Strategies for reducing sediment connectivity and land degradation in desertified areas using vegetation: the RECONDES project

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This paper is written on behalf of the RECONDES project team

Abstract The aim of the EU funded project “RECONDES” is to bridge the gap between research and practice in relation to soil and land degradation and the onset of desertification in Mediterranean lands. The research is on the use of vegetation for restoration and mitigation of desertified areas and the major outcome will be guidelines on how vegetation may be used in the landscape to reduce erosion. Much of the erosion takes place in hot spots and specific locations related to zones of runoff concentration, often exacerbated by land-use practices and structures or lack of maintenance of traditional practices which previously prevented development of long runoff slopes. The major premise of the project is that vegetation can be used to reduce connectivity of flow and sediment transfers within the landscape. Within river channels the effect of vegetated reaches on flow and sediment flux are examined.

Key words connectivity; EU project RECONDES; land degradation and desertification; Mediterranean; vegetation

INTRODUCTION

The role of vegetation in protecting the surface of drylands from erosion, in particular the stabilizing effect plant and root biomass has on the soil, is of increasing interest to researchers studying processes of desertification and policy makers responsible for the sustainable management of desertified lands. In a recent Desertification Synthesis completed as part of the Millenium Ecosystem Assessment (2005) protection of vegetation cover is stated as one of the major instruments for the prevention of desertification. However, at present, our understanding of vegetation and process interactions in drylands is quite limited. Such knowledge is required to facilitate the production of guidelines on the use of vegetation for mitigating desertification. This knowledge gap is being addressed through the EU funded project RECONDES (Conditions for Restoration and Mitigation of Desertified Areas Using Vegetation).

RECONDES seeks to advance understanding of vegetation and process interactions to the point where guidelines may be developed. The project is investigating what kinds and species of vegetation will grow in various parts of dryland catchments, the conditions necessary for growth, and how differing plants may reduce erosion. This knowledge is then being matched to the land degradation processes to produce recommendations on where in the landscape vegetation can be encouraged or planted with maximum effect on land degradation and reduction of off-site effects, including in river channels. The guidelines will be aimed at regional authorities to recommend the kinds of policies and practices which might be implemented and which may be more sustainable than current practices, such as use of check dams in gullies and channels.

EROSION AND DEGRADATION IN DESERTIFIED MEDITERANEAN LANDS

Erosion and degradation occur across a range of scales and land-units in the Mediterranean landscape. Within each of these scales and land-units it is possible to identify particular processes of erosion and land use practices which have directly or indirectly contributed to desertification in the region. Erosion is common in agro-ecosystems of marginal hilly areas characterized by high water deficit and high inter-annual variability in rainfall. The change in land use from a semi-natural vegetation or traditional terraced orchards to intensified plantations with an extremely low crop cover, leaving most of the soil exposed, has large impacts on hydrology and land degradation (De Graaff & Eppink, 1999; Beaufoy, 2002), the off-site effects of which cause gully erosion and extremely high discharges in the river channels.

In semi-natural and abandoned lands, disturbances to the spatial heterogeneity of vegetation cover result in concentrated flow (Tongway & Ludwig, 1996; Cammeraat & Imeson, 1999) leading to high degradation rates and soil quality loss. Many abandoned lands are also terraced with earth dams and, with the halt of cultivation, the maintenance of terraces is also stopped. This leads to the deterioration of the terraces, an increase in the length of slopes over which runoff occurs and accelerated rates of erosion. Soil retained above these terraces may be eroded and released under extreme runoff events (Cammeraat, 2002).

Reforestation using trees has been widely applied throughout the Mediterranean; however, due to the harshness of semiarid environments, their success has been severely limited (Zhang *et al*., 2002). Extensive terracing of lands was undertaken across the Mediterranean in the 1960s and 1970s using heavy machinery, a practice considered to improve water yield to the plants and accelerate development of vegetation and ecosystem restoration. However, in many cases, land degradation was triggered by these aggressive techniques, increasing soil erosion (Chaparro & Esteve, 1995; Williams *et al.*, 1995) and reducing soil quality (Querejeta, 1998). Castillo *et al.* (2001) indicate that the sidebanks may also be a source of sediment and gully initiation because of the long-term devegetation and steep gradient.

Gully erosion is a particular problem, responsible for significant on-site soil losses and off-site consequences (Poesen *et al.*, 2003). In Mediterranean areas, the evidence from several studies is that gully erosion may be responsible for up to 80% of total soil losses due to water erosion, whereas this process only operates on less than 5% of the land area. Once developed, gullies increase the connectivity of flow and sediment transfers from uplands to lowlands areas and the drainage system. Reducing gully erosion, will lead to less sediment export, less reservoir sedimentation, lowering flood risk and allowing more water in uplands to infiltrate. Similarly, deterioration of soil resources and ecosystems is also apparent in valley floors, mainly as a result of erosion during high flows. Efforts that are made to mitigate runoff and concentrated flow leading to gully erosion would also be effective in reducing the potential for erosion and degradation of valley floors.

