Pirineos. Revista de Ecología de Montaña
Vol. 174
Jaca, Enero-Diciembre, 2019, e043
ISSN-l: 0373-2568
https://doi.org/10.3989/pirineos.2019.174003

ASSESSMENT OF THE ECOSYSTEM SERVICES PROVIDED BY AGRICULTURAL TERRACES

Evaluación de los servicios ecosistémicos proporcionados por las terrazas agrícolas

Asunción Romero-Díaz[1]*, Joris de Vente[2], Elvira Díaz-Pereira[2]

[1]Departamento de Geografía, Universidad de Murcia.
[2]Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC)

ORCID identifier of the authors and e-mail:
Asunción Romero Díaz: http://orcid.org/0000-0003-1355-4160. E-mail: arodi@um.es
Joris de Vente: http://orcid.org/0000-0001-7428-0621. E-mail: joris@cebas.csic.es
Elvira Díaz Pereira: http://orcid.org/ 0000-0002-7459-5137. E-mail: ediazpereira@cebas.csic.es
*Corresponding author

Recibido: 13-02-2019. **Aceptado:** 24-03-2019. **Fecha de publicación on-line:** 07-06-2019

Citation / Cómo citar este artículo: Romero-Díaz, A., De Vente, J., Díaz-Pereira, E. (2019). Assessment of the ecosystem services provided by agricultural terraces. *Pirineos, 174,* e043. https://doi.org/10.3989/pirineos.2019.174003

ABSTRACT: Agricultural terraces have been widely used, throughout the world, since ancient times. Their scenic interest is undeniable and some are part of the UNESCO World Heritage. They are a very effective practice for soil and water conservation through the control of runoff and erosion, and provide farmers and society with important Ecosystem Services (ES). Here, we present a study based on 36 examples of terraces documented in detail in the WOCAT (World Overview of Conservation Approaches and Technologies) database, complemented with a review of the scientific literature on the impacts of terraces, the objective being to assess the multiple ES they provide. The results show that the most important ES provided by terrace construction relate to regulating services, like control of erosion, runoff, and other off-site natural risks. In addition, terraces contribute to provisioning services like the supply of food, fiber, and water (quantity and quality), and to cultural services through the maintenance of cultural landscapes. Here, we verify the environmental, geomorphological, and hydrological functions of the terraces, as well as the improvement in the quality of life for the local inhabitants. However, technological advances in agriculture have led to the abandonment of this type of construction, with significant risks of erosion and loss of ES. Our assessment highlights the importance of preserving and restoring terraces as part of regenerative agriculture, with multiple benefits for the functioning of cultural landscapes and for society.

KEY WORDS: Agricultural terraces; ecosystem services; WOCAT; sustainable land management.

RESUMEN: Las terrazas agrícolas son ampliamente utilizadas en todo el mundo desde la antigüedad. Su interés paisajístico es innegable y algunas de ellas forman parte del Patrimonio Mundial de la UNESCO. Son prácticas muy eficaces para la conservación del suelo y el agua a través del control de la escorrentía y la erosión, y proporcionan a los agricultores y a la sociedad importantes Servicios Ecosistémicos (SE). Presentamos un estudio basado en ejemplos de terrazas documentados en detalle en la base de datos WOCAT (World Overview of Conservation Approaches and Technologies), complementado con una revisión de la literatura científica sobre los impactos de las terrazas, con el objetivo de evaluar los múltiples SE que proporcionan. Los resultados muestran que los SE más importantes proporcionados por la construcción de terrazas están relacionados con servicios de regulación como el control de la erosión, escorrentía y otros riesgos naturales externos. Además, la presencia de terrazas favorece servicios de aprovisionamiento como el suministro de alimentos, fibras, y cantidad y calidad del agua. Se constatan las funciones ambientales, geomorfológicas e hidrológicas de las terrazas, así como la mejora de la calidad de vida de los habitantes. Sin embargo, los avances tecnológicos en la agricultura han llevado al abandono de este tipo de construcciones, con importantes riesgos de erosión y pérdida de SE. Nuestra evaluación destaca la importancia de preservar y restaurar las terrazas como parte de la agricultura regenerativa, con múltiples beneficios para el funcionamiento de los paisajes culturales y, en definitiva, para la sociedad.

PALABRAS CLAVE: Terrazas agrícolas, servicios ecosistémicos; WOCAT; gestión sostenible de la tierra.

1. Introduction

World agriculture faces enormous challenges due to the growing population, the increasing demand for food, fibers, and biofuels, soil degradation, and climate change. In the coming decades, these processes will have serious implications for soil and water resources and, as a consequence, for many essential services of the ecosystems dependent on them, such as the production of food, fibers, and fuels, the supply of drinking and irrigation water, erosion and flood control, and climate regulation (Swinton *et al.,* 2007). The conservation of soil and water is essential to face these challenges, due to its potential to increase production, protect natural resources, increase the resilience of agro-ecosystems, and minimize greenhouse gas emissions. There are examples of soil and water conservation from ancient civilizations and from the beginning of agriculture about 10,000 years ago. The best preserved and most documented measures, worldwide, are terraces on slopes and water capture and transport systems for irrigation (Spencer & Hale, 1961; Wilkinson, 2003). The importance of terraces is reflected, for example, in their estimated length in the EU (1,717,454 km) and in the more than 600,000 ha of stone terraces in Peru (Koohafkan & Altieri, 2011).

