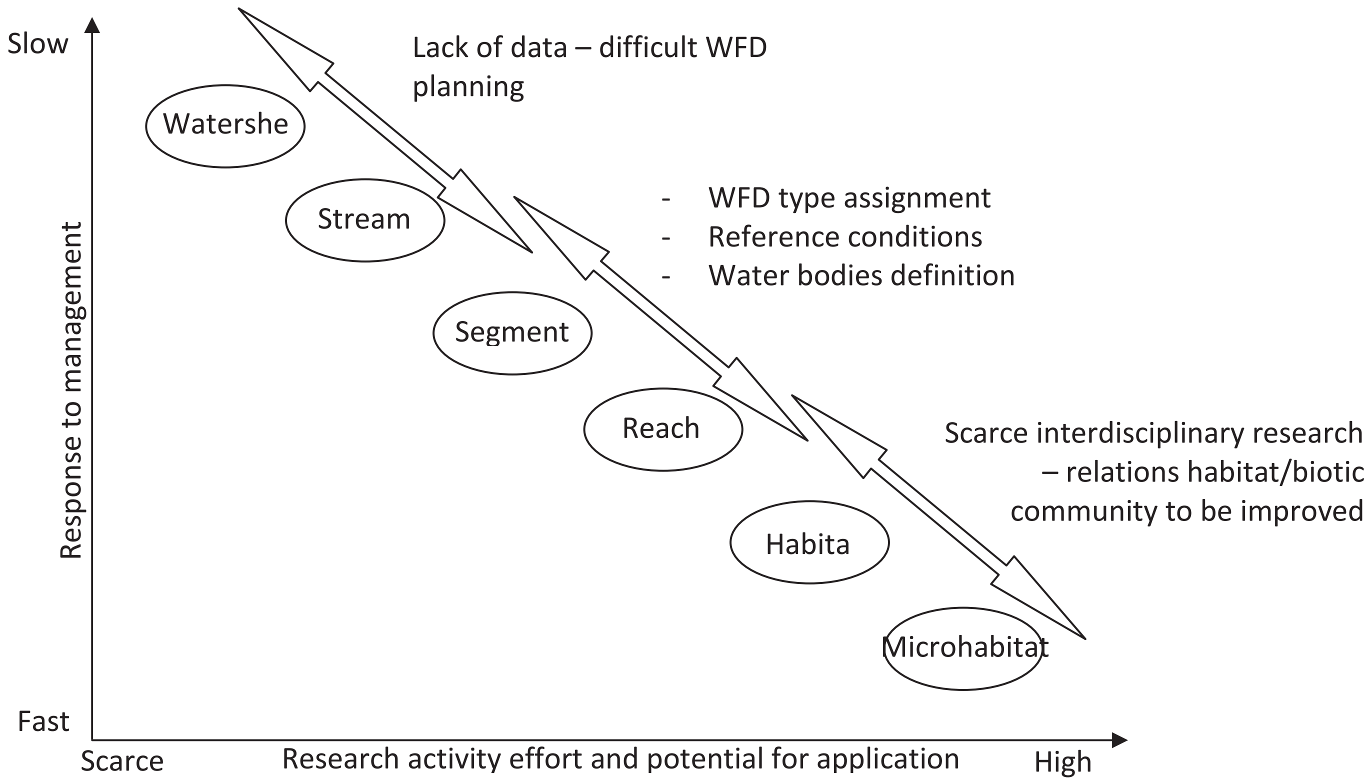

Fig. 1 - Regulatory knowledge and information for WFD implementation in a scale-hierarchical system (from Newson & Large, 2006 mod.)

Data analysis for activity I3 involves 4 steps:

- The definition of relationship between benthic communities (and related classification of ecological status) and local habitat variability, including definition of criteria for reducing uncertainty (I3d1, Buffagni et al, 2013).
- The definition of a list of possible habitat measures for ecological quality restoration, based examples from the INHABIT project (I3d2).
- Indication on how to implement the suggested measures in order to achieve good ecological status (I3d4).
- The analysis of potential of measures on key aspects of nutrient dynamics and possible up-scaling (I3d3).

Demonstration actions on classification and uncertainty (D1). D1 action has involved the application in the study areas of the most up to date methods for classification available for Italian aquatic ecosystems, according to a set of environmental variables (e.g. biotic communities, habitat features, water chemistry etc.).

Results of sites classification are presented for rivers in deliverable D1d1 (Cazzola et al., 2012, in Italian) and in the D1 results pages of INHABIT website (www.life-inhabit.it).

Demonstration actions in regions not directly covered by the project (D2). Approaches developed within the project are applied to river basins in regions not directly included in INHABIT study areas. Results are mainly linked to: methods for biotic communities sampling and analysis; methods for hydromorphological and habitat characterization; relations between biotic communities and environmental variables based on adaptation to real circumstances.

3. CONCLUSIONS

- INHABIT project presents strong application purposes, in accordance with the themes of 'Environmental Policy and Governance' of the LIFE + program, which the project is ascribed to.
- In line with all projects under the LIFE+ programme, INHABIT takes into account scientific and normative themes structured along an extended period of time. INHABIT project activity is set into specific themes, strictly related to WFD implementation (e.g. reference condition definition, typization, development of WFD compliant assessment systems, drafting of the normative technical parts etc.).
- Moving from the present scientific-normative context, INHABIT focuses on aspects generally poorly implemented during the definition of the RBMPs.
- INHABIT project intends to tackle issues related to variability associated to habitat features, determining aquatic environments biotic communities composition and, consequently, ecological status definition. In order to solve these issues, of great relevance in Mediterranean context, INHABIT aims at providing specific tools to be directly implemented into RBMPs.
- The approach adopted in the project considers the simultaneous application of methods, recently developed and highly innovative, taking into account several aspects of aquatic ecosystems. In this context INHABIT represents one of the first examples of this holistic approach applied to a national scale.
- In the management of aquatic environments a difference is observed between the spatial response of biological elements to a local scale and the spatial unit considered in management plans, i.e. the watershed. INHABIT considers habitat features as an ideal connection between biological response (smaller scale) and management unit (wider scale).

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D2D2.2 - HABITAT AND ECOLOGICAL STATUS CLASSIFICATION: THE INHABIT APPROACH

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SUMMARY

The present contribution summarizes the experimental approach adopted within the INHABIT project for rivers presented during Cagliari and Rome workshops. During the INHABIT project 44 and 18 rivers sites were respectively investigated in Sardinia (perennial and temporary rivers) and Piedmont (2 different river types). In all sites benthic and diatoms samples were collected jointly with the characterization of physicochemical variables and habitat by means of CARAVAGGIO method. Through CARAVAGGIO method sites have been characterized both in terms of single habitat features recorded (e.g. bank modifications, flow type, substrate type, etc.) and in terms of results of the indices and descriptors (i.e. HMS, HQA, LUI, IQH and LRD) allowing the quantification of different aspects of the habitat. The investigated river sites reflect a gradient in habitat in terms of alteration and diversification. Water pollution does not affect the investigated sites and at least two reference sites were selected within each of the investigated river types. The approach for collecting data was addressed at obtaining information useful to:

- model reference conditions in relation to habitat characteristics;
- implement river type definition, assessing natural variability;
- improve biological data interpretation in relation to ecological classification;
- infer on the relationship between nutrient uptake length, habitat and biotic communities;
- suggest useful measures to implement RBMPs;
- improve accuracy of ecological status classification.

1. INTRODUCTION

The innovative aspect of experimental activity carried out within INHABIT project relates to the simultaneous collection of biological, habitat, hydromorphological and environmental data. In particular, experimental activities are focused on the study of the habitat-biota relations. Although characterization of biological communities is well established in common monitoring practices, e.g. for aquatic macroinvertebrates in rivers, the relations between the considered biological element and habitat features are usually only superficially studied. This happens in particular when the aim is to assign an ecological quality class. As well, although WFD requires specifically to take into account a series of hydromorphological aspects for the interpretation of biological data (e.g. channel structure, width and depth variation, flow and substrate condition, water continuity), such relationships are often neglected. So far, these conditions have been undoubtedly related to the lack of availability of field methods that could ensure a proper collection of the information. Nevertheless, considering the need to evaluate the results of ecological classifications, the quantification of natural variability of habitat aspects appears to be crucial for a correct classification of ecological status and to quantify its uncertainty. Within INHABIT project, main objectives of the data collection are related to:

- the quantification and modeling of reference conditions in relation to habitat diversification;
- the fine tuning definition of fluvial types and sub-types;
- obtain information allowing to interpret biological data in relation to habitat and local hydromorphology variation;
- obtain information allowing to improve the reliability of classification methods.

The approach adopted for data collection has been presented during the first national workshop of INABIT project (Cagliari, December 2012) and partly resumed during the second national workshop (Rome, March 2013). The present paper aims at providing a general framework of the experimental approach of the project, for rivers. It also aims at presenting some of the preliminary results related to habitat features collected through CARAVAGGIO method. All detailed description related to study areas and type of data collected are reported in the project deliverables (Pd2, Erba et al., 2010; Pd3, Buffagni et al., 2010a; I1d1, Erba et al., 2011; I1d2, Cazzola et al., 2012a e I1d3, Demartini et al., 2012).

2. EXPERIMENTAL APPROACH AND SYNTHESIS OF RESULTS

An overall number of 44 river sites in Sardinia and 18 sites in Piedmont have been investigated. Sites in Sardinia were surveyed in two periods, May 2011 and March 2013. Piedmont sites were surveyed in two seasons in 2011, winter and spring-summer (including a reference site located in Lombardy). In each of the two areas both reference sites and sites affected by hydromorphological and habitat alteration were selected. As general approach, at least two reference sites and a variable number of altered sites has been selected for each stream type, in order to cover a wide range of hydromorphological features. For site selection the criterion of coupling sites positioned at short distance on from the other has been considered; this in order to retain in the couple of sites the same water quality (and virtually the same geographic characteristics) but significant differences in habitat features and/or alterations.

Detailed description of sites and study areas are included in deliverable I1d1 (Erba et al., 2011), criteria for reference sites selection and typological attribution of sites are presented in deliverable Pd2 (Erba et al., 2010). In all sites, following environmental characters have been sampled/considered: aquatic invertebrates, diatoms, water samples for chemico-physical analysis, habitat characterization.

In rivers, benthic macroinvertebrates have been sampled according to a multihabitat technique. The same methodology has been recently adopted in Italy for surface water bodies ecological status classification (operational monitoring), in compliance with WFD requirements (wadable rivers, D.M. 56/09; CNR-IRSA, 2007). Although the collection of 10 sampling units in a single mesohabitat or area (i.e. pool, riffle or generic) is considered as adequate for classification purposes, in order to allow a more detailed analysis sampling in different areas has been reckoned as more appropriate. The same sampling procedure is considered by national legislation for surveillance monitoring, reference sites and sites belonging to the ‘core network’.

The sampling in two distinct mesohabitats has been performed in all sites located in Sardinia (pool and riffle) and in selected sites of Piedmont sites, in this latter cases two samples have been collected, one in each mesohabitats riffle and pool or one in two different ‘generic’ areas. A total number of 20 sampling units have been collected in each site and kept separated. Sampling units have been characterized in terms of depth, water velocity, substrate type and flow type.

For habitat characterization at reach scale CARAVAGGIO method (Buffagni et al. 2005) has been applied in all investigated sites. The method records along a 500m stretch a set of specific characters related to channel and bank habitats. River sections considered are: channel, banks and river surrounding areas. The survey is carried out in two parts, in the first one features of channel and banks are recorded along ten transects (spot-checks) perpendicular to the river flow and equally spaced every 50m; in the second part an overall survey is conducted on the whole 500m stretch recording land use, general bank section and specific features. In figure 1-4 some examples of information that can be obtained with the CARAVAGGIO method are reported. Field forms and application keys are available for download at INHABIT website (http://www.life-inhabit.it/it/download/public-reports-guidelines).

From the application of CARAVAGGIO method it is possible to derive a set of indices and descriptors:

- HMS index (Habitat Modification Score; Raven et al. 1998; Buffagni et al., 2010a);
- HQA index (Habitat Quality Assessment; Raven et al. 1998; Buffagni et al., 2010a);
- LRD (Lentic-lotic River Descriptor; Buffagni et al. 2010a; b);
- LUI (Land Use Index; Buffagni et al., 2010a);

here briefly described. Details for calculation can be found elsewhere (Buffagni et al., 2010a).

HMS index allows a quantification of the morphological alteration. It is obtained by summing up the scores given to single characteristics accounting for alteration in sites morphology (e.g. banks or channel resectioned or reinforced). The higher the score, the higher is the level of alteration. HQA index, as well, is obtained by the sum of scores given to single characters. It accounts for an estimation of habitat diversification (e.g. different types of substrate and flow). To high scores correspond a good level of habitat diversification. LUI index allows the quantification of the land-use at site level. It is obtained by summing up the scores of the land uses recorded at spot-check and sweep-up level on bankface and banktop. To different land uses are given different scores on the basis of the considered impact. Scores from different sections are weighted according to recorded features, like banktop height or bankface length. HMS, HQA and LUI indices can be merged in an overall Index of Habitat Quality (IHQ or IQH in Italian). Such index in considered as mandatory by the Italian Classification decree (DM 260/2010) for the confirmation of high status sites and for selection of river sites. Lastly, the Lentic-lotic River Descriptor (LRD) characterizes the sites in terms of relative dominance of lentic areas or lotic areas, once again calculated by summing up the scores from single characters. Both data recorded along single spot checks and sweep-up are considered. Total LRD scores can have positive or negative values, with negative values associated with lotic characteristics and positive values to lentic conditions. Classification results according to the mentioned indices are reported in deliverable D1d1 (Cazzola et al., 2012b). The list of sites including the codes used in some of the figures is reported in table 1 (Sardinia) and 2 (Piedmont).

Tab. 1 – List of investigated sites – Sardinia.

code fig. 6, 8	River name	Site name	Month-year
S1	Baldu	Baldu Monte Culvert	mag-11
S2	Barrastoni	Barrastoni	mag-11
S3	Baldu	Baldu Down Culvert	mag-11
S4	Canale	Canale Monte Depuratore	mag-11
S5	Cedrino Irgoli Affluente	Cedrino Irgoli Affluente	mag-11
S6	Cialdeniddu	Cialdeniddu	mag-11
S7	Corr'e Pruna	Corr'e Pruna Monte	mag-11
S8	Corr'e Pruna	Corr'e Pruna Ponte	mag-11
S9	Corr'e Pruna	Corr'e Pruna Valle	mag-11
S10	E Gurue	E Gurue	mag-11
S11	Flumineddu	Flumineddu Gorroppu	mag-11
S12	Foddeddu	Foddeddu Valle	mag-11
S13	Liscia	Liscia Valle Lago	mag-11
S14	Lorana	Lorana Monte	mag-11
S15	Lorana	Lorana Valle	mag-11
S16	Museddu	Museddu	mag-11
S17	Picocca	Picocca Ref	mag-11
S18	Posada Affluente	Posada Affluente	mag-11
S19	Porceddu	Porceddu	mag-11
S20	Posada	Posada Valle Guado	mag-11
S21	Safaa	Safaa Alientu	mag-11
S22	Rio San Giuseppe	Rio San Giuseppe Solago/Sarossa	mag-11
S23	Solana	Solana	mag-11
S24	Sperandeu	Sperandeu	mag-11
S25	Saserra	Saserra Ref	mag-11
S26	Tirso	Tirso	mag-11
S27	Sud Limbara	Terra Mala Valle Ponte	mag-11
S28	Sud Limbara	Terra Mala Ref	mag-11
S29	Barrastoni	Barrastoni valle ponte	mar-13
S30	Barrastoni	Barrastoni monte	mar-13
S31	Baldu	Baldu ponte (monte ponte)	mar-13
S32	Baldu	Baldu valle	mar-13
S33	Oddastru	Oddastru valle ponte FS	mar-13
S34	Rio Malchittu	Rio Malchittu Nuraghe	mar-13
S35	Foddeddu (Corongiu)	Corongiu km109	mar-13
S36	Tricarai	Tricarai valle ponte	mar-13
S37	Tricarai	Tricarai ref	mar-13
S38	Foddeddu	Foddeddu Tortolì	mar-13
S39	Monte pecora	Monte pecora ref	mar-13
S40	Mortorinci	Mortorinci valle ponte	mar-13
S41	Mortorinci	Mortorinci ref	mar-13
S42	Gorbini	Oleandro ref	mar-13
S43	Sa Teula	Sa Teula ref	mar-13
S44	Campu E'Spina	Campu E'Spina	mar-13

Tab. 2 - List of investigated sites – Piedmont.

HER	Code fig. 7	River name	Site name	Month-year
HER1	Campiglia - 1	Campiglia	Campiglia REF	apr-11
HER1	Campiglia - 2	Campiglia	Campiglia REF	giu-11
HER1	Loana - 1	Loana	Loana REF	apr-11
HER1	Loana - 2	Loana	Loana REF	lug-11
HER1	Pogallo - 1	Pogallo	Pogallo REF	apr-11
HER1	Pogallo - 2	Pogallo	Pogallo REF	ago-11
HER1	Savenca - 1	Savenca	Savenca REF	mar-11
HER1	Savenca - 2	Savenca	Savenca REF	giu-11
HER1	Savenca SDOP - 1	Savenca	Savenca SDOP	mar-11
HER1	Savenca SDOP - 2	Savenca	Savenca SDOP	giu-11
HER1	Tesso - 1	Tesso	Tesso	mar-11
HER1	Tesso - 2	Tesso	Tesso	lug-11
HER1	Tesso SDOP - 1	Tesso	Tesso SDOP	mar-11
HER1	Tesso SDOP - 2	Tesso	Tesso SDOP	lug-11
HER1	Viona - 1	Viona	Viona	apr-11
HER1	Viona - 2	Viona	Viona	giu-11
HER1	Viona SDOP - 1	Viona	Viona SDOP	apr-11
HER1	Viona SDOP - 2	Viona	Viona SDOP	giu-11
HER6	Sizzone - 1	Sizzone	Sizzone REF	mar-11
HER6	Sizzone - 2	Sizzone	Sizzone REF mulino	mag-11
HER6	Guarabione - 1	Guarabione	Guarabione	mar-11
HER6	Guarabione - 2	Guarabione	Guarabione	mag-11
HER6	Guarabione SDOP - 1	Guarabione	Guarabione SDOP	feb-11
HER6	Guarabione SDOP - 2	Guarabione	Guarabione SDOP	mag-11
HER6	Olobbia - 1	Olobbia	Olobbia	mar-11
HER6	Olobbia - 2	Olobbia	Olobbia	giu-11
HER6	Olobbia SDOP - 1	Olobbia	Olobbia SDOP	mar-11
HER6	Olobbia SDOP - 2	Olobbia	Olobbia SDOP	lug-11
HER6	Strego -1	Strego	Strego	feb-11
HER6	Strego - 2	Strego	Strego	mag-11
HER6	Ceronda -1	Ceronda	Ceronda REF	feb-11
HER6	Ceronda - 2	Ceronda	Ceronda REF	giu-11
HER6	Odda -1	Odda	Odda	feb-11
HER6	Odda - 2	Odda	Odda	mag-11
HER6	Curone -1	Curone	Curone REF	mar-11

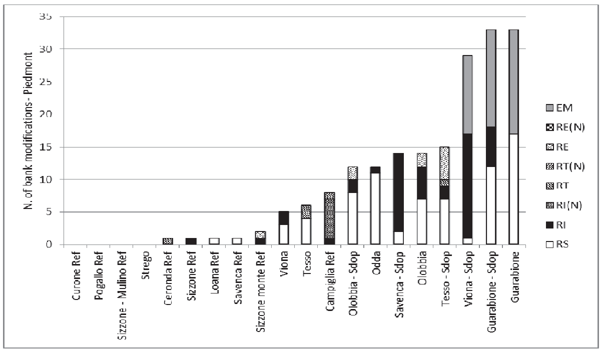

Fig. 1 - Number of bank modification features (Sez.B) identified in Piedmont, per site. Codes: RS (resectioned bank), RI (reinforced bank), RI (N) (reinforcement 'naturalistic' type), RT (reinforcement only top of the bank), RT (N) (reinfrocement top bank 'naturalistic' type), RE (reinforcement only toe of the bank), RE (N) (reinfrocement toe bank 'naturalistic' type), EM (embankement) (from Demartini et al., 2012).

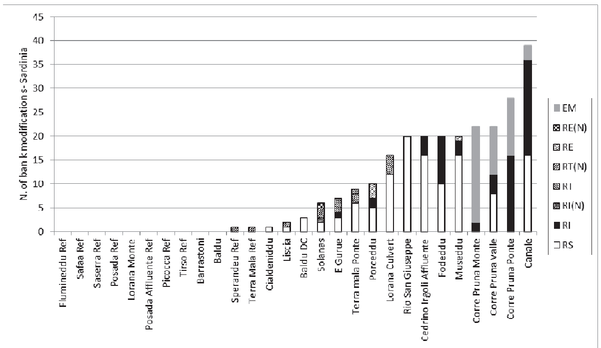

Fig. 2 - Number of bank modification features (Sez.B) identified in Sardinia, per site. Codes: RS (resectioned bank), RI (reinforced bank), RI (N) (reinforcement 'naturalistic' type), RT (reinforcement only top of the bank), RT (N) (reinfrocement top bank 'naturalistic' type), RE (reinforcement only toe of the bank), RE (N) (reinfrocement toe bank 'naturalistic' type), EM (embankement) (from Demartini et al., 2012).

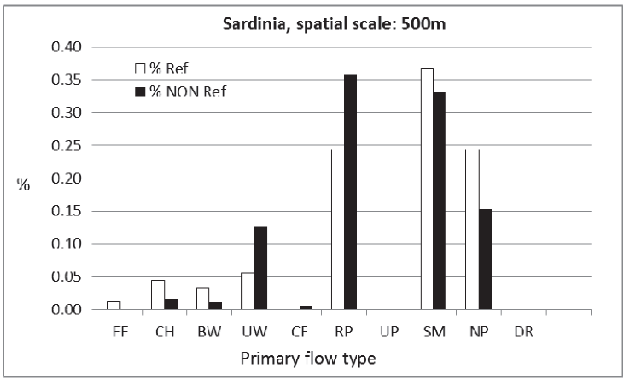

Fig. 3 - Flow types observed in Sardinia in Reference and non-reference sites. Codes: FF (Free-Fall), CH (Chute), BW (Broken standing Waves), UW (Unbroken standing Waves), CF (Chaotic Flow), RP (Rippled), UP (Upwelling), SM (Smooth), NP (No perceptible), DR (Dry).

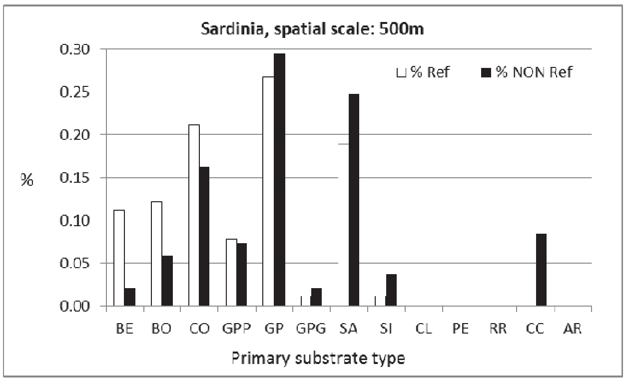

Fig. 4 - Substrate types observed in Sardinia in Reference and non-reference sites. Codes: BE (Bedrock), BO (Boulders), CO (Cobbles), GPP (Pebble), GP (Gravel-Pebble), GPG (Gravel) SA (Sand), SI (Silt), CL (Clay), PE (Peat), RR (Rip-Rap), CC (Concrete), AR (Artificial).

Data collected through CARAVAGGIO method have been archived into CARAVAGGIOsoft database (Di Pasquale & Buffagni, 2006), specifically dedicated to the management of data collected on the field. CARAVAGGIOsoft has been developed in MS Access at CNR-IRSA, based on original RHS database developed by Centre for Ecology and Hydrology (UK). CARAVAGGIO is in fact an implemented version of RHS with particular focus on Mediterranean streams. CARAVAGGIOsoft language is English in order to comply with previous software versions and to ensure comparability among international surveyors. Detailed information on CARAVAGGIOsoft can be found in Di Pasquale & Buffagni (2006).

Figures 5 and 6 show the environmental gradient investigate, respectively in Piedmont (Erba et al., 2011) and Sardinia in terms of habitat alteration (HMS index) and habitat diversification (HQA). In Piedmont sites are ordered by HMS increasing values, first in HER01 and then in HER06. For HMS a single seasonal value is reported for characteristics considered for calculation are not subject to seasonal variability. Different HQA values are instead reported for the two sampling season, although not for the entire set of data. In both the HER in Piedmont, a fair gradient is observed for morphological alteration (i.e. HMS). It is possible to observe some (minor) level of alteration in reference sites as well. HMS value is in any case not exceeding 6, i.e. the boundary value between high status and good status (see Buffagni et al., 2010a). Regarding habitat features, HQA index shows, generally, high scores. All reference sites show scores above the boundary value between high and good status (i.e. 47 in the Alps, HER 1; 42 in small lowland streams, HER 6). Sites in HER06 show in general a higher habitat diversification if compared to HER01 sites. Variability of HQA values between the same site in the two seasons is limited, while it is high among different sites. Site showing the greater seasonal HQA variability is Sizzone. In general, as expected, to high level of morphological alteration does correspond a lower habitat diversification. Marked differences of HMS and HQA are observed in ‘coupled’ sites, i.e. sites positioned on the same stream to a short distance one from the other and showing, thus, (virtually) the same characteristics in terms of water quality and different habitat features. Differences are marked when comparing sites Savenca with its couple Savenca sdop and Viona with coupled Viona sdop. Less obvious are differences between the two sites on Olobbia river and Guarabione river, all showing high habitat alteration.

In Figure 6 sites from Sardinia are ordered by increasing HMS values. A wide HMS gradient is observed with maximum values just below 90. Again, considering HQA index, sites showing marked morphological alteration show the lowest habitat diversification. The two sites located on Lorana river have very different HMS values: 0 (site S14) versus 40 (site S15). Site Corre Pruna Ponte (S8) most differs from the two others on the same river (S7 and S9), both in terms of HQA and HMS. The couple located on the Baldu river has very similar values both for HQA (54 and 57) and HMS (9 and 17).

About site of 2013 the same approach of coupling two sites on the same river located at limited distance has been adopted, in order to obtain different habitat characteristics with the same water quality (e.g. Mortorinci reference HMS =0 and Mortorinci Ponte HMS =34).

57; HMS 9 e 17). Per quanto riguarda i siti campionati nel 2013, è stato mantenuto il medesimo approccio di sdoppiare i siti sul medesimo fiume in modo che i siti presentassero diverse caratteristiche

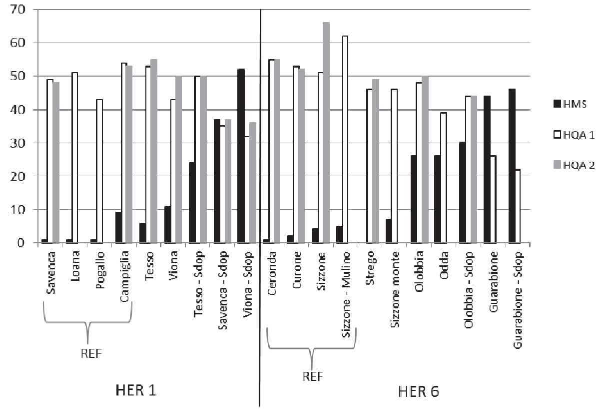

Fig. 5 - Values of indices HMS and HQA in INHABIT sites in Piedmont, hydroecoregions Western Alps (HER01) and Po plains (HER06).

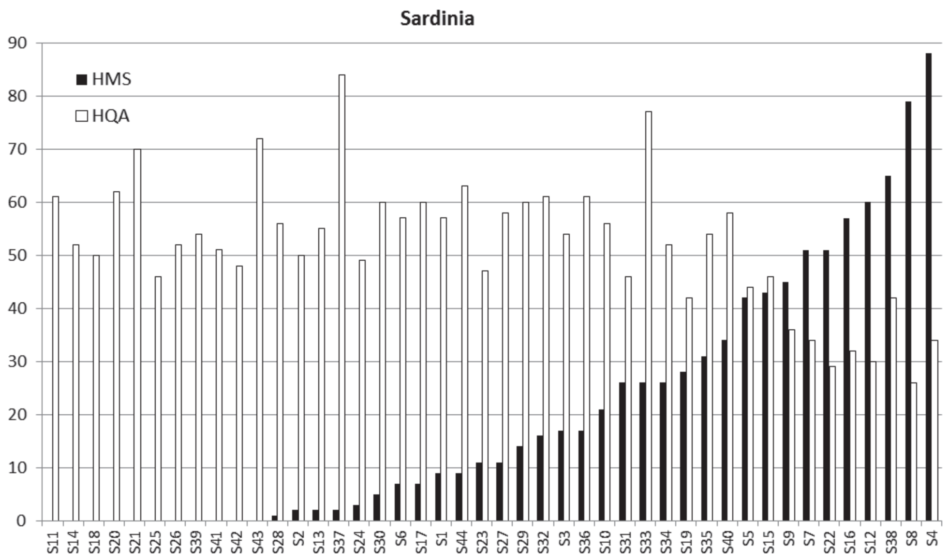

Fig. 6 Values of indices HMS and HQA in INHABIT sites in Sardinia (HER21)

The sites show an high diversification in LRD values. In Piedmont (figure 7) sites cover a gradient between -55 and +35. In Sardinia (Figure 8) although in a typical Mediterranean area some intense lotic conditions can be observed, corresponding to LRD values comparable with Alpine streams (i.e. -40), together with condition of extreme lenticity (i.e. LRD values >30).

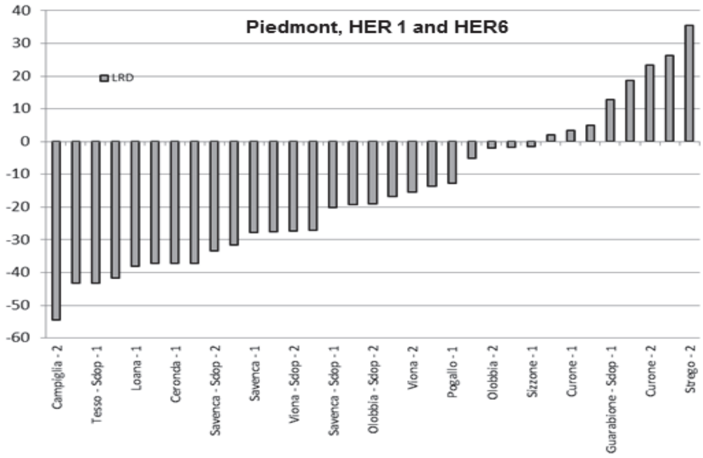

Fig. 7 - Values of LRD descriptor in INHABIT sites in Piedmont (HER01 and HER06)

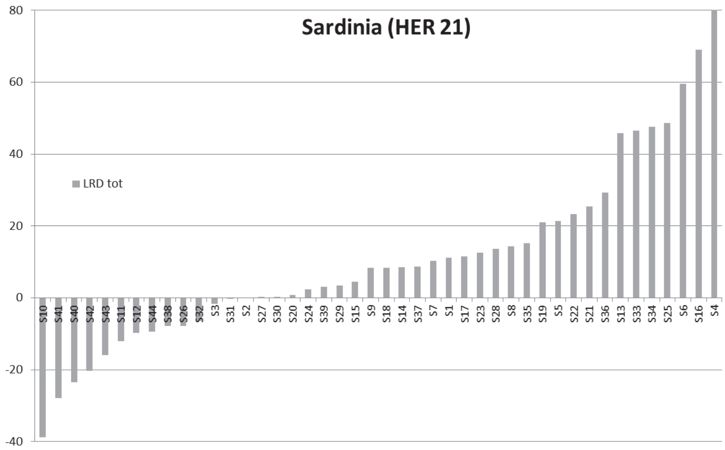

Fig. 8 - Values of LRD descriptor in INHABIT sites in Sardinia (HER21)

3. CONCLUSIONS

- Experimental data collected for rivers during INHABIT project have been archived in dedicated databases. Part of the data have been made available to the participants to project workshops in Cagliari (Dec 2012) and Rome (Mar 2013) and the description of the datasets are available on the project website (www.life-inhabit.it).
- Collected data have been used in the process of validation of reference sites.
- Collected data have, as well, allowed the quantification on natural and anthropogenic variability in investigated water bodies,

providing useful elements for the definition of river types, among other things.

- In particular, through the collected data, it will be possible to define guidelines for a more accurate definition of quality of water body in Sardinia.
- Habitat data will be used in the definition of possible management models and measures definition, aiming at the improvement of water bodies quality.

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D2D2.3 - STRENGTH AND WEAKNESSES OF RIVER TYPOLOGY IN INHABIT STUDY AREAS: ADEQUACY OF REGIONALIZATION AND CRITICAL ISSUES IN MEDITERRANEAN RIVERS

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SUMMARY

The present work, related to a talk given during the I national workshop in Rome (March 2013), summarizes the contribution of the INHABIT project to two important themes related to the process of WFD implementation in the investigated areas. In particular, results obtained from the validation of reference sites in Piedmont and Sardinia together with the validation of river types in the study areas are presented. Procedure for the verification of reference sites according to the national Italian normative is briefly described. Such procedure has been allied to potential reference sites selected for INHABIT project. For what stream type validation is concerned, TWINSPAN analysis has been performed on biological data in order to identify groups of biocoenoses typical of the different types. Obtained groupings have been interpreted by means of a set of abiotic variables known to exert an influence on biocoenotic assemblages.

In relation to river reference sites validation 2 sites in the Po plain (HER 6) and 4 in the Western Alps (HER 1) were validated for Piedmont, together with 16 river sites for Sardinia. River type validation, considering benthic invertebrates communities, emphasized the need to define subtypes in Sardinia and confirms the general validity of hydroecoregion approach in Piedmont.

1. INTRODUCTION

The Water Framework Directive (WFD, 2000/60/EC, EC, 2000) and its related national regulations are key documents of European environmental and water management legislation. Among the innovative aspects to be considered for the implementation of EU normative and for the definition of freshwaters ecological status, the definition of water bodies typology and the selection of type-specific reference sites play a key role. In Italy, criteria for river types definition, included into Ministerial Decree 131/2008 (DM 131/2008), aim at defining homogeneous groups of rivers (i.e. river types) with limited natural variability within the single group. It is important to mention that several characteristics, acting at different spatial scales, concur in influencing biological communities (e.g. habitat availability, current velocity, substrate type etc.). It is generally acknowledged how physical habitat is particularly relevant for the definition of ecosystem functionality (Rabeni, 2000). Although habitat features play a key role in structuring aquatic biocoenoses, such features are rarely considered in ecological quality assessment systems and in stream types definition. It is also agreed how, in temporary rivers, the peculiar hydrological conditions exert a strong influence on abiotic processes and habitat conditions for biological communities (Meyer & Meyer, 2000). Such aspects emphasize the importance of collecting data dedicated to a clear definition of environmental features determining discontinuities in aquatic biocoenoses. This is particularly relevant in Mediterranean area, where unpredictability and variability of hydrological regime play an important role.

After the definition of the stream types, specific stream type reference sites should be selected. Selection and verification of reference sites is a key step in all the processes involving a comparison between observed and expected conditions. The activity carried on within INHABIT project has an important role in the verification, based on abiotic features, of reference status of potential reference sites in the two areas investigated in the project. The present work deals with two topics: in the first part a synthetic description of the process of rivers reference sites is provided, together with the results of the validation of reference sites selection in the two INHABIT areas. In the second part the result of the characterization of the stream types in terms of biotic community (i.e. benthic macroinvertebrates) is presented, with an account of the biological significance of the stream type groups and the influence of some habitat features in such assemblages.

2. CRITERIA FOR REFERENCE SITES VALIDATION AND SYNTHESIS OF RESULTS

2.1 Reference sites validation

Within INHABIT project potential reference sites selected in Sardinia and Piedmont has been verified according to the national procedure. Such procedure consists in a set of questions or 'criteria' to be addressed. Questions are related to pressures acting on sites at different spatial scale and are organized in a table ('check table') (Buffagni et al., 2008). As part of the process of reference sites validation, 'check tables' for Piedmont sites have been presented in Deliverable I1d1 (Erba et al., 2011) and 'check tables' for Sardinia sites are reported in Deliverable I1d4 (Erba et al., 2012a).

Validation process consists in the completion of the check table that includes 57 criteria, dedicated to the quantification of specific anthropic pressures. To each criterion a different weight is assigned according to its relevance: Necessary (IR: weight 1), Important (IM: weight 0.6) and Ancillary (AC: weight 0.2). To each criterion a reference threshold and a rejection threshold are set.

The first step of the testing process must assess if:

- more than 2 IR criteria fall above the rejection threshold
- more than 4 IR criteria fall above the reference threshold
- more than 3 IM criteria fall above the rejection threshold
- more than 6 IM criteria fall above the reference threshold

if one or more of the four statements are met, then the site cannot be considered as reference. If more than one criteria fall above any threshold, then the maximum allowed is 6 criteria above any threshold or 3 criteria above rejection threshold.

A score of 1, 0.5 or 0 is then assigned to each question if it falls, respectively, below the reference threshold, between the reference and the rejection threshold or above the rejection threshold. The assigned score is then multiplied by the relative weight. According to the type of alteration identified the questions are distinguished in 7 categories: Point source pollution (score A); Diffuse source pollution (score B); Riparian vegetation (score C); Morphological alterations (score D); Hydrological alterations (score E and F); Biological pressures (score G); Other pressures (score H). Partial scores obtained by summing up the questions within the same category are divided by the maximum possible score. Scores obtained from the single category are then mediated (weighted mean considering the number of questions per category) to obtain the final score. The total score of 0.9 is set as threshold for rejection.

Final results of reference sites validation, obtained with INHABIT project, have confirmed the reference status for 2 sites in Piedmont, Po plains Hydro-ecoregion (HER6) and 4 sites in HER1 Western Alps. In Sardinia, 16 reference sites have been confirmed, including both sites sampled within INHABIT project and sites investigated in previous projects but analysed during IHNABIT project.

Alongside the results derived from check tables compilation, values of habitat quality indices have been considered, i.e.: HMS, HQA, LUI and IQH (the latter being a cumulative index derived from the previous three). Such indices have been used in several analyses throughout the project and have been presented in some of the INHABIT project deliverables (Buffagni et al., 2010a; Cazzola et al., 2012). The comparison of the results of reference sites validation with habitat quality indices provides additional confirmation of the reference status of the sites on abiotic basis. According to Italian legislation (DM 280/10) 'high' status for IQH index is required for reference sites, with single indices forming IQH falling not below 'good' status.

For all considered reference sites values of habitat indices are consistent with the results of the validation process. All criteria are met (number of questions above the threshold and final score) and classification for all habitat indices correspond to 'high' status for all sites, with the exception of site Picocca ('good' status for HMS) and Mulargia Ref ('good' status for HQA).

2.2 Strength and weakness of typization

Among the objectives of INHABIT project there is the quantification of natural variability in aquatic biocoenoses, in order to improve the accuracy of classification of ecological status (see Erba et al., 2012a; b). The analyses dedicated to the evaluation of natural variability should be performed on reference sites, i.e. sites non affected by sources of variability caused by anthropic factors. However, it is common to experience the lack of availability of data from reference sites, in particular the amount of data can be scattered and not sufficient to guarantee sound analyses. Therefore, it is possible to include additional sites showing unimpaired biocoenoses although interested by a slight level of anthropic alteration. According to this approach, for Sardinian sites analyses have been undertaken on sites classified as 'high' or 'good' status considering the worst class according to indices HMS, HQA, LUIcara and LIMeco. For Piedmont sites analyses have been performed on sites classified as 'non at risk' according to regional Environment Agency (ARPA Piedmont).

Analyses have been performed by means of TWINSPAN (TWo-way INdicator SPecies Analysis, Hill & Šmilauer,2005) with the aim to identify groups of biocoenoses characterizing stream types (i.e. biological validation of stream types). For the interpretation of TWINSPAN tree, abiotic variables known to exert a strong influence on aquatic biocoenoses (e.g. Buffagni et al., 2009; 2010b) have been considered. Typological variables have been also included (DM 131/2008) in order to identify if biotic groupings could be related to differences in types. TWINSPAN trees reported in figures 1 and 2 present resulting groups of sites and indicator families for dichotomies, together with mean values for each groups for variables considered for tree interpretation. Figure 1 shows the results obtained for TWINSPAN analysis in Piedmont. In table 1 the number of samples considered is reported.

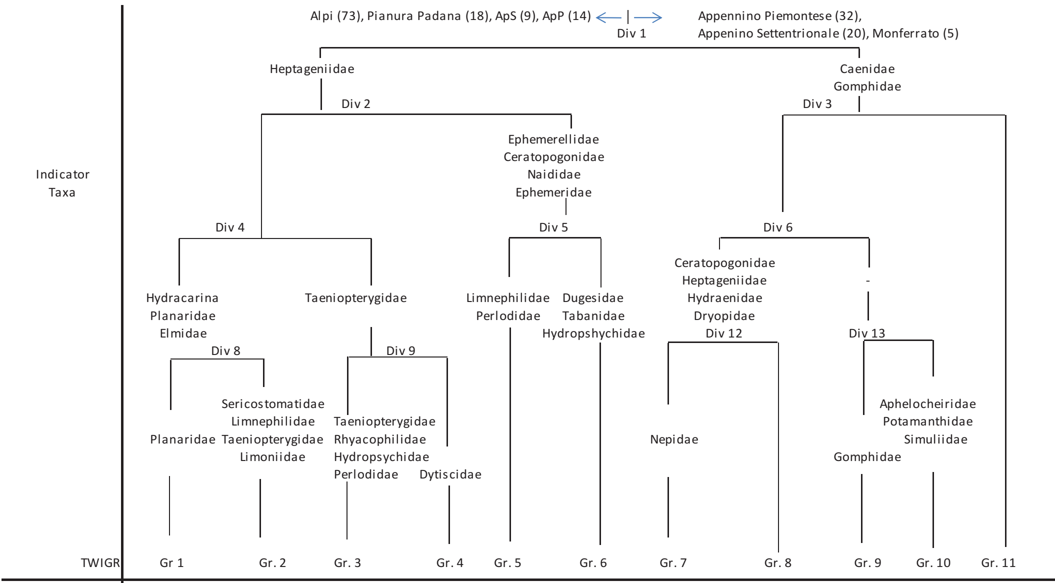
Tab. 1 - Number of samples considered for TWINSPAN analysis for Piedmont sites (data from ARPA Piedmont) and distribution in hydro-ecoregions (HER) and size classes (from Erba et al., 2012).

HER	Size classes				
	Very small (1)	Small (2)	Medium (3)	Large (4)	**TOT**
Western Alps (AlO)	18	27			**45**
Southern Alps (AlM)	10	12	6		**28**
Po Plains (PP)		18			**18**

Monferrato (MO)		2	3		**5**
Northern Apennine (ApS)	8	16	5		**29**
Piedmont Apennine (ApP)	10	10	23	3	**46**
TOT	**46**	**85**	**37**	**3**	**171**

The first dichotomy separates samples of Alps and Po plains from samples of Apennines and Monferrato, although, to a lesser extent, some of the Apennines samples get mixed with Alpine ones and become separated in subsequent dichotomies (Groups 3 and 4). In general, samples from Western Alps are well distinct from all other groups (Group 1), so are samples from Southern Alps (Group 2, where few samples from Western Alps and Po plains are also present). Within group 5 samples from Western Alps and Po plains are equally present; it is likely that this group includes Alpine samples showing feeble mountain features and sites from the plains with hilly characteristics. Group 6 includes samples predominantly from Olobbia river (Po plain) plus a few samples from the Apennines. Lastly, groups 8-10 comprehend sites from Northern Apennines and Piedmont Apennines, suggesting a non-significant distinction between these two HERs in terms of biotic assemblages.

Group 7 represents a particular case, separating 2 of the 5 samples from Monferrato HER. It is possible to infer that Monferrato should be considered as separated from all other HERs, although a sufficient amount of data to support such assumption is at present not available. As general remark, it is possible to notice how size classes have not resulted in being a useful element for groups separation, also considering samples distribution in the different classes of size, mostly belonging to class 1 and 2 (Very small and Small). In contrast, the distinction among different stream types for samples from Western Alps, Southern Alps and Po Plains appears to be relevant. Invertebrate assemblages appear similar for Apennines sites (Northern Apennine and Piedmont Apennine), suggesting the possibility of deriving common reference values for these areas



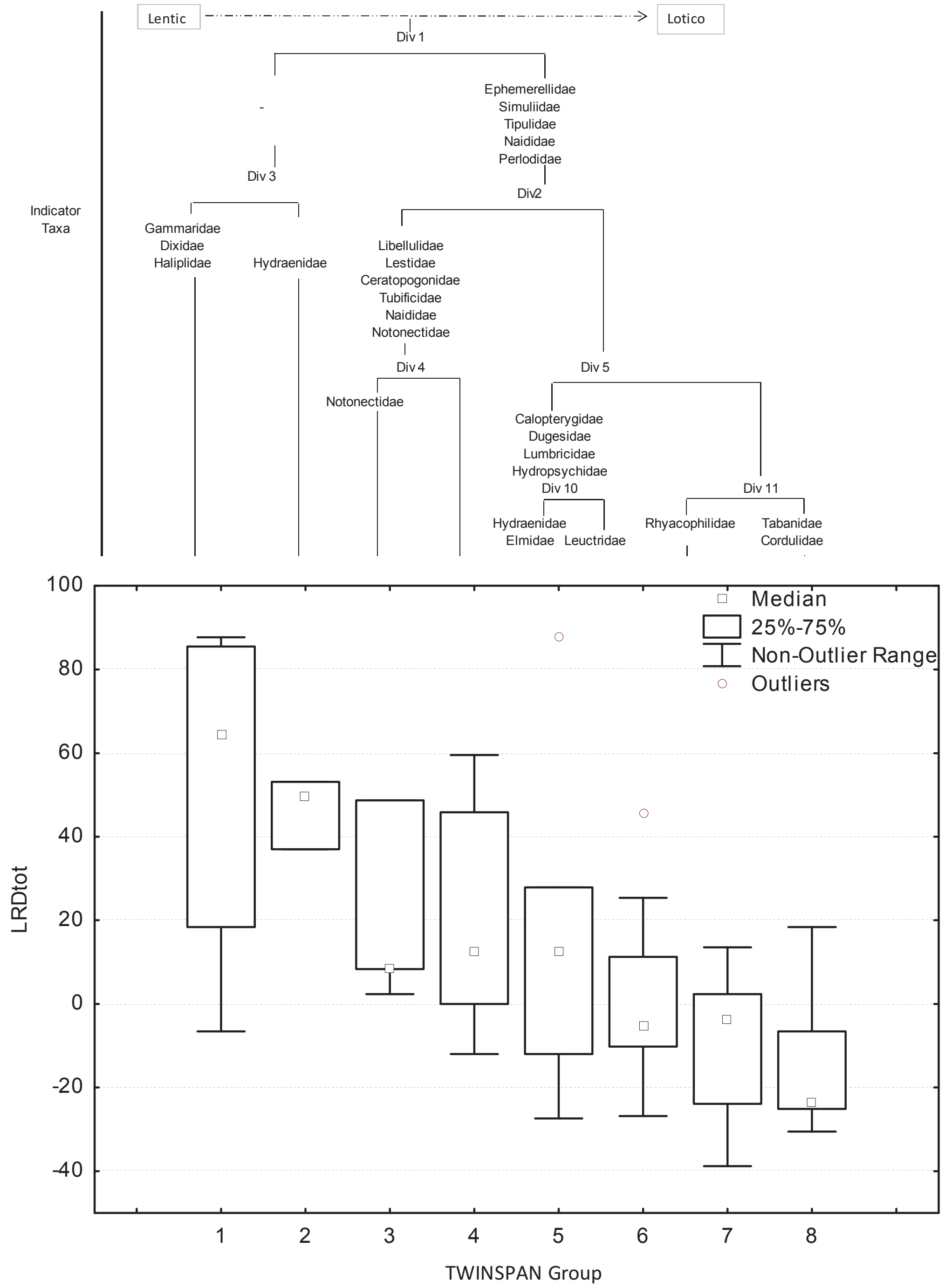
	Gr 1	Gr. 2	Gr. 3	Gr. 4	Gr. 5	Gr. 6	Gr. 7	Gr. 8	Gr. 9	Gr. 10	Gr. 11
n. of samples	37	21	17	6	19	14	2	32	8	16	Miseria (gen11)
HER	AlO	AlM	ApP e ApS	ApP	AlO e PP	PP (e AP)	MO	ApS e ApP	ApS e ApP	ApP	ApS
Orig. and dist. source	SS2; SS1	SS2, SS3	SS1, SS3	SS2, SS1	SS2	SS2	SS2	SS2, SS1, SS3	SS3	SS3	-
Temp. °C	9.5	9.3	4.9	6.2	9.8	10.7	19.5	14.1	18.4	14.4	-
Ca++ mg/l	13.5	32.4	48.2	68.5	10.7	36.1	125.0	66.5	52.6	49.9	-

Fig. 1 - TWINSPAN tree resulting from the analysis of Piedmont samples (data from ARPA Piedmont) classified as 'non at risk' and showing LIMeco class ≥ 'good'. Figure shows indicator families for dichotomies and mean values for group in the variables considered for tree interpretation. Abbreviations for HERs, origin and class of distance to source are reported in Table 1 (from Erba et al., 2012).