ROLE OF VEGETATION IN MITIGATING DESERTIFICATION

The use of plants to prevent degradation and stimulate ecosystem health is a technique which is being researched and applied around the world. Theoretical and empirical evidence indicates the importance of spatial heterogeneity in semiarid landscapes, where vegetated patches alternate with bare surfaces. This patterning of vegetated patches and bare areas develops through the interaction between vegetation and abiotic factors, with increases in water infiltration in vegetated patches (Klausmeier, 1999; HilleRisLambers *et al.*, 2001). Similar approaches by von Hardenberg *et al.* (2001), Meron *et al.* (2004) and Puigdefabregas (2005) highlight the importance of incorporating this spatial heterogeneity in vegetation as part of any proposed revegetation to mitigate desertification.

Within highly developed agro-ecosystems, the potential to reduce runoff and erosion is an area of continuing research. In some circumstances, cover crops are being recommended, e.g. under olive trees on all slopes above 5% (Beaufoy, 2002) but further research is required on their water requirements to determine whether they can be applied to severely degraded soils. Planting of woody vegetation with strong roots along the edges of fields, particularly on terrace walls may be effective in reducing their possibility of failure. Recent research in reforested lands has found that application of organic amendments is yielding good results in restoring degraded areas (Garcia *et al*., 2000; Querejeta *et al*., 2001; Barberá *et al*., 2005).

Traditional vegetative techniques to control gully development, such as grassed waterways, rely on the role of the above-ground biomass in dissipating flow energy, whilst little attention has been given to the role of the below-ground biomass. In a Mediterranean context, where the above-ground biomass may temporarily disappear because of grazing, water stress and fire, roots play a crucial role in reinforcing topsoils. Within the RECONDES project the role of roots in increasing the resistance of soils to erosion is being investigated in detail.

Much research is going on into the use of vegetation for river bank protection, mainly in humid channels. Some work has also been done in drier regions (Graeme & Dunkerley, 1993; Salinas & Guirado, 2002) and the principle of identifying where vegetation is most effective has been recognised (Abernethy & Rutherfurd, 1998). Monitoring of the effects of floods in semiarid channels of Spain shows that densely vegetated reaches can prevent erosion and encourage deposition (Hooke & Mant, 2000; Mant, 2002), however above a certain threshold the plants may be removed. Some limited research has tested the strength of plant aerial parts and plant roots for resistance to flow (Mant, 2002). Further work is required on a greater range of plants and in a wider variety of conditions of substrate, moisture availability and flow hydraulics to identify which plant species are most effective at preventing erosion and the conditions necessary for the growth of each.

THE RECONDES PROJECT

The focus of RECONDES is to address the mitigation of desertification processes by means of innovative techniques using vegetation in specific landscape configurations prone to severe degradation processes. The project examines the use of vegetation in a hierarchy of scales which mesh together. Each builds up a mosaic of patterns which can be combined into the next higher scale. There are four main scales: (1) is of the order of tens of metres and comprises three component land uses/land types—reforested land, cropland, and abandoned/semi-natural land; (2) is the hillslope at the scale of hundreds of metres at which the topography and the distribution of the component land use types becomes more influential; (3) river valley reaches, of the order of 1000 m, at this scale the delivery of water and sediment from the hillslopes and their transmission downstream to the larger catchments are examined, and; (4) of the order of 10 000 m, in which the mosaics of different component land uses, together with varying topography, soil type and other physical conditions are examined.

The key which holds this all together and links all scales is the connectivity of water, sediment and nutrients. The aim is to identify the patterns of connectivity and to examine how vegetation can reduce that connectivity. The greater the connectivity, then the greater the amounts and forces of water created, thus the greater the amounts of erosion and the further the water and sediment is transmitted downstream, with propagation of deleterious effects. The basic hypothesis is that vegetation can reduce erosion by increasing infiltration and thus reducing overland flow, decreasing force of flow by increasing roughness and by increasing resistance to erosion. Thus at the scale of the land unit, the project would identify, for example, how water is accumulating and flowing in reforestation plots, where and how it is eroding the terrace rims and therefore where vegetation needs to be targeted.

EFFECT OF VEGETATED REACHES ON FLOW AND SEDIMENT FLUX

The two main study regions for this project are Cárcavo basin, in the north of Murcia province, southeastern Spain and the Val d’Orcia region, Tuscany, Italy. Within the river channel component, investigations are also being carried out in the Guadalentin Basin (Rambla de Torrealvilla and Rambla de Salada), southeastern Spain. Baseline monitoring is being carried out to detect changes resulting from flows and the effects that seasonal changes have on the condition of the plants. Five basic types of vegetation (functional groups) are identified based on the growth habit of the plants, their rooting depth, their longevity and seasonality. These five categories are trees, shrubs, herbs, grasses and reeds. A list of the dominant species and functional groups identified for these two areas is outlined in Table 1.