Agricultural terraces have different uses, typologies, and ages, in many countries around the world. They are found especially in mountainous areas (Arnáez *et al.,* 2015), and although in the Mediterranean countries a high proportion have been abandoned (MacDonald *et al.,* 2000; García-Ruiz & Lana-Renault, 2011; Romero Díaz *et al.,* 2016), terrace cultivation is still practiced in mountainous areas of Asia, Africa, and South America. At present, terraces are still being built in areas of intensive agriculture adapted for the use of modern machinery. Table 1 provides an overview of the international literature related to terraces from different continents. Asia has the greatest representation, with 18 countries, most studies coming from China. In North America, terraces are frequent, but their importance is much greater in South America, especially in the Peruvian Andes. Terraces are common throughout Africa. In Europe, terraces are most common in Mediterranean countries (Italy, Greece, Spain), although they are also common in parts of Germany, Russia, and the Czech Republic.

The scientific interest in terraces is also shown by the many international conferences on this subject, such as the series of World Conferences on Terraced Landscapes (Mengzi, Yunnan, China in 2010; Cusco, Peru in 2014; Padua, Italy in 2016; Canary Islands, Spain in 2019), and by the various special issues of journals (Balbo & Puy, 2017; Varotto *et al.,* 2019) and review articles (Dorren & Rey, 2004; Stanchi *et al.,* 2012; Tarolli *et al.,* 2014; Arnaéz *et al.,* 2015; Wei *et al.,* 2016; Chen *et al.,* 2017).

Increasingly, the concept of ecosystem services (ES) is used also to evaluate the benefits of sustainable land management practices to society and human well-being. Facing the challenges of environmental and social changes, sustainable management of the ES is a worldwide priority (Quintas Soriano *et al.,* 2018). The Millennium Ecosystem Assessment (2005) defines ES as “the benefits that the population obtains from ecosystems”. Four types of ES are generally distinguished: (i) provisioning (e.g. supply of food, fresh water, fuel, fibers, genetic resources); (ii) regulating (e.g. regulation of climate and water, diseases, pollination); (iii) supporting (e.g. soil formation and nutrient recycling); and (iv) cultural (e.g. spiritual, recreational, aesthetic, educational, cultural heritage). The benefits of ES for society can be direct or indirect and can often be valued economically (Camacho Valdez & Ruiz Luna, 2012; Ferrer *et al.,* 2012), which facilitates the evaluation of the costs and benefits of prevention or restoration measures as compared to the costs and benefits of no action. The ES can be considered as benefits (Costanza, 2008) or, more broadly, as contributions to human well-being (Potschin & Haines-Young, 2011).

The objective of this study was to analyze the impacts of and the ES provided by agricultural terraces, by: (i)

Table 1: Overview of the international research on terraces included in this review.
Tabla 1: Algunas de las investigaciones internacionales sobre terrazas incluidas en esta revisión.

Continent	Country	References
AFRICA	Ethiopia	Gebrernichael *et al*., 2005
	Kenya	Thomas *et al*., 1980
	Rwanda	Kagabo *et al*., 2013
	Tanzania	Wickama *et al*., 2014
	Tunisia	Schiettecatte *et al*., 2005
	Uganda	Siriri *et al*., 2005
AMERICA	Brazil	De Oliveira *et al*., 2012
	Canada	Chow *et al*., 1999
	EE.UU.	Bragg & Stephens, 1979; Haas *et a*l., 1966
	Mexico	LaFevor, 2014
	Peru	Antle *et al*., 2007; Sandor & Eash, 1995
ASIA	Saudi Arabia	El Atta & Aref, 2010
	China	Chen *et al*., 2012, 2017; Liu *et al*., 2004, 2011
	Philippines	Bantayan *et al*., 2012
	India	Sharda *et al*., 2002
	Indonesia	Van Dijk *et al*., 2005
	Israel	Hammad *et al*., 2004; Ore & Bruins, 2012
	Iran	Sharifi *et al*., 2014
	Japan	Qiu *et al*., 2014; Tokuoka & Hashigoe, 2015
	Jordan	Barker *et al*,. 2007
	Korea	Park *et al*., 2014
	Malaysia	Hamdan *et al*., 2000
	Nepal	Tiwari *et al*., 2009
	Oman	Luedeling *et al*., 2005
	Palestine	Hammad *et al*., 2004; Hammad & Børresen, 2006
	Pakistan	Rashid *et al*., 2016
	Thailand	Sang-Arun *et al*., 2006
	Vietnam	Mai *et al*., 2013
	Yemen	Piestsch & Mabit, 2012
EUROPE	Germany	Loczy, 1998
	Cyprus	Galletti *et al*., 2013
	Spain	Arévalo *et al*., 2017; Arnáez *et al*., 2015; Asins 2006, 2009; García Ruíz *et al*., 2013; Lasanta, 1990, 2014; Lasanta *et al*., 2001, 2013; Ramos & Martínez-Casanovas, 2006; Reynes Trias, 2006; Romero Díaz *et al*., 2007, 2016; Romero Martin *et al*., 2016.
	France	Salvador-Blanes *et al*., 2006
	Greece	Koulouri & Giourga, 2007; Price & Nixon, 2005
	Italy	Agnoletti *et al*., 2019; Bazzoffi *et al*., 2006; Brandolini *et al*., 2017; Paliaga *et al*., 2016; Tarolli *et al*., 2014
	Portugal	Pacheco *et al*., 2014
	Czech Republic	Dumbrovsky *et al*., 2014; Kovár *et al*., 2016; Kosulic *et al*., 2014
	Russia	Borisov *et al*., 2012
	Slovenia	Ažman *et al*., 2016; Kladnik *et al*., 2016

Source: own elaboration.

evaluating the environmental and socioeconomic impacts and the cost-benefit ratio of the implementation and maintenance of agricultural terraces; (ii) determining the ES provided in different countries and climates; and (iii) contrasting these results with the data from the scientific literature concerning the impacts of terraces on ES.