In Sardinia (Figure 2) the variable that better explains TWINSPAN biological groups is LRD (Lentic-Lotic character). This confirms results obtained in previous works (Buffagni et al., 2010b). Considering the dichotomies bounds, groups from 1 to 8 are ordered according to decreasing LRD values, i.e. from lentic to lotic samples. Within the different groups samples related to pool and riffle mesohabitats are also separate, in particular pool samples of very lotic sites result similar to riffles and, vice-versa, riffles from lentic sites can be similar to pool samples. While LRD result as a useful tool for the interpretation of the dichotomies, other variables can explain assemblages of some groups. In particular, dichotomy n. 5 can separate samples characterized by lower altitude (groups 5 and 6 with altitude < 100m asl) from samples of higher altitude (groups 5 and 6 with altitude > 200m asl). Dichotomy n. 10 seems to separate samples of sites characterized by wide channel from narrow channel sites. Within the groups, a gradient related to flow permanence appears is not apparent, at least according to regional typology, for samples from intermittent sites (IN) are mixed with ephemeral (EF) and perennial (SS and SR) sites.

3. CONCLUSIONS

- The activity carried out during INHABIT project has provided an important contribution to the process of verification of reference sites.
- In some circumstances, such as Sardinian watercourses, the opportunity arises for a third level typization, in order to take into account the influence of habitat features related to the water level and related hydrological descriptors.
- In general, a water body pertaining to a temporary type should be sampled in periods when the aquatic state (AS) is 'eurheic' (Gallart et al., 2012), in order to ensure the hydraulic connectivity among mesohabitats. Sampling of biocoenoses should always be coupled with an evaluation of habitat characteristics, also in terms of hydric state.
- In particular, lentic-lotic character, as defined by LRD descriptor, plays a primary role in the characterization of the freshwater ecosystem, resulting as the foremost driver for benthic community assemblages and observed environmental gradients.
- Analyses carried out in Piedmont generally confirm the soundness, form the biotic point of view (i.e. according to benthic invertebrates community), of the groups of types obtained through level 1 typization. At present, due to the scarcity of data, biological validity of level 2 typization cannot be confirmed, although some elements, such as the possible irrelevancy of stream size classes, have preliminary arisen.



		1	2	3	4	5	6	7	8
LRD		57.1	46.6	19.5	19.4	18	-0.3	-8.6	-17
Altitude	(m a. s. l.)	151.3	329.4	108	121.9	93	96.4	281	297
Dist from sour.	(km)	11.30	11.20	10.90	11.9	13	11.5	11	9.1
Chan. width	(m)	5.4	13.2	13.8	11.6	27	9.3	13	7.1
Flow regime		IN	IN	EF/IN	SS/IN/EF	IN	IN/EF	EF/IN/SS/SR	IN
Mesohabitat		Pool	Pool&Riffle	Pool	Pool	Riffle	Riffle	Riffle	Pool&Riffle

Fig. 2 - TWINSPAN tree resulting from the analysis of Sardina samples, not altered according to indices HMS, HQA, LUI and LIMeco. Figure shows indicator families for dichotomies and mean values for group in the variables considered for tree interpretation. Graph representing variability of LRD descriptor within TWINSPAN groups is also reported.

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D2D2.4 - ECOLOGICAL STATUS CLASSIFICATION FOR THE INHABIT PROJECT: SUMMARY OF RESULTS FOR RIVERS IN SARDINIA

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SUMMARY

The present document summarizes the results of the classification activity as carried out within INHABIT project. Results are about river sites investigated in Sardina region. Together with INHABIT sites, in order to extend the classification activity, an extra set of sites related to a former research project carried out in Sardinia by CNR-IRSA has been included. Classification activity consisted in the simultaneous application of quality assessment indices related to different environmental elements (macroinvertebrates, habitat conditions and level of pollution by nutrients and reduction in oxygen concentration) and it is intended to highlight the potential of the available data for the development of uncertainty assessment models. The results confirm the assumption of the project that envisaged the inclusion in the sampling plan of sites showing different grades of alteration in habitat conditions and the absence of water pollution. Lastly, an example of classification considering an alternative attribution of sampling sites to water bodies is presented, showing an high degree of variability in the classification results when one or more sites are selected for the inclusion into water bodies.

1. INTRODUCTION

MacrOper system (CNR-IRSA, 2007) was adopted by INHABIT project for sites classification according to benthic macroinvertebrates. The correct application of the system is crucial for a reliable sites classification. In the context of INHABIT project a group of supporting actions addressed to local monitoring authorities has been performed by CNR-IRSA with supervision by ISPRA. Actions were aimed at improving the comprehension of MacrOper application procedures. Some of the results of such activity have been presented during the I national workshop of INHABIT project. Other than benthic community, two other important aspects of the ecosystem have been considered in the investigated river sites: habitat features and water physiochemical characteristics. To each of these aspects a classification has been performed in all investigated sites. Within INHABIT project, 'D1' group of action is dedicated to demonstrate classification effectiveness on investigated sites and to highlight possible aspects related to uncertainty in classification. Such activity group develops one of the project key aspects, related to comprehension of the mechanisms influencing ecological status assessment. In addition to benthic macroinvertebrates, that MacrOper refers to, sites classification is also undertaken according to a set of environmental variables. Classification methods are in most of the cases new for Italy (DM 260/2010), their complete incorporation in monitoring plans being still in progress.
In the present paper classification results for considered environmental variables are presented for study sites in Sardinia. The contents of the present paper are presented more in detail in the deliverable D1d1 (Cazzola et al., 2012) where a thorough description of the indices used for classification can also be found. Results are about the first sampling campaign of May 2011; the result of the second field campaign (March 2013) will be presented

in the final INHABIT deliverables that will be available online by the end of the project.

2. INHABIT PROJECT CLASSIFICATION ACTIVITY

INHABIT activity group D1 aims at demonstrating the effectiveness of classification methods applied on study sites, emphasizing in particular any aspect related to uncertainty in classification. Such activities will develop one of the key aspects of the project related to the understanding of main factors influencing ecological status. In this second part of the paper, results from classification activities undertaken on Sardinian INHABIT sites are presented. Data included, in addition to INHABIT sites, a set of sites investigated in Sardinia in three seasons in 2004 for MICARI project (MIUR, 2002). Classification was performed according to the most up to date procedures, according to Italian national legislation and compliant with WFD, although it can be viewed as a 'pre-inhabit' classification approach, i.e. not taking into account the aspects of innovation identified by the project.
Provided classification is completely comparable to a formal classification. However, it is not among the aims of the activity (nor of INHABIT project itself) to provide an official classification of the investigated sites, as it intended to highlight possible problematic aspects of ecological quality definition, through the analysis of classification results. A more detailed discussion of the classification results is available in D1d1 deliverable (Cazzola et al., 2012, in Italian) or in the D1 results page on INHABIT website (www.life-inhabit.it).
Classification is performed according to a series of environmental variables, listed in table 1 together with considered quality indices.

Tab. 1 - Environmental variables and related indices considered for classification.

Environmental variables	Indices	Acronym
Macroinvertebrates	STAR Intercalibration Index	STAR_ICMi
Morphological alteration	Habitat Modification Score	HMS
Habitat quality/diversification	Habitat Quality Assessment	HQA
Land use alteration	Land Use Index	LUI
General habitat conditions	Index of Habitat Quality*	IQH*
Lentic-Lotic character	Lentic-Lotic River Descriptor	LRD
Water pollution (nutrients concentration and reduction in oxygen saturation)	Livello Inquinamento Macrodesctittori/eco	LIMeco

*: mean value of HMS, HQA and LUI (in EQR)

Classification results are reported in tables 2-5.

Tab. 2 – Classification related to habitat and chemico-physical aspects – INHABIT sites Sardinia. Water body code as defined by RAS (Sardinia Autonomous Region, CEDOC documentation, RAS, 2007) and geographic coordinates are reported for each site.

Cod	Sito	mese/ann	Codice ID CEDOC	Lat	Long	HMS valore	EQR	CL	HQA valore	EQR	CL	LUI valore	EQR	CL	IQH EQR	CL
S1	Barrastoni	05/11	0164-CF001000	41°6'37.30"N	9°13'44.22"E	2	0.98	1	50	0.83	1	0.501	0.987	1	0.932	1
S2	Liscia	05/11	0164-CF000102	41°4'52.64"N	9°17'12.73"E	2	0.98	1	55	0.936	1	0.89	0.977	1	0.964	1
S3	Cialdeniddu	05/11	ND	41°7'2.17"N	9°13'3.90"E	7	0.93	2	57	0.979	1	2.086	0.947	2	0.952	1
S4	Safaa Aglientu REF	05/11	0170-CS0001	41°9'31.61"N	9°10'16.64"E	0	1	1	70	1.255	1	0	1	1	1.085	1
S5	Sperandeu REF	05/11	0171-CF000100	41°8'51.25"N	9°8'9.31"E	3	0.97	1	49	0.809	1	0	1	1	0.926	1
S6	Baldu Monte Culvert	05/11	0164-CF000800	41°4'53.11"N	9°13'19.92"E	9	0.91	2	57	0.979	1	1.034	0.974	1	0.954	1
S7	Baldu Down Culvert	05/11	0164-CF000800	41°4'53.80"N	9°13'21.61"E	17	0.83	2	54	0.915	1	3.005	0.923	2	0.889	1
S8	Sud Limbara Terra Mala Valle	05/11	0177-CF002500	40°48'57.96"N	9°14'28.79"E	11	0.89	2	58	1	1	2.848	0.927	2	0.939	1
S9	Sud Limbara Terra Mala Ref REF	05/11	0177-CF002500	40°48'59.18"N	9°14'23.82"E	1	0.99	1	56	0.957	1	0.139	0.996	1	0.981	1
S10	Saserra REF	05/11	0115_CF000101	40°39'38.80"N	9°27'48.82"E	0	1	1	46	0.745	1	0	1	1	0.915	1
S11	Posada Valle Guado REF	05/11	0115_CF000102	40°39'11.12"N	9°30'9.65"E	0	1	1	62	1.085	1	0	1	1	1.028	1
S12	Lorana Monte	05/11	0102-CF003700	40°22'58.26"N	9°23'49.96"E	0	1	1	52	0.872	1	0	1	1	0.957	1
S13	Posada Affluente REF	05/11	0115-CF001400	40°38'40.15"N	9°35'34.95"E	0	1	1	50	0.83	1	0	1	1	0.943	1
S14	Rio San Giuseppe	05/11	0102-CF002600	40°23'47.08"N	9°28'52.50"E	51	0.49	4	29	0.383	3	4.373	0.888	2	0.587	3
S15	Lorana Multiculvert	05/11	0102-CF003700	40°22'27.98"N	9°23'57.52"E	43	0.57	4	46	0.745	1	1.45	0.963	1	0.759	2
S16	Cedrino Irgoli Affluente	05/11	0102-CF000200	40°24'18.79"N	9°38'21.06"E	42	0.58	3	44	0.702	1	9.832	0.749	2	0.677	2
S17	Flumineddu REF	05/11	0102-CF005500	40°13'0.41"N	9°31'6.89"E	0	1	1	61	1.087	1	0	1	1	1.029	1
S18	Corr'e Pruna Monte	05/11	0035-CF000200	39°17'27.53"N	9°31'37.63"E	51	0.49	4	34	0.489	2	11.02	0.719	3	0.566	3
S19	Corr'e Pruna Valle	05/11	0035-CF000200	39°17'44.63"N	9°31'40.84"E	45	0.55	4	36	0.532	2	8.923	0.772	2	0.618	2
S20	Corr'e Pruna Ponte	05/11	0035-CF000200	39°17'33.97"N	9°31'38.42"E	79	0.21	5	26	0.319	3	13.07	0.667	3	0.399	4
S21	Solanas	05/11	0016-CF000100	39°9'42.66"N	9°26'53.05"E	11	0.89	2	47	0.766	1	3.362	0.914	2	0.857	1
S22	Picocca REF	05/11	0035-CF000102	39°21'8.75"N	9°29'21.26"E	7	0.93	2	60	1.043	1	0.14	0.996	1	0.99	1
S23	Foddeddu	05/11	0073-CF000102	39°55'21.25"N	9°39'41.22"E	60	0.4	4	30	0.404	3	10.28	0.738	2	0.514	3
S24	Porceddu	05/11	0035-CF000400	39°19'38.25"N	9°31'24.25"E	28	0.72	3	42	0.66	1	4.353	0.889	2	0.756	2
S25	Museddu	05/11	0065-CS0001	39°46'34.68"N	9°38'52.13"E	57	0.43	4	32	0.447	3	4.48	0.886	2	0.588	3
S26	Canale Monte Depuratore	05/11	0067-CF000100	39°49'22.80"N	9°39'7.02"E	88	0.12	5	34	0.489	2	11.65	0.703	3	0.437	3
S27	E Gurue	05/11	0074-CF000102	40° 2'13.99"N	9°31'44.94"E	21	0.79	3	56	0.978	1	1.035	0.974	1	0.914	1
S28	Tirso REF	05/11	0222-CF000101	40°33'35.03"N	9°20'14.95"E	0	1	1	52	0.891	1	0.15	0.996	1	0.962	1

Tab. 3 – Classification related to habitat and chemico-physical aspects – MICARI sites Sardinia. Water body code as defined by RAS (Sardinia Autonomous Region, CEDOC documentation, RAS, 2007) and geographic coordinates are reported for each site.

						HMS			HQA			LUI			IQH	
Cod	Sito	mese/anno	Codice ID CEDOC	Lat	Long	valore	EQR	CL	valore	EQR	CL	valore	EQR	CL	EQR	CL
M1	Girasole Foce	02/04	0073-CF001802	39°57'48.79"N	09°39'26.01"E	44	0.56	4	40	0.617	2	1.78	0.955	1	0.711	2
M2	Girasole Foce	06/04	0073-CF001802	39°57'48.79"N	09°39'26.01"E	63	0.37	4	40	0.617	2	0.535	0.986	1	0.658	2
M3	Girasole Foce	08/04	0073-CF001802	39°57'48.79"N	09°39'26.01"E	67	0.33	4	43	0.681	1	0.773	0.98	1	0.664	2
M4	Mannu Valle	08/04	0001-CF000103	39°38'19''N	08°57'52''E	23	0.77	3	39	0.609	2	9.786	0.75	2	0.71	2
M5	Mannu Villamar	06/04	0001-CF000103	39°36'36''N	08°57'37''E	24	0.76	3	41	0.652	2	4.592	0.883	2	0.765	2
M6	Mirenu Condotta	02/04	0073-CF001802	39°57'26.11"N	09°37'3.70"E	45	0.55	4	45	0.723	1	2.626	0.933	2	0.735	2
M7	Mirenu Condotta Briglia	08/04	0073-CF001802	39°57'24.69"N	09°36'57.29"E	46	0.54	4	48	0.787	1	1.897	0.952	1	0.76	2
M8	Mirenu Monte Condotta	06/04	0073-CF001802	39°57'25.59"N	09°36'46.32"E	44	0.56	4	62	1.085	1	0.734	0.981	1	0.875	1
M9	Mulargia B - Autocampionatore	02/04	0039-CS0194	39°41'18.13"N	09°11'41.12"E	57	0.43	4	44	0.717	2	7.951	0.8	2	0.648	3
M10	Mulargia B - Autocampionatore	06/04	0039-CS0194	39°41'18.13"N	09°11'41.12"E	23	0.77	3	47	0.783	1	3.326	0.92	2	0.823	1
M11	Mulargia B - Autocampionatore	08/04	0039-CS0194	39°41'18.13"N	09°11'41.12"E	45	0.55	4	33	0.478	3	11.64	0.7	3	0.577	3
M12	Mulargia C - Guado Intermedio	08/04	0039-CF015401	39°39'10.00"N	09°10'27.27"E	13	0.87	2	55	0.957	1	2.323	0.94	2	0.923	1
M13	Mulargia C - Guado Monte	02/04	0039-CF015401	39°39'16.88"N	09°10'26.75"E	18	0.82	2	46	0.761	2	4.481	0.886	2	0.822	1
M14	Mulargia C - Guado Valle	06/04	0039-CF015401	39°39'4.50"N	09°10'22.85"E	0	1	1	50	0.848	1	0	1	1	0.949	1
M15	Mulargia D - Foce	02/04	0039-CF015401	39°38'33.09"N	09°11'19.47"E	11	0.89	2	61	1.087	1	1.578	0.96	1	0.979	1
M16	Mulargia D - Valle	08/04	0039-CF015401	39°38'34.78"N	09°11'27.98"E	9	0.91	2	53	0.913	1	0.247	0.994	1	0.939	1
M17	Mulargia D - Ponte Centralina	06/04	0039-CF015401	39°38'40.04"N	09°11'19.32"E	8	0.92	2	42	0.674	2	0.375	0.99	1	0.861	1
M18	Mulargia ref	02/04	0039-CS0186	39°39'1.21"N	09°10'6.59"E	0	1	1	58	1.022	1	0	1	1	1.007	1
M19	Mulargia ref	06/04	0039-CS0186	39°38'56.83"N	09°10'7.90"E	0	1	1	48	0.804	1	0	1	1	0.935	1
M20	Mulargia ref	08/04	0039-CS0186	39°39'1.21"N	09°10'6.59"E	0	1	1	29	0.391	3	0	1	1	0.797	2
M21	Oleandro ref	02/04	0073-CF001801	39°57'42.02"N	09°32'40.40"E	0	1	1	57	0.979	1	0	1	1	0.993	1
M22	Oleandro ref	06/04	0073-CF001801	39°57'42.02"N	09°32'40.40"E	0	1	1	57	0.979	1	0	1	1	0.993	1
M23	Oleandro ref	08/04	0073-CF001801	39°57'42.02"N	09°32'40.40"E	0	1	1	56	0.957	1	0	1	1	0.986	1
M24	Leni ref	06/04	0001-CF002800	39°25'57''N	08°40'40''E	1	0.99	1	69	1.234	1	0.145	1	1	1.073	1
M25	Pelau Ponte	08/04	0066-CF000102	39°48'11.49"N	09°35'39.95"E	10	0.9	2	55	0.957	1	4.323	0.89	2	0.916	1
M26	Su Corongiu Monte	06/04	0073-CF000102	39°54'58''N	09°36'34''E	0	1	1	50	0.83	1	0.467	0.988	1	0.939	1
M27	Su Corongiu Ponte	08/04	0073-CF000102	39°55'06''N	09°37'09''E	12	0.88	2	60	1.043	1	3.986	0.898	2	0.94	1
M28	Su Corongiu Valle	02/04	0073-CF000102	39°55'26''N	09°38'27''E	63	0.37	4	51	0.851	1	2.277	0.942	2	0.721	2
M29	Su Lernu Castagna	08/04	0129-CF002200	40°50'42''N	09°33'07''E	5	0.95	1	49	0.826	1	0.58	0.985	1	0.92	1
M30	Su Lernu Monte Padru	06/04	0129-CF002200	40°45'13.31"N	09°31'46.05"E	21	0.79	3	65	1.174	1	1.09	0.972	1	0.979	1
M31	Su Lernu ref	02/04	0129-CF002200	40°43'11''N	09°30'35''E	0	1	1	67	1.217	1	0	1	1	1.072	1
M32	Su Lernu ref	08/04	0129-CF002200	40°43'11''N	09°30'35''E	0	1	1	56	0.978	1	0	1	1	0.993	1
M33	Su Lernu ref	06/04	0129-CF002200	40°43'7.05"N	09°30'52.23"E	0	1	1	59	1.043	1	0	1	1	1.014	1
M34	Su Lernu Valle Padru	02/04	0129-CF002200	40°45'29''N	09°31'48''E	31	0.69	3	60	1.065	1	3.939	0.9	2	0.885	1
M35	S. Lucia Confluenza	02/04	0073-CF002100	39°57'9.52"N	09°36'12.46"E	14	0.86	2	57	1	1	3.36	0.914	2	0.925	1
M36	S. Lucia Ponte	08/04	0073-CF002100	39°57'9.52"N	09°36'12.46"E	26	0.74	3	58	1.022	1	0.878	0.978	1	0.913	1
M37	S. Lucia FFSS	06/04	0073-CF002100	39°57'9.52"N	09°36'12.46"E	14	0.86	2	62	1.109	1	1.615	0.959	1	0.976	1

Tab. 4 – Classification according to STAR_ICMi e LIMeco indices – INHABIT sites Sardinia.

		POOL		RIFFLE		TOT		LIMeco	
Cod	Sito	STAR_ICMi	CL	STAR_ICMi	CL	STAR_ICMi	CL	EQR	CL
S1	Barrastoni	1.015	1	1.014	1	1.015	1	0.688	1
S2	Liscia	1.121	1	0.98	1	1.051	1	1	1
S3	Cialdeniddu	0.851	2	0.712	3	0.782	2	0.625	2
S4	Safaa Aglientu REF	0.992	1	0.984	1	0.988	1	1	1
S5	Sperandeu REF	1.016	1	0.965	2	0.99	1	1	1
S6	Baldu Monte Culvert	1.092	1	1.091	1	1.091	1	0.875	1
S7	Baldu Down Culvert	0.929	2	0.913	2	0.921	2	0.875	1
S8	Sud Limbara Terra Mala Valle Ponte	0.954	2	0.764	2	0.859	2	1	1
S9	Sud Limbara Terra Mala Ref REF	1.024	1	0.798	2	0.911	2	1	1
S10	Saserra REF	1.153	1	1.152	1	1.152	1	1	1
S11	Posada Valle Guado REF	1.022	1	0.899	2	0.961	2	1	1
S12	Lorana Monte	1.114	1	1.039	1	1.077	1	0.656	2
S13	Posada Affluente REF	0.952	2	0.954	2	0.953	2	1	1
S14	Rio San Giuseppe	0.947	2	0.931	2	0.939	2	1	1
S15	Lorana Multiculvert	1.018	1	0.816	2	0.917	2	0.656	2
S16	Cedrino Irgoli Affluente	1.049	1	0.884	2	0.967	2	0.75	1
S17	Flumineddu REF	0.844	2	0.799	2	0.821	2	1	1
S18	Corr'e Pruna Monte	0.903	2	0.75	2	0.827	2	0.688	1
S19	Corr'e Pruna Valle	0.656	3	0.693	3	0.675	3	0.688	1
S20	Corr'e Pruna Ponte	0.867	2	0.627	3	0.747	2	1	1
S21	Solanas	0.812	2	0.88	2	0.846	2	0.875	1
S22	Picocca REF	1.237	1	1.001	1	1.119	1	1	1
S23	Foddeddu	0.802	2	0.714	3	0.758	2	0.625	2
S24	Porceddu	0.674	3	0.841	2	0.758	2	1	1
S25	Museddu	0.791	2	0.745	2	0.768	2	0.813	1
S26	Canale Monte Depuratore	0.628	3	0.56	3	0.594	3	0.625	2
S27	E Gurue	0.552	3	0.486	3	0.519	3	0.875	1
S28	Tirso REF	0.835	2	0.808	2	0.821	2	1	1

Tab. 5 - Classification according to STAR_ICMi e LIMeco indices – MICARI sites Sardinia.

Cod	Sito	mese/anno	POOL STAR_ICMi	CL	RIFFLE STAR_ICMi	CL	TOT STAR_ICMi	CL	LIMeco EQR	CL
M1	Girasole Foce	02-apr	0.55	3	0.633	3	0.592	3	1	1
M2	Girasole Foce	06-apr	0.623	3	0.658	3	0.641	3	0.875	1
M3	Girasole Foce	08-apr	0.793	2	0.605	3	0.699	3	0.656	2
M4	Mannu Valle	08-apr	0.417	4	0.385	4	0.401	4	0.469	3
M5	Mannu Villamar	06-apr	0.433	4	0.307	4	0.37	4	0.469	3
M6	Mirenu Condotta	02-apr	0.63	3	0.561	3	0.595	3	0.75	1
M7	Mirenu Condotta Briglia	08-apr	0.983	1	1.035	1	1.009	1	1	1
M8	Mirenu Monte Condotta	06-apr	0.769	2	0.675	3	0.722	3	0.75	1
M9	Mulargia B - Autocampionatore	02-apr	0.858	2	0.83	2	0.844	2	0.094	5
M10	Mulargia B - Autocampionatore	06-apr	0.786	2	0.658	3	0.722	3	0.531	2
M11	Mulargia B - Autocampionatore	08-apr	0.739	2	0.727	3	0.733	2	0.563	2
M12	Mulargia C - Guado Intermedio	08-apr	0.79	2	0.845	2	0.818	2	0.781	1
M13	Mulargia C - Guado Monte	02-apr	0.794	2	0.638	3	0.716	3	0.156	5
M14	Mulargia C - Guado Valle	06-apr	0.56	3	0.552	3	0.556	3	0.375	3
M15	Mulargia D - Foce	02-apr	0.64	3	0.607	3	0.623	3	0.219	4
M16	Mulargia D - Valle	08-apr	0.742	2	0.783	2	0.762	2	0.813	1
M17	Mulargia D - Ponte Centralina	06-apr	0.711	3	0.752	2	0.731	2	0.594	2
M18	Mulargia ref	02-apr	1.204	1	0.954	2	1.079	1	0.438	3
M19	Mulargia ref	06-apr	0.967	2	0.893	2	0.93	2	0.656	2
M20	Mulargia ref	08-apr	0.638	3	0.913	2	0.775	2	0.875	1
M21	Oleandro ref	02-apr	1.136	1	1.02	1	1.078	1	1	1
M22	Oleandro ref	06-apr	1	1	1.001	1	1	1	1	1
M23	Oleandro ref	08-apr	0.779	2	0.904	2	0.842	2	0.75	1
M24	Leni ref	06-apr	0.924	2	0.899	2	0.912	2	1	1
M25	Pelau Ponte	08-apr	0.881	2	0.803	2	0.842	2	0.781	1
M26	Su Corongiu Monte	06-apr	0.875	2	0.696	3	0.786	2	0.406	3
M27	Su Corongiu Ponte	08-apr	1.157	1	1.229	1	1.193	1	0.469	3
M28	Su Corongiu Valle	02-apr	0.768	2	0.774	2	0.771	2	0.219	4
M29	Su Lernu Castagna	08-apr	0.977	1	0.975	1	0.976	1	1	1
M30	Su Lernu Monte Padru	06-apr	1.154	1	1.101	1	1.128	1	0.688	1
M31	Su Lernu ref	02-apr	0.998	1	0.974	1	0.986	1	1	1
M32	Su Lernu ref	08-apr	0.816	2	1.109	2	0.962	2	0.781	1
M33	Su Lernu ref	06-apr	0.896	2	1.011	2	0.953	2	1	1
M34	Su Lernu Valle Padru	02-apr	1.106	1	0.981	1	1.044	1	0.688	1
M35	S. Lucia Confluenza	02-apr	1.045	1	1.172	1	1.109	1	0.688	1
M36	S. Lucia Ponte	08-apr	1.171	1	1.208	1	1.19	1	0.875	1
M37	S. Lucia FFSS	06-apr	0.971	1	0.974	1	0.973	1	0.75	1

Classification results confirm some of the requirements of the experimental plan, that has considered the selection of sites not affected by water pollution but showing morphological and habitat degradation to a wide range of extent. According to LIMeco index all sites fall in high or good status showing lack of relevant alteration of chemico-physical conditions. Habitat quality indices show an high variability, observed in particular for HMS index (morphological alteration). IQH index, calculated as EQR mean value of the three habitat indices, is a synthesis of habitat derived information, therefore it tends to uniform the classifications observed in the three single indices. Sites of MICARI project, which was based on different experimental assumptions from INHABIT projects, show an high variability in all quality indices, in particular HMS and LIMeco.

Comparing biological classification based on macrobenthic community through STAR_ICMi, a high concordance of results is observed in the two mesohabitats, pool and riffle. In more than 70% of the cases classes are coincident in the two mesohabitats. Where differences are observed it could be argued that different types of alteration impact differently on macrobenthic community of the two mesohabitats. Wilcoxon matched pairs test, run on pool and riffle samples of INHABIT sites, shows quality class of HQA and LUI indices coincident with class obtained for pool samples only, and quality class of HMS coincident with class obtained for riffle samples only.

An example in which the result of classification resulting from the possible inclusion in the monitoring plan of small or very small streams has been considered. The example considered alternative options for the attribution of the stream sites to one or more water bodies. Three classification options are considered, respectively including all the sites in one water body (option 0), in two water bodies (option 1) or three water bodies (option 2).

Results are showed in figure 1 and show an high variability in the classification according to all environmental variables, underlining how the selection of the site, or the sites, to be designated as representative of the water body plays a crucial role when planning activities are undertaken in RBMPs. In such step a quote of variability potentially much higher than the quote integral to classification method precision can be generate.

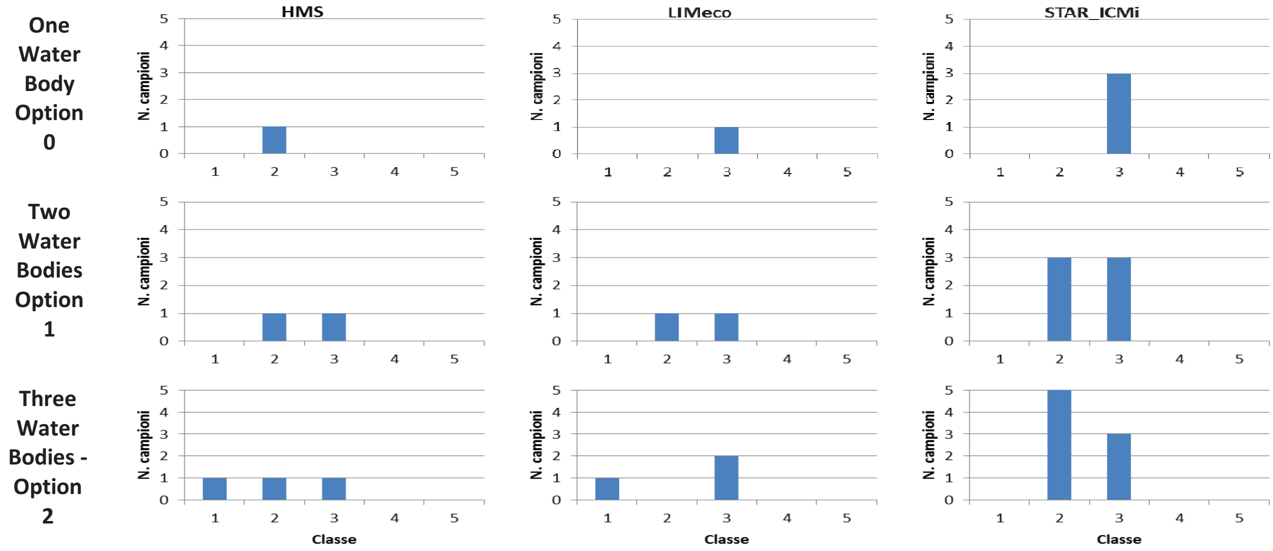

Fig. 1 - Distribution of samples in quality classes according to indices HMS (morphological alteration), LIMeco (nutrients pollution) and STAR_ICMi (benthic community) in three option of water bodies definition, i.e. Riu Mulargia considered as a single water body representative of its tributaries (option 0), Riu Mulargia separated from its tributaries (two water bodies, option 1) and Riu Mulargia separated from tributaries, these distinct in two more groups according to presence or absence of anthropic pressure in the basin (three water bodies, option 2) (from Cazzola et al., 2012).

3. CONCLUSIONI

- Among the key concepts of MacrOper system, the accordance to the method time schedule is particularly relevant. A series of activities must be carried out during the planning phase and expected conditions must be verified on the field.
- Some practical guidelines has been provided in order to properly carry out sampling and classification activities when mismatches between observed and expected conditions are experienced.
- Presented classification results give a synthetic outline of quality condition observed for INHABIT Sardinian sites. This activity represents one of the first simultaneous application of WFD compliant methods newly adopted by Italian legislation.
- Some of the prerequisites of INHABIT experimental plan has been confirmed, sites being not affected by significant water pollution but showing morphological and habitat degradation to a wide range of extent.
- Classification according to pool and riffle mesohabitats are generally coincident in considered sites (Sardinia). When this is not observed, a different sensitivity of the two mesohabitats to the type of alteration, especially with regard to the various aspects of quality of habitat, can be assumed.
- Variability in the classification results found between different sites within the same water body suggests the importance of a proper approach for selection of the sampling sites to be representative of the water body.

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D2D2.5 - NUTRIENTS REMOVAL EFFICIENCY IN TEMPORARY STREAMS: SUMMARY OF MAIN RESULTS

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SUMMARY

Nutrient retention is an important functional property of the aquatic ecosystems. It contributes to the definition of the ecological status and strongly relates to the improvement of water quality.
In order to investigate the relationships between nutrient retention, local hydro-morphology, habitat features and biological community, experiments of nutrient addition in selected river reaches in Piedmont and Sardinia were undertaken, as planned activity of INHABIT project. The obtained data, allowed to estimate some metrics describing nutrient retention efficiency and some hydrological parameters including the - so-called - transient storage zones, that are portions of the watercourse in which the most processes of hydrological nutrient retention occur.
Results show some significant relationships between retention metrics and hydro-morphologic characteristics. Retention efficiency for morphologically altered reaches was also assessed, indicating that the different level of specific alterations can affect more or less adversely the ability in retaining nutrients.

1. INTRODUCTION

Nutrient retention in rivers can be considered as the result of the interactions between hydrological, chemical and biological processes. The hydrological retention depends on hydromorphological stream features, such as discharge, presence of storage areas (e.g. pools, backwaters, dams, debris), channel substrate and channel section. All the mentioned features contribute in increasing water residence time. Any alteration in hydromorphology could have an influence on the exchange processes between sediment and surface water, through modifications in longitudinal and vertical connections and leading to a decrease in the stream nutrient retention efficiency. In general, hydromorphology controls the general conditions triggering the nutrient retention processes, while the biological activity determines the efficiency of nutrient removal (Stream Solute Workshop, 1990; Martí et al., 2006). In particular, nutrient retention characteristics in rivers are synthetized by a set of retention metrics, the most relevant being the so-called 'nutrient uptake length', expressed in meters, representing the overall retention efficiency.
Within INHABIT project we estimated such metrics from nutrient addition experiments. Such experiments were performed through the addition of a concentrated solution of nutrients, i.e. ammonium and orthophosphate, at constant flow, together with a conservative element, chloride, used as hydrological tracer for the estimation of dilution, dispersion and diffusion processes occurring in the watercourse.
Channel hydromorphology and habitat features have an indirect effect on nutrient uptake length, influencing the contact time of water with biochemically active substrates. In this sense, the 'transient storage zones', where biochemical processes are favoured, represent one of the most important parameters for the study of hydrological retention in a watercourse.

2. SITES SELECTION, METHODS AND SYNTHESIS OF RESULTS

2.1. Selection or river stretches

The experimental campaigns for the study of nutrient retention were carried out in 6 river sites in Piedmont belonging to the ‘small lowland river’ type (HER06) and 13 predominantly temporary-regime sites in Sardinia. Sites have been selected according to hydro-morphological and habitat features and alterations in order to cover a wide alteration gradient, from reference sites to heavily altered. Other criteria of selection were linked to the constraints of the selected method, that is applicable on small, not braided streams only, i.e. order I-II, with discharge ≤300 L/s.
Each selected site was characterized for both hydro-morphological and hydro-chemical aspects. A set of physical parameters such as width and depth of the channel were measured, flows and substrates were described and other investigations were made in order to characterize the hyporheic system. On the same sites, simultaneously with the nutrient addition, we applied CARAVAGGIO method and, with few exceptions, sampled macroinvertebrate community.

2.2. Short term nutrient addition

The methodology used to evaluate the nutrient retention dynamics in a watercourse is to increase the nutrient concentration and to subsequently measure its decrease downstream. The process includes the addition, by a peristaltic pump, of a concentrated solution of nitrogen and phosphorus salts at a constant flow, together with chloride as conservative hydrological tracer (Balestrini et al., 2010).
The experiment is performed on a river reach of about 100 meters. Along this distance 6 to 10 sampling points are positioned. In correspondence to the last downstream sampling point the variation of water conductivity, caused by the variations in concentration of the tracer, is measured by a conductivity meter. The collection of samples for the following analytical determination is performed in the "plateau" phase, i.e. when the conductivity is constant in time. This certify that the added solution is well mixed and omogenuosly distributed along the considered stretch.

2.3 Nutrient retention metrics

Three retention metrics for each nutrient have been calculated: i) nutrient uptake length, which indicates the overall nutrient retention efficiency, ii) nutrient uptake rate, which indicates the nutrient retention capacity and iii) nutrient uptake velocity, indicating the amount of nutrient requested by biological communities (Balestrini & Biazzi, 2012).
The calculation of the uptake length consists in comparing the pattern of the tracer and nutrient concentration along the experimental reach. Decreases in the tracer and nutrient concentrations at plateau will be proportionally similar if the considered nutrient is not retained along the reach so this decrease will only be due to physical phenomena such as advection, dispersion and/or dilution. On the other hand, if the decrease of nutrient concentration is higher than that of the tracer, it is possible to attribute this both to abiotic and biotic retention processes occurring within the reach.
Nutrient uptake length is the average distance travelled by a nutrient molecule before it is removed from the water column.
The uptake length is calculated as follows: the equation of the linear regression between reach length and the natural logarithm of the orthophosphate and chloride concentration ratio is calculated (Fig. 1). The angular coefficient – K – of the line represents the slope; the x values represent the distance of each sampling point from the addition point.

The negative inverse of K (- 1/K) represents the uptake length of a determined nutrient, expressed in meters. The smaller the distance (shorter uptake length), the greater the retention efficiency.

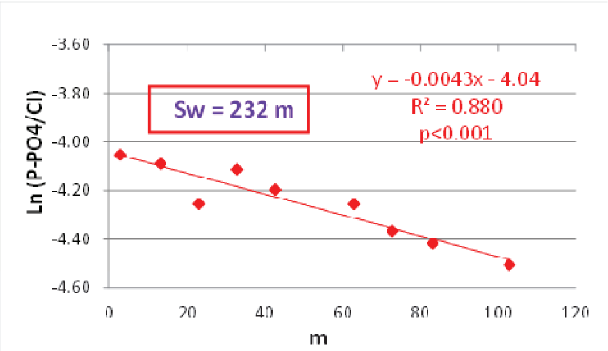


Fig. 1 - Graph of linear regression between reach length and the natural logarithm of the orthophosphate and chloride concentration ratio. The inverse of the slope of the straight line indicates the extent of uptake length in meters.

From the uptake length it is possible to calculate uptake rate and uptake velocity, metrics used to normalize the physical effects and so more appropriate to compare river reaches of different sizes.

2.4. Hydrological factors – "Transient storage zones"

Some important hydraulic parameters are obtained from the conductivity curv: water discharge, average, maximum and minimum water velocity, the cross sectional area 'A' and the cross sectional transient storage areas 'As'. The transient storage zones include areas of the channel where the water moves slower than the average surface velocity and include, for example, small pool or deep pools, areas with small eddies or vortices, side channels, areas with irregularities in the river bed, stagnant waters, debris dams and weirs (e.g. fallen logs in the water). The storage areas include the hyporheic zone, i.e. the sub-superficial portion of the river substrate where a continuous exchange between surface water and groundwater occurs.

The cumulative effects of these morphological features result in a delayed downstream nutrient transport, coupled with an increased residence time of the water within the river reach. These leads lastly to the exposure of a larger water portion to biochemically reactive areas and to the improvement of retention processes (Ensign & Doyle, 2006; Haggard et al., 2001).

Descriptive parameters of transient storage zones are calculated by comparing observed values (by continuous measurements of conductivity) with values simulated by mathematical models. For this reason the measure of conductivity every 5-10 seconds, from the beginning of the addition until the return to the initial concentrations, is necessary. The curve obtained from the conductivity values over time (Fig. 2) shows that the physical factors (e.g. advection, dispersion, dilution and interaction with areas with lower water velocity) affect the solute transport.

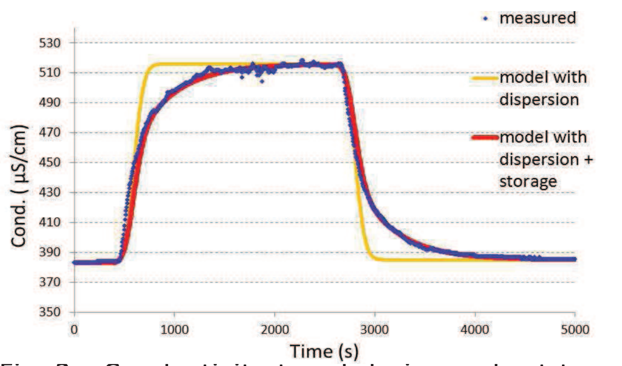


Fig. 2 - Conductivity trend during a short term addition experiment. The measured and the theoretical trends are represented.

To simulate the time response of a tracer in different sampling points of the reach, the model called OTIS (One-Dimensional Transport with Inflow and Storage - Runkel, 1998) has been used.

The model parameters, i.e. dispersion coefficient (D, m2 s-1), "transient storage cross sectional area" (As, m2) and "transient storage exchange coefficient" (α, s-1) are manually adjusted to obtain a curve comparable with the measured one.

Graphically, the effect of "storage zones" resides on the "shoulder" and the "tail" of the conductivity curve (Fig. 2). The exchange coefficient α is reflected, for example, in the initial shape of the shoulder and tail, while the area of the "storage areas" As is reflected in the slope with which the shoulder and tail approach the plateau or the background concentration.

In order to compare As between different river reaches, this parameter is normalized by the average cross sectional area of the river (A, m2), in order to obtain a As/A ratio.

The values of As/A are used to assess the relative importance of physical processes on solute transport and retention processes between different river ecosystems and to examine the relationships between these physical processes and the parameters related to nutrient retention.

Figure 3 shows the values of the cross sectional transient storage areas normalized to cross sectional area of the river in Sardinian sites.

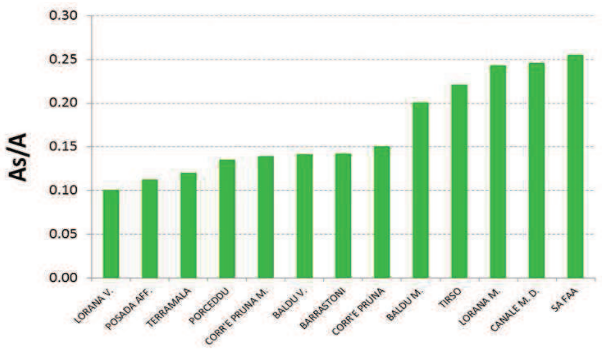


Fig. 3 - Values of As/A ratio of the Sardinian sites

Observed values between 0.10 and 0.26 indicate that hydrological retention processes are not negligible, in all river reaches considered. These values agree with a large number of other observations in the literature (e.g. Butturini & Sabater, 1999). The logarithmic correlation shows that the estimated values are inversely correlated with the discharge (Fig. 4).

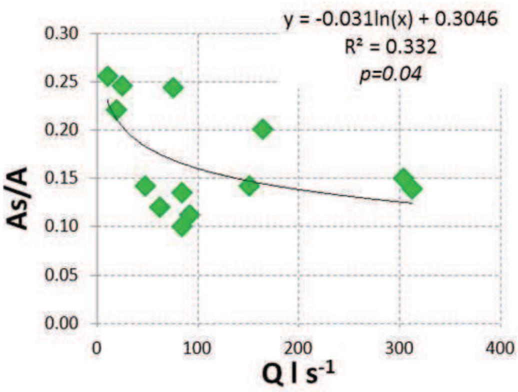


Fig. 4 - Correlation between As / A and discharge in the Sardinian sites

This suggests that the water residence time in the transient storage zones increases with decreasing discharge. In particular, this relationship seems to be more significant at lower discharges.

2.5. Results and discussion

The results for the nutrient retention metrics are shown below (Fig. 5, 6, 7).

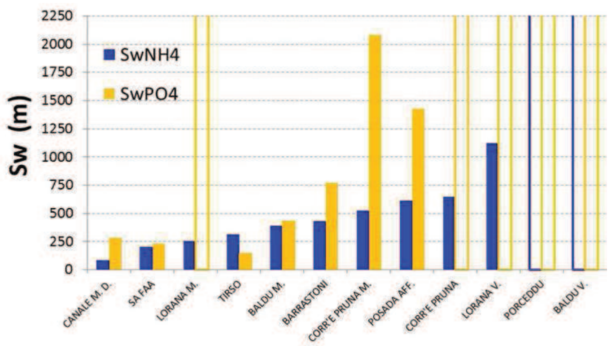


Fig. 5 - Values of uptake lenghts (Sw) of the Sardinian sites. The blank bars indicate that there is no retention.

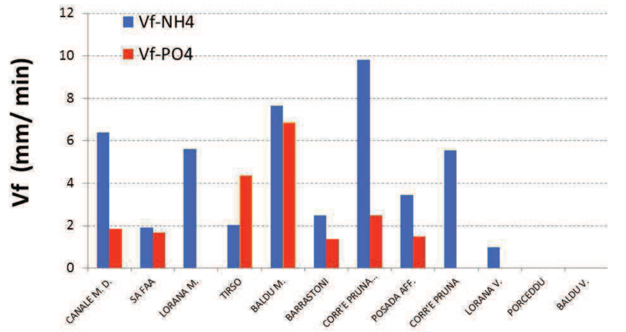


Fig. 6 - Values of mass transfer coefficients (Vf) of the Sardinian sites.

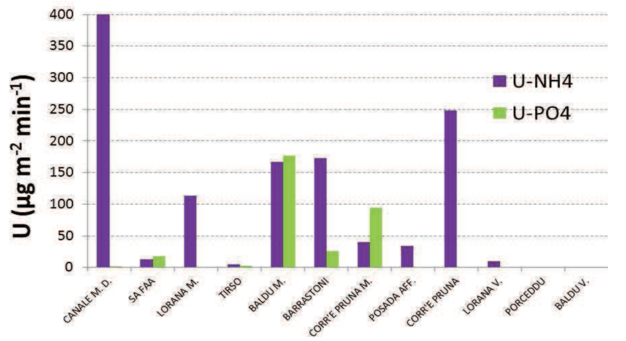
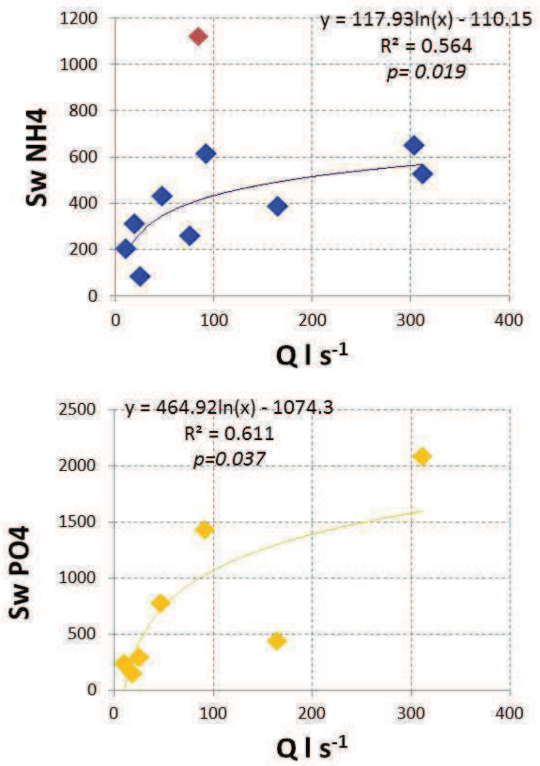


Fig. 7 - Values of uptake rates (U) of the Sardinian sites.

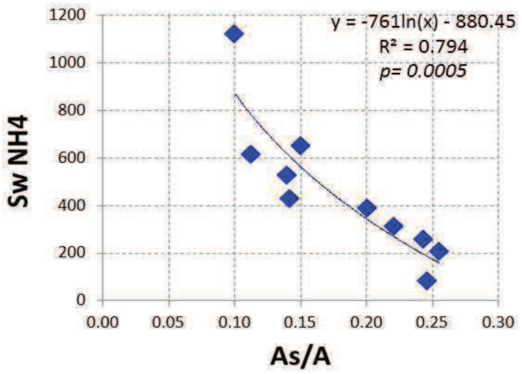
Uptake length values for ammonium calculated for sites in Sardinia range between 83 and 1120 meters, with two sites showing no retention. Values for orthophosphate are generally higher, ranging from 145 to 2083 meters, with 5 sites showing no retention for this nutrient.
The ammonium mass transfer coefficient (uptake velocity - Vf) is between 1 and 9.8 mm/min and it is higher than that of orthophosphate, which is between 1.4 and 4.4 mm/min.
Ammonium uptake rate is 5 to 1280 µg/m2 min, while orthophosphate values range from 1 to 177 µg/m2 min. In two river showing high base concentrations of orthophosphate, the uptake rate is greater for this nutrient. These results suggest that nitrogen is the limiting factor in the Sardinian sites.
For Sardinian sites a statistically significant relationship between the uptake length of both ammonium and orthophosphate and discharge (Fig. 8, 9) was also found.