The morphology of the ephemeral channels of southeastern Spain and the characteristics of the vegetation vary markedly along their courses. Sections of channel devoid of sediment and vegetation contrast with areas of large sediment storages and vegetation. These differences may be a result of complex interactions between variations in sediment supply, bedrock and other influences such as check-dams on channel form–stream power relationships and water availability. Questions about connectivity of sediment transfers and interactions with vegetation can be studied in part through repeated mapping, both in the field and using aerial photographs. A series of base maps of the Cárcavo and Torrealvilla have been produced from the detailed field surveys along the channel network. These maps show the distribution of different plant

Table 1 Plant functional groups and species identified along the ephemeral channels of the Torrealvilla and Cárcavo.

Plant Functional Group	Ephemeral channel species list: Torrealvilla	Cárcavo
Trees	*Populus nigra* [FAN]	*Nerium oleander* [NAN]
	Nerium oleander [NAN]	*Pinus halepensis* [FAN]
	Retama sphaerocarpa [NAN]	*Tamarix canariensis* [NAN]
	Tamarix canariensis [NAN]	*Eucalyptus (sp)* [FAN]
	Eucalyptus (sp) [FAN]	
Shrubs	*Artemisia barrelieri* [CAM]	*Genista spartioides* [NAN]
	Genista spartioides [NAN]	*Salsola genistoides* [NAN]
	Salsola genistoides [NAN]	*Suaeda vera* [NAN]
	Senecio linifialaster [CAM]	*Ballota hirsuta* [CAM]
	Suaeda vera [NAN]	*Anthyllis cytisoides* [NAN]
	Thymelaea hirsute [NAN]	
	Dorycnium pentaphyllum [NAN]	
	Anthyllis cytisoides [NAN]	
	Ballota hirsuta [CAM]	
Herbs	*Dittrichia viscosa* [HEM]	*Dittrichia viscosa* [HEM]
	Rosmarinus officalis [NAN]	*Rosmarinus officalis* [NAN]
	Limonium (sp) [HEM]	*Limonium (sp)* [HEM]
	Foeniculum vulgare [HEM]	
	Polygonum equisetiforme [TER]	
Grasses	*Piptatherum miliaceum* [HEM]	*Piptatherum miliaceum* [HEM]
	Lygeum spartum [HEM]	*Lygeum spartum* [HEM]
Reeds	*Phragmites australis* [GEO]	*Phragmites australis* [GEO]
	Typha dominguensis [GEO]	*Juncus maritimus* [GEO]
	Juncus maritimus [GEO]	*Juncus acutus* [GEO]
	Saccharum ravennae [GEO]	*Schoenus nigricans* [GEO]
		Scirpus holoschoenus [GEO]
		Scirpus maritimus [GEO]
		Saccharum ravennae [GEO]

[TER, GEO, HEM, CAM, NAN, FAN, LIA] refer to the lifeform of the species following Raunkiaer's biotypes, which uses the vegetative form of a plant based on the position of growth point (buds) during adverse times of the year. TER, Therophytes, annuals, survive in form of seeds; GEO, Geophytes, underground buds (usually bulbous, rhizomatous, etc); HEM, Hemicryptophytes, buds at soil surface level; CAM, Chamaephytes, buds near ground level (buds < 25 cm high); NAN, Nanophanerophytes, buds near ground level (buds 25–75 cm high); FAN, Phanerophytes, trees and large shrubs; LIA, Lianes, plants growing leant against other plants.

assemblages in relation to the morphology of the channel. The location of sediment inputs, nature and distribution of sediment storages along the channel, occurrence of bedrock outcrops and position of check-dams are also mapped (see Fig. 1).

Further research is determining what factors may be important in controlling the distribution of riparian assemblages along the Torrealvilla and Cárcavo. Check-dams exert a very strong influence on the composition of vegetation along the channel and its density and plant establishment and survival is enhanced by aggradation, ponding of water and greater channel stability upstream of these structures. The occurrence of check-dams favouring vegetation growth provides the opportunity for the threshold conditions for growth to be identified. Changes in channel geometry, marked variations in the nature and amount of sediment supply and the effect that these have