2. Methods

To assess the impacts, costs, and benefits of agricultural terraces, we used detailed descriptions of the characteristics of terraces from the World Overview of Conservation Approaches and Technologies (WOCAT) database. WOCAT is a global network that supports innovation and decision making in Sustainable Land Management (SLM) appropriate to local conditions. WOCAT aims to facilitate knowledge exchange, decision support, and scaling-up of the implementation of SLM. WOCAT brings together knowledge of a wide range of SLM techniques from all over the world, reporting in a standardized manner their characteristics, effectiveness, advantages, disadvantages, and costs and benefits of application, from which their impacts on ES can be determined. All entries in the WOCAT database are provided by local practitioners and experts and go through an expert review process (WOCAT, 2016).

In this study we review all 36 available technologies related to agricultural terraces from different continents (Table 2), documented in detail in the WOCAT database. We analyze the characteristics of each one regarding: (1) location, type of technology, surface area involved, types and causes of degradation, objectives to be achieved, type of measure; (2) climatic, topographic, soil, hydrologic, and biodiversity characteristics of the areas of implementation; (3) socioeconomic aspects; (4) the costs of establishment and maintenance and the cost/benefit ratio; (5) socioeconomic, sociocultural, ecological, and off-site effects; and (6) the ES provided by the terraces.

The classifications used for the assessment of the impacts are listed in the WOCAT Questionnaire on SLM (WOCAT, 2016). In the WOCAT database the impacts of technologies are considered high (H) when they are above 50%, medium (M) when between 20 and 50%, and low (L) if a measure results in a change of between 5 and 20% in a variable.

3. Results

3.1. *General characteristics of the technologies and where they are applied*

Of the terrace technologies described in WOCAT, 50% originate from Asia, 33% from Africa, 11% from Europe, and 6% from South America, with a notable presence of countries such as Ethiopia or China. The technologies are generally applied in small areas: 30% have an area between 0.1 and 1 km^2, and 70% occupy less than 100 km^2 (only 27% have an area > 1,000 km^2).

Soil degradation in the areas where the terraces are applied usually occurs due to a combination of different causes or drivers: (i) indirect (land tenure, population pressure, education, inputs and infrastructure, poverty); (ii) human induced (deforestation, soil management, disturbance of the water cycle, gradual abandonment of mountain agriculture); (iii) indirect and natural (extreme rainfall, steep mountain terrain); and (iv) indirect and naturally induced. In relation to the terraces, the main type of degradation reported in WOCAT is degradation due to water erosion (75%), followed by the combination of water erosion and chemical soil deterioration (21%) and the combination of water and wind erosion, representing only 4% of the cases. Hence, the main technical functions of terraces are the control of runoff, the reduction of the slope, the increase in water infiltration and soil cover, the incorporation of organic matter into the soil, and the increase in soil fertility. The objective of the interventions is predominantly the mitigation of degradation processes, followed by prevention and rehabilitation. Farmers are aware of the need to implement measures to prevent soil degradation, so in 50% of cases the origin of the technologies is a local initiative, while the other 50% have an external origin.

In 64% of the cases reported, terraces are structural conservation measures, in 14% they are combined structural/vegetative measures, and in 8% a combination of agronomic/vegetative/structural measures. The typology of the terraces is diverse: terraces made with stones predominate, representing 36%; followed by those built with earth and vegetation (25%) and earth alone (22%). The remaining 6% correspond to terraces built with diverse materials such as tires or cement bags filled with earth. The choice of the type of terrace depends on several factors, such as the type of soil, slope gradient, availability of stones, availability of labor, or cost. The dimensions of the terraces vary depending on the technique used and the type of slope. On steep slopes, high terraces predominate (Ethiopia, Peru, Syria). The technique used is usually related to the purpose or to the type of crop to be planted.

From an environmental point of view, 64% of the technologies reported have been developed in semi-arid climates, 19% in sub-humid, and 17% in humid. The predominance of terraces in semi-arid regions is due to the irregularity of rainfall and the serious problems of soil degradation in these environments. Regarding the pre-existing morphology, hillslopes account for 64% of cases. The predominant slope is hilly (16-30%), followed by steep (30-60%) and rolling (8-16%).

The soils from semi-arid regions where the terraces are implemented are mostly shallow (< 50 cm), while those from more humid regions can exceed 120 cm in depth. Regarding the texture, most (72%) have a medium texture (loam), 19% have a coarse (sandy) texture, and the rest have a fine texture (clay). Soil fertility is low or very low in 60% of cases and average in 37%, while only 3% of the soils have high fertility. The superficial soil organic matter content is consistent with the soil fertility, being low (< 1%) in 60% of the cases analyzed and mod-

Table 2: Evaluated technologies from the WOCAT database, specifying their climate conditions and countries.
Tabla 2: Tecnologías evaluadas de la base de datos WOCAT, especificando sus condiciones climáticas y países.