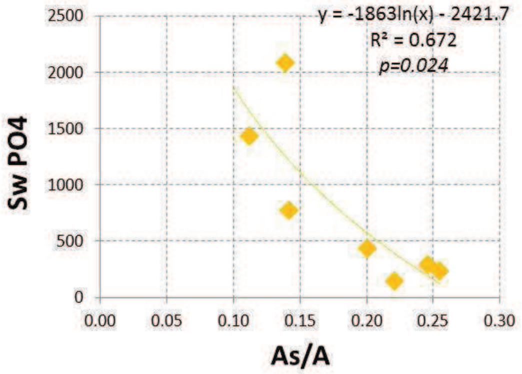


Figg. 8 e 9 - Correlations between ammonium and orthophosphate uptake lengths and discharge of Sardinian sites.

The graphs show that uptake lengths increase at increasing discharge, suggesting a lower retention efficiency. Low discharges support the adsorption to the sediment and the biological uptake, while high discharges determine the nutrient molecule to run higher distance before being removed from the water column.
A statistically significant relation was found between ammonium and orthophosphate uptake lengths and the As/A ratio (Fig 10,11) for the Sardinian sites. This finding indicates the importance of of the hydrological retention in the processes able to reduce the nutrient concentration, particularly NH4, in the rivers. The hydrological retention means a longer

contact time between sediment and water, condition favourable to the uptake processes.





Figg. 10 e 11 - Correlations between ammonium and orthophosphate uptake length and As/A ratio of the Sardinian sites.

No statistically significant relationships were found between the retention metrics and some indices extrapolated from CARAVAGGIO method.

It is worth noting that: i) the application of CARAVAGGIO method is carried out along a 500 meters reach which includes the 100 m reach considered in the nutrient addition experiment, and ii) the CARAVAGGIO derived the HMS (Habitat Modification Score) quantifying a number of alterations, including, as well, artifacts outside of the watercourse (e.g. bridges) not directly affecting processes occuring in water (Balestrini et al., 2012).

Among the Sardinian sites, “Lorana Valle” (culvert, cemented ford), “Corr'e Pruna” and “Canale Monte Depuratore” (channelization and concrete riverbed) showed the higher morphological alterations. In the former, riverbed was made up of pebbles cemented together and covered with a thin layer of periphyton. Periphyton growth has been favoured by the absence of riparian vegetation and, consequently, by strong solar radiation. Presence of periphyton may have improved nutrient retention processes especially for ammonium, although with low efficiency.

The results obtained for the “Canale Monte Depuratore”, where the higher ammonium retention efficiency (83 meters) and a good orthophosphate retention efficiency (286 m) were found, are more unexpected. In this site concrete channel modification presented fractures creating flow and substrate diversification. These conditions, combined with the absence of shading, have promoted algae and macrophytes growth, which are able to assimilate nitrogen and phosphorus transported during nutrient addition experiments.

In these sites the presence of transient storage zones is important, as shown by the high As/A ratio compared to the average of the other sites.

During the Sardinian experimental campaign, the assessment of nutrient retention focused on different reaches of the same river located upstream and downstream of a specific morphological alteration (fords, embankments, culverts). In “Rio Baldu”, a lower retention efficiency was measured downstream of the alteration (a culvert) for both nutrients. In “Rio Lorana”, we observed a difference of even an order of magnitude between the ammonium uptake length in the reach placed downstream of the alterations (1120 meters) compared to that placed upstream (258 meters).For PO_4 there is no retention in both reaches, as the high background concentrations of this nutrient may have saturated the whole system.

3. CONCLUSIONS

- The results suggest the importance of hydro-morphological factors in the nutrient retention.
- The transient storage zones magnitude is a key factor that can explain 70-80% of the ammonium and orthophosphate uptake length variability.
- The hydro-morphological alteration has a great impact on nutrient retention, reducing or eliminating the orthophosphate retention efficiency.
- Further investigation will be performed in order to assess the synergistic effect of multiple factors on nutrient retention. The application of statistical multivariate techniques on a larger data set, including more detailed information resulting from the application on micro-scale of CARAVAGGIO could provide useful information for this approach.
- Further efforts will be focussed to the quantification of microbial and vegetal community and shading and solar radiation.

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D2D2.6 - ANALYSING STREAM FLOW REGIME IN A TEMPORARY RIVER

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SUMMARY

In temporary streams the biological communities are commonly adapted to the occurrence of periods during which the streamflow is very low and the river channel is reduced to a series of pools or becomes completely dry. Their structure and composition varies on temporal changes of aquatic habitats. This paper presents the results of a study aiming at characterizing the hydrological regime of temporary rivers at reach scale and at analyzing the hydrological alterations due to anthropogenic pressures in the Salsola and Celone river basin (Puglia, SE Italy). In a first part, the method identify six classes of flow, the so called *Aquatic States (AS)*, which play a major role in determining the available mesohabitats and subsequently the characteristics of the aquatic life. The monthly frequency of occurrence of the identified *ASs* has been evaluated over a long time period (10-25 years) in order to characterize hydrological regime. In a second part, two indicators based on the statistics of the periods without flows were used, monthly flow permanence and dry season predictability, for describing the flow regime components which may have been altered by anthropogenic pressures. The indexes, which were computed in impacted and natural conditions for each reach, were used as coordinates in a plot to obtain a graphical vision of the regimes. The distance between the points representing the actual (impacted) and natural state in the plot were used to classify the hydrological alterations, in terms of the changes in the statistics of the zero flows periods.

1. INTRODUCTION

In Mediterranean region, rivers are characterized by extreme seasonal variations of flow (Latron et al., 2008; Oueslati et al., 2011) with a marked pattern of low flow and the reduction of the surface water into isolated pools along the river when the flow ceases (Argyroudi et al., 2009). As a result, an intermittent flow with a shifting between lotic and lentic conditions, which influences biotic composition, can be observed (Buffagni et al., 2009).

The Water Framework Directive (EC, 2000) recognizes the importance of hydrological regime and introduces the analysis of hydro-morphological aspects as supporting elements to classify the ecological status of a water body. However, although temporary rivers are quite common in the Mediterranean region, the basic principle of the Water Framework Directive have been developed mostly for perennial rivers (Nikolaidis et al., 2013). Whereas, for temporary rivers the ecological status assessment is more difficult to define and management strategy to restore a good ecological status have to be quite specific. This has been recently pointed out by the EU "MIRAGE" Project[1] (EU Project 7FP ENV 2007). Prat et al. (2013) propose a new method, the so called "The MIRAGE tool box" for assessing hydrological, ecological and physicochemical aspects in temporary rivers.

In this paper, we present the method aimed at characterizing the hydrological regime at reach scale, as described by Gallart et al. (2012), and at evaluating the hydrological alterations in terms of the changes in the statistics of the

[1] *MIRAGE is short for "**M**editerranean **I**ntermittent **R**iver Man**AGE**ment" (see http://www.mirage-project.eu/news.php).*

zero flows periods due to anthropogenic pressures in temporary rivers. Our purpose is to give biologists an overall assessment of regime that can contribute in planning the biological samplings and provide water resource managers an easy tool which could facilitate any investigation into the effects of hydrological modifications within the biotic composition in temporary rivers. The study area is the Salsola and Celone river basin, located in SE Italy.

2. MATERIAL AND METHODS

2.1 Study area

The research was conducted in the Salsola and Celone river basins, two subbasins of the Candelaro, located in the Apulia region in southern Italy (Figure 1). The drainage area is about 503 km^2 and 317 km^2, in that order for the Salsola and Celone basin. The main river courses have lengths of 60 km and 93 km, respectively. The average annual precipitation is about 630 mm. Rainfall is mostly concentrated in autumn and winter; it is unevenly distributed in space and most rainfall events are of high intensity and of short duration. The stream flow varies rapidly and follows the precipitation regime closely. The main economic activity in the plain area is intensive agriculture, the main farm products being durum wheat, tomatoes, sugar beet, olives, and vineyards. In the mountainous part of the basin, which is quite natural, forest lands and pasture are frequent. Water abstraction, point sources discharges (urban sewage) and a dam which was built in 2000 on the Celone river are the main hydrological pressures in the basin.

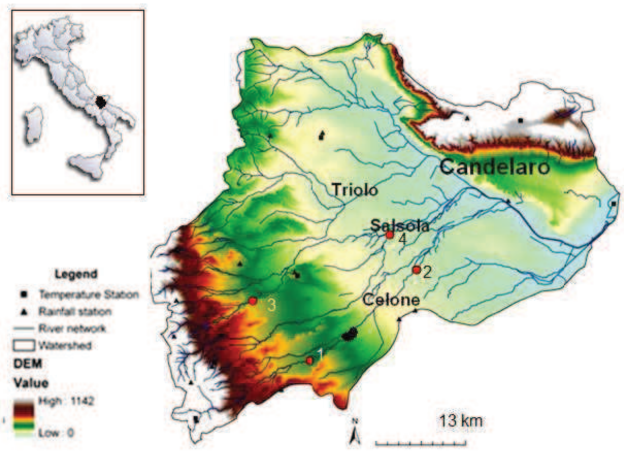


Fig. 1. Study area. Gauging stations: 1 (Celone S. Vincenzo); 2 (Celone P.te FG); 3 (Salsola Casanova); 4 (Salsola p.te FG).

2.2 Characterizing streamflow regime at reach scale

The ecological status of a river is assessed on the basis of the biological communities found in a stream reach. Several authors pointed out the importance of the hydrological conditions in the period during which the samples are done in temporary rivers (Garcia-Roger et al., 2011; Buffagni et al., 2010; Rieradevall et al., 1999; Buffagni et al., 2004). In their investigations they found that when only pools remain in a temporary reach the ecological quality may be excellent although the species composition being different from those in permanent rivers in reference conditions. Gallart et al. (2012) proposed a novel approach to analyzing the regimes of temporary streams in relation to their controls on the structure and composition of aquatic biota. They linked hydrological and ecological conditions and defined the sets of ecological relevant mesohabitats that can occur in a reach in a certain period depending on the hydrological conditions "*Aquatic States*" (ASs). They identified six classes of flow (ASs): *Hyperrheic* (High flow with movement of bed sediment), *Eurheic* (flow with abundant riffles where the river morphology allows their occurrence), *Oligorheic* (continuous slow flow with the presence of abundant connected pools), *Arheic* (flow close to zero with the presence of disconnected pools), *Hyporheic* (surface water is absent, there is only hyporheic flow), *Edaphic* (surface and hyporheic flow are zero). The two last ASs are usually resumed as *dry* condition because they are characterized by the lack of surface water.

In the present work, we tried to summarize all the ASs occurring in four reaches over a year depending on the hydrological conditions recorded over a long time period. The reaches are located near the gauging stations 1, 2, 3, 4 (figure 1). Table 1 summarizes gauging stations characteristics. Monthly streamflow data recorded in gauging stations 1, 3, 4 (from 1965 to 1996) and in the station 2 (from 2000 to 2010), were used to evaluate the statistics of occurrence of aquatic states. The threshold flow values between one AS to another, which depend on the river bed characteristics (i.e. substratum, shape, vegetation), were determined by using flow duration curves and through field observations.

Tab. 1. Gauging stations and data characteristics.

River	Gauge	Drainage Area (km^2)	Headwater elevation (m)	Period of record
Celone	1	85.8	188	1965-96
Celone	2	256	61	2000-10
Salsola	3	43	184	1965-91
Salsola	4	463	38	1965-96

2.3 Temporary Stream Regime (TSR) plot

The hydrological Status of a reach can be defined as a measure of the divergence between the Actual Status (AC) of hydrological regime, which can be altered by anthropogenic pressures, and its Natural Status (RC), which is defined as “Reference” condition. Several approaches have been developed in order to describe the flow regime (Poff et al., 1997) and a large number of indices were developed in attempts to characterize different component of hydrological regime (Richter et al., 1996), which can be evaluated in impacted status and in natural status, and to quantify the divergence between both. These indicators can describe all the aspects of a regime. However, because in the study area it is highly plausible that low flow components of hydrological regime have been altered by anthropogenic pressures, we analyzed only two metrics which describe the flow permanence and the dry seasonal predictability.

The two metrics (Gallart et al., 2012) are the relative annual number of months with flow (Mf) and the six months dry season predictability (Sd6) defined by the following equation (1):

$$Sd_6 = 1 - \left(\sum_1^6 Fd_i / \sum_1^6 Fd_j \right) \quad (1)$$

Where:

Fdi is the multiannual frequency of no-flow months for contiguous 6 wetter months per year and *Fdj* is the multiannual frequency of no-flow months for the 6 dryer months.

These metrics are based only on the statistics of the zero flow periods because the flow interruption is considered to be the most relevant feature controlling the aquatic fauna in a temporary stream. At the same time, their use offers two advantages: firstly, flow interruption is much easier to identify than flow values when inhabitants or technicians are to be interviewed in absence or paucity of data, and secondly, the zero flow condition is also easier to model than a range of flow if the simulated threshold flow value that corresponds to an actual zero flow can be identified.

We used the two above mentioned metrics as coordinates in a plot in order to have a graphical vision of the river types of the basin and as indicators for hydrological regime alterations. To achieve this, we evaluated the metrics in natural and impacted conditions for the studied reaches. The distance between the

points representing the actual (impacted) and natural state in the plot were used to classify the hydrological alterations, in terms of the changes in the statistics of the zero flows periods.
Measured streamflow data were used for calculating the metrics in impacted conditions (AC) and simulated flow values in the same river sections were used to calculate the metrics in natural conditions (RC).

2.4 Modelling streamflow

The SWAT2005 version with Arcgis interface (Winchell et al, 2007) was used in this study to simulate streamflow in natural conditions for the reach 1, 2, 3, 4 in Figure 1. The model is widely used to predict hydrological processes and the impact of point and non-point sources on waters (Arnold et al., 1998). For a comprehensive description of the streamflow modelling in the study area, input data, sensitivity analysis and uncertainty analysis refer to De Girolamo et al., (2013). The model was run on a daily time-step from January 1990 to December 2009, a time period over which only a few years of measured flow data were available. Hargreaves and Samani (1985) method was chosen to evaluate evapotranspiration and SCS Curve Number Method (USDA Soil Conservation Service, 1972) was selected to calculate surface runoff. The Salsola basin was divided into 18 sub-basins, and the Celone into 9 sub-basin. The model was calibrated and validated at the gauging station 1 and 4 (De Girolamo et al., 2013).

3. RESULTS

3.1 Streamflow regime: Aquatic State

Before evaluating the statistics of occurrence of the different flow statuses in a reach it is necessary to define the flow threshold values between one class to another. To achieve this we used the flow duration curves[2] and field measurements. In particular, the threshold value between *Hyperrheic* (flood) and *Eurheic* (riffle) flow status has been fixed as 10% of exceedance frequency of the flow duration curve, which was evaluated for each reach on monthly data as shown in Table 1. The threshold between *Eurheic* (riffle) and *Oligorheic* (connected pools) corresponds to the flex point in the flow duration curve graph. The threshold between Oligoreic and *Arheic* (disconnected pools) is quite difficult to define because it depends on the river section characteristics such as width, vegetation, substratum, and it requires field observations. Figure 2 and figure 3 represent the flow duration curves for the reaches located in vicinity of the gauges 1 and 3, respectively.
Table 2 summarizes the threshold values between the different Aquatic States for the studied reaches.

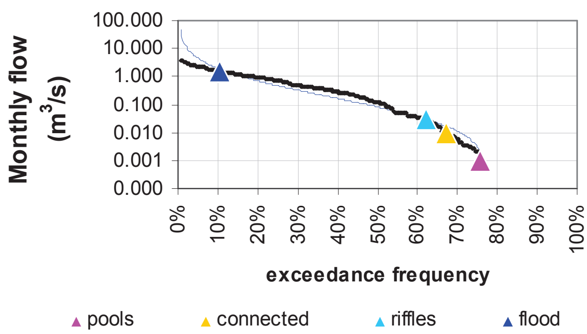


Fig. 2. Flow Duration curve and thresholds for the different quantitative flow status. Celone river reach 1.

[2] *Flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest.*

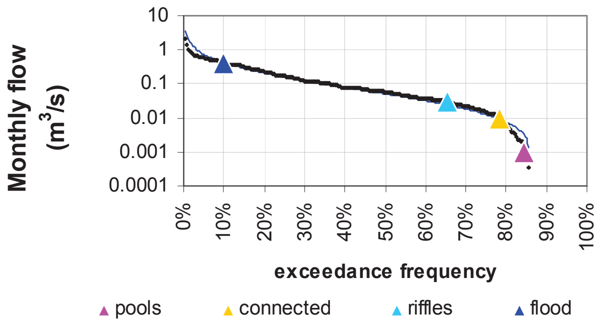


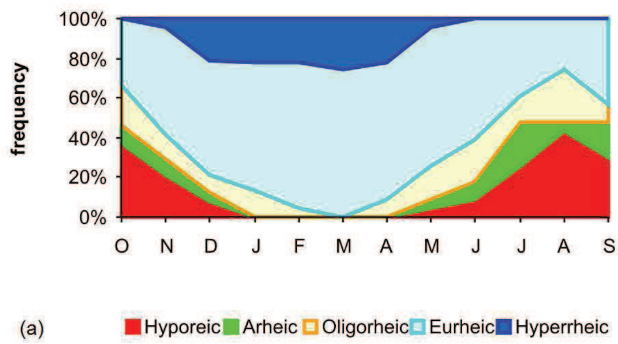
Fig. 3. Flow Duration curve and thresholds for the different quantitative flow status. Salsola river reach 3. In the graph, flood is for hyperheic, riffle for arheic, connected for oligorheic, and pool for arheic.

Tab. 2. Streamflow threshold values between different Aquatic States in each of the study reaches.

	Hyper.	Eurh.	Olig.	Arheic	Dry
Reach 1 Q (m^3s^{-1})	>1.6	>0.03	>0.01	>0.001	<0.001
Exc. Freq (%)	10	62	67	76	
Reach 2 Q (m^3s^{-1})	>2.1	>0.03	>0.015	>0.001	<0.001
Exc. Freq (%)	10	26.5	50	61	
Reach 3 Q (m^3s^{-1})	>0.4	>0.025	>0.008	>0.001	<0.001
Exc. Freq (%)	10	65	80	86	
Reach 4 Q (m^3s^{-1})	>4.00	>0.050	>0.015	0.001	<0.001
Exc. Freq (%)	10	90	95	98	

We assumed the threshold values between arheic and iporheic status related to reach 2 and reach 4, located downstream a dam and a waste water treatment plat (WWTP), respectively, to be the same as gauge 1 and 3, located upstream. In fact, the measures of the extreme low flow in these sections (2, 4) were not available when the monitoring was done (summer 2010, and summer 2011). Downstream the reservoir the Celone river was completely dry while the Salsola was perennial because of a WWTP inlet discharge.

Once the flow thresholds were determined, the relative frequencies of occurrence for each aquatic state was evaluated over the study period (Table 1). The results are shown in the Aquatic States Frequency Graphs (ASFGs) (figure 4 and figure 5). We ordered and cumulated the classes of flow to have a graphical representation of their temporal transition. As figure 4 shows, ASs are more or less the same in the reaches located in the upper part of the basin; from July to November, it has been recorded a high frequency of occurrence for Dry and Arheic conditions. These results suggest that biological samplings should be planned before june and after November when there is a high probability to find continuous flow into the river in these reaches.



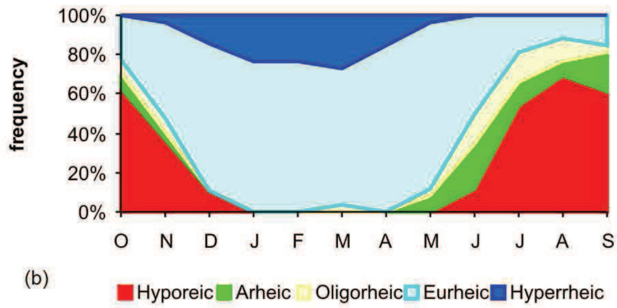


Fig. 4. Aquatic State Frequency Graphs. (a) Salsola reach 3; (b) Celone reach 1.

Figure 5 shows a different behavior in the two reaches located in the plain area. Reach 4 is generally permanent even if dry and oligorheic statuses might occur from June to September. Its natural regime changes on account of wastewater discharges. Reach 2 was completely dry from July to December each year over the period from 2000 to 2010, after the building of the reservoir.

The ASFGs give an overall of regime assessment, in addition, the graphs provide useful information which can contribute in schedule the biological samplings. However, it is important to take in mind that in some reaches, a high interannual variability in streamflow regime was recorded in terms of daily flow (max and min) and in terms of mean daily flow recorded over a spell of time of 3-7-30 and 90 consecutive days, as figure 6 shows. This means that the calendar of samplings need to be adapted year to year.

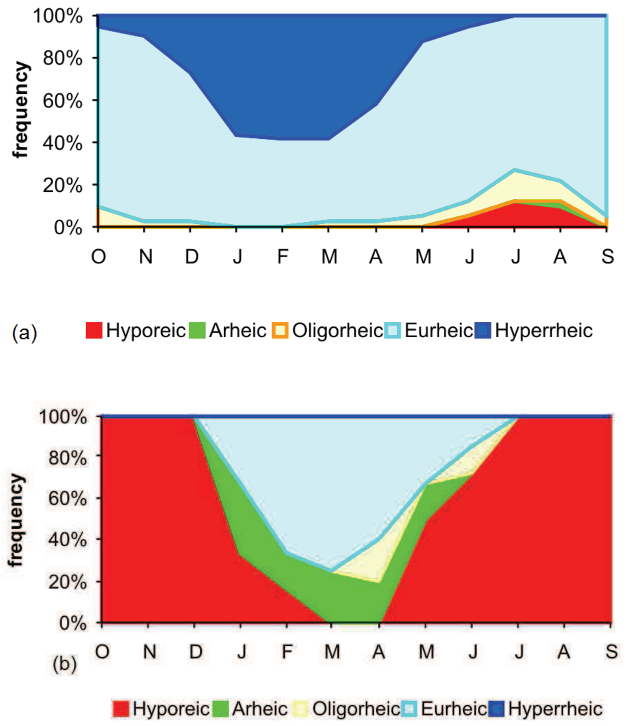


Fig. 5. Aquatic State Frequency Graphs. (a) Salsola reach 4; (b) Celone reach 2.

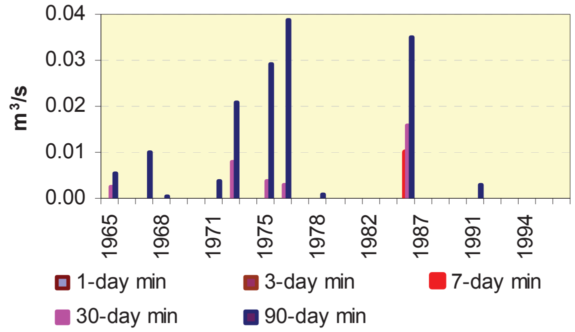


Fig. 6. Minimum flow recorded over 1-3-7-30-90 consecutive days at Celone reach 1.

3.2 Modelling streamflow

As stated above, we used a hydrological model to estimate monthly streamflow in natural conditions. The model was calibrated over the period 1990-92 (Fig. 7) at the gauging stations 1 and 4. The performance of the model simulations was evaluated by using the Nash and Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and correlation coefficient (R^2), which assumed the values summarized in Table 3. At the same gauging stations the model was validated over the period from 1995 to 1996. The NSE and R2 are satisfactory in both gauging stations.

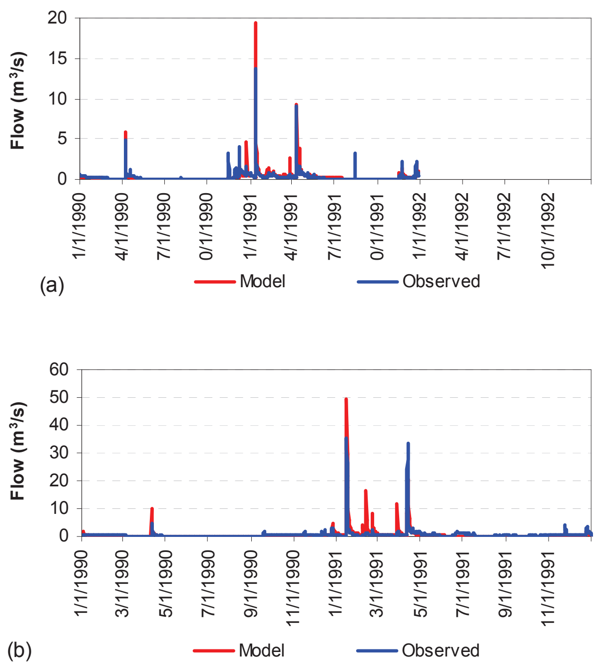


Fig. 7. Observed and simulated streamflow. (a) gauge 1; (b) gauge 4.

Tab. 3. Statistics of the model performances.

	Gauge	NSE	R^2	Period
Calibration	Reach 1	0.61	0.75	1992-94
Calibration	Reach 4	0.56	0.88	1992-94
Validation	Reach 1	0.41	0.77	1994-96
Validation	Reach 4	0.58	0.78	1994-96

The hydrological parameters used in the calibrated simulation are reported in De Girolamo et al., 2013. The SUFI-2 procedure, which was included into SWAT CUP 2009 version 4.3.9 (Abbaspour, 2011), was used to perform uncertainty analysis. We used the coefficient of determination R^2 multiplied by the coefficient of the regression line as objective function (bR^2). As figure 8 shows, the observed streamflow and the "best simulation" for unimpacted conditions were compared with the 95% prediction uncertainty (95PPU) for the reach 4, a large uncertainty interval was found during the dry period. On the other hand, several researchers pointed out the difficulties in simulating dry conditions for most of hydrological models (Kirkby et al, 2011). Because of the "no-flow" condition is a key point in the metric calculations, we identify a "Zero Flow" threshold as the simulated streamflow value that corresponds to actual dry conditions (no flow) in a reach (for more details refers to De Girolamo et al., 2013). The values are: 0.004m^3s^{-1} (reach 3); 0.011 m^3s^{-1} (reach 4); 0.055 m^3s^{-1} (reach 1); 0.065 m^3s^{-1} (reach 2).

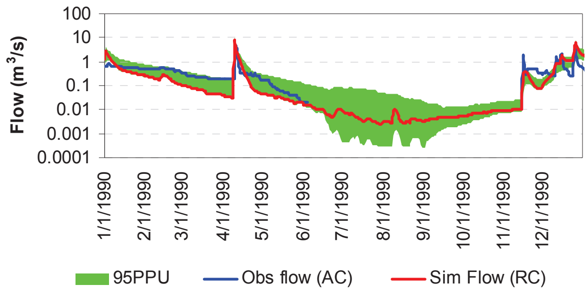


Fig. 8. Observed streamflow, simulated streamflow and the 95% uncertainty predictions (P-Factor = 0.28; R-Factor = 0.20) for the driest year (1990) on recorded at the Salsola reach 4.

3.3 Temporary Stream Regime plot and Hydrological Status Assessment

We represented the hydrological regime of the reaches in the Temporary Stream Regime (TSR) plot as points by using the metrics as coordinates, both in actual (impacted) and natural streamflow conditions (Fig. 9). We used measured streamflow for the actual conditions (impacted) and simulated values for the natural status.

The plot (Fig. 9) shows three separation lines between different regime types (red lines) as Gallart et al., (2012) identified in their research. Within the MIRAGE project four type of streams were defined in function of the controls imposed by the time pattern of occurrence of aquatic mesohabitat on biological communities.

- Permanent (P): the lack of flow is limited to a very short time period, hence it doesn't influence the biological communities.
- Intermittent-Pools (I-P) type: streamflow is discontinuous in dry season and only pools with impoverished communities remain. In these river type the biological sampling calendar needs to be adapted to hydrological regime.
- Intermittent-dry (I-D) type: the river dries out in summer. In wet season the

biological communities are similar to those of permanent rivers, but these may vary from year to year. For these river type the calendar have to be adapted to hydrological regime and biological quality assessment needs to be measured with specific metrics that could be slightly different from those used for permanent rivers.

- Ephemeral: flow are occasional and pools are short lived. Biological quality assessment needs other methods.

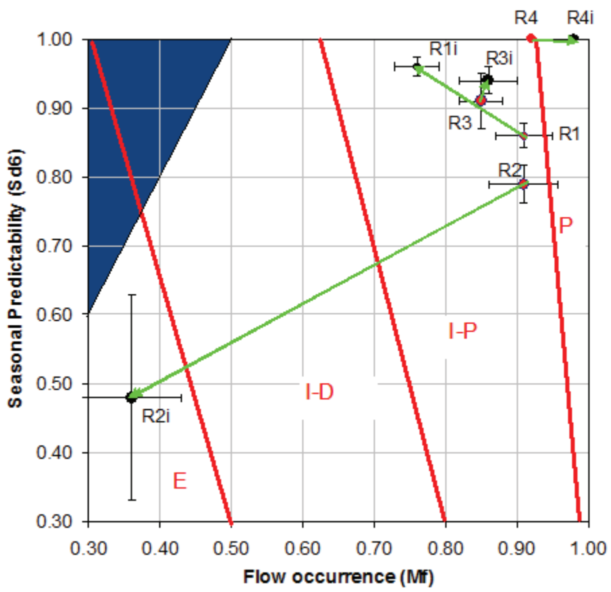


Fig. 9. Plot of interannual Sd6 versus Mf metrics in actual (black points) and natural conditions (red points). Error bars show the standard error.

In the plot, the points representing the river reach R1 and R2 in natural conditions are located on the right in the graph and when we calculate the metrics by using measured data, which include the impacts (water abstractions and reservoir), the points move from the right to the left (R1i and R2i). This means that a reduction in flow occurrence (Mf) was recorded in the actual status. The distance between the corresponding points in unimpacted and impacted conditions is an indicator of the hydrological regime alterations capturing a shift in flow permanence and dry season predictability. In this work, we differentiate only "critical" and "non-critical" flow status alterations, according as the river segment has changed its original classification or not. Hence, the hydrological alterations are critical for Reach 2, which was classified as an Intermittent Pool river in natural conditions while became Ephemeral after the dam was built.

Reach 3 and reach 4 move from the left to the right. For these reaches, inlet discharges which are higher than water abstractions changed their natural regime towards more permanent conditions. In this case, anthropogenic impacts might have a huge influence on water quality modifying chemical and physical parameter such as temperature, pH, BOD5, O2 N-NO3, N-NH4 and P-PO4. As a consequence, the autochthonous species may be substituted by other which can be invasive or of lower ecological value.

In natural conditions all the reaches are classified as Intermittent-Pool type. Nevertheless, a hydrological gradient exists for each river segments, therefore the regime which is defined as a point in the graph can vary from year to year and, when the climatic conditions are extreme, a transposition in flow type and hydrological regime can occur. Figure 10 shows the variability over the years of the two metrics for the reach 1 (in impacted conditions), the regime varies from Permanent to Intermittent-Dry.

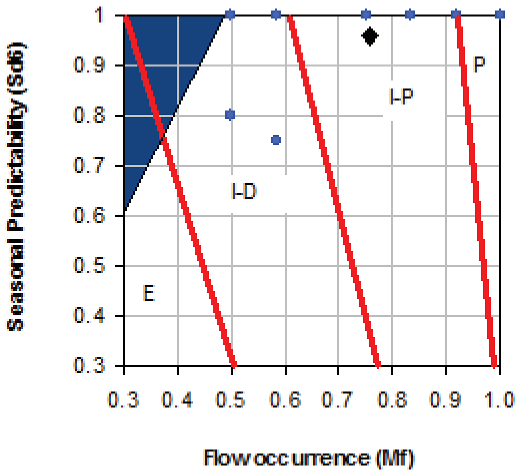


Fig. 10. Plot of annual Sd6 versus Mf metrics in actual conditions for the reach 1 in impacted conditions. Some points represent more than one year. The black point is the average value.

4. DISCUSSION AND CONCLUSIONS

The characterization of river types is an important step in the WFD implementation process. The main objective is to define sets of streams that are comparable in order to define the reference conditions. The classification proposed in MIRAGE project (Prat et al., 2013) and tested in this work is based on local conditions of streamflow. It differentiates the reaches where the flow can be not continuous in Intermittent Dry (I-D) and Intermittent Pool (I-P) and Ephemeral (E). In I-D and I-P rivers biological communities are similar to those of permanent rivers during the wet season, hence the ecological quality assessment can be done with the same methodology used in permanent rivers but the samplings needs to be adapted to the hydrological regime, while for ephemeral streams new methodologies are needed.
The graphs ASFGs show the frequency of occurrence of the Aquatic States in a reach over a long time period. Flows are naturally variable both in space and time in this catchment. Dry and disconnected pools statuses are very frequent and their duration varies both year to year and from reach to reach. The flow status frequency graphs can provide the right information on the stream regime to the Regional Environmental Agencies for setting and fixing the sampling schedule in large areas, where the rivers have a different character. However, in order to understand the relationship between the hydrological regime and communities development for giving a correct interpretation of biological samplings it should be studied the aquatic states occurred few months before biological samplings.
In the present paper, we also tested a method to evaluate hydrological status of a reach which is more easier than the most common approaches used to evaluate the degree of alteration of a stream (Richter et al., 1996; ISPRA, 2011). Because in temporary rivers the most ecologically relevant metrics are flow permanence and the predictability of the dry season (Gallart et al., 2012), the proposed approach analyzes the changes occurring in these factors only. At this purpose we compared the metrics in actual conditions and natural conditions by using measured and simulated streamflow, respectively. Although, a general problem in watershed modelling still to be solved is the common lack of measured data to calibrate and validate the model performances (De Girolamo and Lo Porto, 2012), hydrological models can be a valid support in many different phases of the WFD implementation process. The results of the present work demonstrate that the SWAT model was able to predict streamflow; although, extreme low flow conditions can constitute a critical point in temporary rivers.
In this work, we identified hydrological alterations as “critical” when a transition of hydrological class occurs. However, further studies are needed determining the relationship between flow alteration and ecological response in order to define more detailed hydrological alteration classes.

ACKNOWLEDGEMENTS
The authors gratefully acknowledge Giuseppe Amoruso from the Puglia Civil Protection Service for providing climatic and streamflow data. The authors are indebted to Gianni Niro from the Consorzio di Bonifica della Capitanata for providing data of water volumes released from the reservoir.

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D2D2.7 - ASSESMENT OF LAND EROSION TRENDS, SEDIMENT TRANSPORT BALANCE, ARTIFICIAL STRUCTURES AND RIVER LONGITUDINAL CONTINUITY IN SARDINIAN INHABIT STUDY AREAS

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1.INTRODUCTION

The work here conceived is finalized to the up-scaling of habitat information in catchment areas of the 40-45 sites for which river characteristics were surveyed following the CARAVAGGIO field protocol.

River management measures are usually defined at a basin scale and/or on the whole water course and habitat conditions unquestionably constitute the joining link with biological communities. Therefore, since actual relevance of measures and achievement of restoration objectives is largely based on assessment of biological elements i.e. through the definition of Ecological Status, it is necessary to configure a system able to relate CARAVAGGIO habitat data, which are site-scaled, with broader hydromorphological information, which is usually defined at a much greater scale. Thus, it would be possible to define a first information transfer between different landscape scales, so that CARAVAGGIO data can be used to extrapolate elements suitable to verify and strengthen catchment surveys. At the same time, under certain conditions (primary developed and rich geodatabase), focused land analysis could be used to extrapolate elements useful to infer on potential distribution of relevant bio-physical characteristics occurring along river networks.

The management of river ecosystems needs the development of tools and applications that provide analysis of trends and patterns at large scales. This study performs a large scale analysis on river networks of selected catchments of the Sardinian island looking at the amount and location of weirs and dams within the river network and pointing out their impact on river network structure. Slope and altitude longitudinal changes, tributary confluence effects, river lateral and longitudinal continuity will be also analyzed at the catchment scale. These analyses will be carried out using GIS tools that allow characterizing all river reaches within the river network.

The main objective of this study is to assess the possible effect that different artificial structures (dams and weirs) might have on Sardinia catchments through different approaches. This task will be carried out by performing a river network analysis in which we will characterize all river reaches according to the presence and proximity of human pressures and we will analyze river network characteristics.

2. MATERIAL AND METHODS

2.1 Study area

The study area comprises the Sardinian island, Italy (Fig. 1). The climate is Mediterranean, with an average annual rainfall < 500 mm occurring only in some areas located in the south of the island, and an average annual rainfall of 700-900 mm occurring in the inner hilly areas. Rainfall is concentrated in autumn and winter, while the summer is dry. The island's geology is dominated by granite, schist, trachyte, basalt, sandstone and dolomite limestone formations. Regarding land uses, Sardinian main land cover types are grassland and grazing land (almost 40% of the island's surface) and Mediterranean "macchia" (more than 20% of the surface). Hardwood forests cover almost 10% of total surface.

Sardinian landscape is quite mountainous, being the Gennargentu Ranges in the centre of the island one of the largest mountain chains (highest peak is Punta La Marmora: 1.834 m). Other mountain chains are Monte Limbara (1.362 m) in the northeast, the Chain of Marghine and Goceano (1.259 m), Monte Albo (1057 m), the Sette Fratelli Range in the southeast, and the Sulcis Mountains and the Monte Linas (1236 m). Overall, mountain terrains suppose 18.5% of the island surface, while hilly areas 67.9%, prevailing over the plains, just 13.6% of the island surface. The official river network is composed of 122392 river reaches comprising a total river length of 50148 km. This river network is mainly dominated by the main river axes within the island being the largest Tirso, 151 km long, which flows into the Sea of Sardinia, and the second and third largest the Flumendosa (127 km) and the Coghinas (115 km).

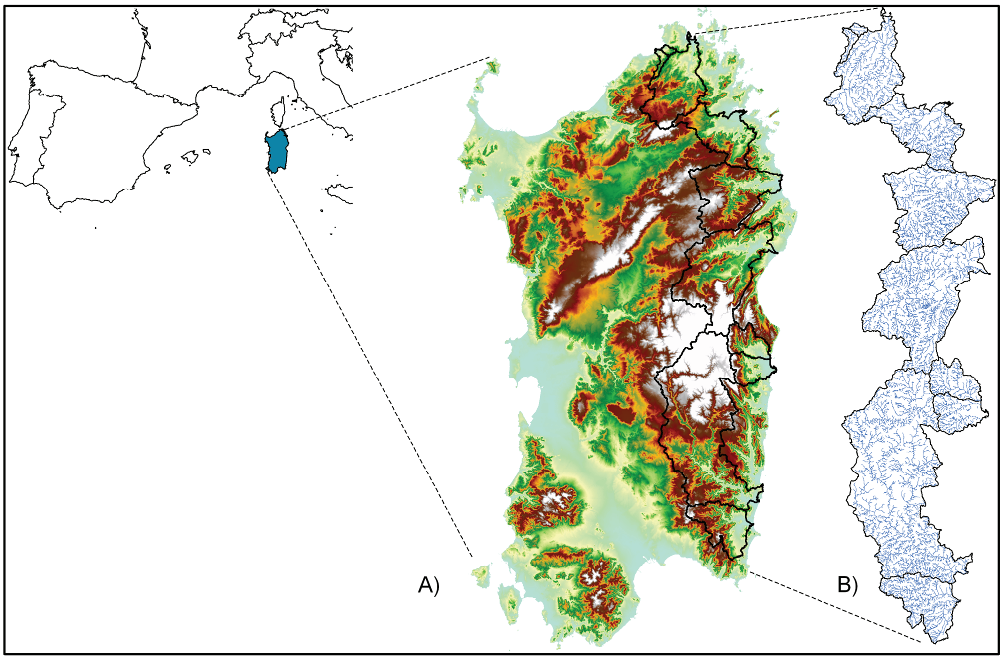

Figure 1. Image showing the location of the Sardinian island in Europe and the digital elevation model (A). The river network and the selected catchments for this study are also shown (B).

The selected catchments by CNR-IRSA to perform this study cover an area of almost 25% of the Sardinian island surface. These catchments are the following (Fig.1B):

- Cedrino catchment: 1078 km^2
- Faa catchment: 17 km^2
- Flumendosa catchment: 1850 km^2
- Foddeddu catchment: 179 km^2
- Liscia catchment: 570 km^2
- Padrogiano catchment: 445 km^2
- Paramaera catchment: 183 km^2
- Picocca catchment: 366 km^2
- Posada catchment: 708 km^2
- Sperandeu catchment: 30 km^2

2.2 Synthetic River Network, topographic and climatic variables

Synthetic river networks (SRNs) developed from Digital Elevation Models (DEM) (Fig. 2) can provide the proper spatial framework and hierarchical organization to sort out river ecosystem information (hydrological, geomorphological, water characteristics and biological) from the reach to the catchment level (Martz and Garbrecht 1998).

We used specific software packages (Buildgrids and Netrace) which are included in the 'NetMap' platform (Miller 2002; www.netmaptools.org) to obtain the Synthetic River Network (SRN) for the whole Sardinian island. The SRN was delineated using flow directions inferred from a DEM with 20 m spatial resolution (it was resampled from a DEM with 10 m spatial resolution due to computational limitations), using algorithms described by Clarke et al. (2008). We applied drainage enforcement in areas of lower relief (slope less than 50%) by reducing the elevation by ten meters of the current cells in the DEM using GIS data with actual locations of river channels to avoid that these cells act as sinks. The actual locations of river channels were derived from the official river network. Then, the river network was divided into reaches ranging from 400 to 800 m length and was also divided in tributary confluences, as these can cause significant morphological changes in the channel and floodplain (Benda et al. 2004). The rainfall data used were derived from a 250 meter resolution map and comprising a period of thirty years. DEM, rainfall data and official river network used as input layers were provided by CNR-IRSA. (Source data: Rainfall "ARPA SARDEGNA-Dipartimento Specialistico Regionale Idrometeoclimatico", DEM and official river network "RAS-Regione Autonoma della Sardegna").

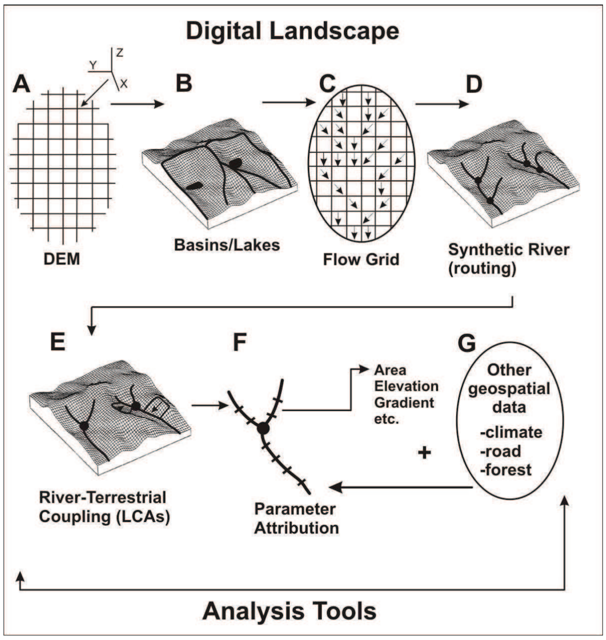

Figure 2. Schematic representation of how Synthetic River Networks were extracted from Digital Elevation Models. Figure taken from Benda et al. (In prep.)

Different variables were calculated using regional regressions developed elsewhere and not calibrated for the Sardinian island. We used these regressions to calculate Bankfull Depth (BFD), Bankfull Width (BFW) and Mean Annual Flow (MAF). These regressions were:

$$BFW = c1*A^{c2}*P^{c3}; \quad BFW = 1.68308*A^{0.436526}*P^{0.440865}$$

$$BFD = c1*A^{c2}*P^{c3}; \quad BFD = 0.63*A^{0.173158}*P^{0.151639}$$

$$MAF = c1*A^{c2}*P^{c3}; \quad MAF = 0.0165867*A^{1.01952}*P^{1.20835}$$

Where, A= Accumulated catchment area (km^2) and P= Mean annual precipitation (in mm).

Different topographic variables were derived from DEMs in combination with previous linear regressions. Climatic variables, such as rainfall were also calculated for the upstream catchment of each river segment using the tools described below for geological and land use variables. Moreover, the upper extent of the network and the resulting channel density (km km-2) was carefully defined using any of the available models which are based on factors that control channel upslope extension and density of resulting channels. There are a number of additional studies that could be consulted to get more specific information of how synthetic river networks could be extracted from DEMs and applications (e. g. Benda et al. 2011, Peñas et al. 2011, Fernandez et al. 2012). The parameters used as inputs in Buildgrids and Netrace are described in Annex I.

2.3 Geological data

The geological cartography used in this study was derived from the “Carta Geologica di base della Sardegna in scala 1:25.000 (2008)” in shapefile format provided by CNR-IRSA (Source data: “RAS-Regione Autonoma della Sardegna"). The initial categories of the geologic thematic map were reclassified into 11 general classes using ArcGIS software (ESRI 2011) and converted to raster. These categories are as follows:

CALC: Calcareous rocks
CLAY: Clay
CONG: Conglomerate rocks
SNDS: Sand
SDIM: Sedimentary rocks
SHLE: Shale (sedimentary)
SLIC: Siliceous rocks
SLTE: Slates
VLC: Volcanic rocks
WATR: Wetlands and water associated ecosystems
OTH: Other type of rocks

In addition to using this classification, three qualitative variables were calculated based on the physical properties of each lithological original class (not from the 11 classes above but from the original lithological classes). These variables were rock conductivity (COND), rock hardness (HARD), and terrain permeability (PERM). Conductivity, hardness and permeability take a relative value of 1 to 5, with 1 indicating a low value and 5 indicating a high value. More details of how these variables were derived can be found in (Snelder et al. 2008) and (Fernandez et al. 2012).

Afterwards, we calculated the surface occupied by each of all these variables (11 + 3 variables) upstream the river reach (MN), within the segment wings (LC) and within 200 m buffer (BF) of the river channel, except for COND, HARD and PERM (only average of these variables for LC y BF). All these calculations were done using extensions different from the NetMap platform.

2.4 Land cover data

The land-use cartographies used in this study are derived from the “Carta dell'Uso del Suolo-1:25.000 (2008)” in shapefile format provided by CNR-IRSA (Source data: “RAS-Regione Autonoma della Sardegna"). The initial categories of the land-use thematic map were reclassified into 10 general classes using ArcGIS software (ESRI 2011) and converted to raster. These categories are as follows:

AGR: Agricultural land
BLF: Broadleaf forest
CNF: Coniferous forest
DEN: Denuded areas
PAS: Pasture
PLT: Plantations
SSH: Moors, heathland, scrub and shrubs
UHD: Urban areas
WAE: Wetlands and water ecosystems
OTH: Other

Following, we calculated the surface occupied by each of these 10 variables upstream the river reach (MN), within the segment wings (LC) and within 200 m buffer (BF) of the river channel. All these calculations were done using different extensions from the NetMap platform.

2.5 Soil erosion data

Soil erosion (i.e. annual sediment yield) data used in this study were derived from the potential and actual soil erosion risk maps elaborated by Grimm et al. (2002) and provided from CNR-IRSA in a raster format (Source data: "Joint Research Centre-JRC-European Commission). Both maps with 250 m spatial resolution were resampled to 10 m. (See also Activity 1).

Following the same procedure as with geological and land cover data, we also calculated the average soil loss and potential soil loss upstream the river reach (MN), within the segment wings (LC) and within 200 m buffer (BF) of the river channel.

2.6 Delineation of inundation surfaces

It is important analyze the spatial variation on inundation-surfaces to better understand the organization of the fluvial landscape and its main controlling factors. To illustrate a wide range of flow inundation-valley topography relations in the selected basins, we delineated surfaces above the DEM-inferred channel using elevation equivalents of one, two, and three bankfull depths according to section 4.1.

2.7 Characterizing human impacts

Human impacts data used in this project were derived from the layers of dams, weirs and bridges provided for CNR-IRSA (Source data: "RAS-Regione Autonoma della Sardegna). These layers contain the geographical location of these pressures for Sardinia with different topology (dam and bridges "points" and weirs "lines").

To integrate the location of the pressures into the SRN, we performed the next procedure for each type of pressure:

Dams: Only dams located into the SRN were taken into account. Dams located in artificial channels or channels unrepresented in the SRN were eliminated. Because the points of the original layer do not intersect with the SRN, we used a visual analysis with the assistance of orthophotos and its location in the official river network to keep the above criteria. (Initial dams: 168; dams considered: 128).

Weirs: The entities classified as weirs in the original layer were converted to point geometry type, where each point characterizes a single weir because in some cases various lines were representing the same weir. Weirs located in artificial channels or channels unrepresented in the SRN were eliminated. Because the entities of the original layer do not intersect with the SRN, we followed the same procedure than with the dams (Initial entities classified as weir type: 455; weirs considered: 307).

Bridges: Due to the large number of bridges in the original layer (24103 points), in this case we could not carry out the same visual analysis performed with dams and weirs. In this case, we performed an analysis of proximity with the SRN. All points with a distance greater than 30 m from the SRN were eliminated. The final number of bridges considered was 13236.

From this initial information, we used ArcGIS software (ESRI 2011) and a variety of geoprocessing tools developed in Python by the Environmental Hydraulics Institute "IH Cantabria" to calculate different variables for the whole Sardinia SRN. The variables calculated for each pressure are as follows:

Distance from the considered river reach to the nearest downstream pressure.