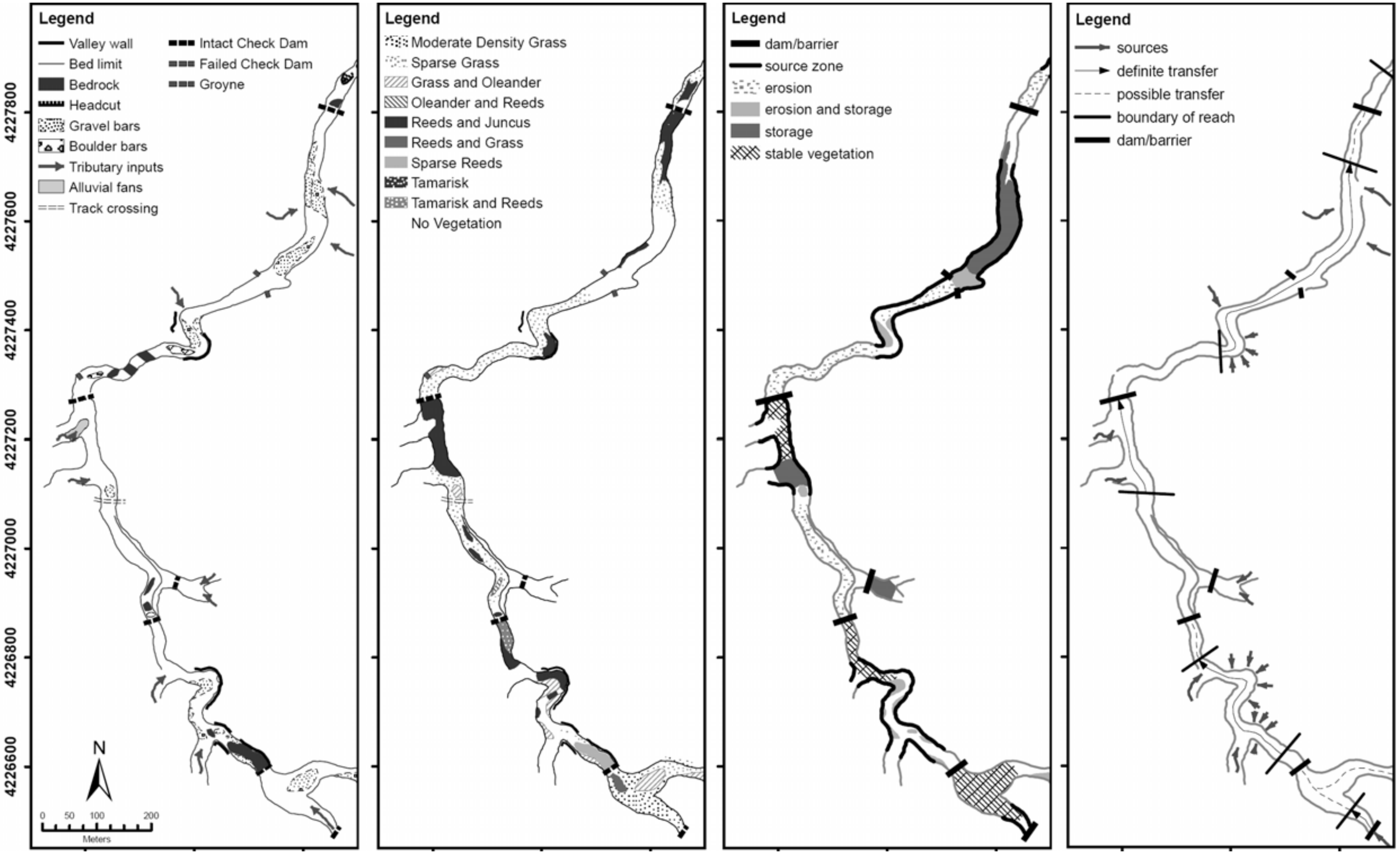

Fig. 1 Mapping and interpretation of a section of Cárcavo channel, SE Spain showing: (a) morphology (b) vegetation (c) status and (d) connectivity.

on flow hydraulics and conveyance, variation in depth of sediments, and groundwater influences may also be important. The effects of these variables are currently being analysed. Additionally, the forces on plants in various flows for different channel morphologies are being calculated to identify thresholds of resistance for different plants.

CONCLUSIONS

RECONDES seeks to advance knowledge on vegetation and process interactions to the point where strategies can be developed for reducing sediment connectivity in desertified areas using vegetation. It is anticipated that the results of RECONDES will be particularly important to land managers at the catchment and regional scales and to those responsible for advising on land management practices. It is expected that the guidelines will indicate where in a catchment remedial practices and revegetation will be most effective. For example, it will seek to show that one particular location or pattern of implementation is more likely to prevent gullying than another. It will also provide guidance at the more local level, e.g. which parts of a reforestation terrace bank should be revegetated and how conditions might be created or enhanced to enable this. It is considered that the use of native vegetation will provide more sustainable solutions than engineering approaches such as check dams.

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