Reference	Climate	SLM technology	Country
AS604en	Semi-arid	Alfalfa intercropping in terraced fruit orchard	Afghanistan
BAN004en	Humid	Valley floor paddy terraced cultivation	Bangladesh
CHN021en	Humid	Orchard terraces with bahia grass cover	China
CHN045en	Semi-arid	Zhuanglang loess terraces	China
CHN050en	Semi-arid	Terrace	China
CHN051en	Semi-arid	Bench terraces on loess	China
CHN053en	Semi-arid	Progressive bench terrace	China
CYP004en	Semi-arid	Agricultural terraces with dry-stone walls	Cyprus
ETH009en	Semi-arid	Konso bench Terrace	Ethiopia
ETH014en	Semi-arid	Stone faced soil bund of Tigray	Ethiopia
ETH015en	Semi-arid	Stone faced trench bund	Ethiopia
ETH019en	Semi-arid	Stone bund of Tigray	Ethiopia
ETH036en	Semi-arid	Sorghum terraces of Diredawa	Ethiopia
ETH606en	Semi-arid	Large semi-circular stone bunds	Ethiopia
GRE004en	Semi-arid	Land terracing in olive groves	Greece
IDS090en	Subhumid	Paddy field terrace	Indonesia
IND019en	Semi-arid	Contour trench cum bund	India
KEN005en	Subhumid	Fanyajuu terraces	Kenya
KEN657en	Subhumid	Agroforestry land use in bench terraces	Kenya
NEP002en	Humid	Improved terraces	Nepal
NEP010en	Humid	Traditional irrigated rice terraces	Nepal
NIC003es	Subhumid	Individual terraces	Nicaragua
NIG018fr	Semi-arid	Murets	Nigeria
NIG073en	Semi-arid	Contour bunds for crops & forest/rangeland	Nigeria
PER001en	Semi-arid	Rehabilitation of ancient terraces	Peru
PHI012en	Humid	Rainfed paddy rice terraces	Philippines
RSA003en	Subhumid	Traditional stone-wall terraces	South Africa
RWA003en	Subhumid	Radical terraces	Rwanda
SPA002en	Semi-arid	Vegetated earth-banked terraces	Spain
SWI002en	Subhumid	Contour small bench terraces with green cover in vineyards	Switzerland
SYR001en	Semi-arid	Stone-wall bench terraces	Syria
TAJ013en	Semi-arid	Combined cut-and-carry and fruit-production system with terraces	Tajikistan
TAJ105en	Semi-arid	Mulching in rainfed vineyards on terraces in the loess hill zone	Tajikistan
TAJ362en	Semi-arid	Gradual development of bench terraces from contour ditches	Tajikistan
THA025en	Humid	Small level bench terraces	Thailand
YEM001en	Semi-arid	Bench terraces covered with small stones	Yemen

Source: own elaboration from the WOCAT database.

erate (1-3%) in 40% of them. Regarding the hydric properties of the soils, the drainage capacity is moderate-high in most cases and the soil water storage capacity is moderate-high in 50% of them.

3.2. Cost-benefit ratio of implementation and maintenance

The cost-benefit ratio of terrace implementation and maintenance is an important aspect for farmers. Analysis of the WOCAT database shows that if the implementation costs of terraces are low, their maintenance costs are usually high and *vice versa*. This is because the terraces built with earth are cheap to build, but have to be repaired continuously, while the cost of building terraces with stone-walls, that require specialized personnel, is much higher but they last longer and have very limited maintenance costs. There are records of centuries-old terraces built with stone from Peru, Syria, and Israel (Ore & Bruins, 2012).

Farmers consider the establishment costs of terraces to be negative in the short term (1 year), but positive and very positive in the long term (10 years). Regarding maintenance, the costs are perceived as positive and slightly positive in the short term, and positive and very positive in the long term (Figure 1).

3.3. Impacts of terrace construction

Socioeconomic and production impacts. The most important positive impacts derived from the construction of terraces are increases in crop yield, fodder production, and farm income. Other benefits mentioned, although less frequently, are the simplification of farm operations, increased animal and wood production, reduced demand for irrigation water, more efficient irrigation and fertilizer use, and a lower risk of crop failure. In a few cases negative effects are reported - such as increased labor constraints, the need for greater agricultural inputs, loss of land, access constraints, and reduced crop production, since the terrace occupies part of the previously productive land. The changes with lower impact are the increased supply of irrigation water, breakage of the structure of the topsoil, hindering of farm operations, increased economic inequality, and, in some cases, reduced animal output.

Sociocultural impacts. The most notable benefits are the improved knowledge of soil conservation and erosion, strengthening of community and national institutions, and improved food security. In three cases the improvement of cultural opportunities and of the situation of certain disadvantaged groups is mentioned. Regarding negative impacts, sociocultural conflicts are mentioned in four cases and the loss of recreational opportunities in one.

Ecological impacts. A high positive impact is associated with the reduced soil loss, increased soil moisture, improved soil cover, and reduced surface runoff, together with increases in the soil fertility and biodiversity. To a lesser degree, the collection of surface runoff improves, the loss of excess water by drainage is diminished, the soil organic matter increases, and the risk of adverse events is reduced. A small number of cases report reductions in the evaporation, soil crusting/sealing, and wind velocity, and increases in the aboveground biomass, plant diversity, quantity of water available, carbon sequestration, and groundwater recharge. The main ecological disadvantages, mentioned in three cases, are related to reduced river flow and an increased number of niches for pests. In two instances, increased fire risk, increased risk of waterlogging, and reduced biodiversity are cited.

Off-site impacts. The positive effects, with high or very high impacts, are related to reduced flooding and siltation downstream. In second place is increased streamflow in the dry season, followed by reduced surface water pollution, reduced damage to infrastructure in the fields of neighbors, and a decline in wind transported sediments. To a lesser extent, there is increased groundwater recharge, the sediment yields in the valley bottom decrease, and the water buffering/filtering capacity improves. By contrast, reduced sediment yields are considered a disadvantage in six cases, in four of which reduced river flows are also evaluated negatively.

3.4. Ecosystem services provided by terrace construction

Based on the impacts that derive from terracing, we identified a series of provisioning, supporting, regulating, and cultural ES provided by terraces.

Provisioning Ecosystem Services. Often, the term *provisioning ES* refers mainly to the supply of food, fiber, fuel, and water, but we also include the supply of land available for production, since this was mentioned in two cases. Increases in the provision of food and, as a consequence, improvements in food security stand out, as do, to a lesser degree, the increased animal output, reduced risk of crop failure, and increased fodder production. In some cases, terraces have improved the quality and quantity of the available water. The water quality rises due to improved buffering and filtering, thereby reducing groundwater and river pollution. The quantity of water available increases due to a reduced demand for irrigation water, thus enhancing the harvesting of water and its availability. Wood production constitutes a provisioning ecosystem service in six of the technologies present in the WOCAT database and land supply does so in two (Figure 2).