Distance from the considered river reach to the nearest upstream pressure. In this case, because of computational limitations, the distance was limited to 5000 m.

Number of pressures upstream from the considered river reach.

Number of pressures in the considered river reach.

These variables were used to delimit which river reaches might be affected by the presence or proximity of a dam or weir. We supposed that a river reach was affected by dams when the distance upstream or downstream to the nearest dam was less than or equal 5000 m. In the case of weirs, this distance was limited to 1000 m because their effects are more remarkable at a lower spatial level (i.e. more local). We will comment only on the possible effects that these areas might have on river network morphology and structure.

2.8 River network analysis

River network analysis will be based on the description of slope and altitude longitudinal gradients, tributary confluence effects, local sediment yield from valley sides and variation on predicted floodplain widths for different flood stages. Among the 10 selected catchments a more detailed description will be performed for Posada, Flumendosa, Picoca and Cedrino catchments. This will be used as an example to illustrate river network analysis and to check how the presence of dams and weirs might impact river network characteristics.

3. RESULTS

3.1 Delineation of the SRN

The obtained SRN comprises 63364 river reaches with an average length of 433.5 m. The official river network comprises 122392 segments and it has an average length of 409.7 m. There are some differences between both river networks in relation to their extension. This difference is caused because SRN is not able to capture artificial channels, while the official river network provided does.

3.2 Characterizing human impacts

The length of river reaches that might be affected morphologically by dams is superior in small catchments areas (1020.34 km) decreasing with increasing catchment sizes (60.51 km for the largest catchment size class; Fig. 3). However, we find the contrary pattern if we take into account the percentage of affected river reaches for each catchment size class. Less than 5% of river reaches in small catchments might be morphologically affected by dams, while more than 30% of river reaches might be affected by dams in large drainage areas (Fig. 3). This trend is also similar in the case of weirs, although no weirs are located in river reaches draining the largest size catchment class (Fig. 3). These results illustrate the problem of longitudinal connectivity as the larger the drainage area of the river reach the more important (i.e. “more connected”) it is for upstream and downstream river network connectivity.

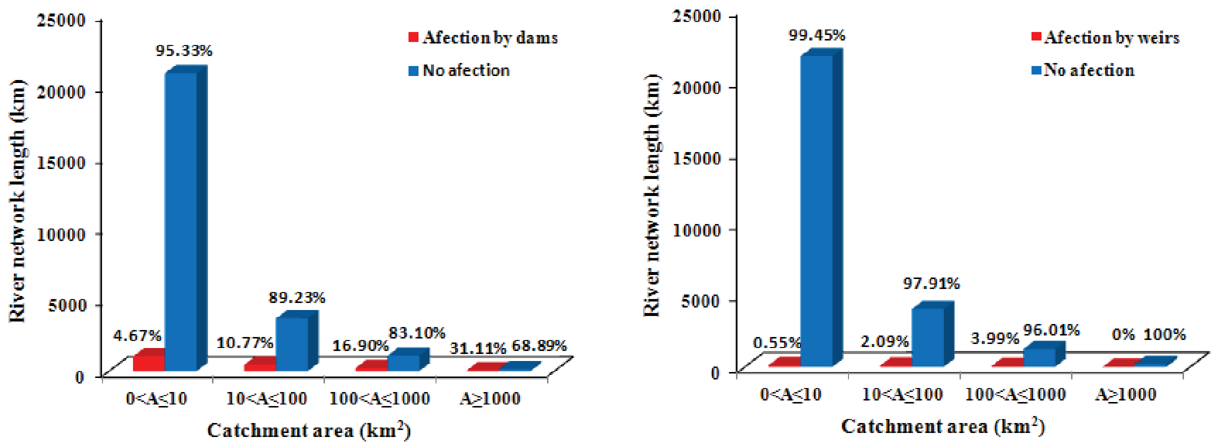

Figure 3. Accumulated river network length (km) according their affection by dams or weirs for different catchment area and percentage.

Taking into account the selected basins for Sardinia, the catchment with a larger accumulated river network length with possible morphological affection by dams was the Flumendosa basin with 218.36 km possibly affected. By contrast, Padrogiano, Faa, Pramaera and Sperandeu did not present any large dams (Fig 4). In the case of possible affection by weirs, only three of the selected basins presented affection by this human construction. The catchment with larger accumulated river network length possible affected was the Cedrino basin with 60.35 km, followed by Picocca basin (47.92 km) and Padrogiano basin (7.11 km).

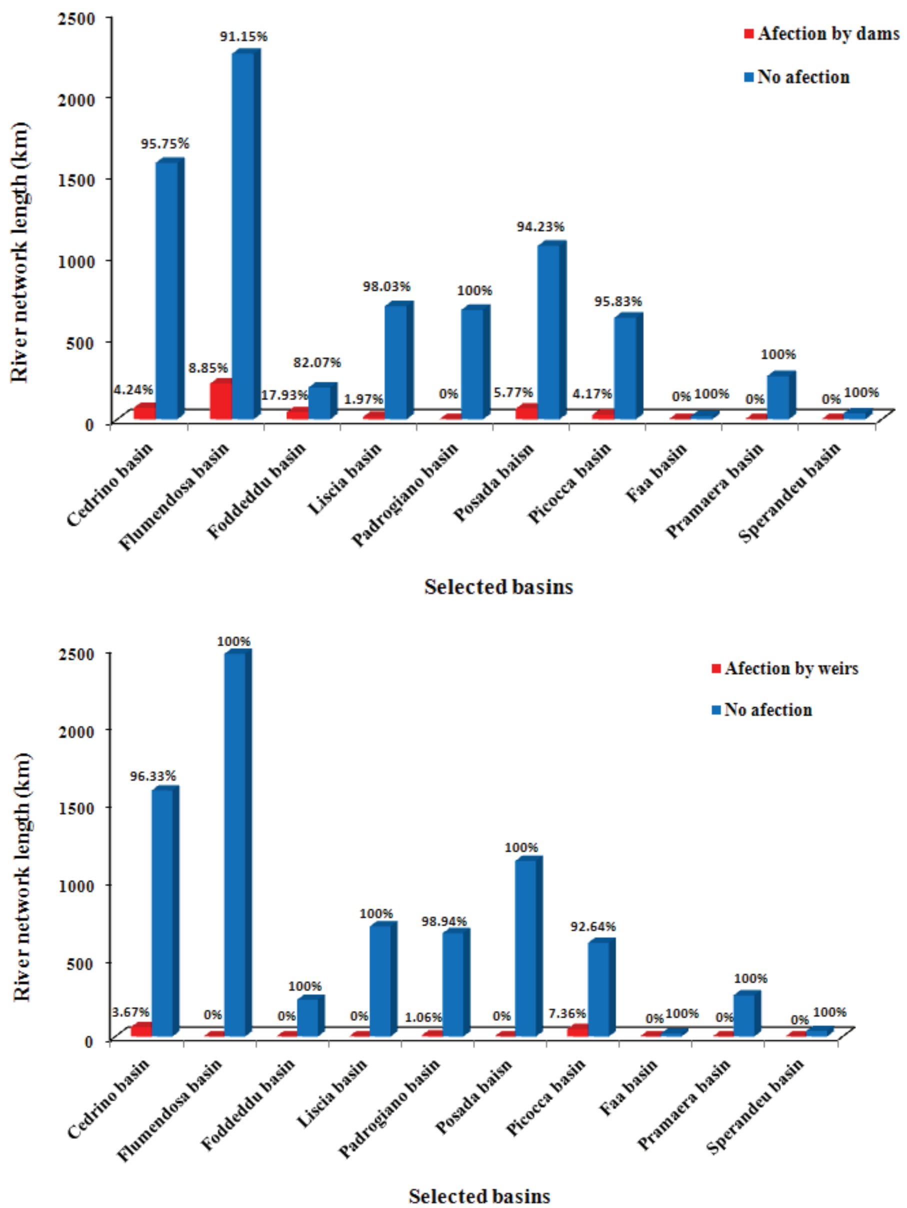

Figure 4. Accumulated river network length (km) according their affection by dams or weirs for selected basins and percentage.

3.3 River network analysis

The River network analysis performed in this study will be restricted to the Posada, Flumendosa, Picocca and Cedrino catchments. However, all variables have been calculated and represented in annexe II.

We will comment on the effects that certain dams and groups of weirs (Table 1) might have on river network structure within these Sardinian catchments.

Basin	Major fluvial axis	Number	Distance from mouth (km)	Description
Cedrino	A	1	13.64	Weir
Cedrino	A	2	23.27 - 41.6	Several weirs and a dam
Cedrino	A	3	55.26	Dam
Cedrino	B	1	0.8 - 9.62	Several weirs
Cedrino	B	2	18.08	Weir
Cedrino	B	3	27.68 - 28.40	Several weirs
Flumendosa	A	1	27.09	Dam
Flumendosa	A	2	38.19	Dam
Flumendosa	A	3	48.57	Confluences of a tributary with a dam
Flumendosa	A	4	57.26	Dam
Flumendosa	A	5	85.97	Confluences of a tributary with two dams
Flumendosa	A	6	133.32	Two dams
Flumendosa	B	1	27.76	Dam
Picocca	B	1	4.96	Weir
Picocca	B	2	5.57	Confluences of a tributary with several weirs
Picocca	B	3	8.93	Confluences of a tributary with several weirs
Picocca	B	4	10.46	Confluences of a tributary with several weirs
Posada	A	1	14.07	Dam
Posada	A	2	27.32 - 30.73	Two dams

Table 1. Description of dams and weirs located in the major fluvial axis of the selected basins.

Posada Catchment

The Posada basin drains almost 700 km^2 and could be divided in two major fluvial axes with a length of 80 and 30 km (Major fluvial axis A and B, respectively). This catchment has estimated channel gradients ranging from greater than 6% in the headwaters to less than 1% through broad-valley segments downstream (Annex II, page 72). The highest altitude river reach in the major fluvial axis is located at approximately 900 m. Wide fluvial landscapes (200–500 m) are predicted to occur within river kilometre (K) 0 to 8, although with considerable differences in surface area between one and two bankfull depths (Annex II, page 72). The differences among these surfaces evidences the many flood defence structures present in the lower part of the basin. Although we cannot link the different surfaces to any flood event because we do not have regional regressions, we can approximate that 50 to 100 year flood events are severely restricted in this lower part.

Following upstream within the major fluvial axis, at k15 we find a large dam (Sector 1, Fig. 5) that modifies completely the natural pattern of floodplain widths. A bit further up (K25) it is remarkable the junction among the two main catchment tributaries, increasing the probability of finding tributary effects (i.e. wider floodplains, side channels, mid channel bars, meanders, terraces, log jams, deeper pools and changes in substrate composition).

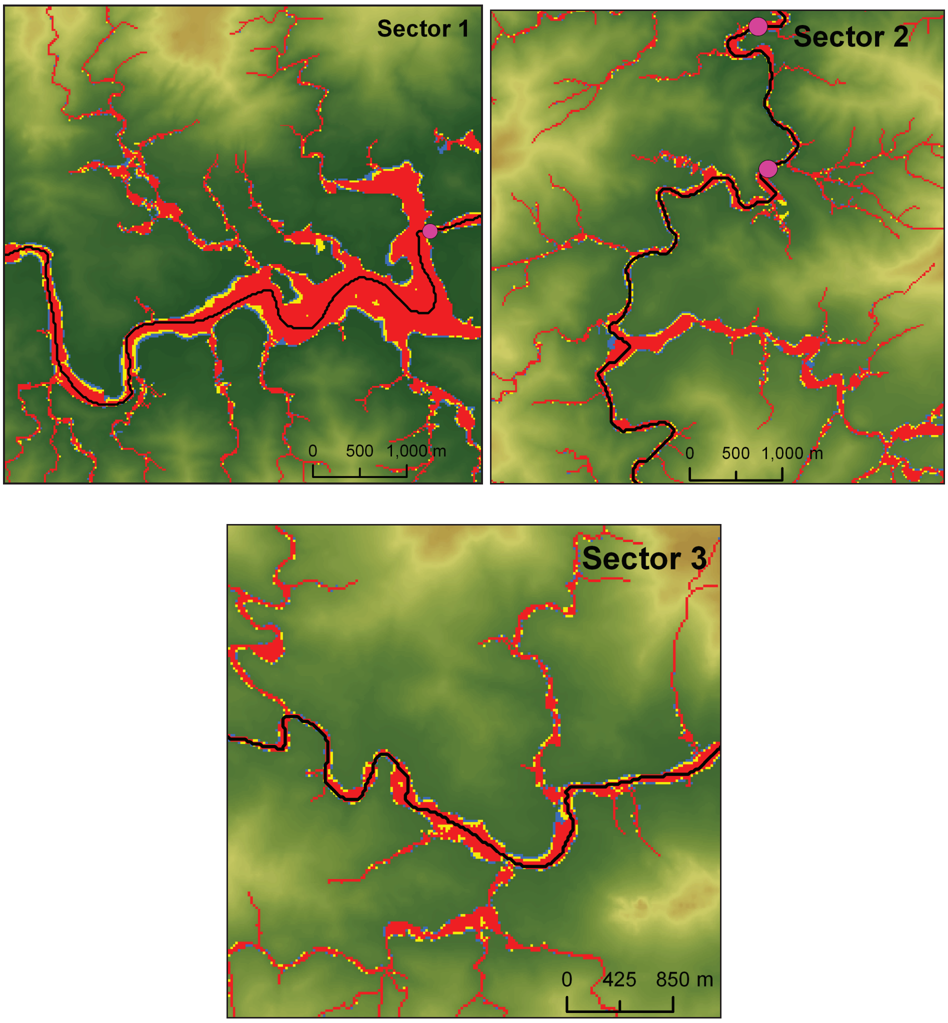

Figure 5. Images showing the sectors of Posada basin signaled in annex II. Floodplain widths at 1xBankfull Depths (red), 2xBFD (yellow) and 3xBFD (blue) are shown. Dams and weirs are depicted with pink and green circles, respectively.

However, the many dams located upstream of both main tributaries (visible in google earth, although not present in the official dam GIS layer, but see the 2 dams in sector 2; Fig. 5), probably prevent or limit their formation. From K25 to about K40 we find the largest contribution of sediment from the hillsides, although the presence of two large dams within the main tributary could cause severe influences on river habitats below them, trapping most of this sediment There is also another important tributary junction a bit

further upstream at K35 in which a major tributary coming from the east produces a clear floodplain enlargement increasing from 75 km upstream to almost 400 m within the junction.
Upstream from RK45 hillsides, high terraces and alluvial fans bound both sides of the channel, thereby reducing the width of the fluvial landscape. However, there are many tributaries of increasing relative importance size as we move upstream, what raises the chances of finding confluence effects.
Finally, following the major fluvial axis B upstream the confluence of the two main tributaries (Annex II, page 72) there is also an important tributary junction that produces wider fluvial landscapes (Sector 3, Fig). Upstream from here (K15 of the major fluvial axis B) river reach gradients increase and also the sediment yield from hillsides. Upstream from here hillsides constrain the fluvial landscape.

Flumendosa Catchment

The Flumendosa basin drains almost 1850 km^2 and could be divided in two major fluvial axes with a length of 150 and 60 km (Major fluvial axis A and B, respectively). This catchment has estimated channel gradients ranging from greater than 10% in the headwaters to less than 1% through broad-valley segments downstream (Annex II, page 73). The highest altitude river reach in the major fluvial axis is located at approximately 1300m. Wide fluvial landscapes (200–500 m) are predicted to occur within river kilometre (K) 22 to the junction of the main two tributaries in the catchment (Sector 1, Fig.6).

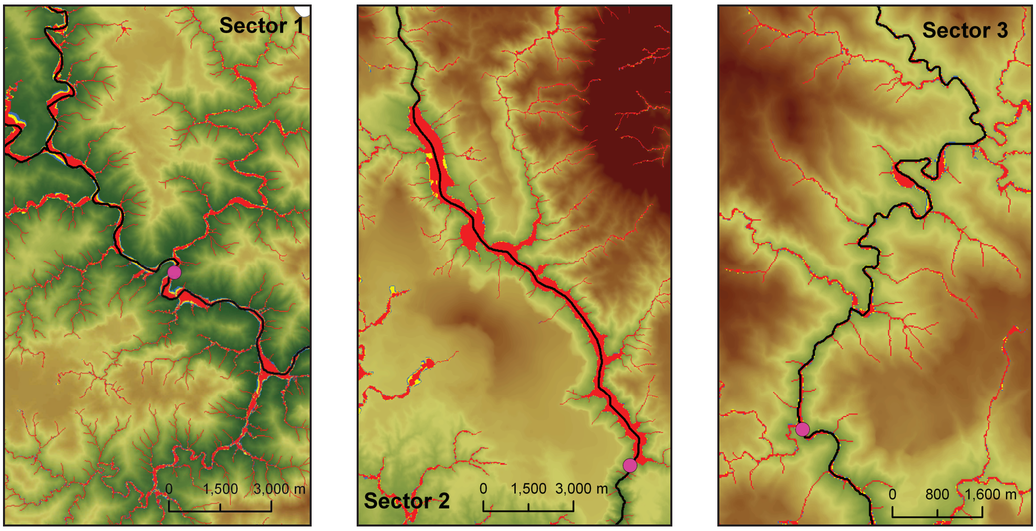

Figure 6. Images showing the sectors of Flumendosa basin signaled in annex II. Floodplain widths at 1xBankfull Depths (red), 2xBFD (yellow) and 3xBFD (blue) are shown.

Following the main tributary, there are also wide fluvial landscapes above the junction till about K40. This could be also linked to the increased probability of tributary effects registered in those river reaches. Major dams in the catchment such as that one present just upstream the main junction of tributaries A and B (Sector 2 and Sector 3, Fig. 6) produce an alteration of the natural fluvial landscape width and also trap a lot of the sediment yield coming from the hillsides at around k60 of tributary A and K30 of tributary B (Annex II, page 73). Upstream these large dams there are still junctions with a large probability of confluence effects that might create wider fluvial landscapes but not being larger on average than 150 m. This limitation is because the fluvial landscapes is mainly constrained by hillsides and fluvial terraces.

Picocca Catchment

The Picocca basin drains almost 370 km^2 and could be divided in two major fluvial axes with a length of 45 and 22 km (Major fluvial axis A and B, respectively). This catchment has estimated channel gradients that rarely exceeding 6% (Annex II, page 75). The highest river reach in the major fluvial axis is located at approximately 850m. Wide fluvial landscapes over 500m are predicted to occur within river kilometre 0 to K9 (Annexe II, Page 75). This floodplain widening is preceded by large sediment yield from the hillsides from K10 to K22 (Sector 1; Fig. 7). This section is also influenced by large tributaries coming from the western side of the catchment, raising the probability of confluence effects. The major fluvial axis B has a much lower gradient (below 2% for most of its length) with sediment yield from the hillsides below 40 t/ha year, except for the upper most part of the catchment. Tributary confluence effects and valley widths are high along most of the catchment due to the many tributaries draining from the west side and the low catchment gradient. There seems that the many weirs present in these western tributaries (2 to 4 in Annexe II, page 75) might have a severe effect on sediment retention and implications for the main river axis morphology.

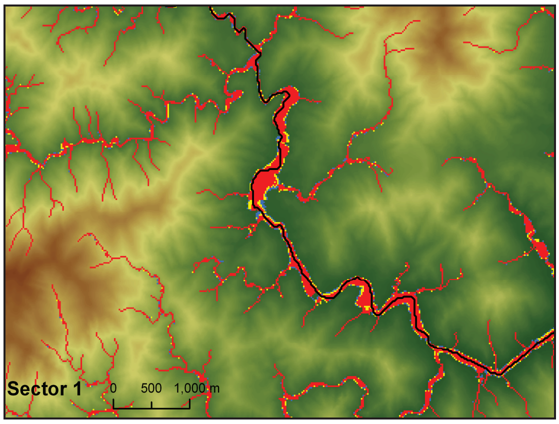

Figure 7. Images showing the sectors of Picocca basin signaled in annex II. Floodplain widths at 1xBankfull Depths (red), 2xBFD (yellow) and 3xBFD (blue) are shown.

Cedrino Catchment

The Cedrino basin drains almost 1078 km^2 and could be divided in two major fluvial axes with a length of 70 and 38 km (Major fluvial axis A and B, respectively). This catchment has estimated channel gradients that rarely exceed 4%, but for the upper most part of the headwaters (Annexe II, page 76). The highest river reach in the major fluvial axis is located at approximately 950 m. Wide fluvial landscapes over 1000 m wide are predicted to occur within river kilometre 0 to K10 (Sector 1, Fig. 8), right below the confluence of the two major tributaries within the catchment, where the probability of confluence effects is predicted to be high. This large floodplain shows considerable differences in surface area between one, two and three bankfull depths. This could be indicating the presence of flood defences restricting the width of the fluvial landscape. Moreover, the many weirs present in this area might also be restricting and conditioning the possibility of reaching a full fluvial landscape development (Sector 1; Fig. 8).

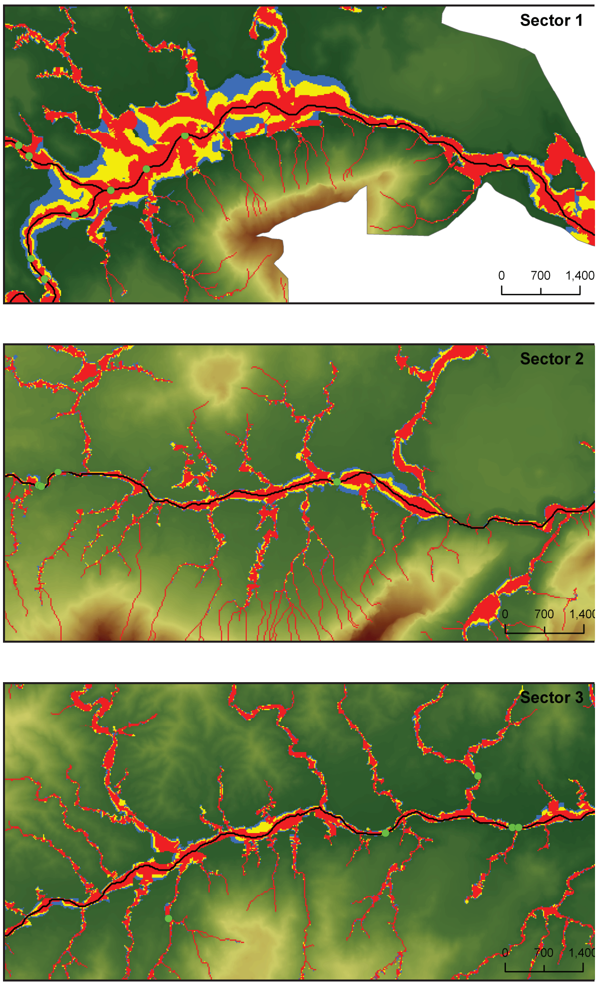

Figure 8. Images showing the sectors of Cedrino basin signaled in annex II. Floodplain widths at 1xBankfull Depths (red), 2xBFD (yellow) and 3xBFD (blue) are shown.

River reaches between K20 and K40 have a large probability of tributary effects and they have large contributions of sediment from adjacent hillsides. This results in larger floodplains within this sector of up to 500m (Sector 2, Fig. 8). However, the many weirs and a large dam on the lower part of this sector might disrupt severely natural morphological dynamics. From K7 to K18 in the second largest tributary of the catchment there is also a high likelihood of confluence effects due to many tributaries that join the main channel. This also reflects wider fluvial landscapes reaching over 400m (Sector 3, Fig.8). Again, there are some weirs in that sector that might prevent these river reaches from getting its natural shape trough sediment trapping and disrupting natural river morphological dynamics.

4. CONCLUSIONS

The main conclusions of this study could be summarised in the following:

The analyses of the possible effects that dams and weirs might have on the selected Sardinian catchments reflect that a greater length of river reaches draining larger catchment areas is affected within the river network. Moreover, the location of this river reaches (in middle to lower parts of the basin) accentuates the possible effects, as they are spatially important for longitudinal river network continuity.

Floodplain widths are mainly restricted by flood defences in the lower part of the selected Sardinian catchments. Confluence effects area also predicted to be important on maintaining wider fluvial landscapes in the middle parts of the catchments, although morphological dynamics might be severely affected by the location of some dams and weirs which might trap most of the hillside sediments above their location.

The selected Sardinian catchments have on general a low river reach gradient (< 3%) but for the most upstream river reaches (>6%). The production of sediment from local hillsides is quite related to hillside gradient and vegetation. We believe these places might be really important for in-stream physical habitat characteristics. Whether natural or human altered sites, it is well needed to establish a link between hillside condition and downstream changes on physical habitat attributes.

The presence of large dams (p.e. Cedrino and Flumendosa catchments) alters not only the morphological river dynamics by trapping sediments, but also by disrupting the natural flow regime. Although we do not present any analyses on flow regime alteration within this study, this effect should be also taken into account when looking at the effects that this pressures have on river network morpho-dynamics.

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ANNEXE I

INPUT PARAMETERS
(BUILDGRIDS AND NETRACE)

The following table contains all parameters used as inputs in the software packages Buildgrids and Netrace (included in the NetMap platform).

INPUT PARAMETERS FOR Bld_grds AND Netrace	
2	flow direction algorithm (1 for D-infinity, 2 for D-infinity + convergence)
25	radius (m), length scale for calculating slope and curvature
10	dig; depth of DEM incision for drainage enforcement
75	dig-radius, width of "swale" incised for drainage enforcement -- this incision is only applied for flow directions, nothing else
0.5	dig maximum slope, slope gradient above which drainage enforcement is not applied
2	Channel threshold criteria: 1 = Drainage area; 2 = Specific drainage area.
100	channel_area_threshold for low-gradient areas (area in square meters times slope to the c_exp power)
400	channel_area_threshold, high-gradient areas
2	c_exp, slope exponent
0.2	S_min, slope below which low-gradient threshold applies
0.3	S_max, slope above which high-gradient threshold applies
0.0005	Plan_min, minimum plan curvature for channel head in low-gradient areas
0.005	Plan_min, minimum plan curvature for channel head in high-gradient areas
100	min_flow_length (m), distance overwhich Plan_min must be equaled or exceeded for a channel head
500	Xmin, minimum window length for channel gradient calculation
1500	Xmax, maximum window length
0.001	Smin, gradient at and below which Xmax applies
0.2	Smax, gradient at and above which Xmin applies
2	Fit Order, integer, polynomial order for fit to channel elevations for gradient
50	junction_length ! channel length used to estimate junction angles
1.683	cw1, channel width function, method 1: cw = cw1*(Mean_annual_flow^cw2)
0.436526	cw2, channel width function, method 2: cw = cw1*(Area^cw2)*(Prec^cw3)
0.440865	cw3, channel width function, cw in meters, area in km2, prec in m, maf in m3/sec
0.63	depth_coefficient_1, method 1: channel depth = coef_1*(mean_annual_flow^coef2)
0.173158	depth_coefficient_2, method 2: channel depth = depth_coefficient_1*(area**depth_coefficient_2)*(prec**coef3)
0.151639	depth_coefficient_3, channel depth in meters, area in km2, prec in m, mean_annual_flow in m3/sec
2	reach method: 1) channel widths, 2) specified length !
10	# of channel widths for a reach, for reach-method 1
400	minimum reach length in meters, for reach-method 2
800	maximum reach length in meters, reach-method 2

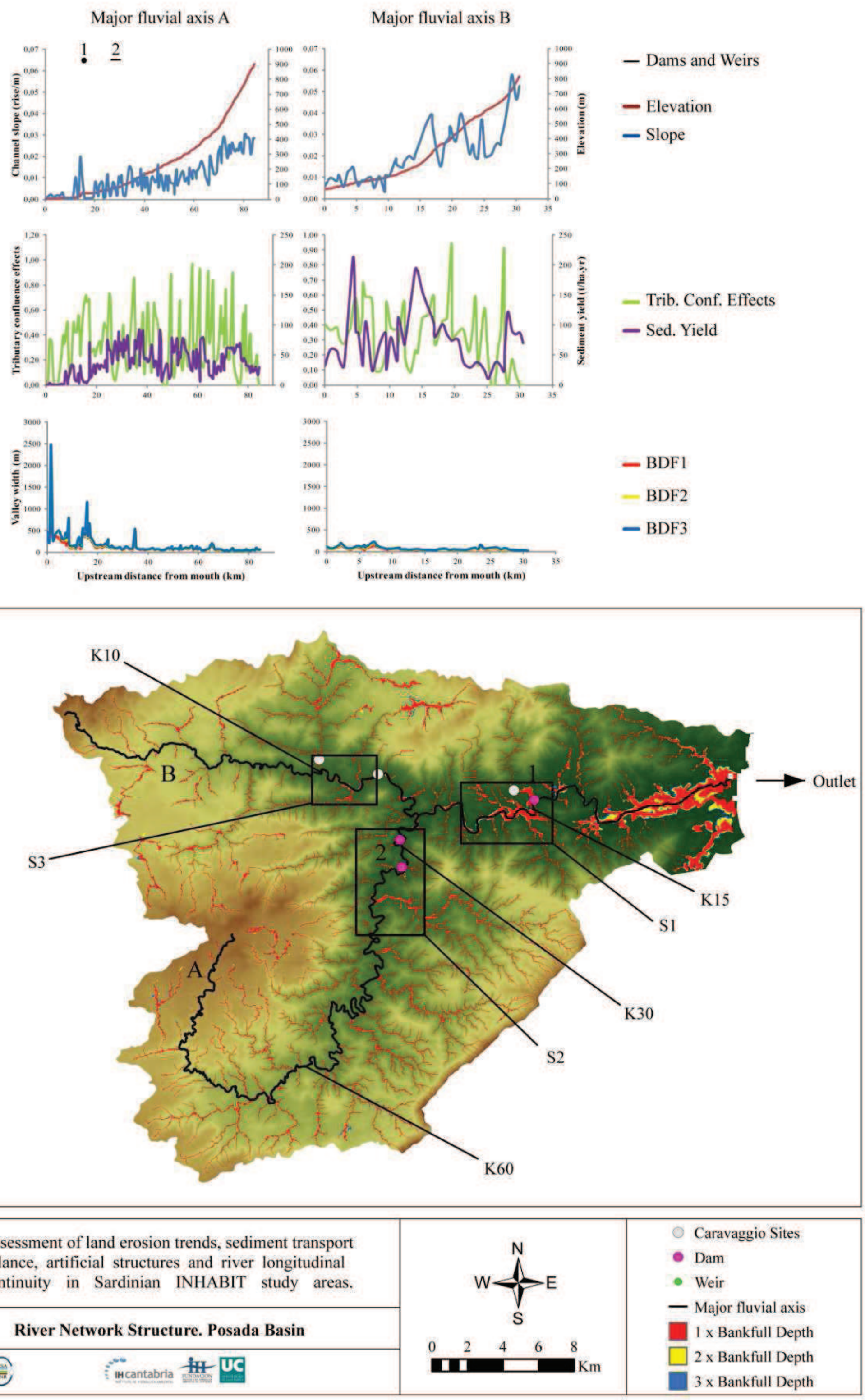
0.04	area (km^2) at and below which minimum reach length is enforced, reach-method 2
50	area (km^2) at and above which maximum reach length is enforced, reach-method 2
150	minimum reach length for increasing max_grad_down
200	maximum reach length for increasing max_grad_down
0.04	Drainage area (sq km) at and below which minimum reach length applies
50	Drainage area (sq km) at and above which maximum reach length applies
1	Area weighting for reach breaks (larger values increase effect of tributary inputs)
2-1-3	vh, number of bank-full depths above channel to qualify as floodplain
6.32E-06	Mean annual flow, coefficient 1, flow = c1*(Area^c2)*(Precip^c3)
0.99	Mean annual flow, coefficient 2, Area in square kilometers, Precip in m
1.593	Mean annual flow, coefficient 3
0	gcoef1, field_gradient% = gcoef1 + gcoef2*(DEM_gradient%^gcoef3)
1.019785	gcoef2
0.825982	gcoef3
0.2	end of calibrated gradient
0.3	start of DEM gradient, linear combination in between
3.79	trib effects coefficient 1
1.96	trib effects coefficient 2
0.0874	trib patch size coefficient 1
0.3867	trib patch size coefficient 2
0.5	decay rate for tributary effects, 1/km

INSTRUCION FILE FOR Netrace	
SHAPEFILE options	
y	Force reach breaks at channel junctions (y/n)
2	1) Fixed-length reaches, or 2) homogenous reaches
2	Gradient calculation method: 1) via contours, 2) poly fit over centered window, 3) none
2	Channel width estimation method: 1) a*(Mean_annual_discharge^b), 2) a*(Area^b)*(Prec^c), 3) none
2	Channel depth estimation method: 1) a*(Mean_annual_discharge^b), 2) a*(Area^b)*(Prec^c), 3) none
1	Mean annual discharge method: 1) a*(Area^b)*(Prec^c), 2) none
1	Valley width calculation method: 1) inundation flow path 4) none
n	Debris flow model (y/n) requires additional data files
n	Basin ID (requires .flt grid file of basin IDs)
0	Maximum number of channel networks to trace (zero = no limit)
RASTER output options	
y	Hillslope pixel distance to nearest stream channel, raster file (y/n)
y	Hillslope pixel delivered-to-channel-reach ID, raster file (y/n) (requires reach shapefile)
y	Create valley floor raster image vmask_ID.flt (.hdr) (y/n) (requires reach shapefile)

ANNEXE II

MAPS AND GRAPHICS OF RIVER NETWORK ANALYSIS

INDEX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Major fluvial axis B
Channel slope (rise/m)
Elevation (m)
Dams and Weirs
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
Upstream distance from mouth (km)
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B
S3
A
K60
S2
K30
S1
K15
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Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Posada Basin
N
W
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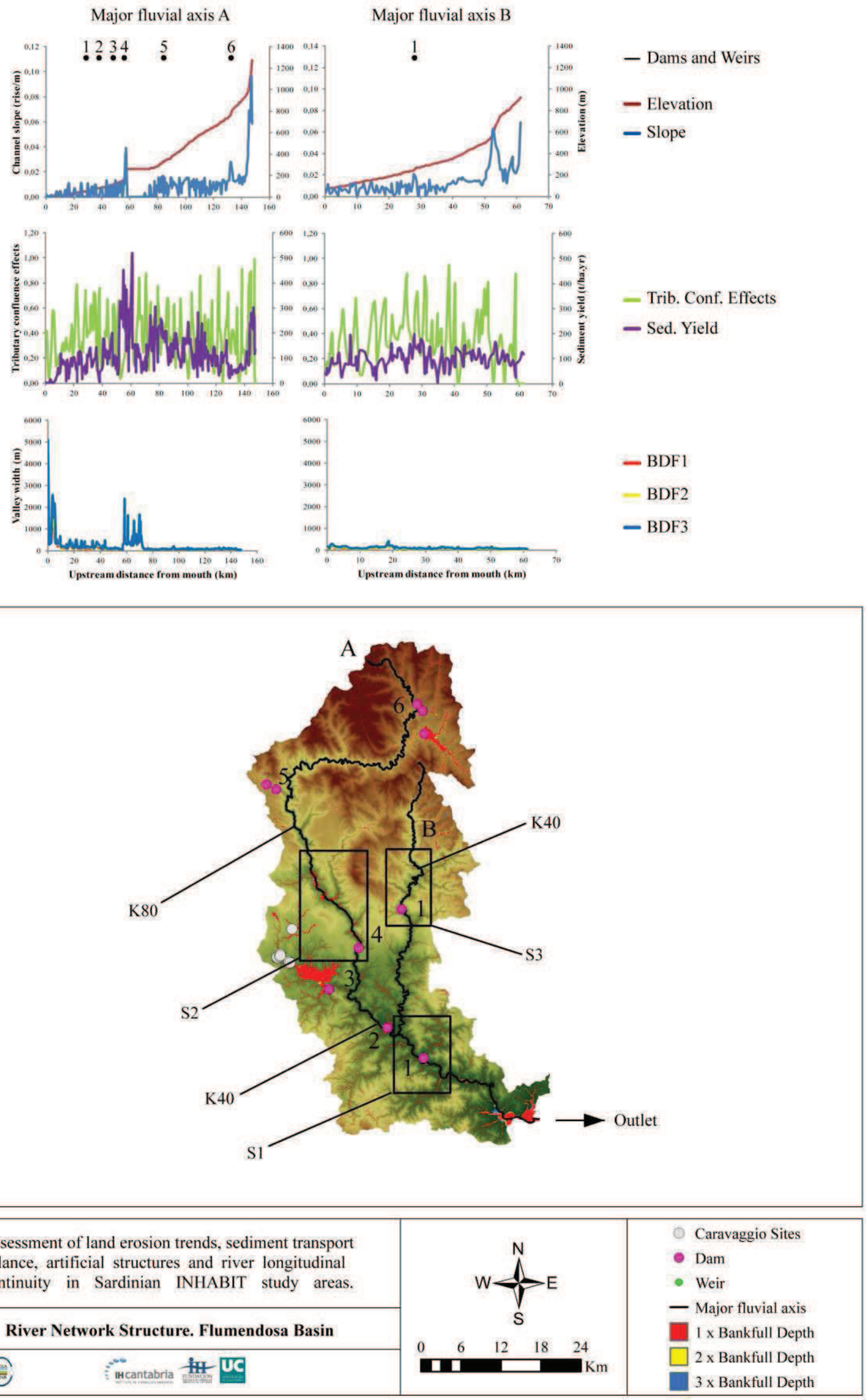
S
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth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Channel slope (rise/m)
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Dams and Weirs
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Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
A
B
K40
K80
S1
S2
S3
Outlet
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Flumendosa Basin
N
W
E
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6
12
18
24
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
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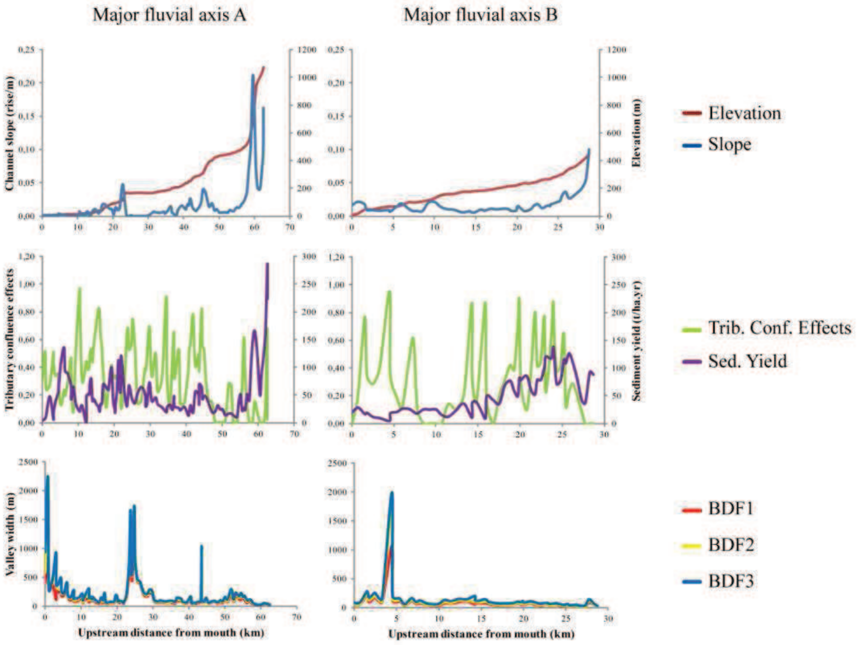
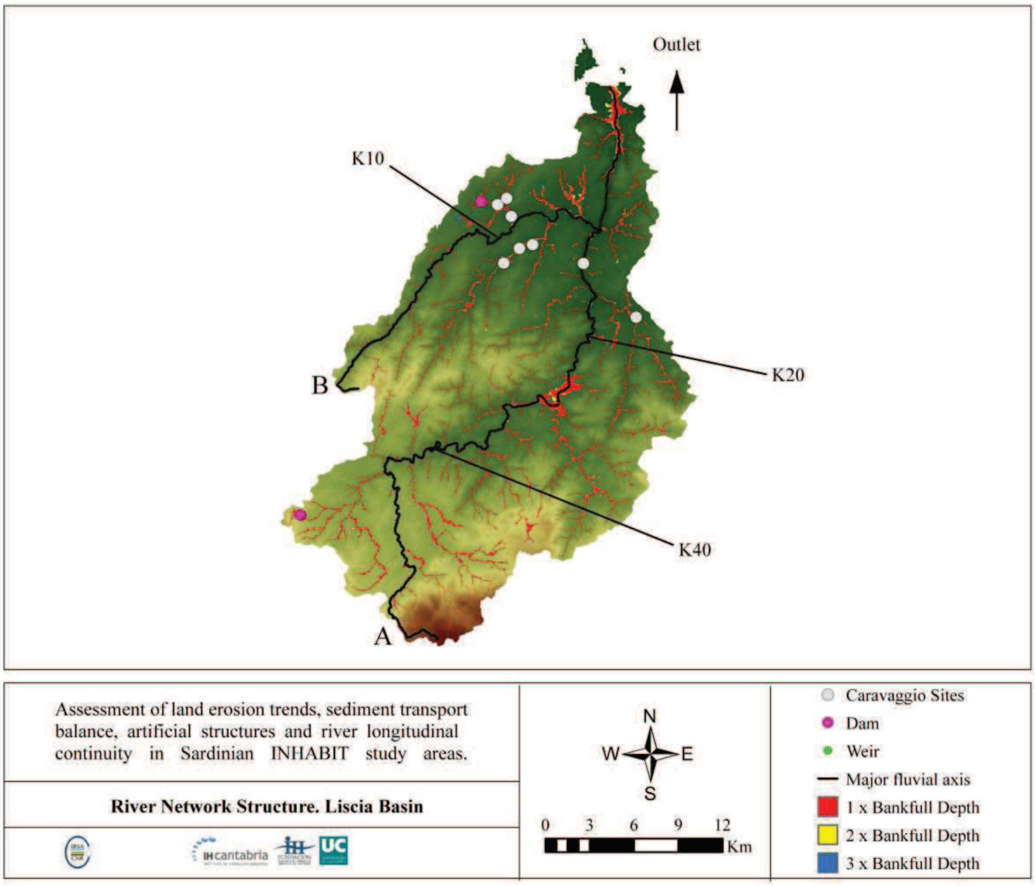
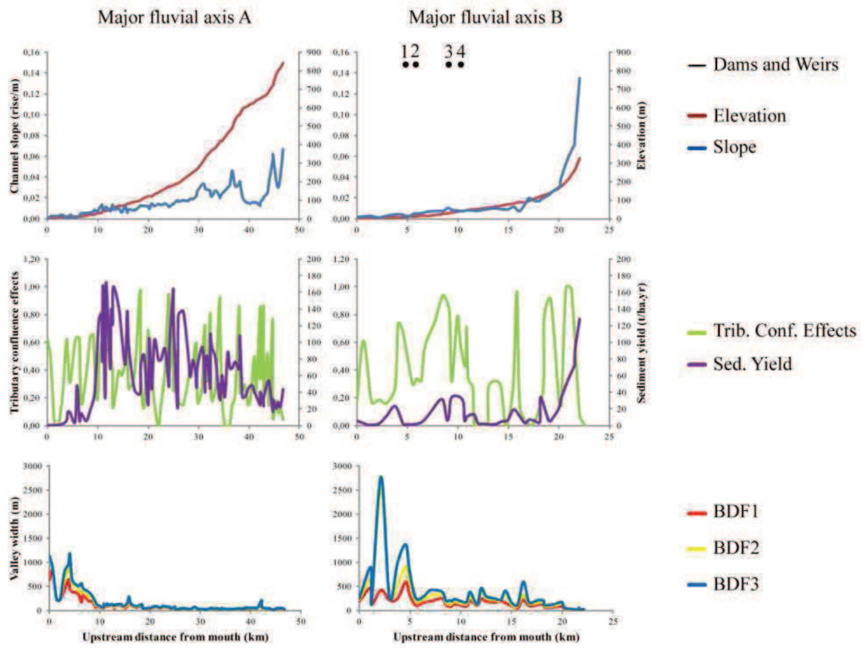
2 x Bankfull Depth
3 x Bankfull Depth

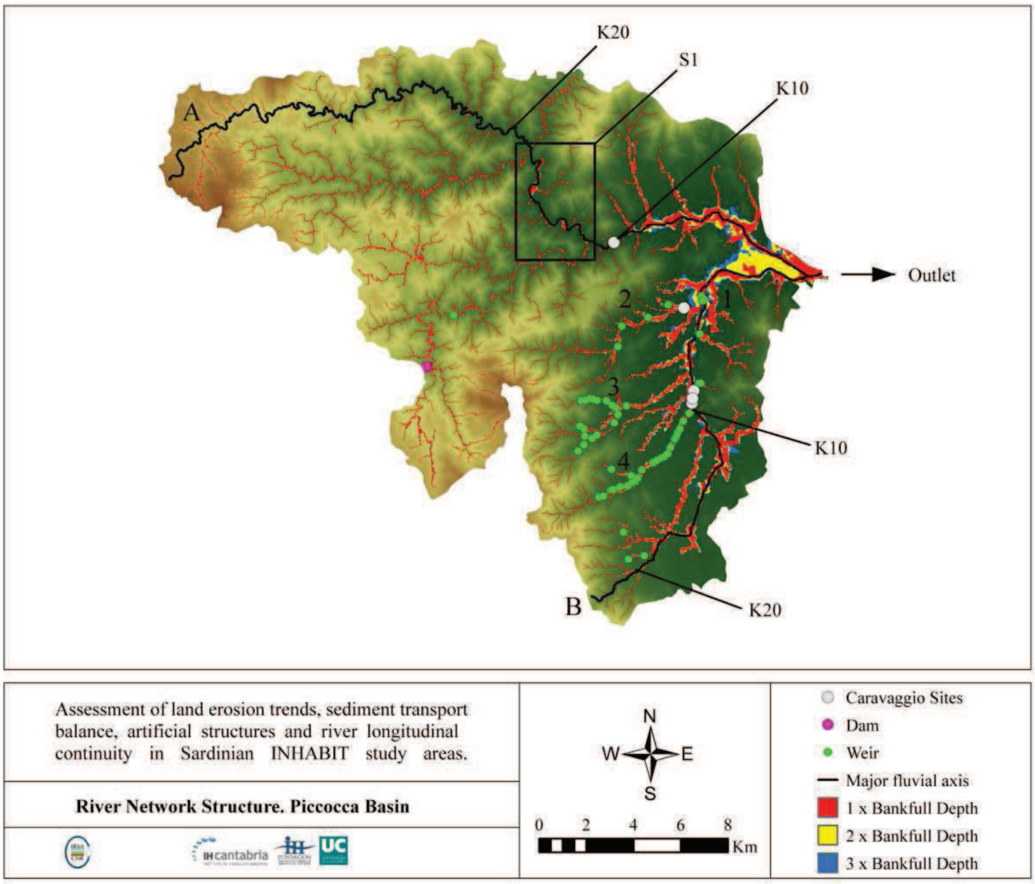




Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.