Regulating Ecosystem Services. In order of importance, these are: (i) reduction of natural hazards, (ii) reduction of erosion, (iii) water regulation, (iv) climate regulation, (v) biological regulation, and (vi) health (Figure 3). By reducing runoff and erosion, the floods, sedimentation, and damage to infrastructure downstream and in neighboring fields are reduced. Water regulation involves increased soil moisture, decreased runoff, reduced

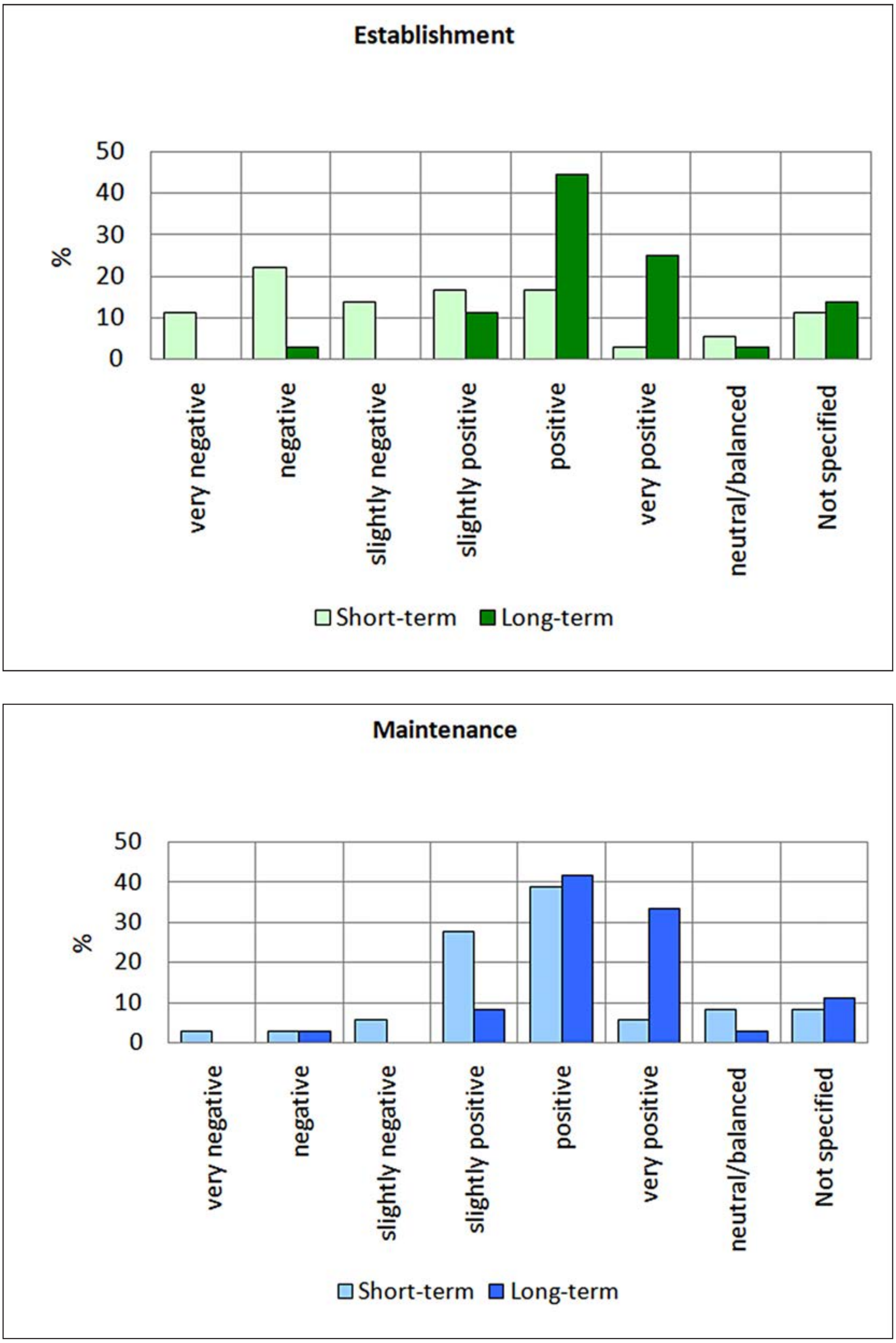

Figure 1: Cost-benefit ratios for the establishment and maintenance of terraces in the short term and long term. Source: own elaboration from WOCAT database.

Figura 1: Relación coste-beneficio para la implantación y mantenimiento de terrazas a corto y largo plazo. Fuente: elaboración propia a partir de la base de datos WOCAT.