River Network Structure. Liscia Basin


Major fluvial axis A
Major fluvial axis B
1 2
3 4
Channel slope (rise/m)
Elevation (m)
Dams and Weirs
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
Upstream distance from mouth (km)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K10
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Outlet
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1
3
4
K10
B
K20
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Piccocca Basin
N
W
E
S
0 2 4 6 8
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
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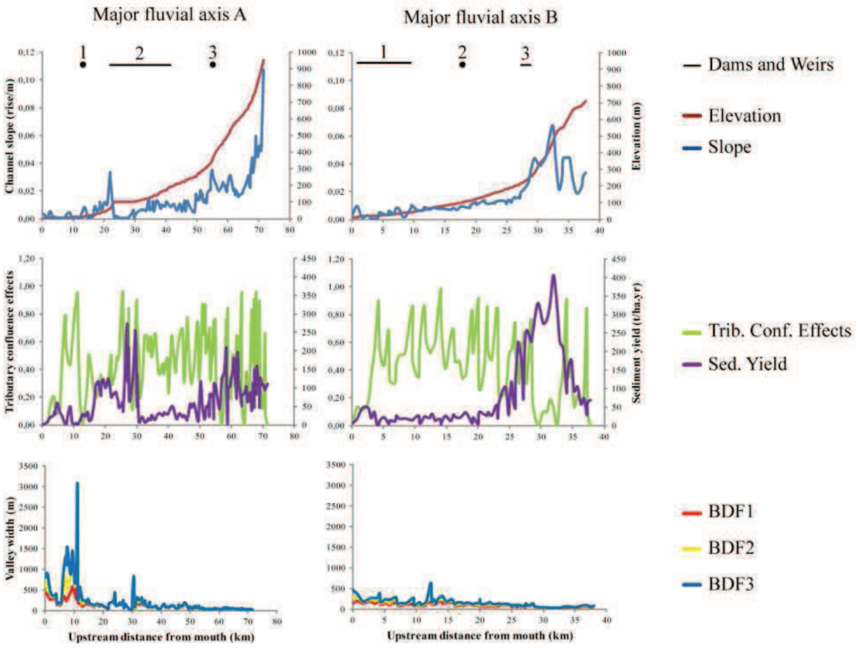
2 x Bankfull Depth
3 x Bankfull Depth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Major fluvial axis B
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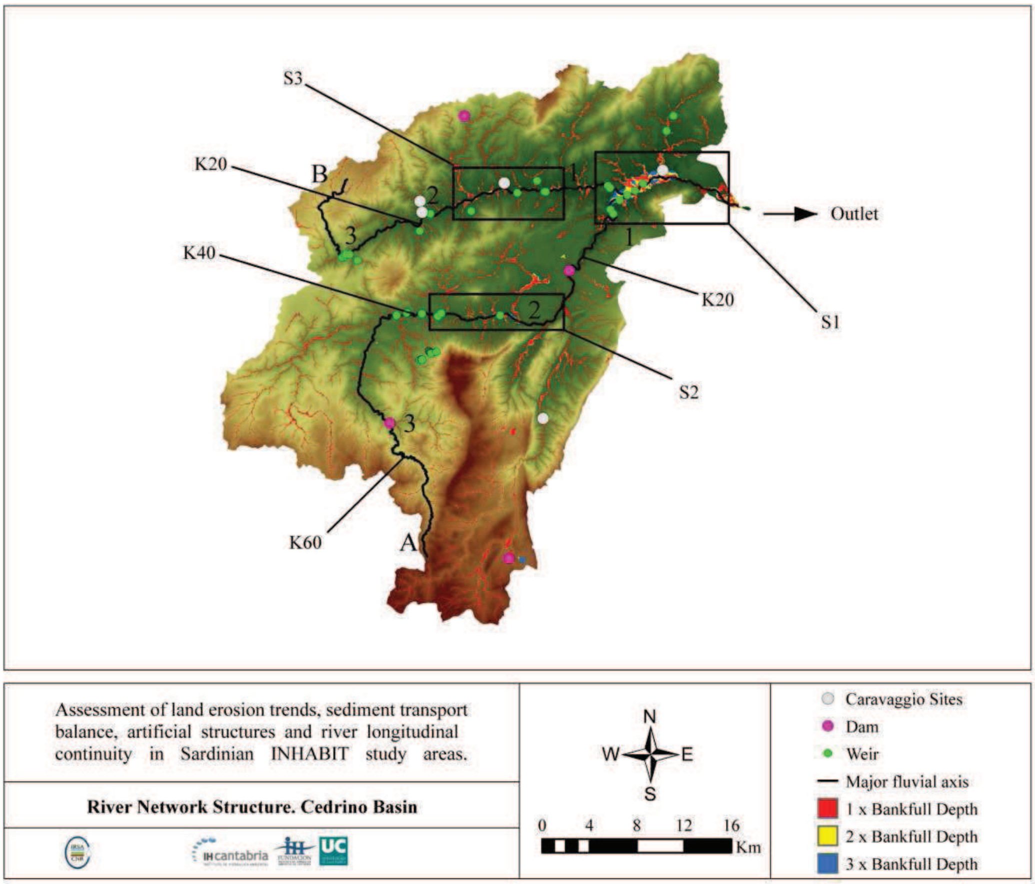
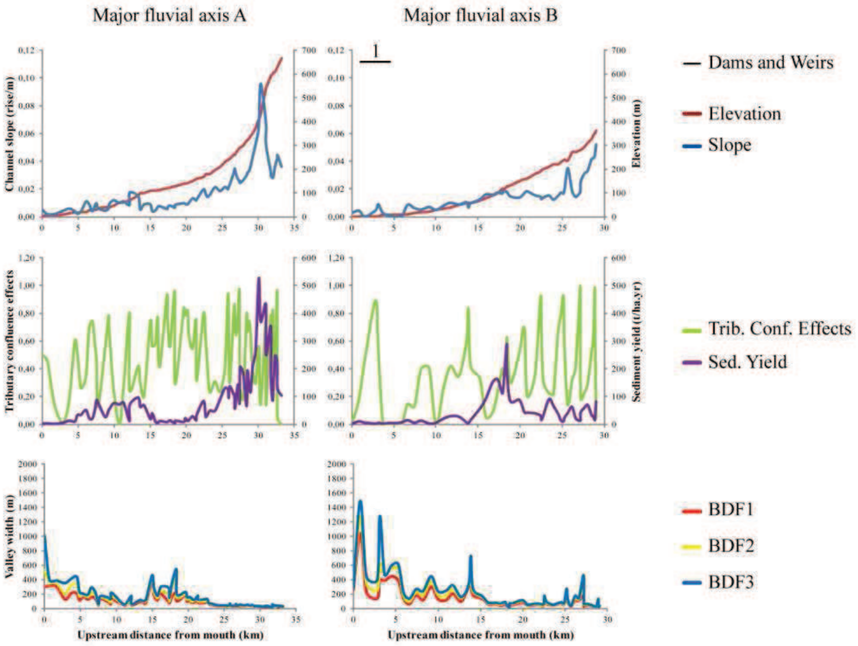
Elevation (m)
Tributary confluence effects
Sediment yield (t/ha.yr)
Valley width (m)
Upstream distance from mouth (km)
Dams and Weirs
Elevation
Slope
Trib. Conf. Effects
Sed. Yield
BDF1
BDF2
BDF3


S3
K20
B
K40
K60
A
Outlet
K20
S1
S2
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Cedrino Basin
N
W
E
S
0 4 8 12 16
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth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Major fluvial axis B
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Elevation (m)
Dams and Weirs
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
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Valley width (m)
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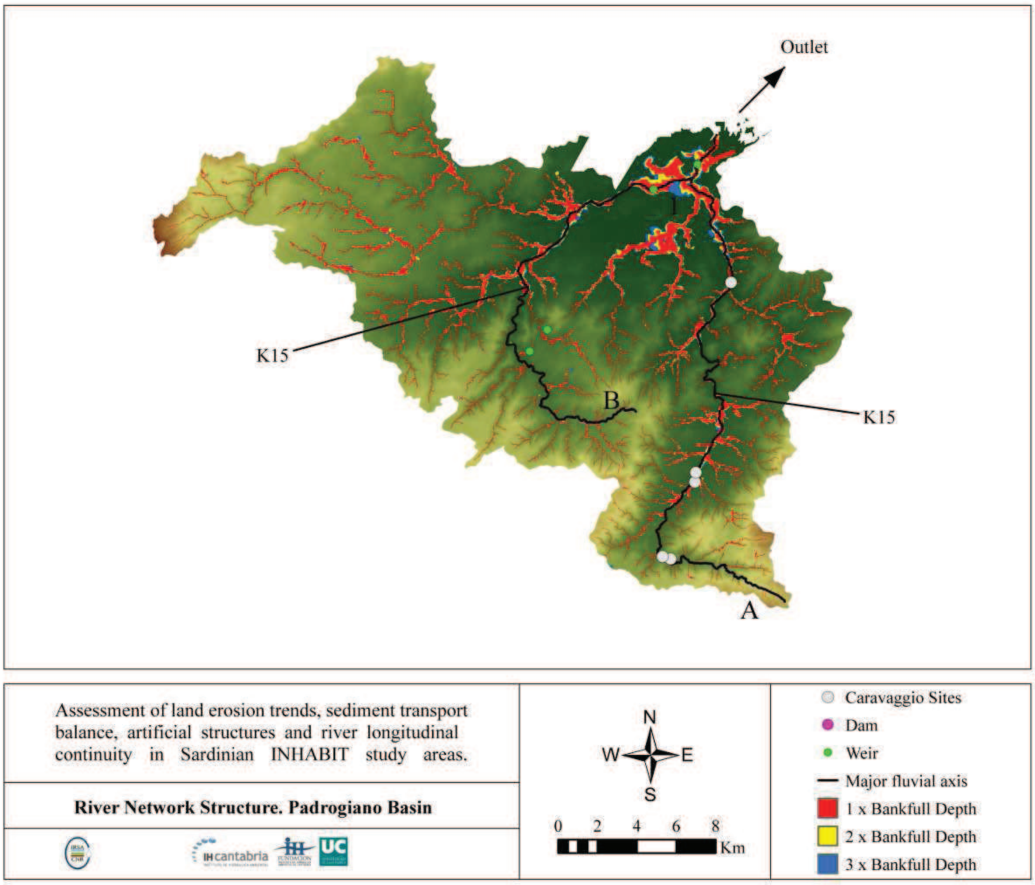
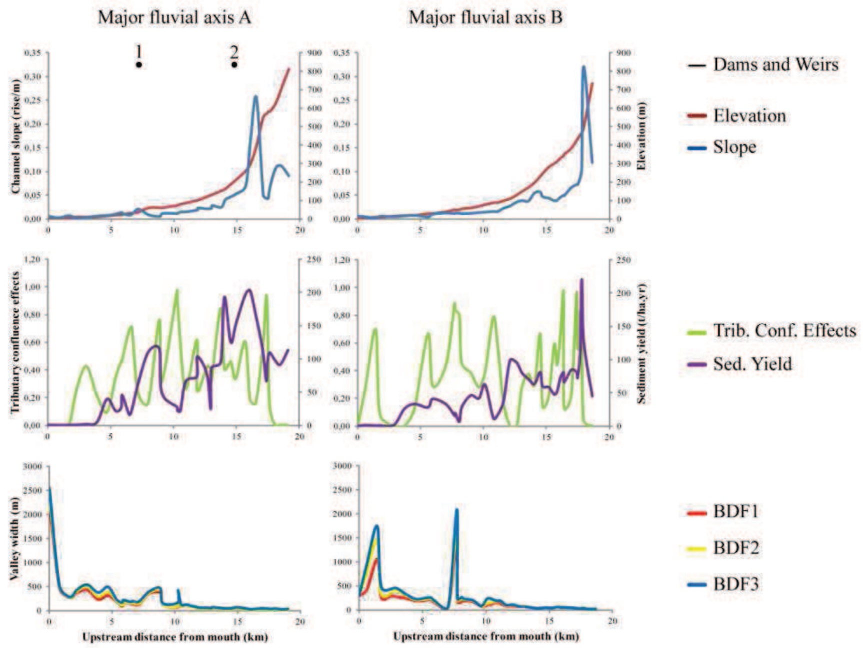
BDF2
BDF3
Upstream distance from mouth (km)


Outlet
K15
B
K15
A
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Padrogiano Basin
N
W
E
S
0 2 4 6 8
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth


Major fluvial axis A
Major fluvial axis B
Channel slope (rise/m)
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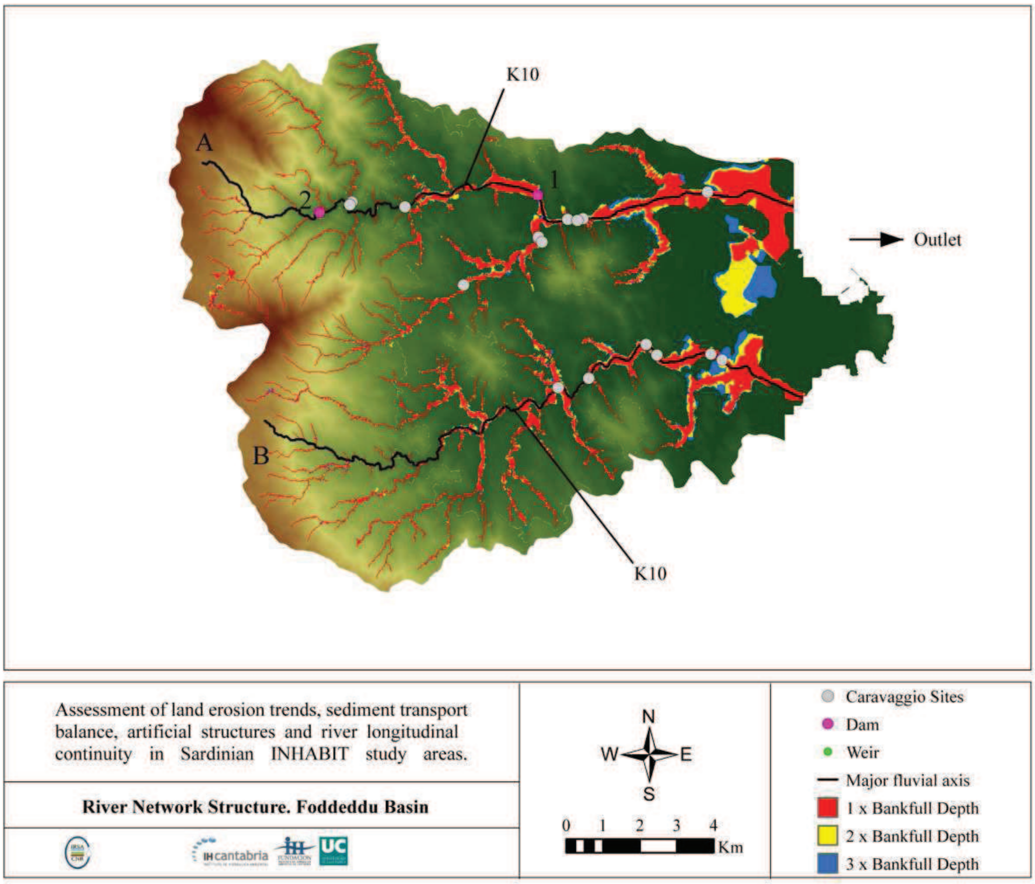
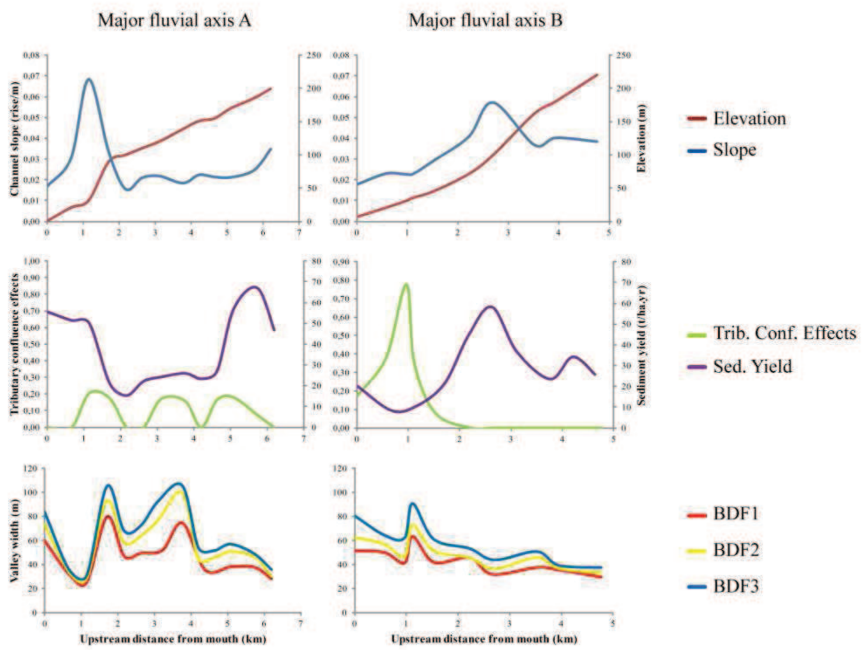
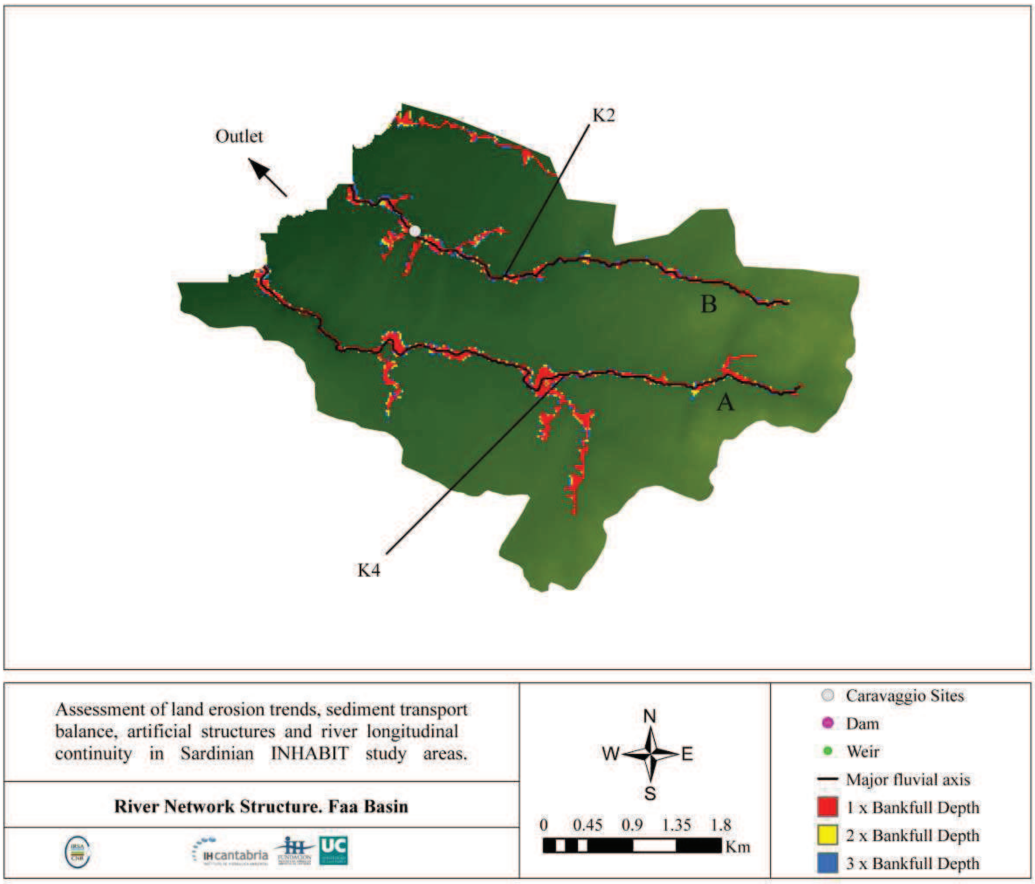
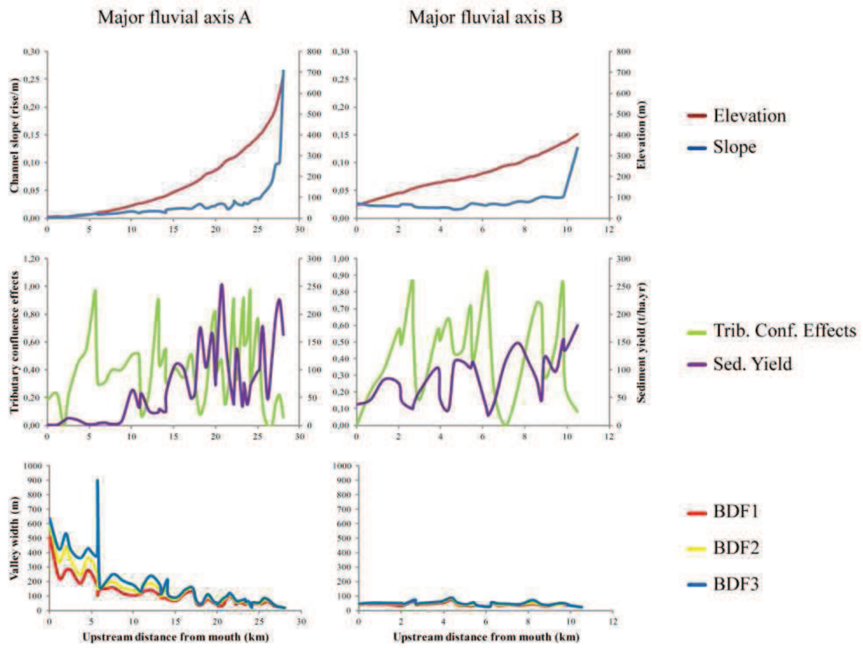
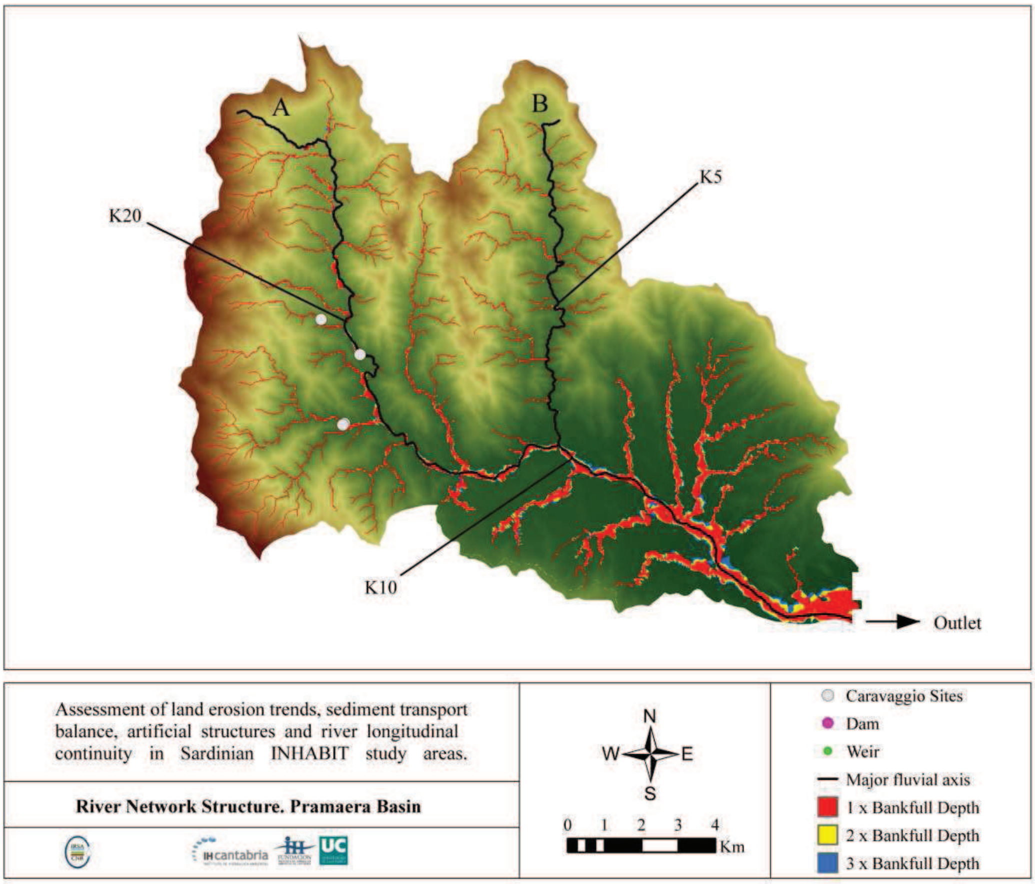
Slope
Trib. Conf. Effects
Sed. Yield
BDF1
BDF2
BDF3

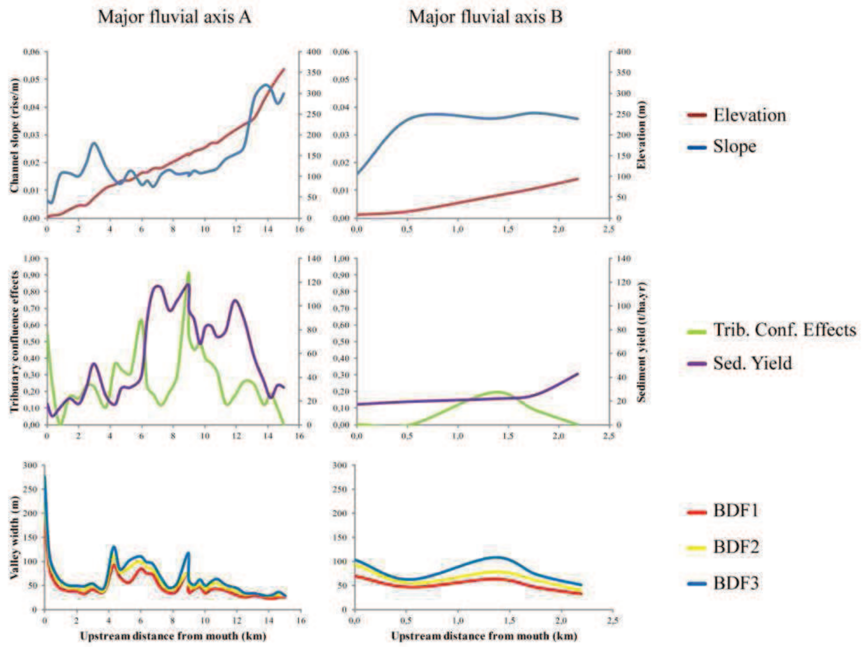

K10
A
B
1
2
Outlet
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Foddeddu Basin
N
W
E
S
0 1 2 3 4 Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth

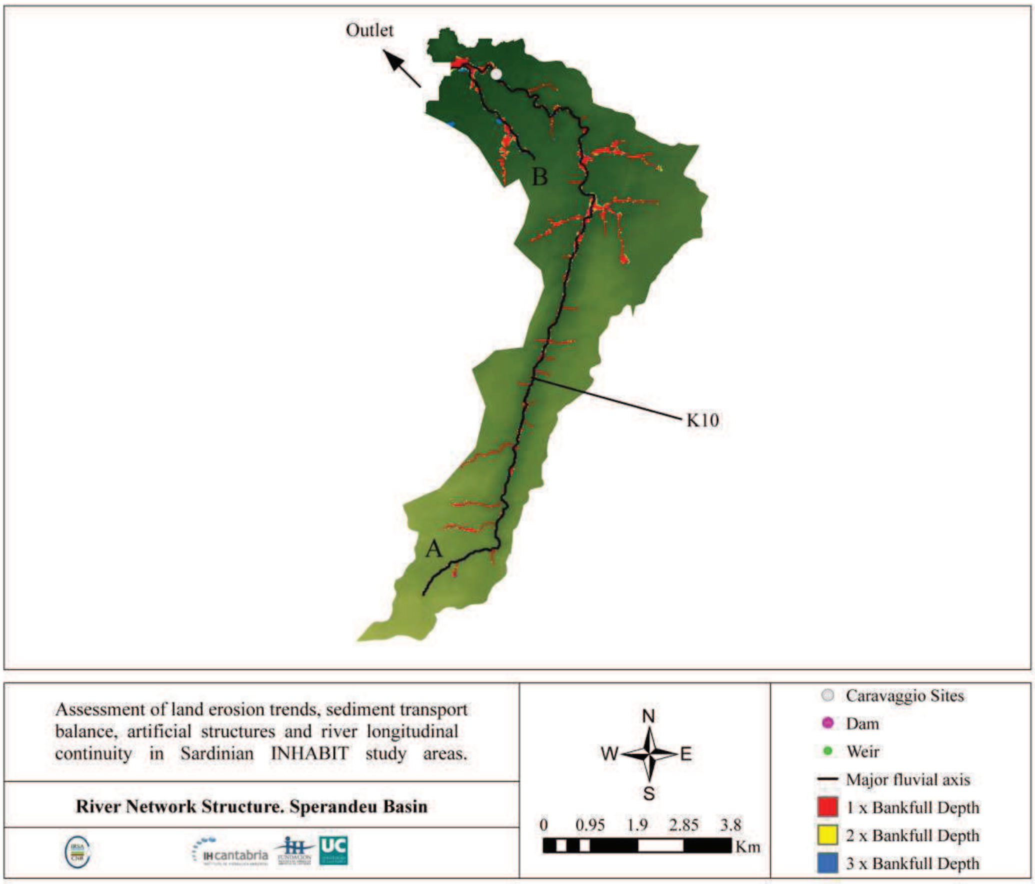

Major fluvial axis A
Major fluvial axis B
Channel slope (rise/m)
Elevation (m)
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
Upstream distance from mouth (km)


Outlet
K2
B
A
K4
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Faa Basin
N
W
E
S
0 0.45 0.9 1.35 1.8
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth


Major fluvial axis A
Major fluvial axis B
Channel slope (rise/m)
Elevation (m)
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
Upstream distance from mouth (km)


A
B
K20
K5
K10
Outlet
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Pramaera Basin
N
W
E
S
0 1 2 3 4
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth


Major fluvial axis A
Major fluvial axis B
Channel slope (rise/m)
Elevation (m)
Elevation
Slope
Tributary confluence effects
Sediment yield (t/ha.yr)
Trib. Conf. Effects
Sed. Yield
Valley width (m)
BDF1
BDF2
BDF3
Upstream distance from mouth (km)
Upstream distance from mouth (km)


Outlet
B
K10
A
Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian INHABIT study areas.
River Network Structure. Sperandeu Basin
N
W
E
S
0 0.95 1.9 2.85 3.8
Km
Caravaggio Sites
Dam
Weir
Major fluvial axis
1 x Bankfull Depth
2 x Bankfull Depth
3 x Bankfull Depth

D2D2.8 - ASSESSMENT OF MAIN PROCESSES RELATED TO BANK EROSION AND DEPOSITIONAL/EROSIONAL ZONES AT THE CATCHMENT SCALE IN SARDINIAN INHABIT STUDY AREAS

Authors:

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Università della Cantabria - Environmental Hydraulics Institute "IH Cantabria

1. INTRODUCTION

Riparian zone is very important in river management, because the vegetation in riparian zones carries out important ecological, hydraulic and hydrological functions. For this reason, the conservation of riparian areas in good quality is crucial for maintaining many important ecological functions in fluvial ecosystems. This study aims at identifying river reaches within selected basins of Sardinia that have a high risk of bank instability due to soil characteristics and a degradation of riparian condition. To do that a riparian condition model developed in Spain will be applied to the selected river catchments and, this data, will we crossed with soil erosion on valley side wings. This will allow identifying what river reaches might be at a higher risk of suffering different impacts (e.g. siltation, changes on channel form, and so on) at large scales and, thus, prioritizing river network zones for restoration. CARAVAGGIO information on riparian vegetation and bank erosion will be used to validate large scale models and results.
The main objective of this study is to perform a river bank stability and riparian condition evaluation at a catchment scale by using a riparian condition model and GIS data in selected basins of Sardinian.

2. MATERIAL AND METHODS

For the selection of the study area (Sardinia, Italy) and river basins, and for the explanation of the preparatory work on the layers of information (river network, DEM and definition of the three bankfull depth, geological data, land cover, soil erosion) see previous contribution "*D2d2.9 - Assessment of land erosion trends, sediment transport balance, artificial structures and river longitudinal continuity in Sardinian inhabit study areas*".

2.1. Delineation of riparian areas

There exist several approaches to delineate riparian areas (e. g. McGlynn and Seibert 2003, e. g. Dodov and Foufoula-Georgiou 2006) and defining discrete boundaries can be a difficult task. Hence, several GIS-based methods have been published in the last years regarding floodplain/riparian zone delineation. In this activity, riparian zones were delineated following the methodology exposed in Fernández et al. (2012) for the whole Sardinian Synthetic River Network (SRN).
Within this study, we delineated hydrological meaningful potential riparian zones for SRN using a GIS-based geomorphologic approach relying on the DEM. The principal steps of this phase were the following:

- **Definition of valley morphology**

The geomorphological attributes used to define river types were channel and riverbank slope, valley floor width and riverbank geological hardness. Riverbank was considered as a buffer of 200 m from the river channel. The values of channel and riverbank slope were calculated at the endpoint of each segment from the DEM. Valley floor width was obtained from BFD-2 surface, derived as described in section 4.1. Riverbank geological hardness was obtained from the geological variables within the buffer (200m of the river channel). These four variables have been obtained for the whole SRN using NetMap tools and they were related to the flood height at a given location.
After data standardization, these four attributes were used to classify the SRN in

geomorphological types by using PAM (partition around medoids) clustering in R software (R Core Team 2013). PAM clustering was perform using three pre-established number of clusters to classify the river reaches as belonging to open valleys, shallow-vee valleys or deep-vee valleys.

- **Generation of geomorphological floodplain surfaces**

Consistent with the methodology cited in section 4.1, we assessed valley width at an elevation equivalent to the next number of bankfull depths (BFDs) for each river segment in function of their valley morphology. The criteria used were:

- 0.75*BFD in open and shallow-vee valleys
- 1.25*BFD in deep-vee valleys

This step generated a surface which intersects valley walls at these BFDs above the channel. This is considered as the riparian zone. The segments of shallow vee and deep vee valleys were considered in the same category because in accordance with Fernández et al. (2012), similar patterns are found for open and shallow vee valleys.

- **Assigning land use categories to riparian zones**

In the last step, the resulting floodplain surfaces for each river reach within the SRN polygon was intersected with the land-use thematic map to obtain the percentage of each land use category. Thus, we were able to quantify land use composition within riparian zones.

2.2. Riparian condition model

Several methodologies for assessing riparian condition currently exist (Qualitat del Bosc de Ribera-QBR; Munne et al. 2003, Riparian Quality Index-RQI; González del Tánago et al. 2006, Gonzalez del Tanago and Garcia de Jalon 2011). All these methods are applied within homogeneous river reaches not longer than 500 m, but crucial items in riparian management cannot be understood without a continuous evaluation of the riparian corridor for entire river networks. For this reason, we use the riparian condition model developed by Fernández et al. (In prep.) which use riparian land-cover data for modeling riparian condition over large areas in Spain through two type of models (multiple linear regression and random forest). The model selected in this study was the multiple linear regression one because it obtained a better fit when predicting riparian condition and also got lower deviations in the prediction of riparian condition classes. The adjusted R^2 obtained in this model in Spain was 0.62 using a leave-one-out cross validation procedure. These results indicate that the predicted data have a good fit with observed data (Fig. 3).

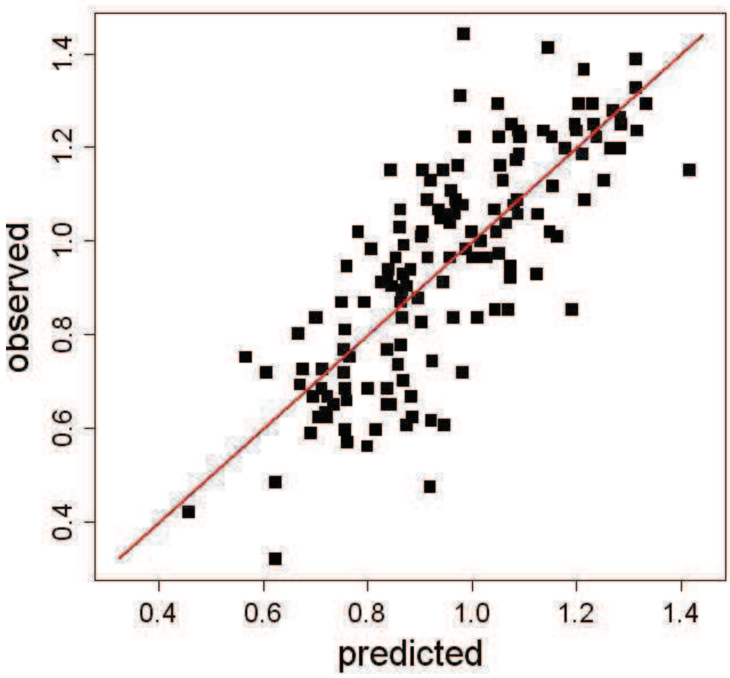


Figure 3. Observed vs Predicted riparian condition values in the linear regression model used by Fernandez et al. (In prep).

To execute the model, each segment was considered as an observation and the relative extension of three different land-use classes were used as predictor variables (agricultural land, broadleaf forest and urban areas). Before

performing linear regression, the predictor variables were arcsine-square root transformed. For more information about the parameters of the model see Fernández et al. (In prep.).
In the present study, the predicted values of the model for the Sardinian SRN were classified into four classes of riparian condition:

- Bad (0≤RC<40)
- Poor (40≤RC<60)
- Moderate (60≤RC<80)
- Good (80≤RC)

All statistical analysis were performed using R software (R Core Team 2013) and the package "MASS" (Venables and Ripley 2002) for multiple linear regression.

2.3. Evaluation of river bank instability risk

The evaluation of river bank instability risk was performed by using data from the riparian condition model and actual soil loss from the valley wings of each river reach. The actual soil loss was calculated by intersecting the area of the valley side wings for each river reach with the actual soil erosion loss for Italy (Grimm et al., 2002).
We estimated the risk of bank instability on low, medium and high by classifying the soil loss of the valley side wings in four classes and intersecting that classification with the modelled riparian condition classes (see table 1).

		Bank Instability Risk		
Soil loss (t/ha/yr)	0 *>SL* ≤1	Medium	Low	Low
	1 *>SL* ≤5	Medium	Medium	Low
	5 *>SL* ≤10	High	Medium	Low
	10 *>SL*	High	High	Low
		Bad-Poor	Moderate	Good
		Riparian condition		

Table 2. Classes of river bank stability risk according to their riparian condition and actual soil loss

2.4. Validation of large scale data

Different datasets and procedures were used to validate the large scale projections and GIS calculations with field information. The main data source for ground truthing our results were the 72 sites provided by CNR-IRSA sampled following the CARAVAGGIO protocol.
The characterization of the riparian zone for the entire river network was validated with the Caravaggio data by means of quantile regressions of broadleaf forest within the riparian zone to Natural land uses within 5 m of the banktop.
Riparian condition modeled data were related to Land Use Index from sites where the Caravaggio protocol was applied by means of a simple linear regression. Finally, bank instability results were related to Caravaggio data by using quantile regressions to relate the amount of cliffs, on one hand, and eroding banks and local bank erosion, on the other hand, to broadleaf percentage within the riparian zone and modeled riparian condition scores, respectively.
Finally, aerial imagery was also used to check that predictions and riparian characterization have been accomplished properly and that results followed the expected patterns given the actual landscape configuration in the Sardinia Island.

3. RESULTS

3.1 Delineation of the SRN

The obtained SRN comprises 63364 river reaches with an average length of 433.5 m. The official river network comprises 122392 segments and it has an average length of 409.7 m. There are some differences between both river networks in relation to their extension. This difference is caused because SRN is not able to capture artificial channels, while the official river network provided does.

3.2. Characterization of riparian areas and evaluation of riparian condition

Open valleys supposed 21.5% of the Sardinian SRN (13641 segments). This group presented the widest valleys (118.2 m on average), the lowest geological hardness (average=1.4) and the lowest channel and riverbank slopes (0.0145 and 0.061 on average, respectively; Fig. 4).

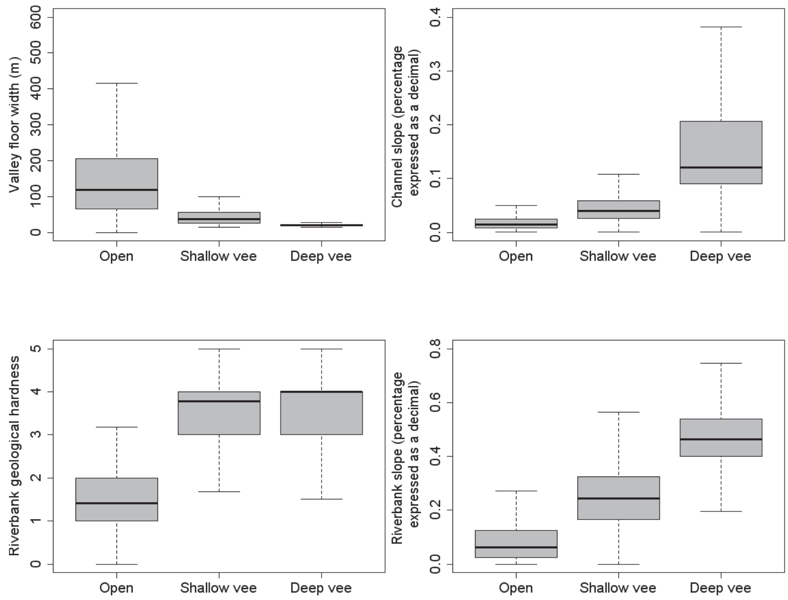


Figure 4. Boxplots of the four variables involved in the river reach classification for the three geomorphological valley types.

Shallow-vee valleys covered 50.7% of the Sardinian SRN (32098 river reaches) presenting intermediate characteristics between the other two groups. Finally, the third group included 27.8% of the Sardinian SRN (17625 river reaches) and corresponded with deep-vee valleys. This third group showed narrower valley widths (less than 20 m on average), high geological hardness (4 on average) and the steepest channel and riverbank slopes (0.1202 and 0.462 on average, respectively).

Before running any models based on land use composition on the riparian zones we checked that the percentage of some important land uses within the riparian zone for the model were related to the dominance of certain land uses recorded in the Caravaggio protocol. Linear regression between percentage of broadleaf forest in the riparian zone (obtained with GIS techniques) and the number of spot checks in which natural land uses dominated within 5m of the banktop were not good (R^2 = 0.05; Fig.5). However, quantile regressions highlight that the percentage of broadleaf vegetation within the riparian zone increases the minimum number of spots check in which natural land uses dominate (tau= 0.2; Fig.5).

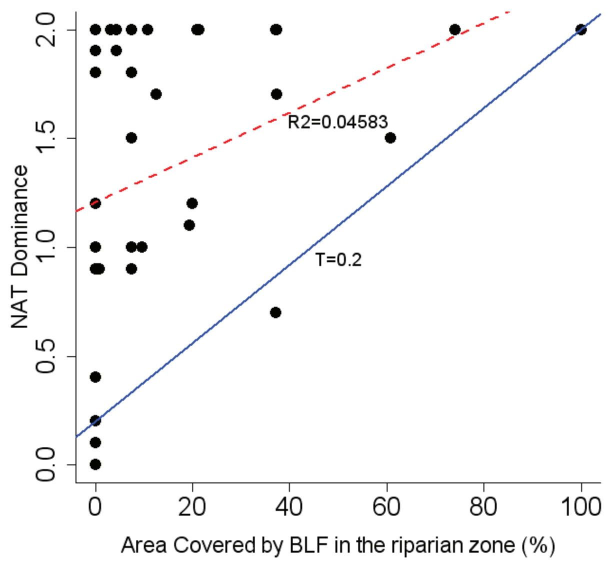


Figure 5. Quantile (blue line tau=0.2) and linear regression (dashed red line) between the area covered by Broadleaf forest (BLF) within the riparian zone derived using GIS layers and the observed dominance of natural land uses (NAT) within 5 m of banktop using the CARAVAGGIO field protocol.

Riparian forest was better conserved in Deep-V valleys than in open or shallow-V valleys. Less than 1% (64 river reaches) of Deep-V valley river reaches presented Bad riparian condition, while almost more than 40% of river reaches within this valley type presented Good riparian condition (Fig. 6). In opposition, almost 14% and 16% of river reaches showed bad and good riparian condition within Open or shallow-V valleys, respectively, while river reaches within the poor riparian condition class were the dominant (almost 53%).

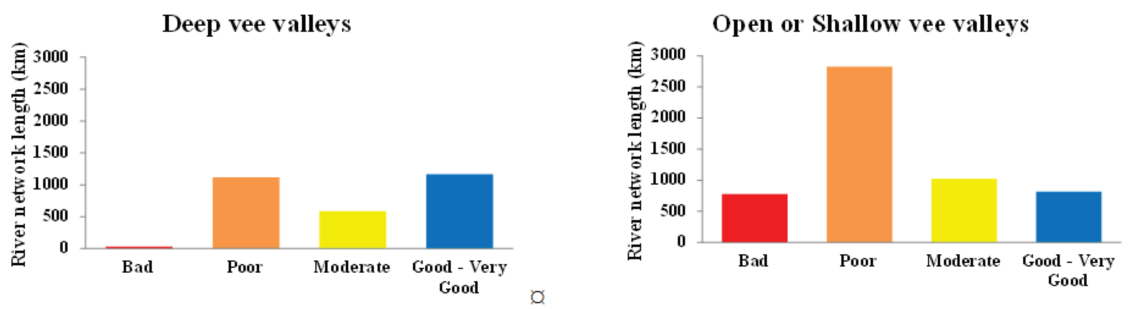


Figure 6. Accumulated river network lenght (km) according their riparian condition for each valley type

Pramaera (33.8%), Picocca (31.2%), Flumendosa (27.8%) and Cedrino (27.6%) catchments were the ones with a largest percentage of its river network in a good riparian condition, while Foddeddu (25.8%) and Padrogiano (16.2%) catchments had the largest percentage of their river network within the bad riparian condition class (see graphs and maps in annex II). It is also remarkable the large proportion of the river network in bad and poor riparian condition classes in the Faa (96.3%), Sperandeu (73.7%) and Padrogiano (78.1%) catchments.

Modeled riparian condition scores were significantly related to the Land Use Index derived from the Caravaggio field protocol (LUI; R^2 = 0.32; Fig. 7). This indicates that the riparian condition modeled scores are related to land use ground information in an appropriate manner.

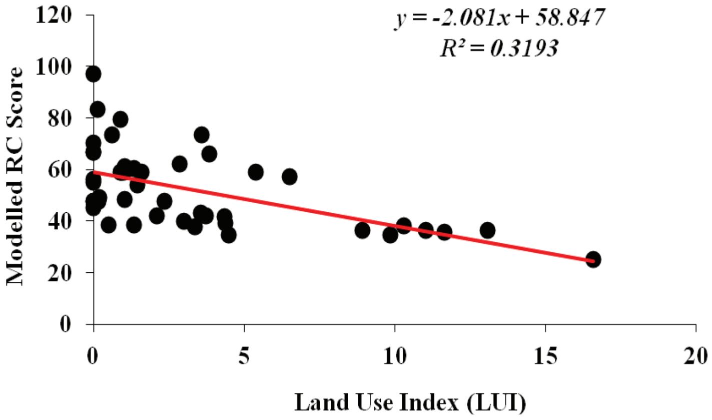


Figure 7. Linear regression between the Land Use Index (LUI) derived from the CARAVAGGIO field protocol and the modeled riparian condition (RC) score.

Finally, modeled riparian condition was also checked in different areas of the 10 selected catchments in order to observe which landscape configuration was actually creating the different results. Bad riparian condition classes were always dominated by Urban and human developments or by agricultural land uses, while poor riparian condition was generally associated to agricultural land uses in which pasture and scrubs and shrubs mosaics might also be present (Fig. 8 A and B). The moderate riparian condition class was mainly composed by a matrix of scrubs and shrubs, in which broadleaf vegetation might be present but scarce (Fig. 8 C). Finally, good riparian condition is mainly associated with the dominance of large woody vegetation (Fig. 8 D).

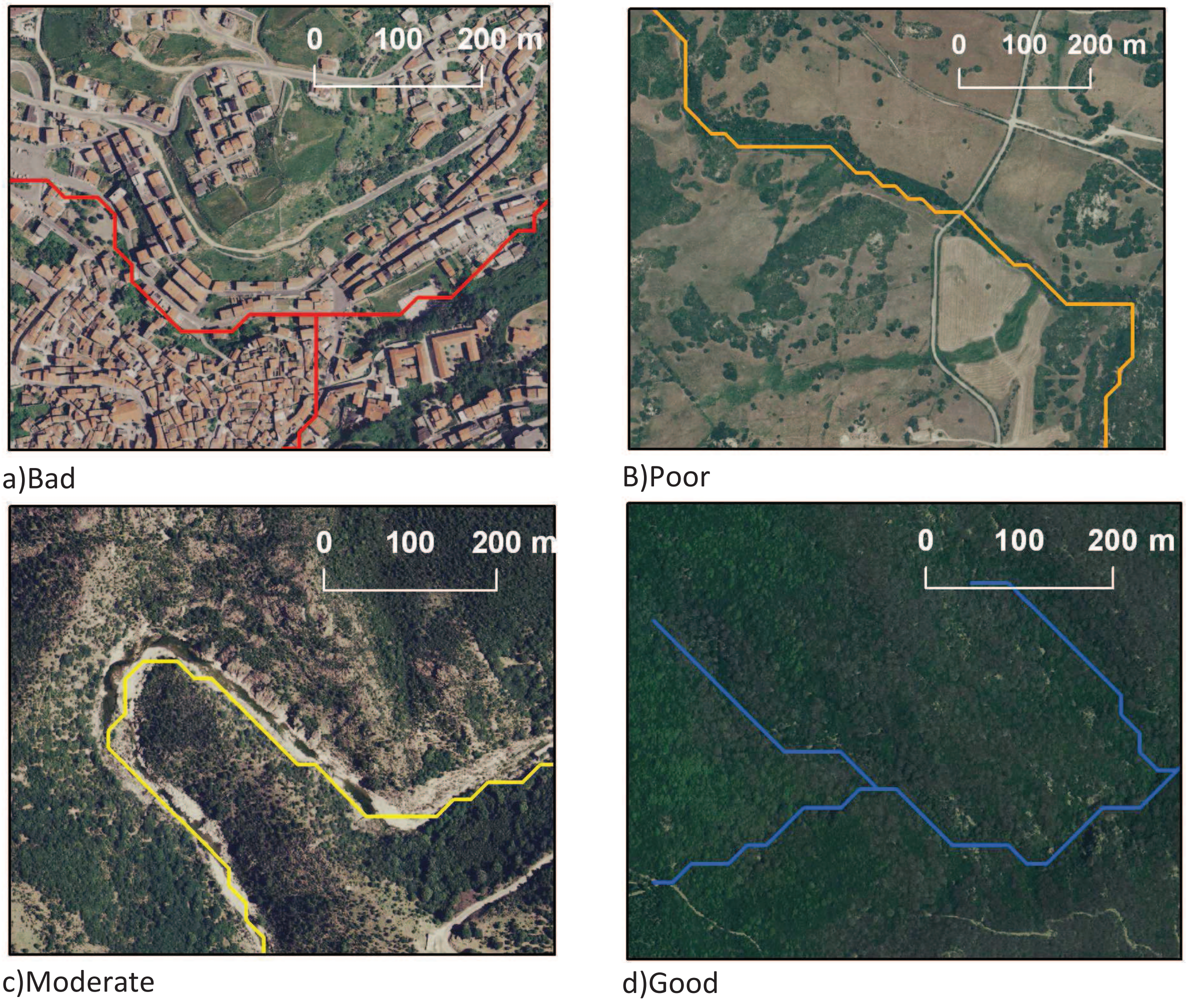


Figure 8. Images showing examples of the four classes of riparian condition and aerial pictures showing landscape configuration for those areas. These areas are signaled in annex II.

3.3 Evaluation of river bank instability

More than 40% (1189 km out of 2896 km) of the SRN contained in Deep-V valleys presented a low risk of bank instability, while low risk of bank instability in open or shallow-V valleys was only achieved by 16% (873 km out of 5437 km) of the SRN in this valley type (Fig 9.) High risk of bank instability was achieved by 43% and 46% of the SRN in Deep-V and open or shallow-V valleys, respectively, while 16% and 38% of the SRN reached a moderate risk of bank instability in those valley types (Fig. 9).

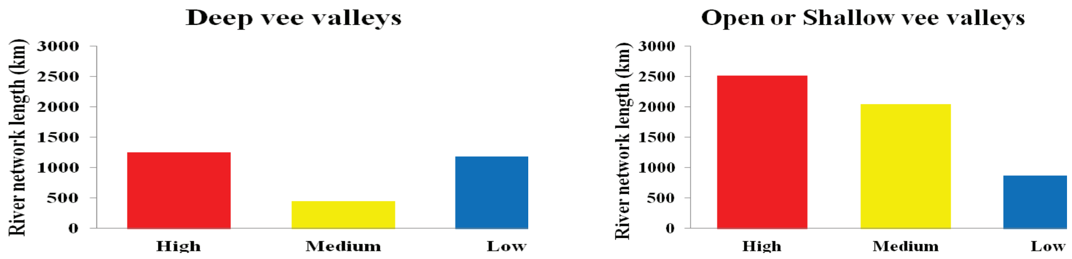


Figure 9. Accumulated river network lenght (km) according their bank instability for each valley type.

Linear regressions of percentage of broadleaf forest within the riparian zone and riparian condition scores with the number of spot checks with Eroding Banks and Local Erosion and with the number of spot checks with Cliffs, respectively (Fig. 10), showed a poor fit for both regressions being R^2 values less than 0.05. However, we see that there is a much better fit when using quantile regressions (tau: 0,9; Fig. 10). Increasing the percentage cover of broadleaf forest in the riparian zone or increasing the riparian condition score decreases the number of spot checks in which we record characteristics associated to bank instability (i.e. eroding banks, local bank erosion or cliffs).

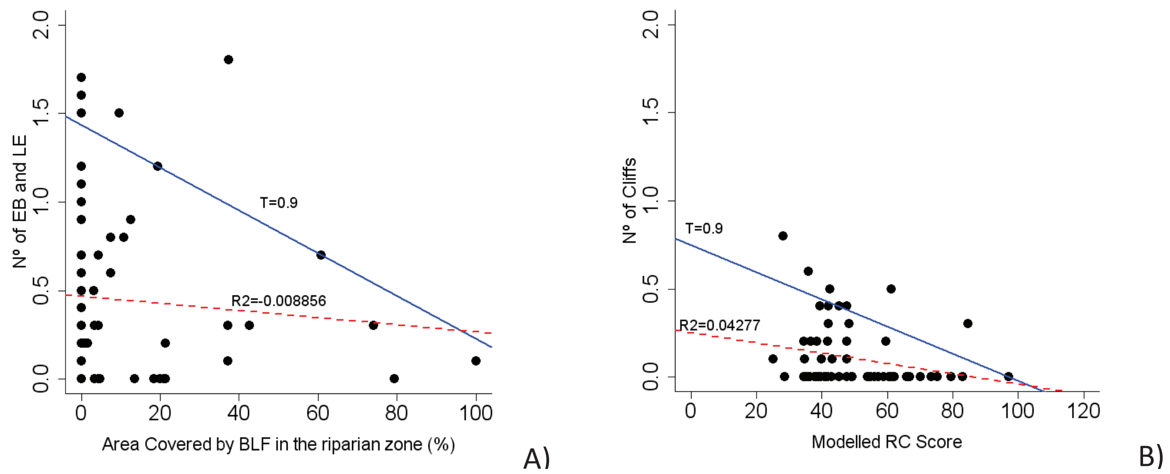
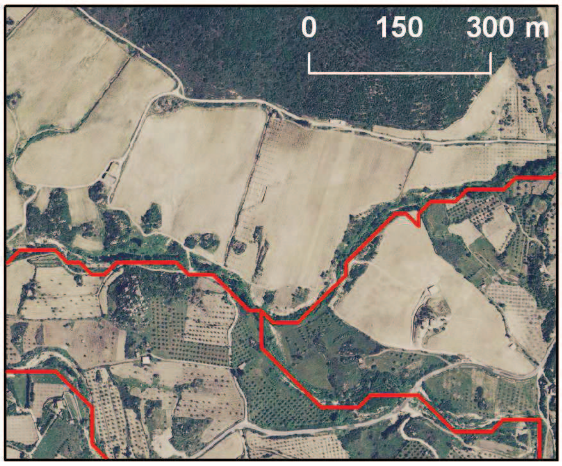


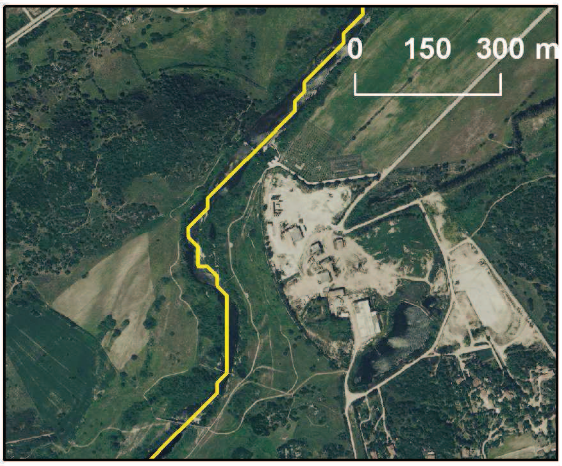
Figure 10. Quantile (blue line tau=0.9) and linear regression (dashed red line) between (A) the area covered by Broadleaf forest (BLF) within the riparian zone derived using GIS layers and number of spot checks with Eroding Banks (EB) and Local Erosion (LE) and between (B) modelled riparian condition (RC) scores and number of spot checks with Cliffs.

The risk of bank instability was also checked in different areas of the 10 selected catchments in order to observe which landscape configuration was actually creating the spatial pattern observed. In general, high risk of bank instability was dominant in landscape areas in which agricultural land dominated and riparian condition was low with scattered trees along river bank sides.

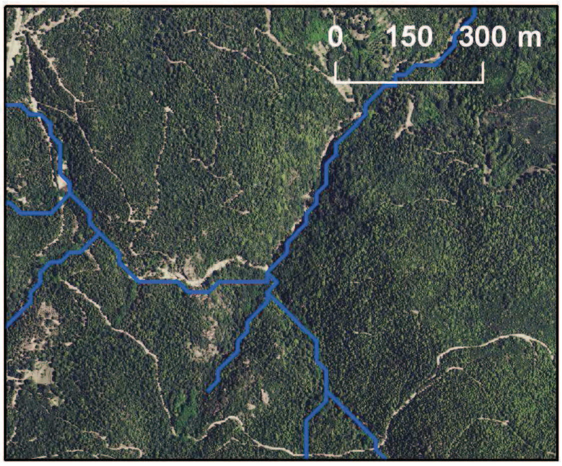
Medium risk of bank instability prevailed in landscape matrix dominated by scrubs and shrubs in which agriculture land might also be present and riparian forests were clumped but not continuous. Finally, low risk of bank instability was important in large forested areas or in more complex landscape matrix but always continuous and well conserved riparian forests (Fig. 11).



A) High



B) Medium



C) Low

Figure 11. Images showing examples of the three classes of bank instability risk and aerial pictures showing landscape configuration for those areas. These areas are signaled in annex II.

4. CONCLUSIONS

The main conclusions of this study could be summarised in the following:

1. The use of SRN for large scale planning of riparian attributes and assessment of risk of physical degradation and modification of natural channel morphology is a powerful tool that could be applied to different world regions given the existence of GIS information with proper resolution.
2. The methodology used all throughout the study seems to be validated by some key physical relationships between GIS derived information and information gathered within the study sites following the Caravaggio protocol.
3. The riparian condition score is highly dependent on the percentage cover of broadleaf forest within the riparian zone. Agriculture and Urban and other human developments are also important to define the scores of the bad and poor condition classes. Other land uses such as pastures and scrubs and shrubs might need to be considered in regions such as Sardinia, in the case that these land uses are the "natural" vegetation within riparian zones. However, the relationships between riparian condition and percentage cover of broadleaf forest within the riparian zone with bank instability characteristics give strength to the obtained results.
4. The estimation of bank instability risk was highly dependent on riparian condition, although denuded areas with high gradients were also important.
5. The large variability observed on the relationships between riparian condition and percentage cover of broadleaf forest within the riparian zone with bank instability characteristics at the lower range of riparian condition might be due to other variables playing important roles. We believe that bank material composition, bank slopes, the presence of a well conserved understory, tree spatial distribution and the role played by other woody vegetation (p.e. roots of shrubs and scrubs) could also be important. All these aspects deserve further research in order to achieve a better integration of results for large and small management scales.

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ANNEXE I

INPUT PARAMETERS
(BUILDGRIDS AND NETRACE)

The following table contains all parameters used as inputs in the software packages Buildgrids and Netrace (included in the NetMap platform).

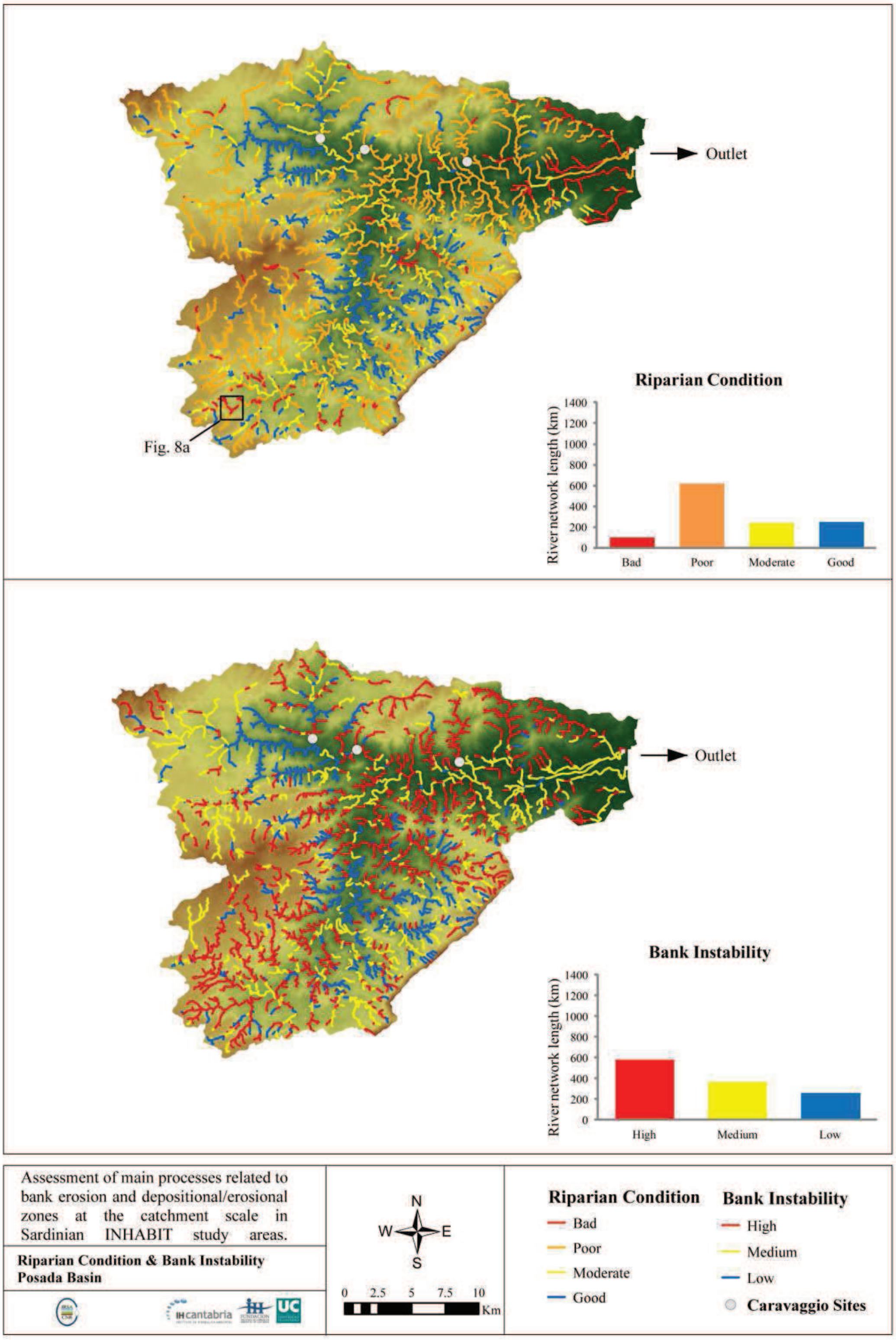
INPUT PARAMETERS FOR Bld_grds AND Netrace	
2	flow direction algorithm (1 for D-infinity, 2 for D-infinity + convergence)
25	radius (m), length scale for calculating slope and curvature
10	dig; depth of DEM incision for drainage enforcement
75	dig-radius, width of "swale" incised for drainage enforcement -- this incision is only applied for flow directions, nothing else
0.5	dig maximum slope, slope gradient above which drainage enforcement is not applied
2	Channel threshold criteria: 1 = Drainage area; 2 = Specific drainage area.
100	channel_area_threshold for low-gradient areas (area in square meters times slope to the c_exp power)
400	channel_area_threshold, high-gradient areas
2	c_exp, slope exponent
0.2	S_min, slope below which low-gradient threshold applies
0.3	S_max, slope above which high-gradient threshold applies
0.0005	Plan_min, minimum plan curvature for channel head in low-gradient areas
0.005	Plan_min, minimum plan curvature for channel head in high-gradient areas
100	min_flow_length (m), distance overwhich Plan_min must be equaled or exceeded for a channel head
500	Xmin, minimum window length for channel gradient calculation
1500	Xmax, maximum window length
0.001	Smin, gradient at and below which Xmax applies
0.2	Smax, gradient at and above which Xmin applies
2	Fit Order, integer, polynomial order for fit to channel elevations for gradient
50	junction_length ! channel length used to estimate junction angles
1.683	cw1, channel width function, method 1: cw = cw1*(Mean_annual_flow^cw2)
0.436526	cw2, channel width function, method 2: cw = cw1*(Area^cw2)*(Prec^cw3)
0.440865	cw3, channel width function, cw in meters, area in km2, prec in m, maf in m3/sec
0.63	depth_coefficient_1, method 1: channel depth = coef_1*(mean_annual_flow^coef2)
0.173158	depth_coefficient_2, method 2: channel depth = depth_coefficient_1*(area**depth_coefficient_2)*(prec**coef3)
0.151639	depth_coefficient_3, channel depth in meters, area in km2, prec in m, mean_annual_flow in m3/sec
2	reach method: 1) channel widths, 2) specified length !
10	# of channel widths for a reach, for reach-method 1
400	minimum reach length in meters, for reach-method 2
800	maximum reach length in meters, reach-method 2
0.04	area (km^2) at and below which minimum reach length is enforced, reach-method 2

50	area (km^2) at and above which maximum reach length is enforced, reach-method 2
150	minimum reach length for increasing max_grad_down
200	maximum reach length for increasing max_grad_down
0.04	Drainage area (sq km) at and below which minimum reach length applies
50	Drainage area (sq km) at and above which maximum reach length applies
1	Area weighting for reach breaks (larger values increase effect of tributary inputs)
2-0.75-1.25	vh, number of bank-full depths above channel to qualify as floodplain
6.32E-06	Mean annual flow, coefficient 1, flow = c1*(Area^c2)*(Precip^c3)
0.99	Mean annual flow, coefficient 2, Area in square kilometers, Precip in m
1.593	Mean annual flow, coefficient 3
0	gcoef1, field_gradient% = gcoef1 + gcoef2*(DEM_gradient%^gcoef3)
1.019785	gcoef2
0.825982	gcoef3
0.2	end of calibrated gradient
0.3	start of DEM gradient, linear combination in between
3.79	trib effects coefficient 1
1.96	trib effects coefficient 2
0.0874	trib patch size coefficient 1
0.3867	trib patch size coefficient 2
0.5	decay rate for tributary effects, 1/km

INSTRUCION FILE FOR Netrace	
SHAPEFILE options	
y	Force reach breaks at channel junctions (y/n)
2	1) Fixed-length reaches, or 2) homogenous reaches
2	Gradient calculation method: 1) via contours, 2) poly fit over centered window, 3) none
2	Channel width estimation method: 1) a*(Mean_annual_discharge^b), 2) a*(Area^b)*(Prec^c), 3) none
2	Channel depth estimation method: 1) a*(Mean_annual_discharge^b), 2) a*(Area^b)*(Prec^c), 3) none
1	Mean annual discharge method: 1) a*(Area^b)*(Prec^c), 2) none
1	Valley width calculation method: 1) inundation flow path 4) none
n	Debris flow model (y/n) requires additional data files
n	Basin ID (requires .flt grid file of basin IDs)
0	Maximum number of channel networks to trace (zero = no limit)
RASTER output options	
y	Hillslope pixel distance to nearest stream channel, raster file (y/n)
y	Hillslope pixel delivered-to-channel-reach ID, raster file (y/n) (requires reach shapefile)
y	Create valley floor raster image vmask_ID.flt (.hdr) (y/n) (requires reach shapefile)

ANNEXE II

MAPS AND GRAPHICS OF RIPARIAN CONDITION AND BANK INSTABILITY FOR SELECTED BASINS


Outlet
Fig. 8a
Riparian Condition
River network length (km)
1400
1200
1000
800
600
400
200
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
1400
1200
1000
800
600
400
200
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Posada Basin
N
W
E
S
0 2.5 5 7.5 10
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites

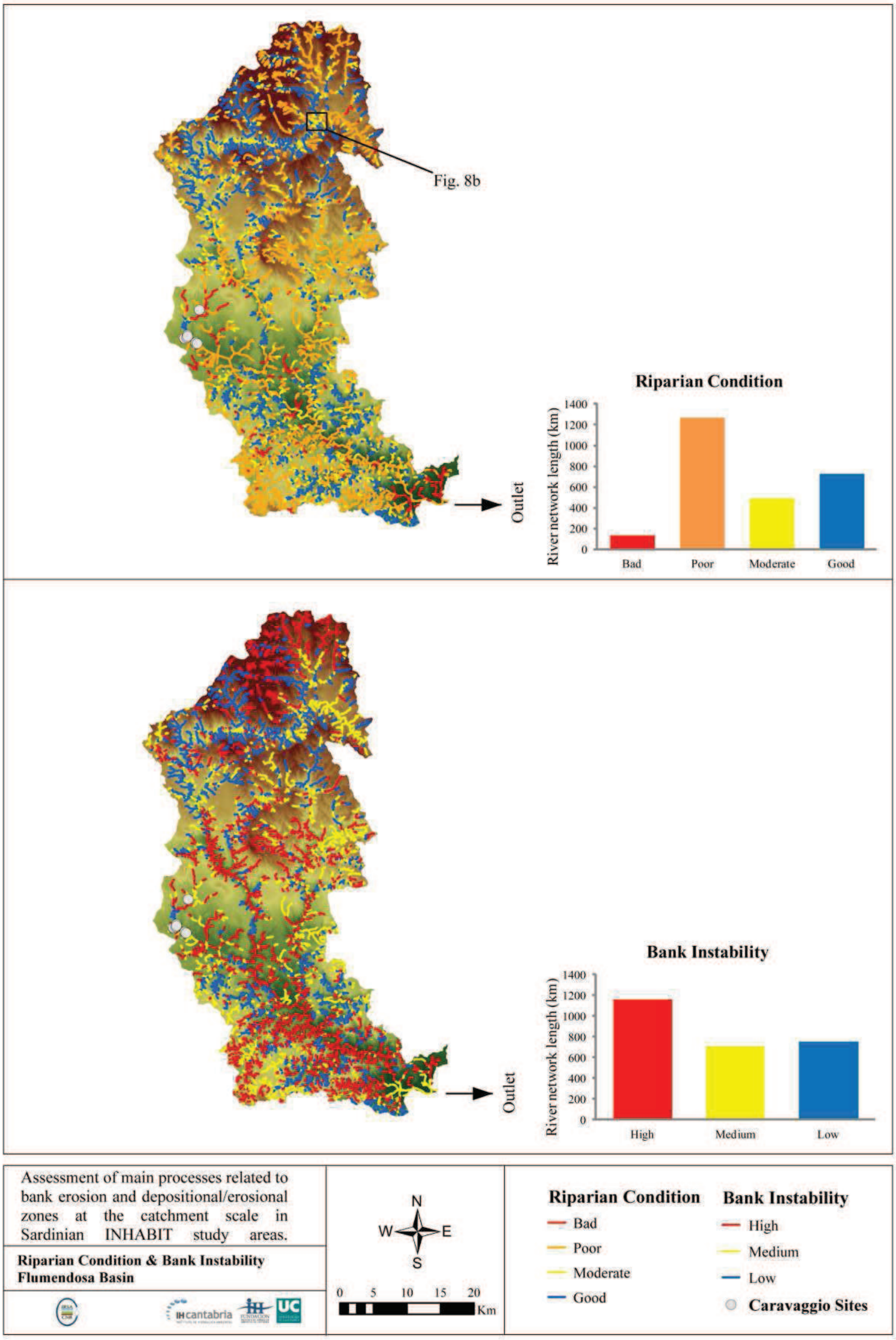
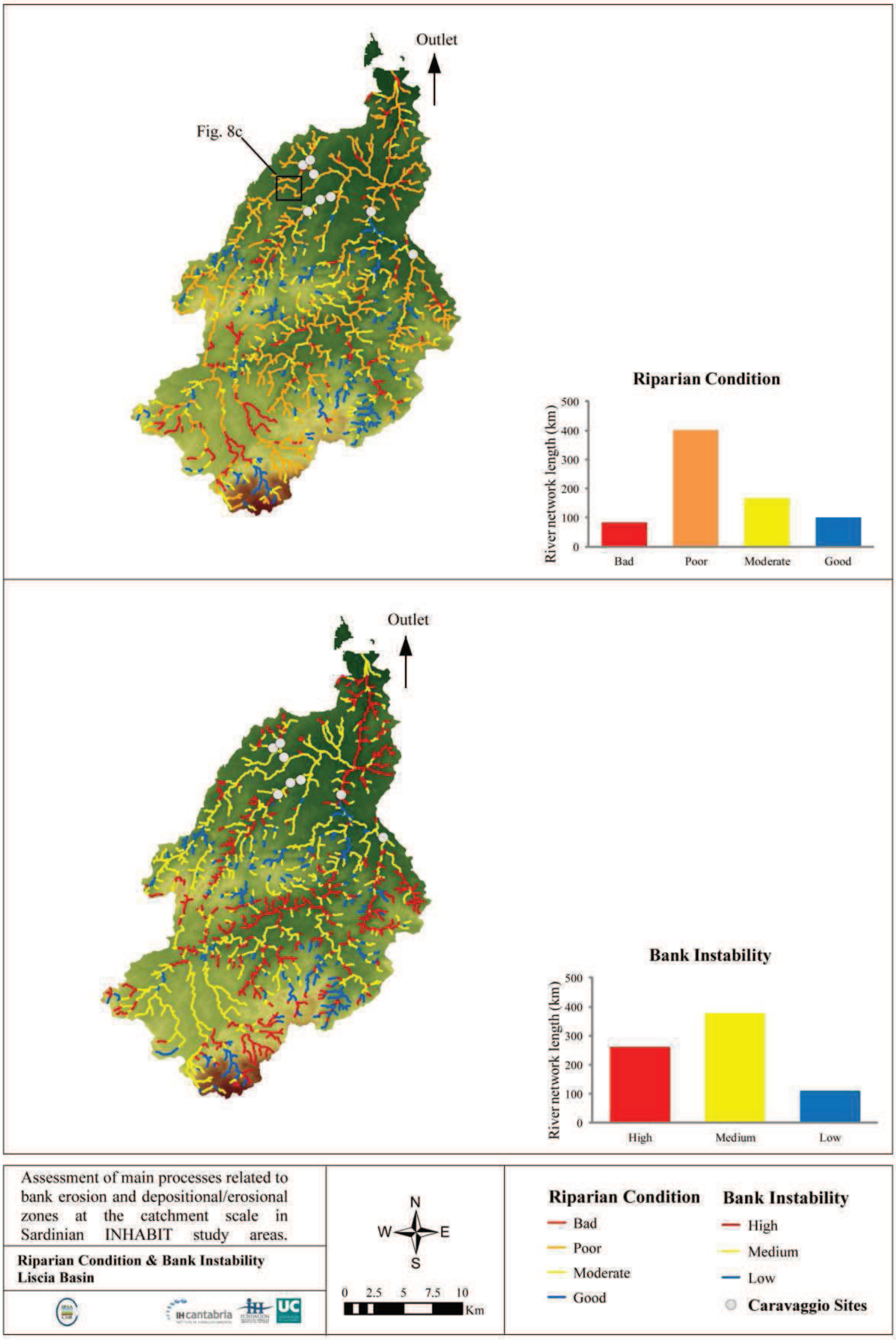
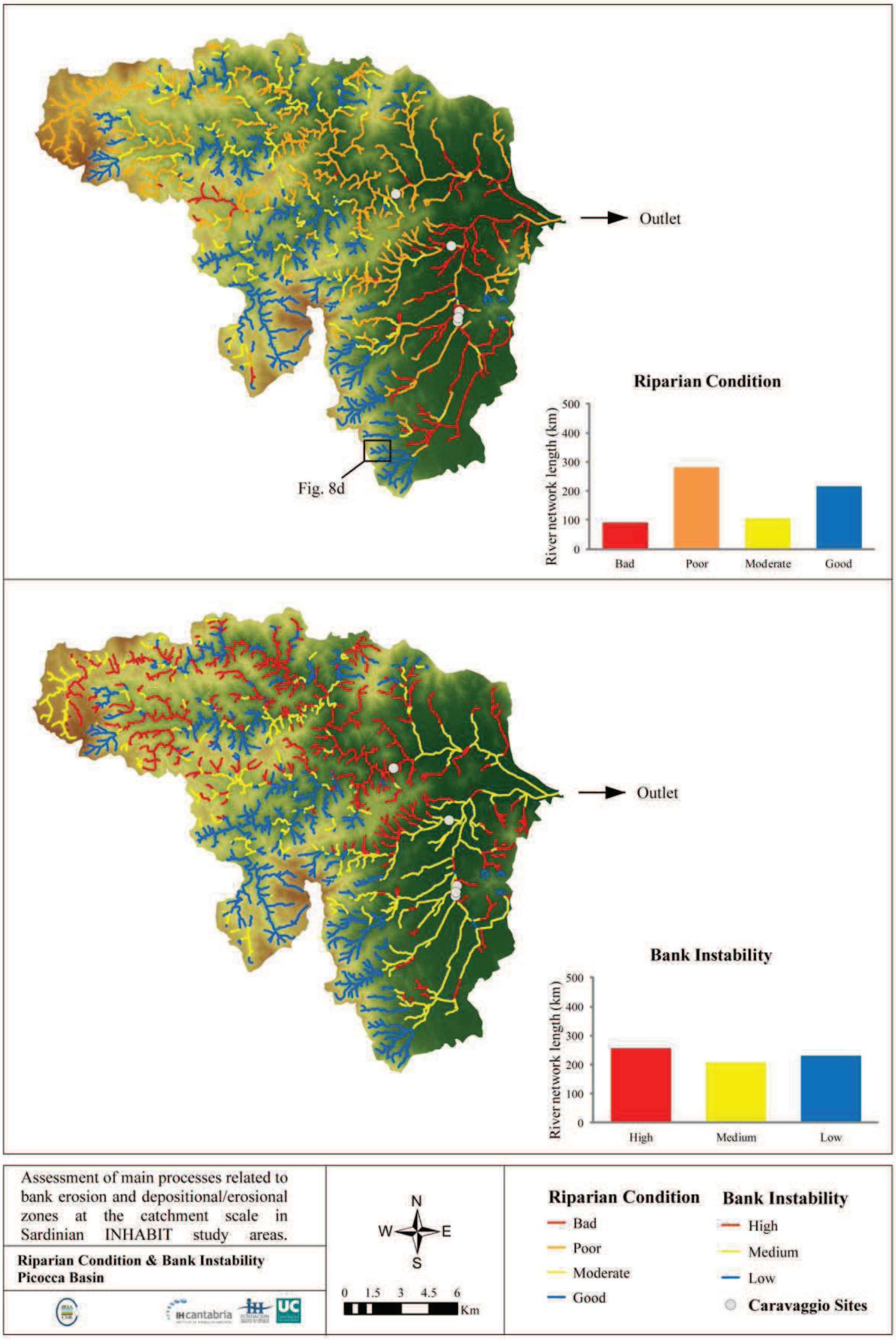
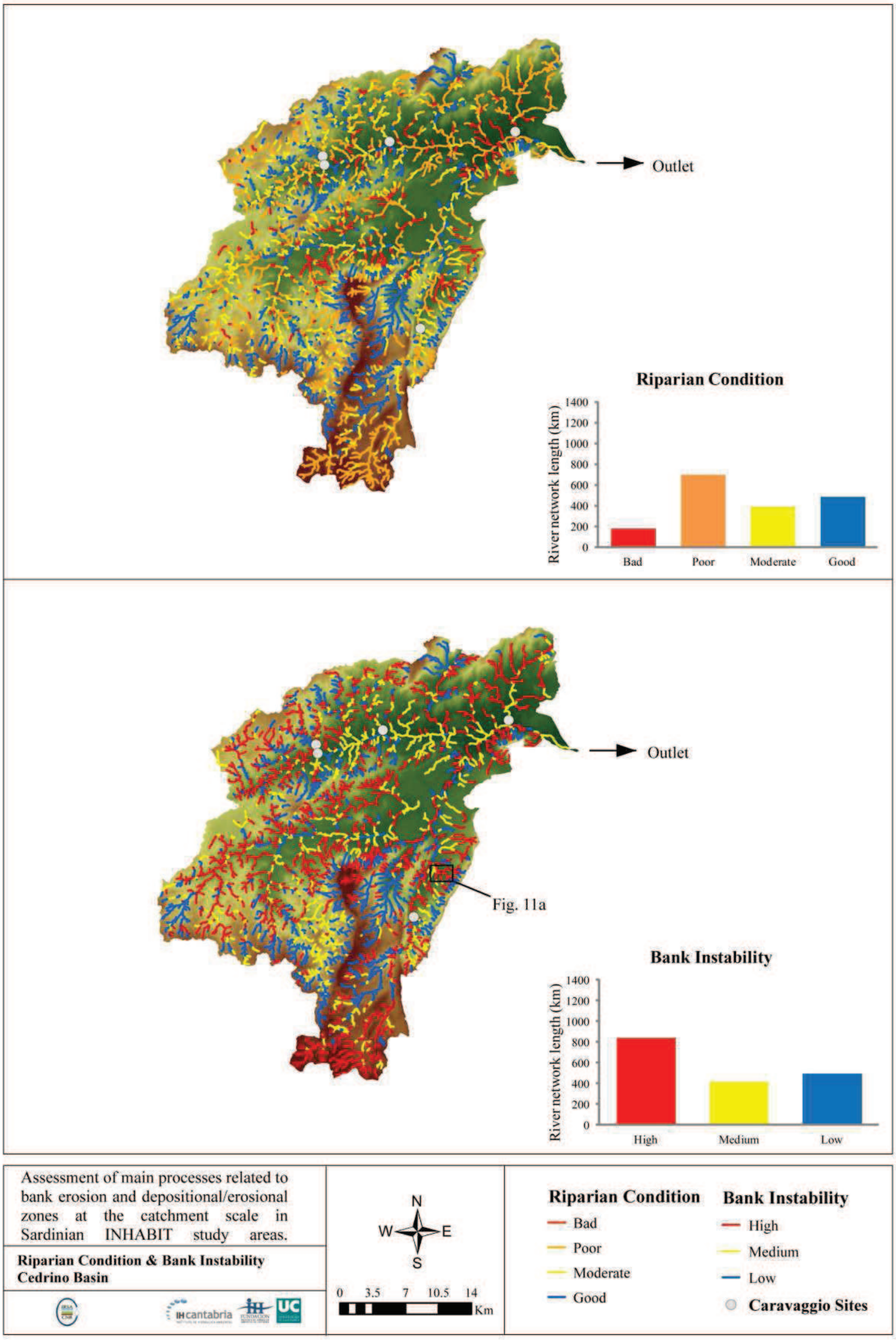
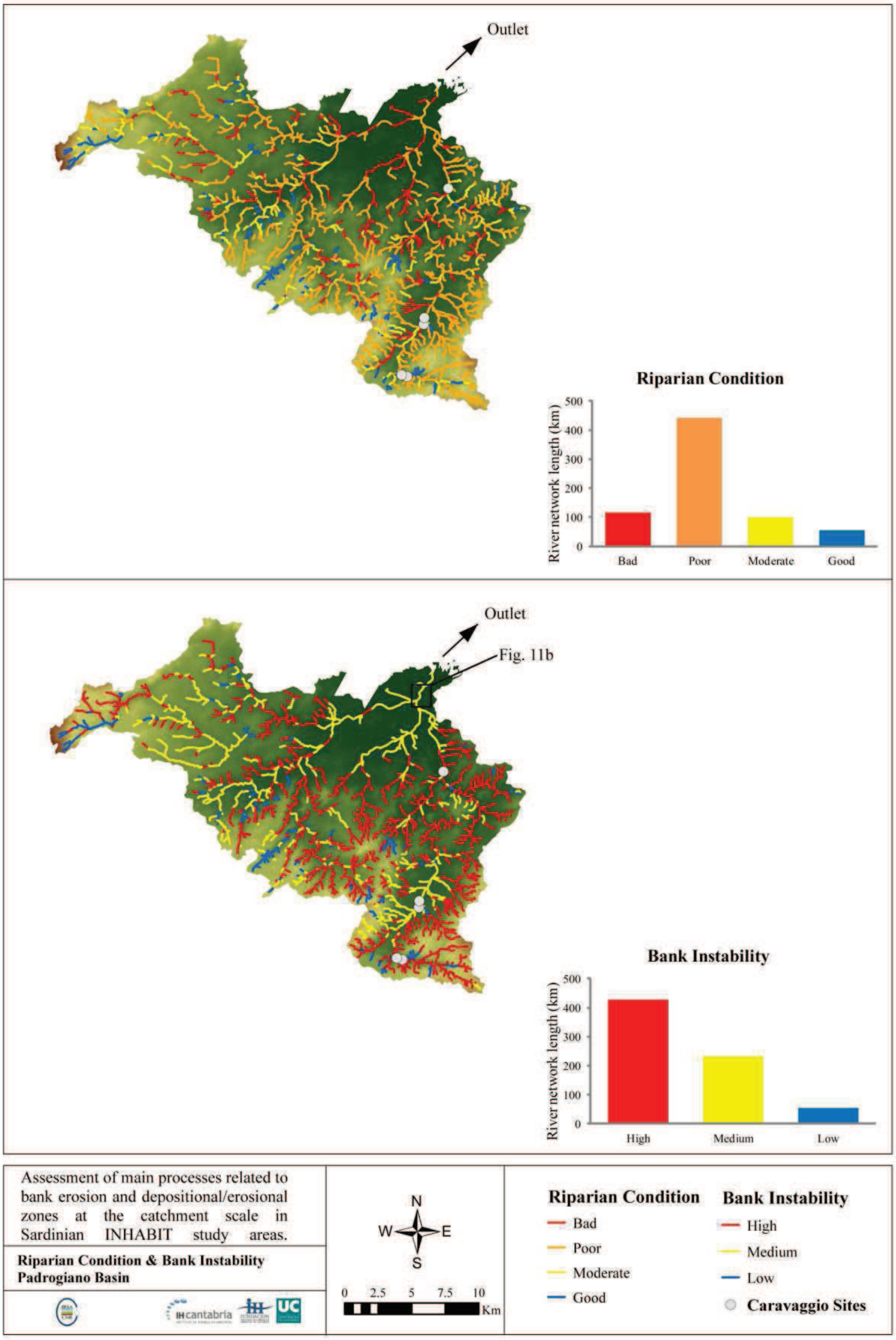


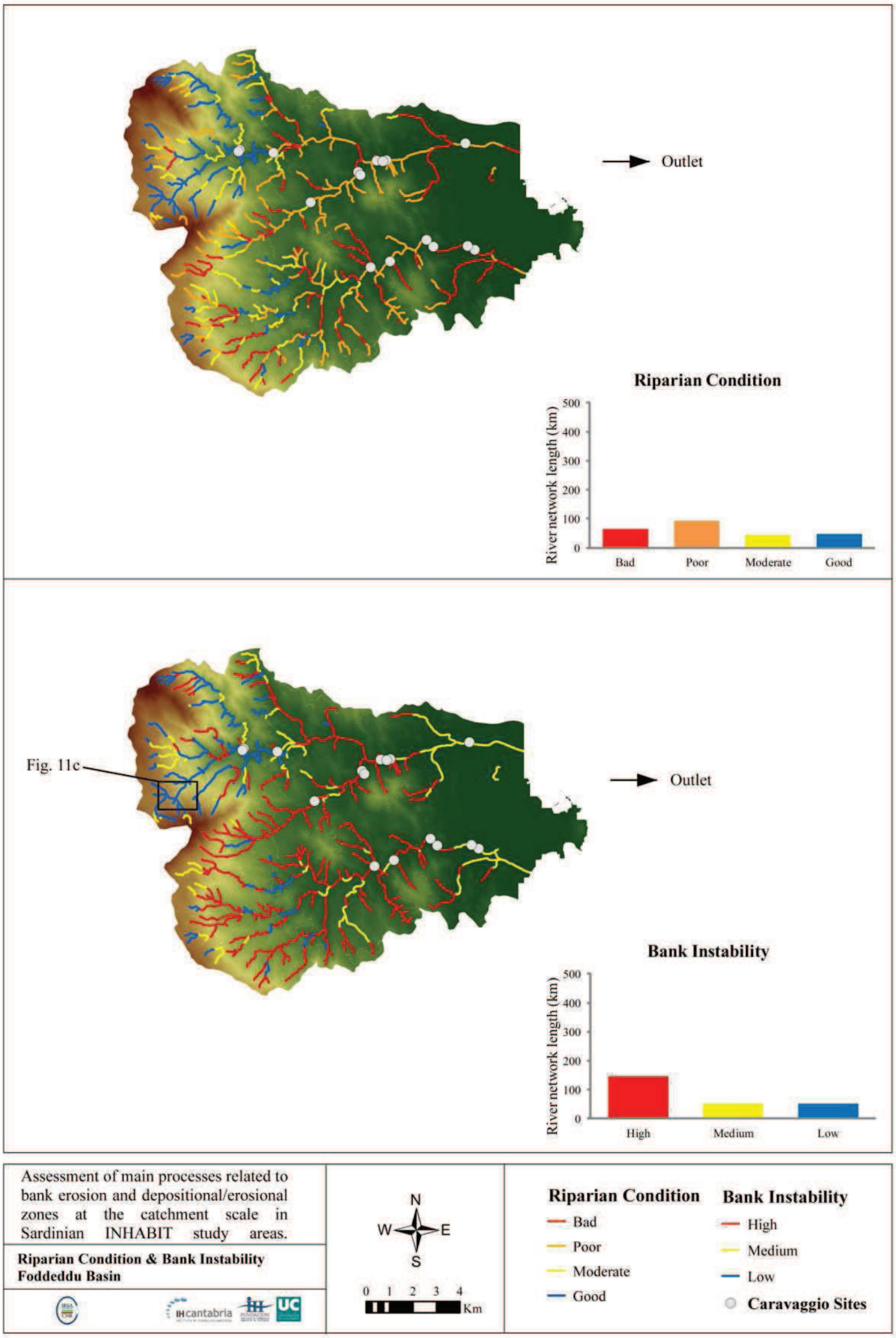
Fig. 8b
Outlet
Riparian Condition
River network length (km)
1400
1200
1000
800
600
400
200
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
1400
1200
1000
800
600
400
200
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Flumendosa Basin
N
W
E
S
0 5 10 15 20
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites

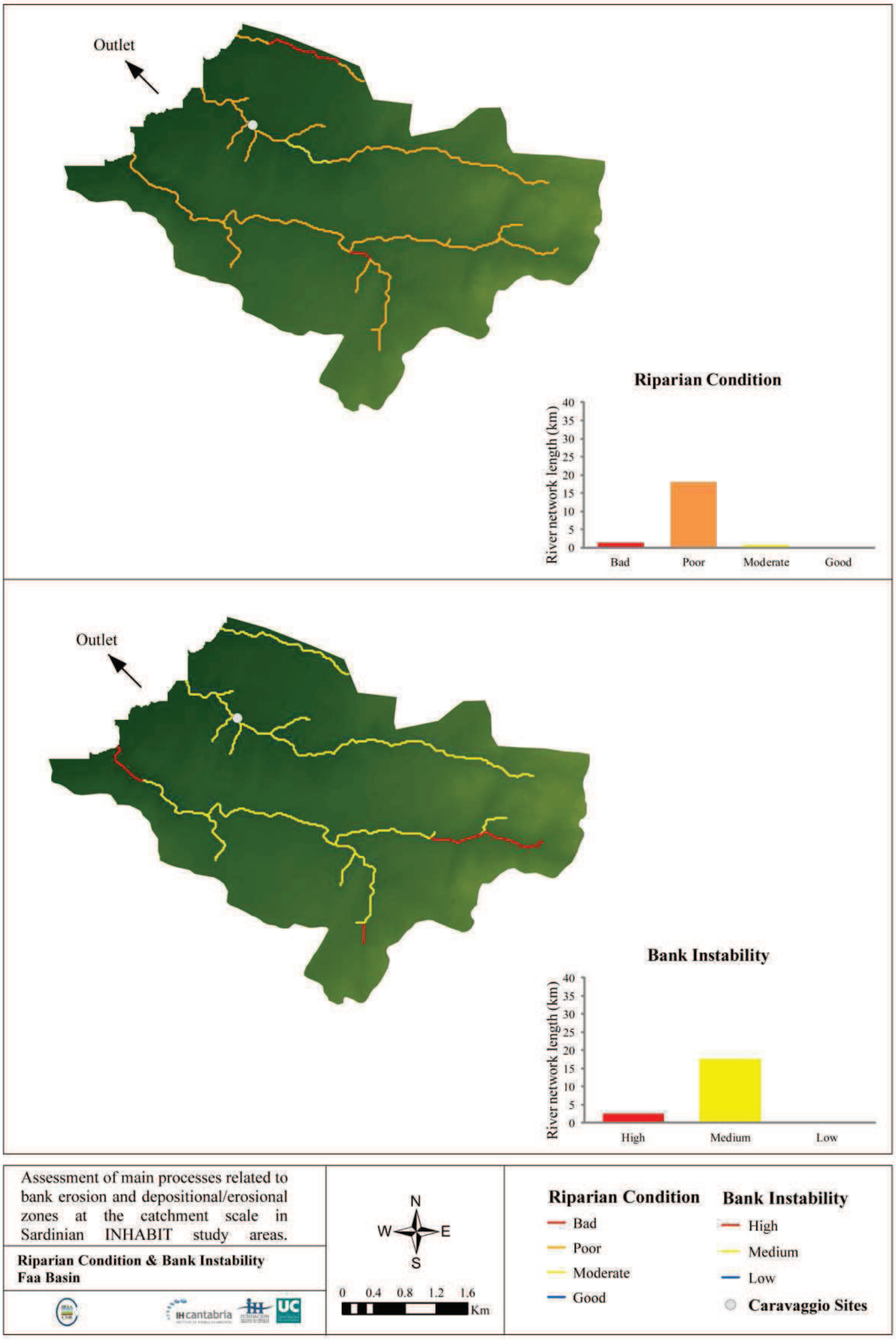

Outlet
Fig. 8c
Riparian Condition
River network length (km)
500
400
300
200
100
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
500
400
300
200
100
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Liscia Basin
IH cantabria
UC
N
W
E
S
0 2.5 5 7.5 10
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites

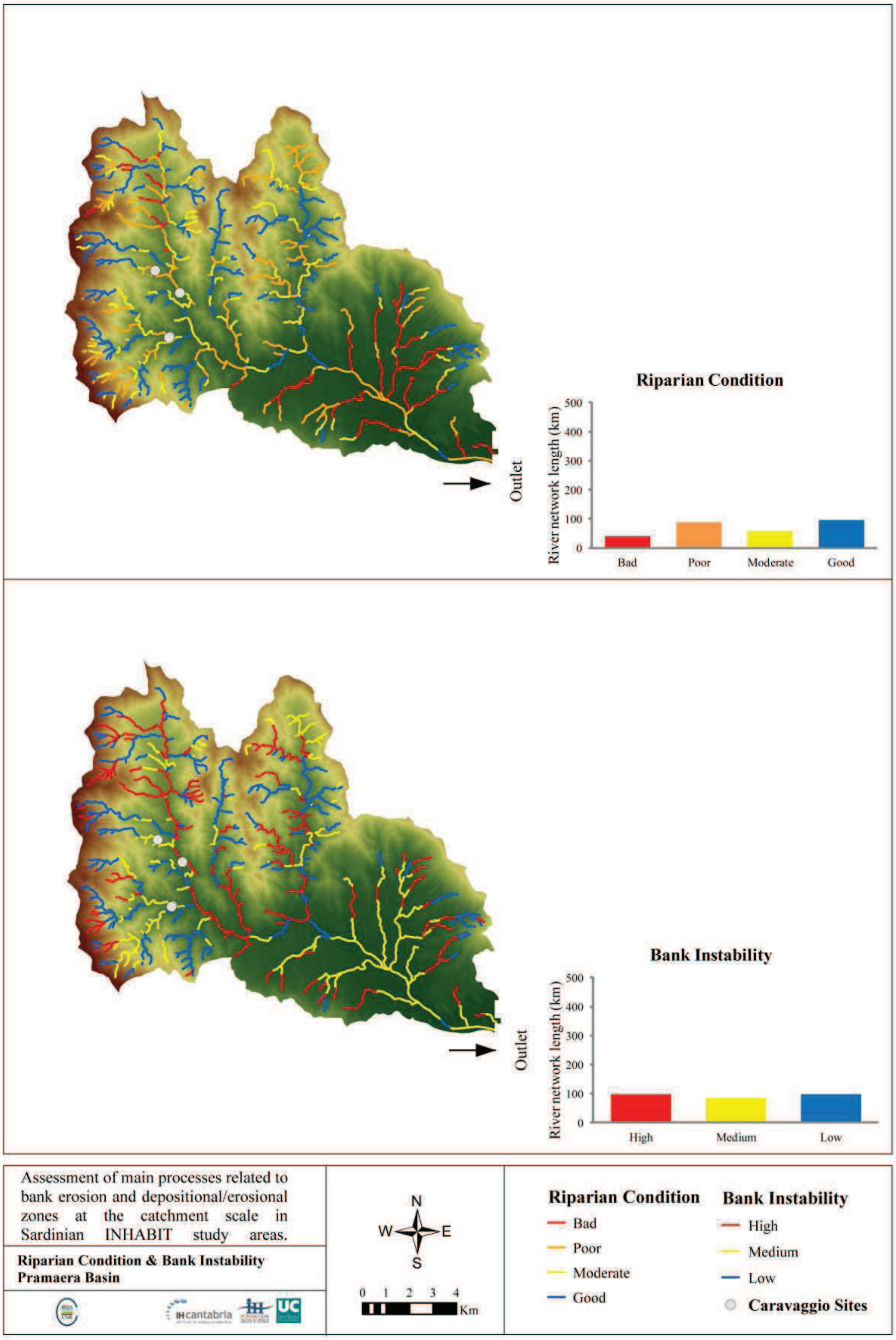

Outlet
Fig. 8d
Riparian Condition
River network length (km)
500
400
300
200
100
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
500
400
300
200
100
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Picocca Basin
N
W
E
S
0 1.5 3 4.5 6
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites

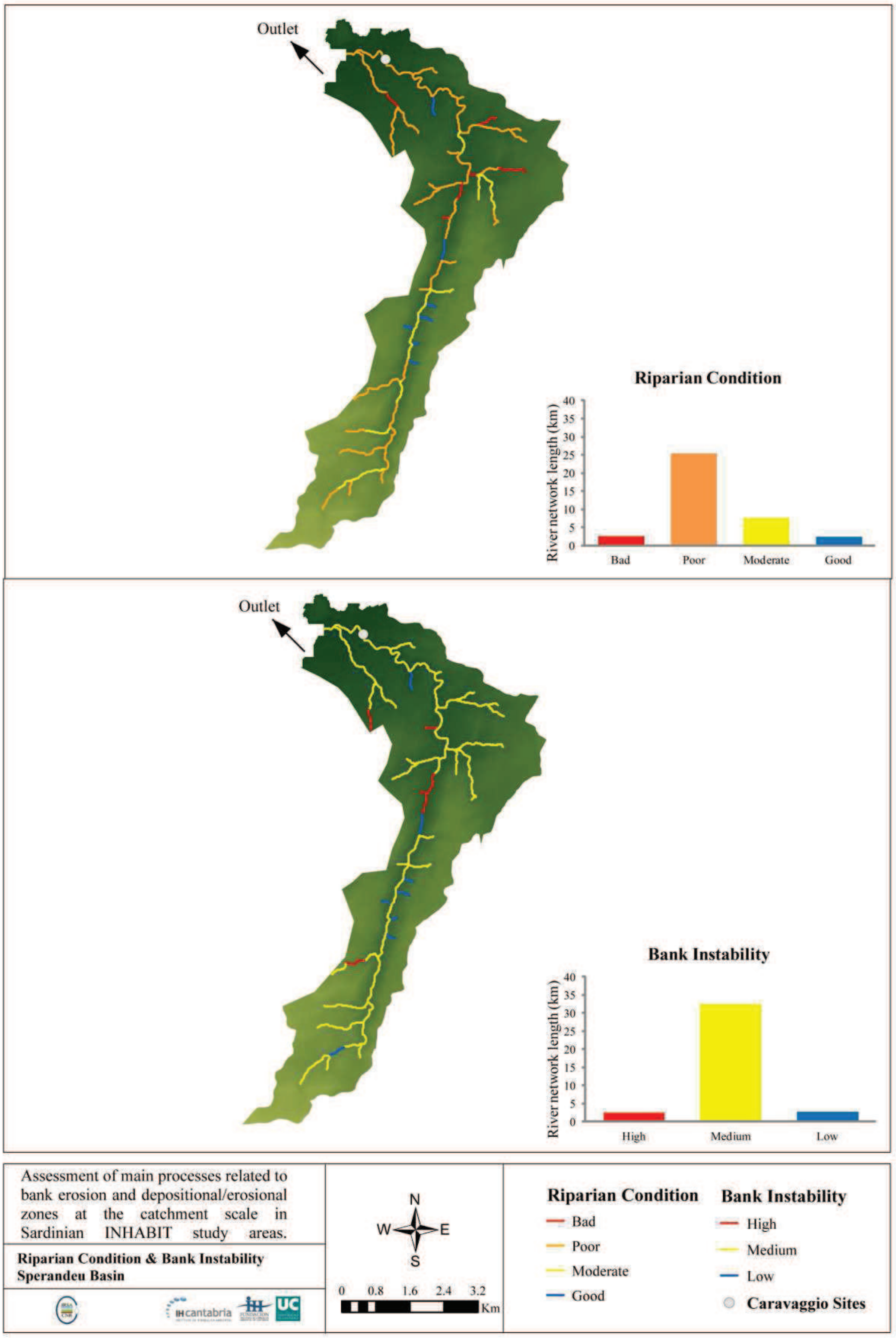

Outlet
Riparian Condition
River network length (km)
1400
1200
1000
800
600
400
200
0
Bad
Poor
Moderate
Good
Outlet
Fig. 11a
Bank Instability
River network length (km)
1400
1200
1000
800
600
400
200
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Cedrino Basin
IH cantabria
UC
N
W
E
S
0 3.5 7 10.5 14
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites


Outlet
Riparian Condition
River network length (km)
500
400
300
200
100
0
Bad
Poor
Moderate
Good
Outlet
Fig. 11b
Bank Instability
River network length (km)
500
400
300
200
100
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Padrogiano Basin
N
W
E
S
0 2.5 5 7.5 10
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites


Outlet
Riparian Condition
River network length (km)
500
400
300
200
100
0
Bad
Poor
Moderate
Good
Fig. 11c
Outlet
Bank Instability
River network length (km)
500
400
300
200
100
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Foddeddu Basin
IHcantabria
UC
N
W
E
S
0 1 2 3 4
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites


Outlet
Riparian Condition
River network length (km)
40
35
30
25
20
15
10
5
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
40
35
30
25
20
15
10
5
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Faa Basin
N
W
E
S
0
0.4
0.8
1.2
1.6
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites


Riparian Condition
River network length (km)
500
400
300
200
100
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
500
400
300
200
100
0
High
Medium
Low
Outlet
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Pramaera Basin
IH cantabria
UC
N
W
E
S
0 1 2 3 4
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites


Outlet
Riparian Condition
River network length (km)
40
35
30
25
20
15
10
5
0
Bad
Poor
Moderate
Good
Outlet
Bank Instability
River network length (km)
40
35
30
25
20
15
10
5
0
High
Medium
Low
Assessment of main processes related to bank erosion and depositional/erosional zones at the catchment scale in Sardinian INHABIT study areas.
Riparian Condition & Bank Instability
Sperandeu Basin
N
W
E
S
0 0.8 1.6 2.4 3.2
Km
Riparian Condition
Bad
Poor
Moderate
Good
Bank Instability
High
Medium
Low
Caravaggio Sites

D2D2.9 - DEVELOPING ECOLOGICAL ASSESSMENT SYSTEMS FOR RIVERS IN CYPRUS ALONG A GRADIENT OF HYDROLOGICAL STABILITY

Authors:

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SUMMARY

The assessment of ecological quality in Mediterranean area needs to account for the key role played by hydrological stability. Biological, physico-chemical and hydromorphological data were collected in correspondence to the biomonitoring stations between 2005 and 2011, totaling more than 500 samples collected along a gradient of hydrological stability. Noteworthy, the stations were located mostly in correspondence to hydrological measuring stations and it was thus possible, by means of the Indicators of Hydrological Alteration (IHA) software (TNC, 2007), to compute hydrological parameters. Based on such data, an hydrological regime classification was performed following Oueslati et al. (2010) approach. Along the line of the efforts undertaken during the European Intercalibration exercise, well established and newly developed biological metrics and multi-metric indices were tested. The importance of accounting for hydrological variability in the assessment of ecological quality in Mediterranean streams was clearly confirmed by the significant differences in biological assemblages observed in response to changes in hydrological stability. In this context, an ecological assessment was successfully developed and validated against pressures acting in the area. Considerations on the ecological management of the different hydrological regime types were suggested as well.