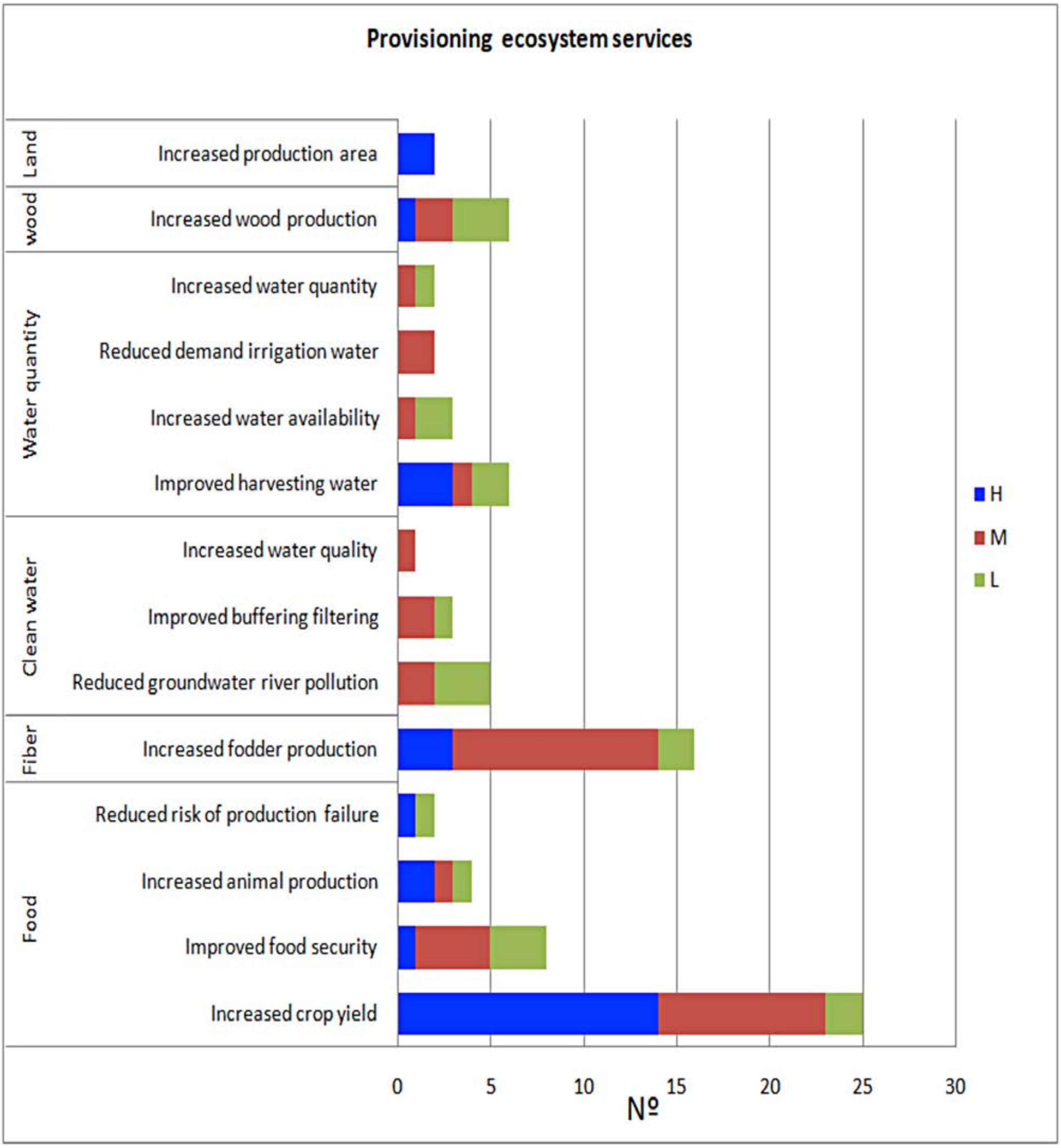

Figure 2: Provisioning ecosystem services provided by terraces. Impact: H = high, M = medium, and L = low. Source: own elaboration from WOCAT database.

Figura 2: Servicios ecosistémicos de aprovisionamiento proporcionados por las terrazas. Impacto H = alto, M = medio y L = bajo. Fuente: elaboración propia a partir de la base de datos WOCAT.

evaporation, water retention, and recharge of aquifers. Climate regulation is achieved by the sequestration and stabilization of carbon in soils. Regarding biological regulation and health, terraces are less important, although in some cases increases in the diversity of plants and animals and in the abundance of beneficial species, and an improvement in the functioning of the ecosystem, are mentioned.

Supporting Ecosystem Services. These ES, identified in fewer cases, refer to: (i) genepool protection, due to

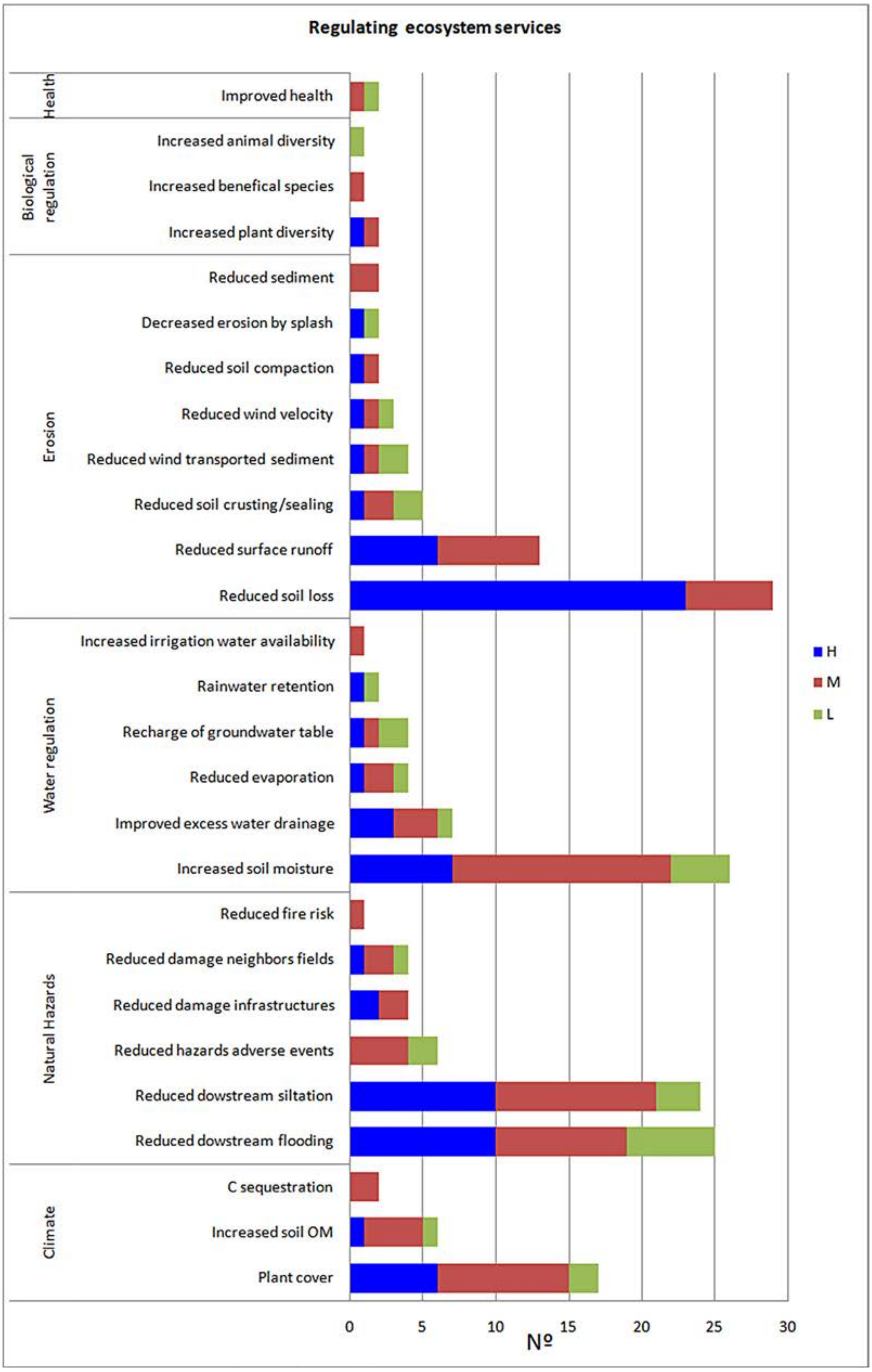

Figure 3: Regulating ecosystem services provided by terraces. Impact: H = high, M = medium, and L = low. Source: own elaboration from WOCAT database.

Figura 3: Servicios ecosistémicos de regulación proporcionados por las terrazas. Impacto H = alto, M = medio y L = bajo. Fuente: elaboración propia a partir de la base de datos WOCAT.

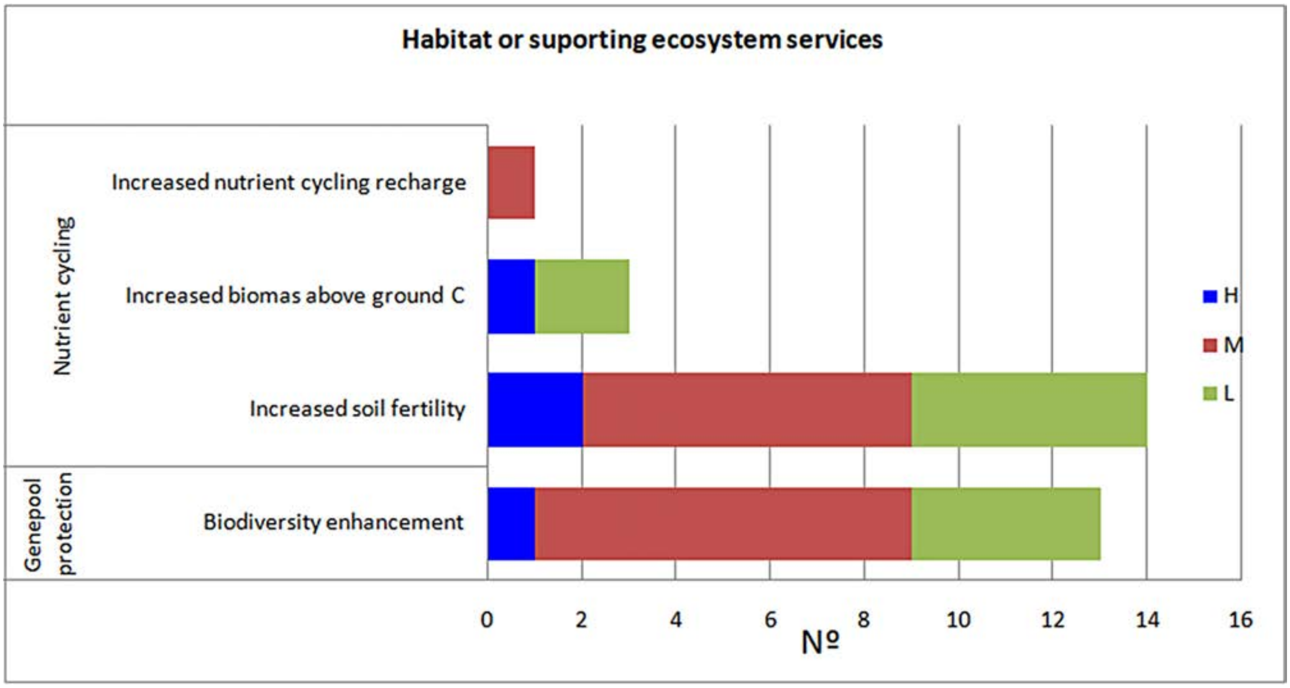

Figure 4: Supporting ecosystem services provided by terraces. Impact: H = high, M = medium, and L = low. Source: own elaboration from WOCAT database.

Figura 4: Servicios ecosistémicos de soporte proporcionados por las terrazas. Impacto H = alto, M = medio y L = bajo. Fuente: elaboración propia a partir de la base de datos WOCAT.

enhancement of (soil) biodiversity, and (ii) nutrient cycling, due to increased soil fertility, aboveground biomass, and nutrient cycling recharge (Figure 4).

Cultural Ecosystem Services. Cultural ES include the potential for recreational activities, education, and strengthening of institutions. It is worth pointing out the improved knowledge of soil erosion and conservation (64% of cases) and the strengthening of community institutions (42% of cases) (Figure 5).

4. Discussion

Here, we discuss the results obtained from the analysis of terrace technologies described in the WOCAT database and the review of the scientific literature. Table 3 summarizes a selection of studies related to the ES provided by terraces.