1. INTRODUCTION

Cyprus, the third largest island in the Mediterranean Sea, has poor availability of water, so an accurate management of this precious resource must be implemented. One of the priorities is to develop methods for assessing the ecological quality that can be applied to the Mediterranean character of its watercourses. The identification of the hydrological regime of rivers is recognized as a key tool for the management of aquatic resources.
Moreover, the Republic of Cyprus, as a member state of the European Union is obliged to implement the Water Framework Directive 2000/60/EC (WFD) which requires EU member states to assess the status of water bodies using biological quality elements. The WFD requires the Republic of Cyprus to develop assessment methods for evaluating ecological status of rivers based on biological quality elements (BQEs). Once these methods have been developed at the national scale, the WFD requires each member state to participate in the Intercalibration exercise (IC). The IC aims at the harmonization of national ecological assessment systems and classifications (European Commission, 2003), in order to ensure a uniform interpretation of the 'good ecological status', and thus quality, of surface waters all over Europe.
The Republic of Cyprus between 2005 and 2009 developed methods for Intercalibration macro-types R-M4 (permanent rivers) and R-M5 (temporary rivers) based on STAR-ICMi index.
In the present paper is presented an overview of the results of the implementation of the WFD in Cyprus with consideration on ecological

assessment and water management in an important island of the Mediterranean basin.

2. ECOLOGICAL CLASSIFICATION USING INVERTEBRATES AND RIVER TYPOLOGY

2.1 Study area

More than 500 biological samples were collected from 2005 to 2012 in Water Development Department monitoring stations. The samples were collected from CNR-IRSA (2005-2006), WDD (2007-2011) and Prothea (2011-2012) (see Buffagni *et al*., 2012a and Buffagni *et al*., 2012b). The WDD monitoring stations cover all the quality gradient, including reference sites as required by the WFD and include R-M4 (permanent rivers) and R-M5 (temporary rivers) intercalibration macro-types.

2.2 Biological sampling and biological metrics

The biological sampling were conducted according to the guidelines outlined for the Aqem method (i.e. Multi-habitat, proportional sampling) and by identifying the pool/riffle sequence (Aqem consortium, 2002; Buffagni *et al*., 2004).
Ten macroinvertebrates samples were collected according to a multihabitat proportional technique, in riffle and ten in pool. An open surber sampler was used to collect macroinvertebrates (area 0.05 m^2; mesh size 0.5 mm). All taxa collected were identified at the family level.
STAR ICMi index (STAR Intercalibration Common Metric index, Buffagni *et al*., 2007) was calculated for all the biological samples, considering separately pool and riffle samples, using ICMeasy software (Belfiore & Buffagni, 2006).

2.3 Hydromorphological information and environmental data

The characterization of hydro-morphological and habitat features of the investigated sites has been performed by the application of the CARAVAGGIO method (Buffagni *et al*., 2005). The CARAVAGGIO represents an implementation of the SE_RHS method (Buffagni & Kemp, 2002) and seems the only hydromorphological method which satisfies the demands of the WFD concerning Mediterranean rivers, as far as the habitat and local hydromorphological features are concerned
This method requires to recognize channel and bank features in 500 m distance along a river. The method is based on a detailed survey pertinent to the features observed along a transect located every 50 m (spot-check) for an amount of 10 spot-check. For each spot-check features related to the bank (e.g. bank material, vegetation structure, bank modification), to the bank-top (e.g. land use on bank-top, width of the bank-top vegetation strip) and to the channel (e.g. channel width, substrate, flow-type, vegetation type) are collected. Moreover a general survey along 500 m river stretch is provided (i.e. sweep-up). During the sweep-up features related to the entire stretch are surveyed (e.g. bank profiles, land use on bank-top and bank-face).
Four indices were derived based on the information collected.

- The Lentic-lotic River Descriptor (LRD) allows to characterize streams by their lentic-lotic character and to quantify the hydrological impact (Buffagni *et al*., 2009).
- The Habitat Quality Assessment index (HQA; Raven *et al*., 1998) assesses the ecological quality and diversity of the site through the habitat richness evaluated on the basis of the extent and variety of natural features recorded.
- The Habitat Modification Score (HMS; Raven *et al*., 1998) is an index based on the data regarding morphological modification of river channels due to human activities (e.g., bank reinforcement, channel re-sectioning,

culverting, number of weirs, etc.) recorded in the CARAVAGGIO method.
- The Land Use Index (LUI; Erba *et al.*, submitted) quantifies land-use pressure through land use categories recorded with CARAVAGGIO that include natural, agricultural and urban land-uses, The scoring system is partially based on Feld (2004).

The CARAVAGGIO was performed at least one time in all WDD monitoring stations, from CNR-IRSA (2005-2007) and Prothea (2011-2012). With all the CARAVAGGIO application is associated a biological sample but not all the biological samples have CARAVAGGIO data associated. In general HQA, HMS and LUI don't change much over seasons and years so these pressures data are considered valid for all the biological samples of a determinate site. Instead LRD descriptor changes by season and LRD data are associated only with the biological sample of the same date.
In addition to the data collected from CARAVAGGIO other environmental data were obtained from the WDD (e.g. Land Use at catchment and buffer level, estimated human population density in the river catchment) and index were calculated from these data (e.g. Land Use Index at buffer and catchment level).

2.4 Physiochemical data and Organic Pollution Descriptor

In order to describe sites in terms of organic pollution, OPD descriptor (Organic Pollution Descriptor) was calculated, using the data collected monthly from the WDD in all the monitoring stations. The parameters considered in the construction of the Organic Pollution Descriptor (OPD) were: oxygen saturation deficit [O%], BOD5 [BOD_5], ammonia nitrogen [$N\text{-}NH_4$], nitrate nitrogen [$N\text{-}NO_3$], nitrite nitrogen [$N\text{-}NO_2$], total phosphorous [TP], orto-phosphates [$P\text{-}PO_4$], chloride [Cl], COD [COD], *Escherichia coli* [*E. coli*].

2.5 Integrated Pressures

Based on the indices presented above, here used to characterize anthropic pressures in a concise way, a combined index of overall quality was calculated. The indices combined to obtain an integrated pressures index were the OPD, the Habitat Modification Score (HMS), the Land Use Index at the catchment scale (LUIcatch), and the estimated human population density in the river catchment upstream (POP). These indices were selected from a larger set of variables after multivariate analysis on benthic samples i.e. in general terms, they are supposed to properly represent the main pressures acting on the benthic communities in Cyprus temporary rivers.

2.6 Hydrological data

Hydrological data were exported for the closest hydrological gauging station for the different samples and a set of hydrological descriptors were extracted based on Oueslati *et al*. (2010). A preliminary hydrological classification was performed as well and it was here preliminary discussed with respect to biological information.
The hydrological variables available were: Mean annual flow, Median number of zero days, Richards-Baker Flashiness (RB) Index, Annual Coefficient of Variation (CV), Flow predictability, Constancy/predictability and Base flow index. These indices were calculated using Indicators of Hydrologic Alteration (IHAs: Richter *et al*., 1996).

It has to be taken into account that the hydrological variables were computed using non consistent time range between stations (i.e. the data was derived from different time ranges in e.g. station A and station B) and that the data derived from non reference sites were not corrected by natural flow estimation technique.

Based on such variables, WDD has conducted an hydrological classification based on clustering technique

- Cluster analysis was done using the "tree clustering" functionality of statistica 8
- Only standardized data was used for the clustering
- Amalgamation (joining) rule: ward`s method
- Euclidean distances (non-standardized) were used as distance metrics

A brief summary of the results obtained by the WDD are here summarized:

Flow Period

- Up To 1 Month Dry Period: Perennial
- 1-8 Months: Intermittent. Here there should be 2 subcategories: 1-4.5 dry months, and 4.5-8 dry months
- 8-11 Dry Months: Harsh Intermittent (Following Oueslati *et al.*, 2010 with the 8 months (0.67 Year) Boundary)
- >11 dry Months: Ephemeral/Episodic

Flashiness:

- <0.4 Not Flashy
- 0.4-0.8 Flashy
- 0.8-1.2 Highly Flashy
- >1.2 Hyperflashy

No categories are set for flow predictability. It is only used for sub-clustering of perennial rivers.

Applying the above boundaries to the IHA parameters worked out for Cyprus flow gauging stations, the following hydrologic types emerged (Tab. 2):

Tab.1. Hydrological types for Cyprus rivers.

Type Code	Type name	Type characteristics
1a	Perennial	less than 4 dry weeks
1b	Perennial Highly Predictable	less than 4 dry weeks, Colwell's predictability around 0.6 (it is around 0.4 for all other perennial sites)
1c	Perennial (Artificial Perennial)	non-natural perennial flow (sewage outfall u/s, ...)
2a	Intermittent	Dry period 1-4 ½ months, R-B index <0.4
2b	Intermittent Flashy	Dry period 1-4 ½ months, R-B index 0.4-0.8
3a	Prolonged Intermittent	Dry period 4 ½ - 8 months, R-B index <0.4
3b	Prolonged Intermittent Flashy	Dry period 4 ½ - 8 months, R-B index 0.4-0.8
4a	Harsh Intermittent	Dry period 8-11 months, R-B index <0.4
4b	Harsh Intermittent Flashy	Dry period 8-11 months, R-B index 0.4-0.8
4c	Harsh Intermittent Highly Flashy	Dry period 8-11 months, R-B index 0.8-1.2
5	Ephemeral/Episodic Hyperflashy	Flow period < 1 month, R-B index >1.2

2.7 Statistical Analysis

Multivariate ordination techniques were used to explore the main axes of variation of biological community. Several different multivariate analyses (MVAs) were run, to appreciate which approach is more suited to analyze the available data. Detrended Correspondence Analysis (DCA) was first run on the invertebrate data in different combinations (e.g. REF samples only, all samples, all but 'fuzzy', filled-in matrices only), to calculate the length of the variation gradient i.e. if it is more than 3-4 standard deviation units for major axes DCA or CA are best suited than Principal Components Analysis (PCA; Legendre and Legendre, 1998). Usually, when the calculated length of the variation gradient (from DCA) results less than 3 standard deviation units for the axes, a PCA analysis can be preferred. Nonetheless, in the results shown here, due to a large majority of analysis based on long gradients, DCA was kept as the reference approach for all the data combinations. In more general terms, an indirect technique of analysis was selected with the aim of focusing on the major pattern of variation in community composition, without a priori assumptions on relevant variables. Environmental and water quality data, together with benthic metrics, were then correlated to the ordination axes and hence employed to clarify the observed gradients. The analysis was performed by the computer program CANOCO, version 4.0 (Ter Braak & Smilauer, 1997). Biological data were used as based 10 logarithm of density in order to downweight very abundant taxa (Ter Braak & Smilauer, 1997). In order to avoid mathematical inconsistency, 1 was added to each raw value. Occasionally an ordination diagram was produced (biplot), from the application of DCA (CANOCO; Ter Braak, 1991) to the benthic invertebrate data matrix and corresponding environmental variables and metrics.

An indicator species analysis (Hill *et al*., 1975), which provides a classification of samples based on their taxonomic composition outlining the indicator species pertaining to each dicotomic group division, was performed to support the definition of river types. For this analysis, TWINSPAN (Hill, 1979), based on species abundances (pseudospecies cut levels were 0,2, 5, 10 and 20). The dichotomous divisions were stopped when each TWINSPAN sample group contained a minimum of Ntot: -1 samples of the potential habitats.

2.8 Typology

Multivariate analyses were performed in order to identify fuzzy and not fuzzy sites. After several analysis, a single criterion to identify fuzzy and not fuzzy sites was defined by using biological information. The choice for the taxon indicating the potential occurrence of fuzzy conditions for the site under investigation led to the Baetidae (Ephemeroptera) Family, whose representatives in Cyprus seem to show ecological preferences suited to make their presence an indicator of relatively 'stable' i.e. not fuzzy, conditions.). For Baetidae, over 160.000 nymphs were collected and an average per sample of around 30 specimens found. A density in the sample lower than the 25%ile of all samples (20) was adopted as a criterion to attribute samples to a 'fuzzy area' for analysis i.e. samples with less than 20 Baetidae specimens are attributed to fuzzy, while samples with >= 20 Baetidae specimens are considered stable, both perennial and intermittent.

After identification of fuzzy/ non fuzzy sites in order to have biological classification on reference sites, 7 biological groups were identified and interpreted based on TWINSPAN analysis on biological samples collected in Reference sites only. Due to the apparent weak boundaries all sites/samples were included in the analysis, from both R-M4 and R-M5 Intercalibration macro-types. Two main categories were identified, intermittent and perennial, plus the fuzzy category. discussed above crossing the biological groups with abiotic descriptors, as discussed below, 4 types are finally proposed for the use in WFD Cyprus typology, which quite well reflect Hydrological type attribution performed by WDD, Intermittent typical (INt), Intermittent 'fuzzy'

(INf), Perennial 'typical' (PEt) and Perennial 'low diversity'(PEp).
In order to allow a classification of samples according to abiotic parameters, the TWINSPAN classification tree was interpreted using abiotic parameters. To further clarify, the only classification performed was based on biotic data, abiotic ones were used only to interpret the biological results.

Tab. 2. Simplified procedure to identify the four types proposed for Cyprus.

step 1	step 2	TWINSPAN benthic group	code	Proposed river type for WFD classification
Number of 0 flow days ≤ 50	low diversity site: Yes	7	PEp	Perennial low diversity
	low diversity site: No	6	PEt	Perennial (typical)
50 < Number of 0 flow days ≤ 125	samples with Baetidae ≤ 20 ind/m^2 at site ≤ 20%	5	INf	Intermittent/Fuzzy
	samples with Baetidae ≤ 20 ind/m^2 at site > 20%	4		
Number of 0 flow days > 125	overall erosion > 10	3	INt	Typically intermittent
	overall erosion ≤ 10	1, 2		

The selection of criteria for abiotic classification is based on discriminant analysis results and direct data inspection and comparison between Twinspan groups. Among the main factors explaining groups separation are: Number of zero flow days, Erosion of banks and channel, Base flow index (perennial reaches 'side'), Bank slope.
A simplified framework was derived to allow a more straightforward definition and identification of river types and it is presented in Table 1. This is a simple 2 step procedure: 1) Step 1 requires the identification of the number of 0 flow days; 2) Step 2 is based on three main features: the habitat and benthic diversity of the site (statutory for perennial WBs), the number of Baetidae per samples and the overall erosion level (both for additional detail on biotic community only i.e. not strictly needed).

2.9 Typology and ecological classification

Some statistical testing of the response of the STAR_ICM index have been performed, for the 4 types identified, against a combination of pressures: OPD+LUIcatch+HMS+POP (see cap. 2.5 about integrated pressures). The results are quite good and show how the metrics and the STAR_ICMi are well able to discriminate between different levels of pressure/impact at the site.
Based on such decision, the STAR_ICMi index and its metrics has been tested* both graphically and statistically to assess their ability to discriminate between quality classes.
Here are presented two Box&Whiskers graphs (Fig.1 and 2) representing STAR_ICMi index vs classes of integrated pressures for sample collected in "INt" group (Typically intermittent) in pool area (Fig.1) and for sample collected in "INf" group (Intermittent/Fuzzy) in riffle area.

2.10 LRD approach for ecological classification

In general terms, the significance of hydro-morphology in supporting the interpretation of biological communities and in setting RBMPs for European aquatic ecosystems is now recognized and authoritatively stated by the WFD. In particular, as far as rivers are concerned, together with morphological conditions and river continuity, the WFD indicates the hydrological regime - and thus the derived habitat descriptors identified at the site scale - as one of the key supporting elements when assessing ecological status and interpreting biological patterns. Additionally, while flow-related aspects are indisputably relevant in all river systems, they are expected to be crucial in the Mediterranean area, because of the strong seasonality observed there i.e. from high floods to dry channels at the same site. The importance of local hydraulic

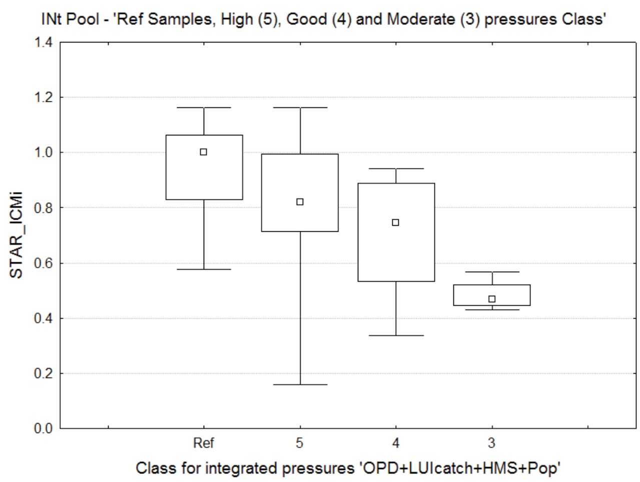

Fig. 1. STAR ICMi index vs classes of integrated pressures for INt typological group - pool.

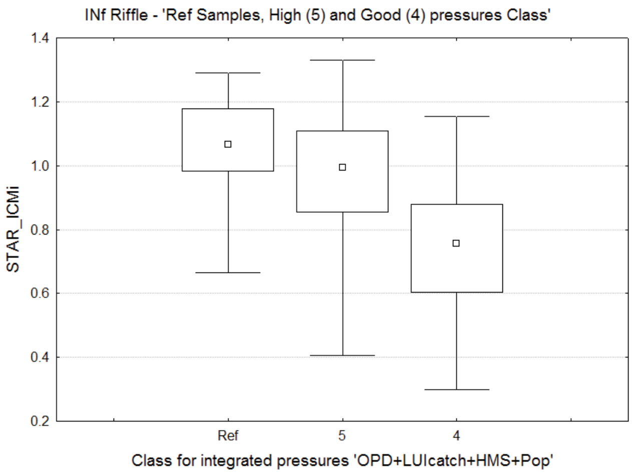

Fig. 2. STAR ICMi index vs classes of integrated pressures POP for INf typological group - riffle.

conditions in influencing the freshwater biotic community is historically acknowledged by the scientific community. Many authors, at different spatial scales and in varying degrees of detail, have demonstrated the link between e.g. water velocity, turbulence, hydraulic stress, shear stress and invertebrate taxa.

In spite of this, most current methods based on invertebrates or other BQEs for the assessment of ecological quality do not take such relationships into account, even though they can have a strong impact on structuring communities and may exert a great influence on the quality evaluation of water bodies. In general terms, the shift of a river site towards an increasingly lentic character generally leads to the disappearance of sensitive taxonomic groups or species, which are more frequently associated with lotic conditions. Not surprisingly, the responsiveness of most of frequently-used quality metrics to the lentic-lotic character of river sites was evidently demonstrated across Europe. Therefore, the application of tools able to quantify habitat conditions in terms of e.g. lentic-lotic character of rivers are important for improving understanding of biological metric variability. Usually, an increase in lentic conditions is associated with a decrease in quality metrics value, thus possibly causing an underestimation of ecological quality; please, see Buffagni at al. (2013) for details.

For Cyprus rivers, based on a large dataset, we can fully confirm this effect. In fact, if the presence of lentic habitat conditions is due to natural phenomena, the obtained ecological status classification can be partly unsubstantiated if methods employed are not adequately corrected

Without getting too specific in the analyzes carried out to propose a correction factor based on the LRD for the ecological classification of the Cyprus river, here it is presented an example of a use of descriptor LRD for the interpretation of the biological results.

In particular in Figure 3 is represented the plotting of STAR_ICMi values against the correspondent LRD value, for type INt. For reference samples, both the actual (observed) value in INt and the median values for each season (all types) are shown. The blue line delimitates the range covered by reference sites.

In the same figure, all the other INt samples are plot, with an indication of the level of flow reduction (1: no reduction; 0: important abstraction; 0.5: intermediate; data obtained by WDD). The orange line delimitates the area defined by sites with important abstractions.

It clearly appears how the two areas i.e. reference sites and sites with important flow withdrawals, when LRD is combined to the benthic information, are quite well distinguished. As a first approximation, and thinking about further refinements to further cope with seasonal differences, this seems quite a straightforward approach to highlight major problems occurring at different sites

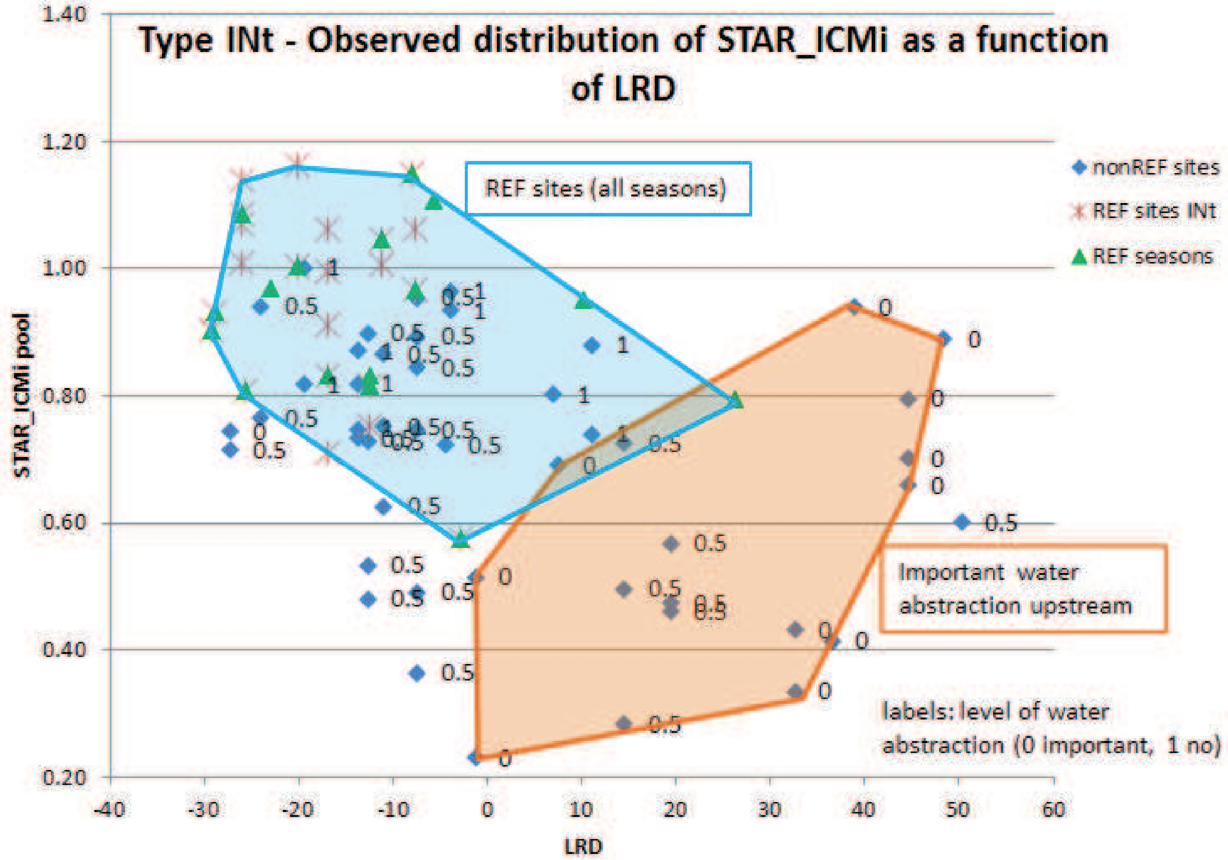

Fig. 3. STAR ICMi index vs LRD values for INt typological group - pool. In the graph are displayed levels of flow reduction for water abstraction: 1: no reduction; 0: important abstraction; 0.5: intermediate.

3. CONCLUSIONS

In Mediterranean rivers, types attribution highlights complex issues, especially in relation to the perennial-temporary axis, presence of fuzzy areas and the real biological significance of the types. For this study, there was the opportunity to match directly hydrological and general environmental data and expertise (provided by WDD), habitat information (especially from CARAVAGGIO application) and biological data. Obviously, due to the aims of the work, such aspects were related to the different pressures acting at the investigated river sites.

In general, in water courses with strong seasonal and interannual variability (e.g. in the whole Mediterranean area), the amount of water flowing (e.g. Q and water level) and its variations have a strong influence on the biocenosis. This is true also in unperturbed conditions i.e. in the absence of abstractions, reservoirs, inter-basin transfer, discharges, etc. Therefore, the analysis of BQEs should, in turn, be associated with the habitat characteristics observed, and especially those dependent on the 'water level' observed when a given sample is collected. More in details, descriptors that are an appropriate function of this level, which determines the state of habitats present at the time of sampling, should be taken into account and added to genuine hydrological information. In particular, the lentic-lotic character - as defined by the LRD descriptor - plays a major role in characterizing the river ecosystem. It has been found that it is often one of the most important factors in structuring aquatic biocenosis and in generating the observed gradients in communities. It represents a summary of some of the main effects of the hydrologic / hydraulic conditions on the biocenosis.

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D2D2.10 - ANALYSIS OF RIVERINE DIATOMS FROM CYPRUS: A FIRST OVERVIEW OF THE ASSEMBLAGE COMPOSITION AND ECOLOGICAL STATUS ESTIMATES

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SUMMARY

The Republic of Cyprus, as a member state of the European Union, is obliged to implement the Water Framework Directive 2000/60/EC. The results of a study of benthic diatoms (part of the Biological Quality Element "macrophytes and diatoms) of Cypriot rivers are presented here. About 200 diatoms samples were collected between 2005 and 2012 from perennial and temporary water courses along the national monitoring network. The river sites cover a wide environmental gradient and are subject to both natural hydrological variability of Mediterranean sites, and anthropogenic pressures due to agricultural and urban land use.

More than 350 taxa belonging to more than 70 genera were identified with a number of unique and interesting taxa and putative new species.

For every sample fixed, identificated and counted, different indices were calculated using the OMNIDIA software, in particular the IPS index, *i.e*. the national assessment method adopted in Cyprus to assess ecological quality using phytobenthos.

1. INTRODUCTION

Diatoms are an important component of aquatic ecosystems and constitute a useful tool for water quality monitoring where the primary objective is either a measure of general water quality or of specific components of water quality (*e.g.* eutrophication, acidification). The method is based on the fact that all diatom species have tolerance limits and optima with respect to their preference for environmental conditions such as nutrients, organic pollution and acidity (EN 13946:2003).

The biotic indices based on the relative abundance of epilithic diatom species are used for a variety of applications in Europe. In each case it is important that surveys are designed in such a way that data can be collected from the full range of river types and translated into information useful for management purposes (Kelly *et al*., 1998).

The Republic of Cyprus, as a member state of the European Union, is obliged to implement the Water Framework Directive 2000/60/EC (WFD) which requires EU member states to assess the status of water bodies using biological quality elements (BQEs). The IPS index (Coste in Cemagref, 1982) is the national assessment method for Cypriot rivers for phytobenthos. During a project in 2007-2008, epilithic diatom communities were studied in 27 sites, for a total of 60 samples collected in 3 sampling campaigns (National and Kapodestrian University of Athens & ENVECO S.A., 2008). The data were used to develop a national assessment method for the BQE phytobentos and the IPS index, Indice de Polluo-Sensibilite was finally established as the national assessment method for Cyprus rivers. The IPS index is correlated with parameters related to organic pollution, ionic strength, and eutrophication and gives an integrated estimate of water quality.

The project here presented was implemented by Prothea in collaboration with MUSE - Science Museum of Trento and Martyn Kelly of Bowburn Consultancy (Durham, UK), and it was commissioned by the Water Development Department (WDD) of the Republic of Cyprus (Contract no. TAY10/2012). The aim of the project was the analysis of benthic diatom samples from locations around Cyprus and the evaluation of ecological status of Cyprus rivers. Preliminary results obtained during the project are presented here.

2. AREA OF STUDY AND SAMPLE COLLECTION

In the course of a macroinvertebrates sampling project in 2005-2006 in Cyprus rivers and during different seasonal sampling campaigns in 2010, 2011, 2012 phytobenthos samples were collected from the national monitoring network which comprise temporary and perennial rivers (Fig. 1).

In most of the stations sampled, biological data concerning the BQE Benthic Invertebrates were also being collected and physicochemical data are available for all sites, covering the period 2007-today. The river sites considered in the national monitoring network cover a wide environmental gradient and are subject to both natural hydrological variability of mediterranean sites, and antropogehic pressures due to agricultural and urban land use (Fig. 2). The samples were collected from both reference (45 samples) and non reference sites, according to the national definition and in line with the WFD requirements.

Almost 200 epilithic diatom samples had been collected and preserved by the Water Development Department, Prothea and the Italian Water Research Istitute (CNR-IRSA).

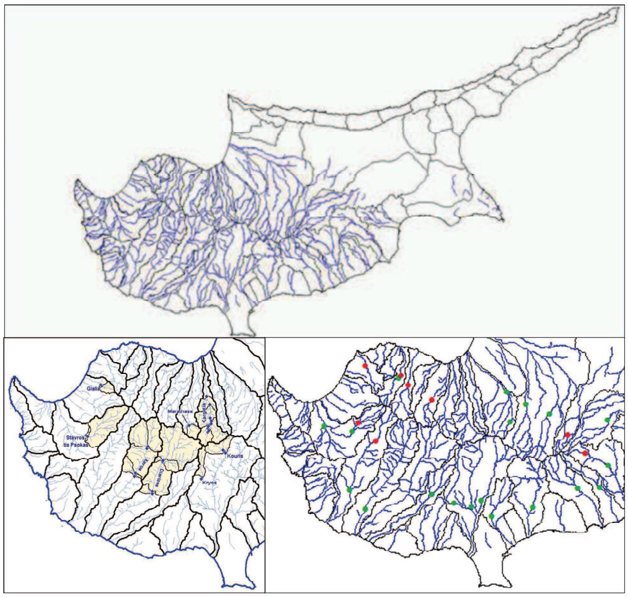

Fig. 1: Detail of river catchments and sampling sites in the Republic of Cyprus. The bottom maps represent perennial river sites (RM4) on the left and temporary river sites (RM5) on the right.

3. MATERIALS AND METHODS

3.1 Preparation of permanent slides

All samples were kept in a cool dry place. Most were preserved with acetic Lugol's iodine, while the rest were preserved using ethanol. Diatoms samples were cleaned using oxidizing agents to eliminate the organic matter (hydrogen peroxide solution 33% and potassium dichromate) and hydrochloric acid to remove calcium carbonates. Permanent slides were prepared using Naphrax® according to European standard CEN 13946: 2003 (Water quality. Guidance standard for the routine sampling and pre-treatment of benthic diatoms from rivers. European Committee of Standardization, 2003) for 185 samples and each slide was labeled with the station name, station code, date of sampling and date of mounting.

Materials were digested, and permanent mounts were obtained for all the 185 samples, as they were conserved in good conditions.

However, as 11 samples did not have enough material digested to be processed quantitatively, indices were computed for a total of 174 samples.

3.2 Identification of samples

The analysis of phytobenthos followed European standard CEN 14407: 2004 (Water quality. Guidance standard for the identification, enumeration and interpretation of benthic diatom samples from running waters. European Committee of Standardization, 2004). All samples were identified to species or lower taxonomic levels (*i.e.* variety) as required for the calculation of indices in OMNIDIA software, counting a minimum of 400 individuals per slide. Broken valves were included in the sample and identified when at least three quarters (¾) of the valve were present according to the options given in CEN 14407: 2004. Girdle views were handled by comparing the girdle view to the valve views of similar species and several valve characteristics (*e.g.* length, shape, types of striae, number of striae) were checked in order to identify species from the girdle view.

Identification and nomenclature followed mainly Krammer & Lange-Bertalot (1986-1991), Lange-Bertalot & Krammer (1989), Round *et al.* (1990), Lange-Bertalot (1993), Lange-Bertalot & Metzeltin (1996), Krammer (1997a,b), Reichardt E. (1997), Reichart E. (1999), Rumrich *et al.* (2000), Lange-Bertalot (2001), Krammer (2000; 2002; 2003), Lange-Bertalot *et al.* (2003), Krammer & Lange-Bertalot (2004), Werum & Lange-Bertalot (2004), Mann *et al.* (2008), Levkov (2009), Lange-Bertalot *et al*. (2011), Hofmann *et al.* (2011), and and a list of papers for taxa that were only recently or very-recently described and taxa for which amended taxonomic concepts and/or names were only very-recently published.

3.3 Calculation of biotic indices

The calculation of indices for each sample were conducted using the latest version of OMNIDIA software (OMNIDIA 7) (Lecointe C. *et al*., 1999, Lecointe C. *et al*., 1993), the latest database (BASE2009) and the identification results were harmonised according to MEDGIG's "Final harmonisation of diatom names as requested by the Water Development Department. Percentage of each species in terms of relative abundance were calculated. The ecological status of the sites has been calculated using the IPS index - Indice de Polluo-Sensibilite utilizing all the identified species level taxa. The scale runs from 1 (worst water quality) to 5 (best water quality). In order to standardize the IPS calculation approach with the national threshold selected in Cyprus, the IPS index was converted to the scale of 0-20. Such index is referred to as "IPS020" (Lecointe *et al*., 1993; ARCADIS, 2006).

3.4 Organic Pollution Descritor

To describe river sites in terms of water (organic) pollution, the Organic Pollution Descriptor (OPD) (Erba *et al*. unpublished) was computed. The variables considered here are: Oxygen saturation deficit [%], chloride [mg/l], BOD5 [mg/l], ammonium [mg/l], nitrite [mg/l], nitrate [mg/l], ortho-phosphate [μ g/l], total phosporous [μg/l], COD [mg/l], *Escherichia coli* [UFC/100 ml]. A score is assigned to each chemical variable available in the dataset. The scores obtained from each chemical parameter are then averaged to obtain the final index value. Increasing value of OPD indicates an increase in water quality.

Agios Nikolaos upstream Fishfarm | Stavros tis Psokas Rizokremos | Kryos Koilani

Fig. 2. Pictures of river sites with different level of degradation

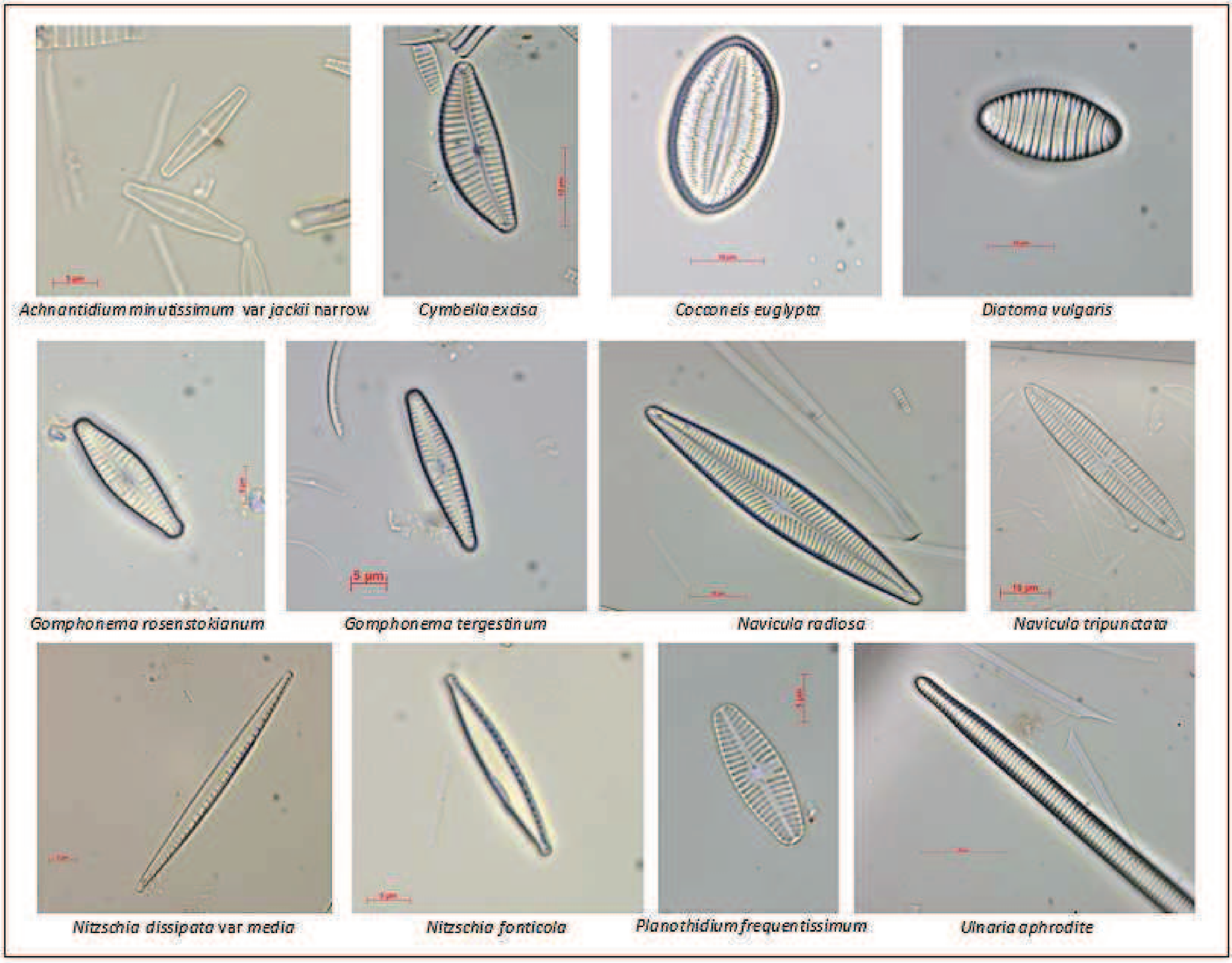

Fig. 3: Examples of taxa from the Cyprus dataset

4. IDENTIFICATIONS AND CYPRUS PECULIARITIES

It should be highlighted that the taxonomic analysis of the diatom samples from the running waters of Cyprus is being carried out with the maximum detail possible (species and variety). Not only was the most recent nomenclature used but also the newest taxonomic concepts. To do so, the existing literature on Mediterranean, subtropical, and tropical running-water diatoms was compiled, and several authors working on the environmental quality, ecology, and taxonomy of Mediterranean streams were contacted. More than 350 taxa belonging to more than 70 genera were identified (Annex 1) with a number of unique and interesting taxa. New putative species were identified and they will be subject of extensive further research to define their taxonomical status and ecological preferences.

Several peculiarities were highlighted during the identifications in a mediterranean area with few studies as Cyprus. There were several putative new species. For this reason, great care was applied in using the “cf.” and “sp. aff.” notations. For several of the putative new species further research to ascertain will be carry out.

We followed the established international scientific usage:

• "sp. aff. " (Latin for *affinis* = related to) indicates that the specimen is closely related to the named species but shows features that make it obvious that it is a different species;

• "cf." (Latin for *confer* = compares with) indicates that the specimen resembles the named species very closely, but has certain minor features not found on the type specimens. Whether it is a different population of the named species or a different species altogether would require more research into the species' population variations than was undertaken by the author.

For several of the putative new species we do intend to carry out further research to ascertain if they are new species.

Many interesting biogeographic, autecological, and taxonomical observations were possible but the most relevant was the finding of a diatom species new to science belonging to the genus *Navicula* (*Navicula cyprica* Cantonati & Lange-Bertalot MN = manuscript name). It was observed in five stations with similar environmental settings. As expected, the new species could not be observed in the fresh material for chromoplast analysis, due to the very-low abundance. Besides *N. cyprica*, there are other two species that will be described as new to science. For several of the putative new species the authors intend to carry out extensive further research to ascertain their current taxonomical status.

The detailed taxonomic analysis thus allowed to look for:

- species new to science:
    - *Navicula cyprica* sp. nov. MN

- species new to science (the current taxonomic situation of the species group they belong to does not allow straightforward application of taxonomic concepts; this impediment can only be overcome by defining new species concepts):
    - *Ulnaria aphrodite* sp. nov. MN
    - *Ulnaria cyproacus* sp. nov. MN

- putative species new to science (they closely resemble existing species but do not completely fit in the taxonomic description of established taxa; further observations are necessary to confirm and characterize them as species new to science):
    - *Achnanthidium linear*-lanceolate-capitate
    - *Achnanthidium minutissimum* cf. var. *jackii* narrow
    - *Cymbella* sp. aff. *vulgata*
    - *Encyonema* sp. aff. *tenerum*

- *Halamphora* sp. aff. *auricolaria*
- *Halamphora* sp. aff. *oligotraphenta*
- *Halamphora* sp. aff. *subcapitata*
- *Navicula* sp. aff. *antonii*
- *Navicula* sp. aff. *caterva*
- *Nitzschia* sp. aff. *ebroicensis*

- taxa that were only recently or very-recently described:

- *Achnanthidium druartii* Rimet *et al.* (2010)
- *Achnanthidium tepidaricola* Van de Vijver *et al.* (2011a)
- *Caloneis langebertalotioides* Reichardt E. (2012)
- *Craticula langebertalotii* Reichardt E. (2012)
- *Crenotia rumrichorum* Wojtal A.Z. (2013)
- *Encyonopsis* sp. ends not protracted about 4.5 µm
- *Surirella neglecta* Reichardt E. (2012)
- *Ulnaria vitrea* Reichardt E. (2011)

- taxa for which amended taxonomic concepts and/or names were only very-recently published:

- *Achnanthidium deflexum* Potapova & Ponader (2004)
- *Achnanthidium lineare* Van de Vijver *et al.* (2011b)
- *Cocconeis euglypta* Romero & Jahn (2013)
- *Cocconeis lineata* Romero & Jahn (2013)
- *Gomphonema rosenstockianum* & *G. tergestinum* Novais *et al.* (2009)
- *Navicula* (*Caloneis*) *pseudo-stauropteroides*
- *Nitzschia soratensis*, *N. inconspicua* & *N. frustulum* Trobajo *et al.* (2013)

- species that are being described as new in manuscripts other than the publications that will be the outcome of the present project:

- *Cymbella alkalilacustris* MN
- *Diatoma polonica* MN
- *Diploneis parmafallax* MN
- *Navicula veronensis* Lange-Bertalot, Cantonati & Angeli MN

5. ECOLOGICAL QUALITY AND RELATIONSHIP WITH PRESSURES

The ecological quality of Cyprus rivers based on BQE phytobenthos was evaluated applying the IPS Index (176 samples; Fig. 4). Most of the sites resulted in High and Good Classes. Such results are to be considered preliminary and further analysis will be carried out.

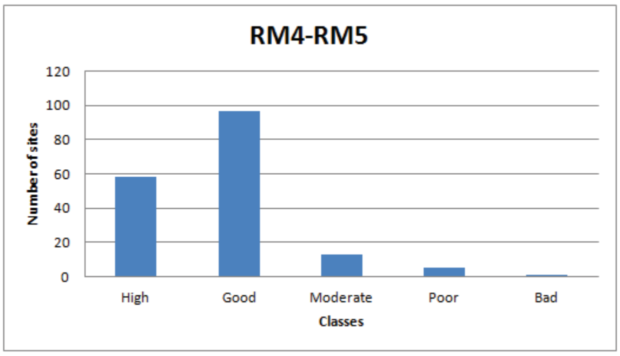

Fig. 4: Number of sites for each ecological quality class for all sites (RM4-RM5) based on IPS Index

The ecological classification of the samples were then related to Organic Pollution Descriptor (OPD).
Fig. 5 shows the relation between class distribution and the Organic Pollution Descriptor (OPD) calculated for the samples. The boxplots show a clear trend of declining IPS values in lower quality classes as depicted by the OPD, although some overlaying of classes was observed. Further analysis including other stressors and integrated pressures will be carried out in future studies.

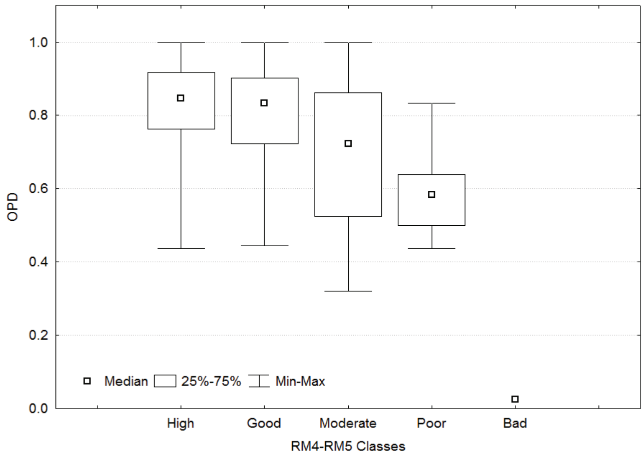

Fig. 5: Class distribution against OPD values

6 CONCLUSIONS

- For the first time, a comprehensive identification of the diatoms in Cyprus was completed at the species/variety level for both temporal and perennial rivers.
- New putative species were identified and they will be subject of extensive further research to define their taxonomical status and ecological preferences.
- Biological indices based on diatoms relative abundances were computed to assess ecological quality and relationships with stressors were observed.
- Additional analysis will be focused on understanding the ecological preferences of diatoms taxa in Cyprus and to calculate specific optima for different stressors to increase the precision and accuracy of the biological metrics used for ecological assessment.
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Acknowledgements
The data collected for this project were counted and analyzed with the help of Daniele Demartini (Prothea), Michela Segnana and Marcella Mogna (MUSE).

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ANNEX 1

List of the taxa identified in the samples analysed.

Genus	Species	OMNIDIA code
Achnanthidium	*deflexum*	ADPY
Achnanthidium	*druartii*	
Achnanthidium	*eutrophilum*	ADEU
Achnanthidium	*lineare*	ACLI
Achnanthidium	*linear-lanceolate-capitate*	
Achnanthidium	*minutissimum* cf var *jackii* narrow	AMJA
Achnanthidium	*minutissimum* cf var *jackii* narrow *TER*	
Achnanthidium	*minutissimum*	ADMI
Achnanthidium	*minutissimum* spp group	ADMI
Achnanthidium	*pyrenaicum*	ADPY
Achnanthidium	*saprophilum*	ADSA
Achnanthidium	*straubianum*	ADSB
Achnanthidium	*tepidaricola*	
Adlafia	*bryophila*	ABRY
Adlafia	*minuscula muralis*	ADMM
Amphipleura	*pellucida*	APEL
Amphora	*copulata*	ACOP
Amphora	*inariensis*	AINA
Amphora	*indistincta*	
Amphora	*lange-bertaloti tenuis*	
Amphora	*micra*	
Amphora	*ovalis*	AOVA
Amphora	*pediculus pediculus*	APED
Aulacoseira	*granulata*	AUGR
Brachysira	*neglectissima*	BVIT
Brachysira	*vitrea*	BVIT
Caloneis	cf. *bacillum*	CBAC
Caloneis	*fontinalis*	
Caloneis	*lancettula*	
Caloneis	cf. *langebertalotioides* narrow	
Caloneis	sp.	
Caloneis	sp. aff. *silicula*	CSIL
Cavinula	*intractata*	
Cocconeis	*euglypta*	CEUG
Cocconeis	*lineata*	CLNT
Cocconeis	*pediculus*	CPED
Cocconeis	*placentula*	CPLA
Cocconeis	*pseudolineata*	CPPL
Craticula	*ambigua*	CAMB
Craticula	*elkab*	
Craticula	*buderi*	
Craticula	*lange-bertalotii* narrow	
Crenotia	*rumrichorum*	
Cyclotella	*meneghiniana*	CMEN
Cyclotella	sp.	
Cymatopleura	*solea*	CSOL
Cymbella	*affinis*	CAFF
Cymbella	*alkalilacustris MN*	
Cymbella	*compacta*	CCMP
Cymbella	*excisa*	CAEX
Cymbella	*hantzschiana*	
Cymbella	*helvetica*	CHEL
Cymbella	*kolbei*	CKOL
Cymbella	*kolbei angusta*	
Cymbella	*lange-bertalotii*	
Cymbella	*neocistula*	CNCI
Cymbella	*parva*	CPAR
Cymbella	cf. *parviformis*	

Genus	Species	OMNIDIA code
Cymbella	cf. *perparva*	
Cymbella	*subcistula*	CSCI
Cymbella	cf. *saxicola*	
Cymbella	*vulgata plitvicensis*	
Cymbella	cf. *vulgata plitvicensis*	
Cymbella	sp. aff. *vulgata*	
Cymbellonitzschia	*diluviana*	
Cymbopleura	*affinis*	
Cymbopleura	*frequens*	
Cymbopleura	*incerta*	
Cymbopleura	sp.	
Cymbopleura	*subaequalis*	CSAQ
Cymbopleura	*sublanceolata*	
Delicata	*delicatula angusta*	
Delicata	*judaica*	
Delicata	*verena sandrae*	
Delicata	cf. *verena sandrae*	
Delicata	*verena*	
Denticula	*tenuis*	DTCR
Diadesmis	*contenta*	DCOT
Diatoma	*ehrenbergii*	DEHR
Diatoma	*mesodon*	DMES
Diatoma	*moniliformis*	DMON
Diatoma	*polonica MN*	
Diatoma	*polonica MN TERATO*	
Diatoma	*vulgaris vulgaris*	DVUL
Diploneis	*elliptica*	DELL
Diploneis	*fontium*	
Diploneis	*krammeri*	
Diploneis	*parmafallax MN*	
Diploneis	*petersenii*	DPET
Diploneis	*separanda*	DOBL
Encyonema	*alpiniforme*	
Encyonema	*brehmiforme*	
Encyonema	*minutum*	ENMI
Encyonema	*silesiacum*	ESLE
Encyonema	sp. aff. *tenerum*	
Encyonema	*ventricosum*	ENVE
Encyonopsis	*cesatii*	ECES
Encyonopsis	cf. *cesatii*	
Encyonopsis	*falaisensis*	
Encyonopsis	*fonticola*	
Encyonopsis	cf. *fonticola*	
Encyonopsis	*krammeri*	ECKR
Encyonopsis	*lanceola*	
Encyonopsis	*microcephala*	ENCM
Encyonopsis	*minuta*	ECPM
Encyonopsis	*rumrichae*	
Encyonopsis	cf. *rumrichae*	
Encyonopsis	sp.	
Encyonopsis	sp. (*"rupicola* var. *minor"*)	
Encyonopsis	*subminuta*	ESUM
Encyonopsis	sp. ends not protracted about 4.5 µm	
Entomoneis	*paludosa subsalina*	EPSU
Eolimna	*minima*	EOMI
Eolimna	*subminuscola*	ESBM
Eolimna	*tantula*	
Epithemia	*adnata adnata*	EADN

Genus	Species	OMNIDIA code
Epithemia	*argus*	EARG
Epithemia	*goeppertiana*	EGOE
Epithemia	*sorex*	ESOR
Epithemia	*turgida granulata*	
Epithemia	*turgida*	ETUR
Eucocconeis	*austriaca*	EUAU
Eucocconeis	*laevis*	EULA
Eunotia	*arcubus*	
Eunotia	*intermedia*	EUIN
Eunotia	*soleirolii*	ESOL
Fallacia	*insociabilis*	FINS
Fallacia	*lenzii*	FLEN
Fallacia	*monoculata*	FMOC
Fallacia	*pygmaea*	FPYG
Fallacia	*subhamulata*	FSBH
Fallacia	*sublucidula*	FSLU
Fragilaria	*amphicephaloides*	
Fragilaria	*austriaca*	
Fragilaria	*crotonensis*	FCRO
Fragilaria	*famelica*	FFAM
Fragilaria	*gracilis*	FGRA
Fragilaria	*mesolepta*	FMES
Fragilaria	*perminuta*	FPEM
Fragilaria	*recapitellata*	FVAU
Fragilaria	*rumpens*	FRUM
Fragilaria	*tenera*	FTEN
Fragilaria	*vaucheriae*	FVAU
Fragilaria	widely spaced striae	
Frustulia	*spicula judaica*	
Frustulia	*vulgaris*	FVUL
Gomphonema	*angustatum*	GANG
Gomphonema	*auritum*	GANG
Gomphonema	*capitatum*	
Gomphonema	*clavatum*	GCLA
Gomphonema	*cymbelliclinum*	GCBC
Gomphonema	*dichotomum*	GDIC
Gomphonema	*elegantissimum*	GELG
Gomphonema	*innocens*	
Gomphonema	*lateripunctatum*	GLAT
Gomphonema	*micropus*	GMIC
Gomphonema	*micropus aequale*	GMIC
Gomphonema	*micropus aequalidictum*	GMIC
Gomphonema	*minutum*	GMIN
Gomphonema	*olivaceum*	GOLI
Gomphonema	*parvulum parvulum f. parvulum*	GPAR
Gomphonema	*pseudotenellum*	GPTE
Gomphonema	*pumilum rigidum*	GPRI
Gomphonema	*rosenstockianum*	GROS
Gomphonema	*sarcophagus*	GSAR
Gomphonema	*subclavatum*	GCLA
Gomphonema	*tergestinum*	GTER
Gomphonema	*uniserhombicum*	GRHB
Gomphonema	cf. *uniserhombicum narrow*	
Grunowiinitzschia	*lorenziana*	
Gyrosigma	*acuminatum*	GYAC
Gyrosigma	*kuetzingii*	
Halamphora	sp. aff. *auricolaria*	
Halamphora	sp.	
Halamphora	*normanii*	ANOR

Genus	Species	OMNIDIA code
Halamphora	sp. aff. *oligotraphenta*	AOLG
Halamphora	*paraveneta*	
Halamphora	cf. *subcapitata* small	ASCA
Halamphora	sp. aff. *subcapitata*	
Halamphora	*submontana*	
Halamphora	*tenella*	
Halamphora	*veneta*	
Hannaea	*arcus arcus*	HARC
Hantzschia	*abundans*	HABU
Hantzschia	*amphioxys*	HAMP
Luticola	*goeppertiana*	LGOE
Luticola	*mutica*	LMUT
Luticola	*nivalis*	LNIV
Luticola	*ventriconfusa*	LVCF
Luticola	*ventricosa*	LVEN
Mastogloia	*baltica*	
Mastogloia	*elliptica*	
Mastogloia	*grevillei*	
Mastogloia	*lacustris*	
Mayamaea	*atomus permitis*	MAPE
Melosira	sp.	
Melosira	*varians*	MVAR
Meridion	*circulare*	MCIR
Microcostatus	sp.	
Muelleria	*terrestris*	
Navicula	sp. aff. *antonii*	NANT
Navicula	sp. aff. *antonii "moskalii*-like" outline	
Navicula	cf. *aquaedurae*	NAQR
Navicula	cf. *associata*	NXAS
Navicula	cf. *broetzii*	
Navicula	*capitatoradiata*	NCPR
Navicula	*cari*	NCAR
Navicula	*cariocincta*	NCCA
Navicula	cf. *cataracta-rheni*	NCTT
Navicula	sp. aff. *caterva*	
Navicula	*cincta*	NCCA
Navicula	*cryptocephala*	NCRY
Navicula	cf. *cryptocephala*	
Navicula	*cryptotenella*	NCTE
Navicula	cf. *cryptotenella*	
Navicula	*cryptotenelloides*	NCTO
Navicula	*cyprica* sp. nov.	
Navicula	sp. aff. *cyprica 1*	
Navicula	sp. aff. *cyprica 2*	
Navicula	*erifuga*	NERI
Navicula	*escambia*	
Navicula	*germanii*	
Navicula	*gregaria*	NGRE
Navicula	*leistikowii*	
Navicula	*libonensis*	NLIB
Navicula	*linearis*	
Navicula	*margalithii*	NMGL
Navicula	*oblonga*	NOBL
Navicula	*radiosa*	NRAD
Navicula	*reichardtiana*	NRCH
Navicula	*rostellata*	NROS
Navicula	*simulata*	
Navicula (Caloneis)	*pseudo-stauropteroides*	
Navicula	*subalpina*	

Genus	Species	OMNIDIA code
Navicula	cf. *subalpina*	
Navicula	*tripunctata*	NTPT
Navicula	*upsaliensis*	NUSA
Navicula	*vandamii mertensiae*	NVDA
Navicula	*veneta*	NVEN
Navicula	*veronensis MN*	
Navicula	*vilaplanii*	NVIP
Navicula	*wildii*	
Navicula	*wygaschii*	NCTE
Navicula	sp. aff. *wygaschii*	
Naviculadincta	*pseudomuralis*	
Navicymbula	*pusilla*	
Neidiomorpha	*binodiformis*	
Neidium	*affine*	NEAF
Nitzschia	*abbreviata*	NINC
Nitzschia	*acicularis*	NACI
Nitzschia	*acidoclinata*	NACD
Nitzschia	*actinastroides*	NAST
Nitzschia	*acus*	
Nitzschia	cf. *adamata*	
Nitzschia	*adamata*	NZAD
Nitzschia	*affebroicensis*	
Nitzschia	*alpinobacillum*	
Nitzschia	*amphibia amphibia*	NAMP
Nitzschia	*amphyosis*	
Nitzschia	*angustata*	NIAN
Nitzschia	*angustatula*	NZAG
Nitzschia	cf. *aniae*	
Nitzschia	*archibaldii*	NIAR
Nitzschia	cf. *brevissima*	
Nitzschia	*calida*	NICA
Nitzschia	*capitellata*	NCPL
Nitzschia	*communis*	NCOM
Nitzschia	*constricta*	NCOT
Nitzschia	*costei*	
Nitzschia	*debilis*	NDEB
Nitzschia	*denticula*	NDEN
Nitzschia	*dissipata media*	NDME
Nitzschia	*dissipata*	NDIS
Nitzschia	*dubia*	NDUB
Nitzschia	*fonticola*	NFON
Nitzschia	*frustulum*	NIFR
Nitzschia	*gracilis*	NIGR
Nitzschia	*hungarica*	NIHU
Nitzschia	*inconspicua*	NINC
Nitzschia	*intermedia*	NINT
Nitzschia	*lacuum*	NILA
Nitzschia	*liebetruthii*	NLBT
Nitzschia	*linearis*	NLIN
Nitzschia	*microcephala*	NMEL
Nitzschia	*oligotraphenta*	
Nitzschia	*palea debilis*	NPAD
Nitzschia	*palea*	NPAL
Nitzschia	*paleacea*	NPAE
Nitzschia	*perminuta*	NIPM
Nitzschia	*pura*	NIPR
Nitzschia	*pusilla*	NIPU
Nitzschia	*recta*	NREC
Nitzschia	*salinarum*	NSAL

Genus	Species	OMNIDIA code
Nitzschia	*sigma*	NSIG
Nitzschia	*soratensis*	
Nitzschia	*sublinearis*	NSBL
Nitzschia	*subtilis*	NISU
Nitzschia	*tabellaria*	
Nitzschia	*tenuis*	NZLT
Nitzschia	*thermaloides*	NTHE
Nitzschia	*umbonata*	NUMB
Nitzschia	*vitrea salinarum*	
Nitzschia	*vitrea vitrea*	NIVI
Pinnularia	sp. aff. *acuminata* var. *novazealandiae*	
Pinnularia	*borealis*	PBOR
Pinnularia	*kneuckeri*	
Pinnularia	*irrorata*	
Pinnularia	cf. *isselana* small	
Pinnularia	*rhombarea* var. *variarea*	
Planothidium	*frequentissimum*	PLFR
Planothidium	*lanceolatum*	PTLA
Psammothidium	*grischunum*	PGRI
Pseudostaurosira	*brevistriata*	FBRE
Reimeria	*uniseriata*	RUNI
Rhoicosphenia	*abbreviata*	RABB
Rhopalodia	*gibba gibba*	RGIB
Rhopalodia	*parallela*	
Rossithidium	*petersenii*	RPET
Sellaphora	*bacillum* cf. *"radiate"*	
Sellaphora	*joubaudii*	SJOU
Sellaphora	*pseudopopula*	
Sellaphora	*pupula* cf. *"tidy"*	
Sellaphora	*seminulum*	SSEM
Sellaphora	*stroemii*	SSTM
Simonsenia	*delognei*	SIDE
Stauroneis	*smithii*	SSMI
Staurosira	*venter*	SSVT
Staurosirella	*pinnata*	SPIN
Stephanodiscus	sp.	
Surirella	*angusta*	SANG
Surirella	*brebissonii kuetzingii*	SBKU
Surirella	*brebissonii*	SBRE
Surirella	*brightwellii*	SBRI
Surirella	*helvetica*	SHEL
Surirella	*linearis*	SLIN
Surirella	*neglecta*	
Surirella	*ovalis*	SOVI
Surirella	cf. *ovalis*	
Surirella	*terricola*	STER
Surirella	cf. *terricola*	
Tabularia	*fascicolata*	
Ulnaria	*aphrodite MN*	
Ulnaria	cf. *aphrodite MN*	
Ulnaria	sp. endings like aphrodite but central area	
Ulnaria	*cyproacus* MN	
Ulnaria	*cyproacus* MN terato	
Ulnaria	*vitrea*	
Ulnaria	*ungeriana*	UUNG
Ulnaria	cf. *ungeriana*	
Ulnaria	spp.	
Ulnaria	sp. *robust,* narrow ends, central area	
Ulnaria	sp endings like *vitrea* but central area	

D2D2.11- CYPRUS: ECOLOGICAL RESTORATION AND SPECIES RE-INTRODUCTION IS REQUIRED!

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SUMMARY

Stream ecosystems in Cyprus are largely degraded by anthropogenic pressures yet a variety of fishes survive there. Here a fish assemblage classification initially depicts seven biotic groups identified from a wide-ranging fish sample database (80 sampled sites in streams). These fish-based ecotypes correspond to natural cool-water upland rivers, mid-sections (frequently near dams), and warm-water coastal lowlands reaches. As expected, in such heterogeneous and anthropogenically degraded conditions non-indigenous species dominate, but native species are surprisingly scarce. Since extinction and local extirpation rates are presumably high, native fish cannot expand to re-colonize isolated basins without human restorative intervention. Here we therefore promote the prospect of utilizing native fish assemblage needs to pursue restoration of flow regimes, natural stream connectivity, science-based fish re-introductions and control of non-indigenous fish species.

1. INTRODUCTION

Describing fish communities is a basic need for planning ecological restoration (Angermeier & Schlosser, 1995). Most of Cyprus' streams are degraded by multiple anthropogenic pressures, including severe disturbances to hydrology, natural habitat and connectivity. Largely as a consequence of this degradation, Cyprus also has very "disturbed" fish communities relative to what is assumed to have existed. Many stream sites with adequate habitat have no fishes at all (Zogaris *et al*., 2012). Also, due the insular biogeographical character of the small river basins and the long-term isolation of the island itself, it has been hypothesized that some fish species that may have existed on the island may now be extinct (Zogaris, 2012). At least one species (*Salaria fluviatilis*) can be presumed extinct until further surveys are completed (Zogaris *et al*., 2013). Native Mediterranean Toothcarp and the Eel are also now remarkably scarce as reflected in available historical research. Certainly a complete description of the fish communities and research on type-specific reference condition baselines in needed in a conservation context. This report provides a generalization of existing fish assemblages based on cluster analysis classification of many recently sampled sites. Through interpreting the initial fish community patterns we provide expert judgment on potential actions for restoration measures concerning fishes in Cyprus' lotic systems.

2. CYPRUS' UNIQUE STREAM CONDITIONS

2.1 Study area

It is not known if the depauperate freshwater fish fauna of Cyprus is solely a result of biogeographic isolation or a product of extended periods of local aridity, and/or recent anthropogenic aquatic habitat degradation. Today, Cyprus' inland freshwater fish fauna includes 22 confirmed species; but only three native freshwater fishes, namely: European eel, *Anguilla anguilla* (L.), freshwater blenny, *Salaria fluviatilis* (Asso, 1801) and Mediterranean toothcarp, *Aphanius fasciatus* (Valenciennes, 1821) (Zogaris *et al*., 2012). At least five euryhaline marine fish such as mugilids, *Atherina* smelts, and Sea Bass are also known to enter inland waters locally. Cyprus' inland waters have a distinctly insular biogeography and geological history, being located on a long-isolated Middle Eastern island within a semi-arid region. Cyprus arose from the sea due to tectonic changes during the Mesozoic (22 million years ago) and has been isolated from the surrounding mainland with the exception for a short-term connection with the arid coast of western Asia during the Messinian Salinity Crisis, about 5 million years ago (Hadjisterikotis *et al*., 2000). Cyprus' small rivers may have had river-confluences with basins of the adjacent mainland during this short period when the eastern Mediterranean Sea dried-out. However, the over-riding influence on Cyprus' biota during the last 4000 years has been humankind. The island has seen many biotic extinctions and introductions; including a mammalian megafuanal collapse (Hadjisterikotis *et al*., 2000). In recent decades over 110 dams and intensive water management have degraded natural flow regimes in nearly every river. The changes to the rivers, including climate-driven droughts, are so complex that describing biotic reference conditions is especially challenging (Zogaris *et al*., 2012).

2.2 Materials and Methods

This report is based on recent work done on stream fish research in inland waters with support from the Water Development Department of Cyprus. Electrofishing in freshwaters and fry-nets in brackish waters was used in a standardized application as described in Zogaris *et al*. (2012). Here we present a biotic assemblage classification of fish-based samples from stream sites. The statistic package Prime 6b is used for cluster analyses.

2.3 Results

The sites investigated are fairly representative of the mostly lotic systems located primarily in perennial stream areas of the western half of the island (Fig. 1). The cluster analysis using fish densities present during systematic sampling shows a pattern of 7 groups when arbitrarily cut at 37 % similarity. These groups connect well with the expert-based generic stream abiotic typology (cold-water salmonid, middle sections and river mouths) (Fig. 2). The seven species assemblage types are briefly described in Table 1. Only three of the seven types are dominated by native fish communities; this represents only 19 sites in total (i.e. only 15,2 % of the sites investigated).

Tab. 1. Description of biotic groups of fish assemblages as defined by the cluster analysis.

Biotic Group	Generic Abiotic Stream Typology	Number of sites in Group	Characteristics
Brown Trout	Mountain	14	Restricted to Mountain, usually Trout-only
Rainbow Trout	Mountain	11	Restricted to Mountain, usually Trout-only
Lacustrine (Reservoir Fishes)	Middle-course, Mountain	22	Widespread; often mono-species group (Rutilus); this changes very close to reservoirs Lake-fish type. Near reservoirs, usually in warmer middle-course segments more than one species present.
Eel dominated	Middle-course, Coastal	9	Few sites but characteristic –often inland in Middle-course sections.
Mosquitofish dominated	Mountain, Middle-course,	13	Often inland in Middle-course sections but also near-and in reservoirs in mountain areas. Usually mono-species.
Non-eel dominated coastal sites (Aphanius dominated)	Coastal	4	Rare. Aphanius often in high densities.
Non-eel dominated coastal sites (Mugilid dominated)	Coastal	6	Common; but probably only during wet years; mugilids in varying densities.

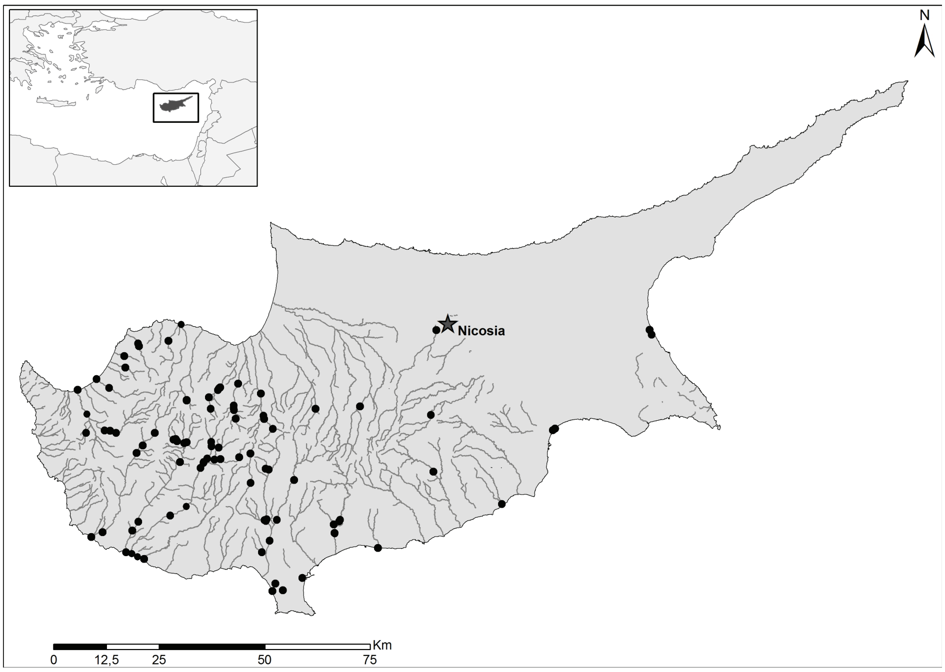

Fig. 1. Sites sampled with fish present (N:80) in Cyprus.

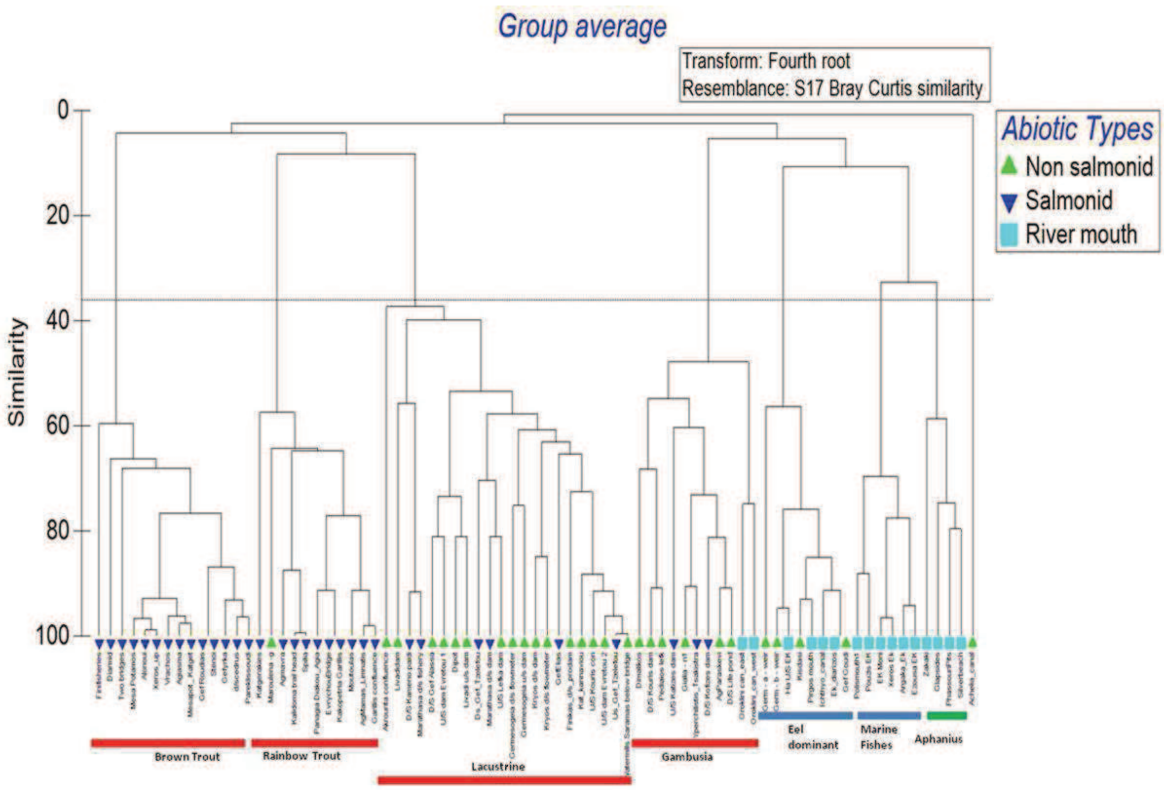

Fig. 2 Cluster analysis dendrogram showing the site names (as in Zogaris *et al.*, 2012).The cut-off is an arbitrary line at 37 % similarity and this isolated seven biotic groups (also labled in thick horizontal lines at bottom). “Abiotic types” refer to a simple expert-judgement based generic river typology.

2.3 Overwiew

Our initial assemblage classification shows that fish create biotic assemblages in Cyprus' rivers. Zogaris *et al*. (2012) provided an initial classification of biotic assemblages using a presence/absence matrix of only 45 sites, including reservoirs. Our work at present reports on sites only within streams and coastal river mouths and includes 80 sites. The patterns among the two classifications are similar. Stream fishes seem to be influenced by the presence of a cold-water "salmonid" upland area, a mid-section dominated by many dams and associated lacustrine-fish communities, and a coastal section where the longitudinal connectivity with the sea and coastal wetland habitats provides important habitat for native species and the influence of marine transient fishes.

It is notable that native fishes are remarkably scarce in the island's streams. Although island due have depauperate freshwater ichthyofaunas, even on far-
off oceanic islands native fishes exist or several marine species have adapted to inland waters (e.g. Neal *et al*., 2009).

A large temperate Mediterranean island such as Cyprus could have several native species, as are found in Sicily and Sardinia for example. Zogaris *et al*. (2013) refer to the problem of increased extinction rates on islands and we suggest that severe anthropogenic pressures have occurred on Cyprus may be the cause of recent extirpation and extinctions. Interviews with locals on Cyprus provide evidence for widespread extirpation of fishes and this has been attributed to intensive DDT use (from 1946 to 1978). This complete poisoning of every available water-source during the long summer droughts in order to combat mosquitoes was responsible for the local extirpation of several species, not just fishes, and this has been mentioned many times with convincing evidence for Cyprus (Gucel *et al*., 2012, Zogaris *et al*., 2013).

Although there is an urgent need for more historical research to understand the past conditions and the real effects of pressures we must strive to apply fishes in policy-relevant stream ecosystem restoration measures.

3. CONCLUSIONS

What can be recommended based on the current knowledge of the fish assemblages? Below are some restoration approaches that may support both the implementation of the Habitats Directive and the WFD since fish are biotic components of ecosystems that affect both biodiversity and may be used as a biotic quality element for monitoring. Potential approaches for restoring fish communities include the following:

- *Restoring natural flow regimes.* Flow regimes on Cyprus have been degraded by water storage, water abstraction and transfers. Many intermittent areas are presumably artificially intermittent (*sensu* Skoulikidis *et al*., 2011) and effects on fishes include local extirpation from summer river desication (Benejam *et al*., 2010). There is little doubt that fish will benefit from restorative flows and this includes: a) marine fish migration in the lower parts of the river; b) protection of summer refugia for maintaining fish populations, c) helping species overcome low barriers during their movements (e.g. downstream movement of adult eels in autumn); and, d) supporting reophilic cold-water species such as established salmonids in upland river reaches.
- *Maintaining a connection to the sea.* Flows must maintain a river's connection to the sea. This does not only involve specific hydrological flow regimes, but also attention should be given to natural-like variation in flow that creates significant sediment movements. Flood pulses in winter can create scoured channels near the sea and these deep pools may connect

to underground inflows that maintain long-pool refugia during the summer. Eel elvers are assumed to enter into rivers on Cyprus during late winter and spring, so at this time the freshwater plume produced in the sea presumably provides an important entrance signal for migrating elvers.

- *Removing barriers to fish movement.* Barriers are everywhere in Cyprus streams and are known to stall fish movements. Experience has shown in Greece that consecutive barriers can lead to fish extirpations. In studying the effects and restoring this problem, a management scale-specific "riverscape" approach is required (see Fausch *et al*., 2002). The effects of barriers must be assessed and on-site restoration applied. Priorities for this are needed in the major rivers and wetlands that host proven eel populations (see Zogaris *et al*., 2012).
- *Studying and controlling invasive species spread.* Non-indigenous species spread primarily due to stocking, accidental and intentional. Dams seem to influence this spread. The issue is one of the most important threats to biodiversity in freshwaters (Dudgeon *et al*., 2006). Yet we know very little of the effects of species on stream ecosystems or on their biotic interactions in Cyprus. More work on this aspect is needed and controls on intentional and unintentional introductions must be strictly enforced.
- *Scientific re-introduction of native species.* There is opportunity on Cyprus for science-based re-introductions (*sensu* Seddon *et al*., 2007). Care must be exercised to protect the genetic provenance of populations and avoid any chance of damage to local biota by unintentional spread of non-indigenous species. Again conservation biogeography is important here. In an ecoregional context, Cyprus may be a unique ecoregion as suggested in Zogaris et al. (2012) however its closest biogeographical freshwater region is Southern Anatolia (Abell *et al*., 2008). One would expect freshwater species that may have inhabited the island in the past to be related to southern Anatolian waters to some degree, so this may be a potential source-area for re-introductions. Today we know of only *Salaria fluviatilis* and *Aphanius fasciatus* as natives of the island's inland waters and research should be promoted to explore transplants from native stock areas. If *Salaria* is confirmed as extinct, a genetic conservation study should decide if stock should be sourced in Southern Anatolia or Crete. "Recovery plans" for the above two species are required. Furthermore, a plan to protect certain naturalized assemblages (i.e. Brown Trout) or introduce species from within the ecoregion will also be very useful.

It is important to explore the philosophical and practical aspects of naturalized introduced species and the issue of anthropogenic fish species assemblage interventions. Not all researchers agree that any non-indigenous species is harmful and should be considered "alien" for eternity (see Copp *et al*., 2005). In many parts of Europe naturalized species have become "part of the landscape" and are treated as established aspects of the ichthyofauna and some are used as environmental indicators (Vandekerkhove & Cardoso, 2010). On Cyprus even naturalized non-indigenous species, such as Brown Trout, have evolved specific fish community characteristics and seem to have persisted in Cyprus' upland waters for at least 70 year since their introduction. We should not that species that may have existed in the distant past may have left vacant niches, so their extinction can be "reversed" only by strategic introductions (Schlaepfer *et al*., 2011). We must take in a broader view in terms of scale and time, especially in terms of the uncertainties that climatic changes may have on stream systems.

Fish are here to stay in Cyprus' streams; and our opinion is that humans should intervene to help guide a "restorative development" of natural assemblages.

Our work introduces a very simple assemblage taxonomy which is not comprehensive or validated. It incorporates best available knowledge from a recent multi-year survey of many river basins on the island. A flexible and adaptive framework for assemblage taxonomy is important for conservation. As part of our restoration obligations we should consider the fish assemblage both within the application of the Habitat Directive and WFD. Community ecology approaches may bring a more holistic approach for restoration planning with a deeper appreciation of local natural history.

Acknowledgements

A large number of people have contributed in various ways to this work. In the context of community classification and analyses we would particularly like to thank Yorgos Chatzinikolaou, Vassilis Tachos, Leonidas Vardakas, Theocharis Vavalidis, Teresa Ferreira and Pedro Segurado. We are especially grateful to WRC Beaumont for all help field work and to many volunteers who assisted in sampling. Gerald Dorflinger was instrumental for support in field and office.

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D2D2.12 - RIVER MACROINVERTEBRATE COMMUNITIES: EXAMPLES OF OPEN ISSUES IN GREECE

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SUMMARY

The purpose of the present work is to highlight serious problems resulting from the classification processes in the five grade quality scale as the EU Directive (2000/60/EC) requires concerning water and especially river ecosystems. We were led in this study upon the ascertainment of an imbalance which appeared at regular intervals by the various research programs being elaborated in Greece. Thus, after an experience which originated from studies conducted in hundreds of sampling stations, in different river types, in all seasons of the year and from contemplating the impact of different types of pollutants and especially the issue of reference conditions, the need for a different approach in the area of classification was revealed. Therefore, using this data and taking into account various parameters such as biodiversity, especially macroinvertebrate fauna, chemical and physico-chemical characteristics and of course hydro-morphology, we recognize and focus on the problem, wherein the weak points are being highlighted and subsequently a number of concrete solutions are being proposed. Of course, it should be taken into consideration seriously, that an undisturbed system and specifically an undisturbed river is a difficult concept, since from ancient times the modifications and arrangements of the rivers were a common phenomenon, which was accompanied by a variety of environmental descriptions. This procedure was essential and concerned human health, a regime that also applies today as it is evidenced by the recordings of various environmental conditions and extreme climatic events in conjunction with the various pollution loads.

1. INTRODUCTION

The present work provides a status and generally covers a topic strongly connected with the implementation and application of the Water Framework Directive 2000/60/EU in Greece. According to the demands of the later legislation, numerous research projects have been carried out on the Greek freshwater sources, focussing overwhelmingly on the effects of pollution towards the aquatic element. Thus, more or less, all river types, especially those indexed according to the WFD 2000/60/EU at System A and river types RM1, R-M2, R-M4 and R-M5, have been investigated (excluding the non wadeable rivers). Concerning the application of the Biological Quality Elements (BQE) as an assessment tool, the most dominant one, which was first studied and then applied, is macroinvertebrate fauna, followed by fish fauna as well as other elements. After the implementation of benthic macroinvertebrates for over three decades it was found that the combination and correlation of them with habitats, has not been adequately studied. It is quite often confirmed that the results from the implementation of several methods concerning the hydromorphological features such as the River Habitat Survey with its environmental management tools of Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS) (Raven et al., 1998) or other similar methods (Buffagni & Kemp, 2002; Buffagni & Erba, 2002), are not identical with the corresponding results from the use of macroinvertebrates or the results deriving from chemical analysis. Meaning that there is a mismatch observed in terms of classification (Gritzalis & Koussouris, 1999; Vourdoumpa & Gritzalis, 2000; Karaouzas & Gritzalis, 2002). In particular, strongly modified parts of rivers, with excellent chemical quality, are being classified as 'bad' due to poor and limited variety of habitats (Fig. 1; Fig. 2).

Fig. 1. Vosvozis River (Rodopi, Thrace) various modifications; moderate water quality; very poor benthic fauna.

Fig. 2. Nedon River (Kalamata City, Messinia, Peloponnese), a typical case of high water quality and extremely poor benthic fauna, (only 3-4 species), in a heavily modified river corridor.

Thus in Greece it remains a necessity to develop an integrated system for the estimation and classification of specific rivers, which will be based on the results from the studies concerning the relationships between BQE's, hydromorphological and chemical (water and sediment) analysis at a microhabitat level.

2. BENTHIC MACROINVERTEBRATE DIVERSITY & PHYSICAL CHARACTER OF THE RIVER

2.1 The physical character and causes of modifications at the rivers in the antiquity

The City of Selinus (Selinunte =Italian) was one of the most important ancient Greek colonies in Sicily (Italy) 628/7 BC. This ancient Greek colony is closely related to Belice (=Hypsas River in ancient Greek) and Modione Rivers (=Selinus River in ancient Greek). During this era, the inhabitants of Selinus City were afflicted by a pestilence from the marshy-type landscape. This situation wiped out the Selinuntines and caused dystocia for women. A solution to this problem, regarding human health, was suggested by the Greek pre-Socratic philosopher Empedocles (ca 490-430 BC), whereby this harmful situation was resolved by structuring the appropriate drainage works and performing modification constructions (Gritzalis, 2008).

The Peloponnesian rivers in Greece have been well studied and described according to the ancient Greek literature (Spiro, 1903). To the later, a significant contribution originates also from the Latin authors, since there are significant remains from the Roman era concerning the effects on the riverine systems (Fig. 3).

Fig. 3. Louros R. (Preveza, Epirus), a modification from the antiquity (Roman Aqueduct).

Thus, according to the Latin literature, the eminent Roman poet *Vergilius* (BC 70-19), states for the Alpheios R. (Peloponnese) that *"...confunditur Alpheo rursuque discedit..".* Additionally, he describes the riparian vegetation of the river which was covered by laurels (*Laurus nobilis* L.). Another significant river of Peloponnese (Evrotas R.) is also mentioned by the Latins. The widely known *Publius Ovidius Naso* (20 March 43 BC – AD 17/18), for his excellent contribution to the letters, characterizes Evrotas R. as chilly *"...frigidus..."*, also another Roman poet, Statius (AD ca 45-96) states "...*et asper Evrotas*...", focusing on the turbulent character of the specific Lakedaimonian river, while at the same time *Cicero* mentions in his work "*De inventione*" concerning the flooding events of Evrotas River. In the extracts given by the *Argives*, Evrotas River, is referred to as: "...*olorifer*..." ("*Taygetique phalanx et oloriferi Eurotae dura manus*..."), a fact which reveals that the area could be regarded as an ideal stagnant landscape for swans (*Cygnus spp*.). The myrtles (*Myrtus communis* L.) according to *Catullus* (Roman poet, ca 84-54 BC) were part of the riparian flora of the river. Nowadays, the rich vegetation at Evrotas Channel is dominated by the species *Arundo donax* L., a status which was more or less similar to the one during antiquity, as it is referred by many ancient Greek and Latin authors e. g. *Pausanias*, *Callimachus*, *Solinus*, *Pomponius Mela*, *Valerius Provos* etc. The later descriptions contribute to the origin of the name Evrotas which probably derived from the ancient Greek word "*evros*" (=mould), due to the presence of the aquatic and helophyte vegetation which appeared during the period of reduced water quantity. Generally, the lacustrine character of the ancient landscape of Sparta is also mentioned by various other researchers (Katahoritis,1905; Sakellariou, 1998; Raftopoulou, 2000; Gritzalis, 2008).

2.2 Material and methods

In order to apply a freshwater quality assessment method based on macroinvertebrates or on other Biological Quality Element, a protocol is required. Thus, have been developed various protocols concerning the macroinvertebrate fauna (e.g. AQEM, 2002; Jáimez-Cuéllar *et al*., 2002). A protocol usually is a unique source of various gathered biotic and abiotic data and provides different kind of information.

Similar situation is observed for the sampling methods and for the Biotic Indices. Concerning to the later numerous assessment tools have been developed worldwide (Alba-Tercedor & Sánchez-Ortega, 1988; Armitage *et al*, 1983; De Pauw & Vanhooren, 1983; Pinto *et al.*, 2004; Skoulikidis *et al*, 2004; Skriver *et al.*, 2000), which are based on the multimetric approach (Barbour & Yoder, 2000), but their performance in a river's stretch different results are observed (Solimini *et al*., 2000; Gritzalis, 2013).

Special attention was given to organic pollutants as well as to various hydrochemical variables (total hardness, $Ca^{2+,}$ $Mg^{2+,}$ Na^+, K^+, HCO_3^- , SiO_2, etc). Conventional pollution parameters (total nitrogen, total phosphorous, nitrate, nitrite, orthophosphate, and ammonia) and major ions (sulphate, magnesium, chloride, sodium, calcium, and potassium) were also determined. In rare cases, sediment samples were analysed for various heavy metals concentrations (Cr, Mn, Co, Ni, Cu, Zn, Mo, Pb etc). Additionally, total sulphur and total and organic carbon were measured. To that effort, the limited data on the hydromorphological features is a remarkable characteristic phenomenon. The first hydromorphological data were gathered during the last fifteen years by the application of the River Habitat Survey (RHS) (Raven *et al*., 1998). Later on, and due to the demands of the EU funded Research Project STAR (www.eu-star.at) more data was collected, while in the meantime a limited number of this data was collected by an updated version of RHS which was developed by Buffagni & Kemp (2002) and Buffagni & Erba (2002).

In Greece the development of a classification system concerning fresh waters has taken place, named the Greek River Nutrient Classification System (GR_NCS) established by Skoulikidis (2006) & modified by Laschou

(2010). This system is used in order to assess the physico-chemical status of the rivers and assign the quality class in which each station belongs. According to this system every station is being classified in quality classes based on the concentrations of several nutrients and dissolved oxygen. Each site receives a score, the higher the concentrations of the nutrients the lower the score and the average value of all the scores represents the quality the class in which the station belongs.

Therefore, taking into account the definition of "Pollution" from the Directive 2000/60/EC which is the following: ..."the direct or indirect introduction, as a result of human activity, of substances or heat into air, water or land, which may be harmful to human health or to the quality of aquatic ecosystems or to terrestrial ecosystems that are directly dependant on aquatic ecosystems, or which may result in damage to material property, or which impair or interfere with amenities and other legitimate uses of the environment"..., and on the other hand the fact that the European Parliament and the Council of the 23rd of October 2007, established an appropriate Directive whereas its purpose was to attempt the establishment of a framework concerning the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community (Directive 2007/60/EC), we approach and focus the missing links for an integrated and reliable assessment water quality method in Greece.

2.3 Results and discussion

After having study more than 280 sampling stations in all seasons and especially during spring, summer and autumn, it was ascertained that HQA & HMS were incompatible with BQE, particularly macroinvertebrates, as well as with the chemical status of water. As mentioned above, the amendment of rivers is not something new, but consists part of organized societies since antiquity. This certainly intends to protect human health, as evidenced by the interest of ancient Greeks and Romans towards the environmental characterization of surface runoff which is demonstrated by the collection of information related to quality, physicochemical descriptions and extreme weather conditions. Of course nowadays, especially in the EU, the appropriate instructions have been issued, that highlight the obligations of the member states towards human health which is threatened both by various pollutants and by disastrous floods. Under these statements as well as from our experience from the data collected in Greece it is considered a necessity to adopt a different approach in order to highlight the actual problem that is, to protect human health from environmental degradation but at the same time the authorities to estimate the real situation at a specific segment of the river and to avoid the specification by an expert – judgment approach.

In these remarks mentioned above, the following summarized cases are advocating which derived from the elaboration of several research programs:

- Biodiversity numerically may be identical at a sampling station prescribed as high with a station prescribed as bad, also both stations could have zero HMS, similar high HQA values, but a tremendous difference may occur in the composition of the assemblages concerning the sensitive macroinvertebrate taxa.

-Sampling stations with very high HQA values, zero HMS values, almost no contaminants but with a recorded reduced biodiversity due to the natural existence of sulfur-bacteria Fig. 4, or ferro-bacteria.

Fig. 4. Typical sampling station with sulfur-bacteria (SW Thessaly)

-High water quality, but fluctuation in the flood area due to the presence of a hydroelectric dam, something that has as a consequence the switching of the quantity and quality of habitats leading to the reduction of macroinvertebrates biocommunity (Fig. 5), while flow alternations contribute to this phenomenon.

Fig. 5. Fluctuations of the water surface due to a hydroelectric power plant (Ladon R., Peloponnese)

- In certain cases, (e.g. Samothrace island N. Aegean sea Greece), the water quality is excellent, the HMS is 0, the HQA is > 97, the rivers however did not have fish fauna due to natural causes. Also in Rhodes island (S. Aegean sea), the only fish species present in the rivers is *Ladigesocypris ghigii* species, a fact that raises concerns about the classification of the rivers (Gritzalis, 2006).
- Regarding flora, large variations were found in the correlation of habitat and abundance between rivers in Northern and Southern Greece due to temperature and flood regime. The same phenomenon is also observed during the same season and especially from the end of spring to the end of summer between upland and lowland rivers which also belong at the same type (R-M1, R-M2 etc).
- At almost all stations with emerging flora, the 85% of macroinvertebrates is found at an adult form
- Also the following phenomenon is often observed, the chemical classification to be stable (i.e. high), the same to apply for HQA and HMS, but an alteration in the bio-community to be recorded, apparently due to the biological cycle of benthic macroinvertebrates.
- It was also found, at pristine sites, after taking into account all the factors and the criteria regarding the definition of reference conditions (Reynoldson & Wright, 2000; Wallin *et al*., 2003; Nijboer *et al*., 2004) a disharmony to exist between HQA and macroinvertebrates. Namely, low rating for HQA, and high biodiversity, especially regarding EPT (Ephemeroptera, Trichoptera and Plecoptera) taxa.

3. CONCLUSIONS

Therefore, in summary, we reached the following conclusions – recommendations:
- The amendments - pollutants and environmental approaches are not only a current problem, but they have been identified since antiquity
- The regime in Greece relating to open issues on macroinvertebrates is a fact, as it is demonstrated from the information provided above.
- Although several institutions have started to deal with these topics, during the last 25 years, the data is enough; however it is not such as being in other European countries.
- Multihabitat approach should be applied more extensively.
- Through a jointed European project strong evidence should be highlighted among BQE, chemistry and hydromorphological characteristics so as to avoid misconceptions concerning ecological quality, especially to data

administrators that do not have a direct view of the study area.

Acknowledgements

The authors would like to thank all those colleagues who participated in these studies. We are pleased to acknowledge the colleagues across Europe as such studies reflect collaborative research. This paper also was made possible by grants from the E.U. and the Greek General Secretariat of Research & Technology, Ministry of Development (AQEM & STAR) and from the funds of Prefecture of Messinia, Municipalities of Kalamata, Messini, Oichalia & Triphylia for the implementation of the Research Project: 847.

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