4.1. *Provisioning Ecosystem Services*

Our analysis demonstrates that many terraces are designed to provide a larger area for cultivation on slopes, spaces that would otherwise be very difficult to cultivate, while guaranteeing long-term agricultural cultivation (Figure 2). Thus, terraces contribute to greater agricultural production potential. Haas *et al.* (1966) highlighted their contribution to the increase in the provision of food and water, indicating that there is greater soil moisture in the terraces, contributing to higher crop yields. Hammad *et al.* (2004) reported that terraces contributed to increased wheat production, while Hammad & Børresen (2006) found a 2.5-times higher yield with terraces. In addition, several studies indicated how terraces, especially those made with stones, favor drainage, water conservation (Chow *et al.,* 1999), and groundwater recharge (Liu *et al.,* 2004). Schiettecatte *et al.* (2005) and Rashid *et al.* (2016) considered terraces very effective water harvesting techniques.

4.2. *Regulating Ecosystem Services*

Terraces reduce the slope gradient and surface runoff, favoring the infiltration of water so that soil erosion processes decreases. For this reason, terraces deliver numerous regulating ES to the owners of the land and to society (Figure 3). As erosion decreases and water retention increases, the production of food, fiber, and wood together with the quantity and quality of the water available improve and income increases. This retention of soil and water minimizes natural risks (e.g. floods), reducing construction and maintenance costs for infrastructure like irrigation channels or reservoirs, especially in regions affected by irregular or intense seasonal rainfall (Sandor & Eash, 1995). This function of water retention in soils and reservoirs will be increasingly important if the climate

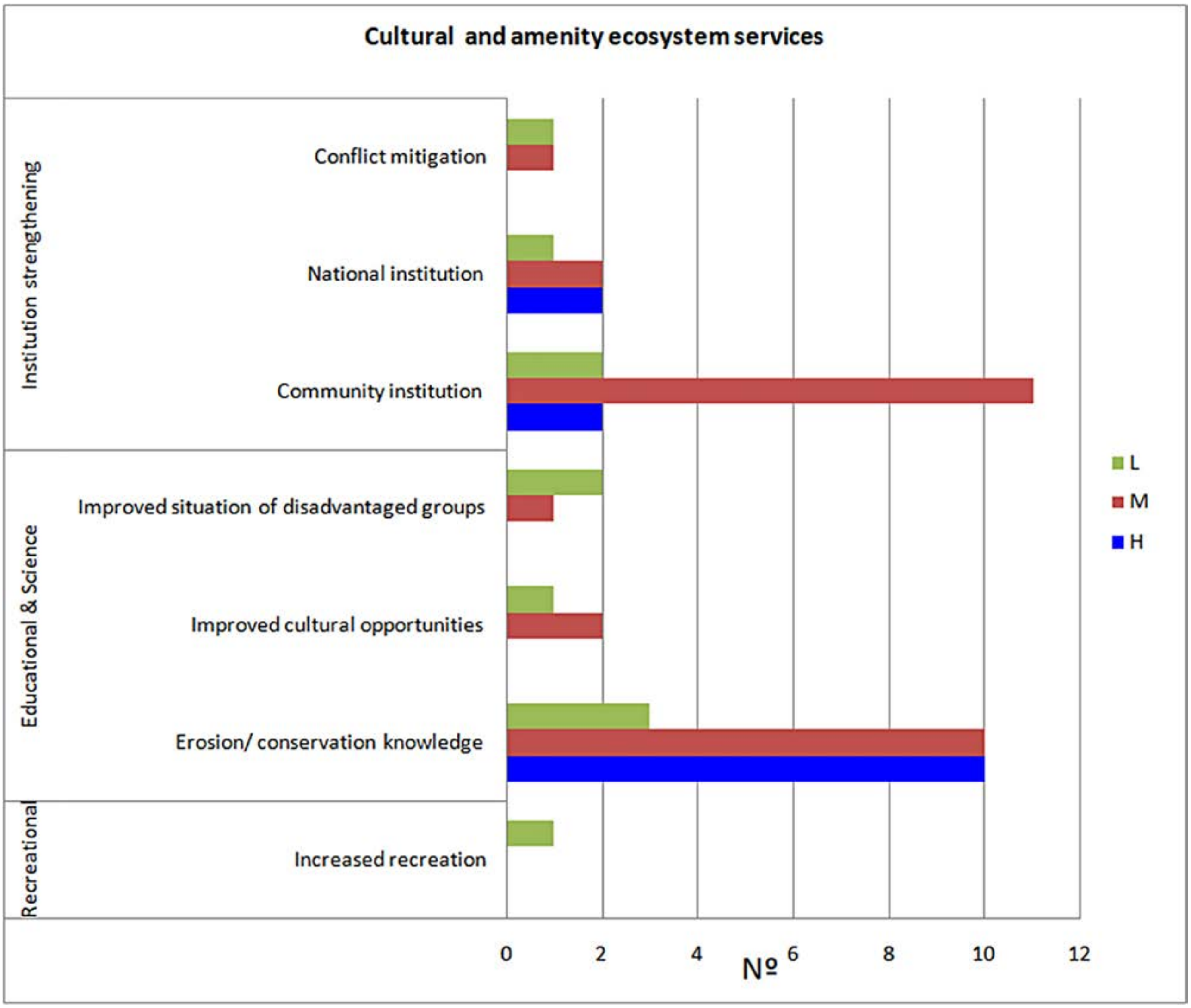

Figure 5: Cultural and amenity ecosystem services provided by terraces. Impact: H = high, M = medium, and L = low. Source: own elaboration from WOCAT database.

Figura 5: Servicios ecosistémicos culturales y recreativos proporcionados por las terrazas. Impacto H = alto, M = medio y L = bajo. Fuente: elaboración propia a partir de la base de datos WOCAT.

change projections characterized by a decrease in precipitation and increased droughts and torrential rains materialize (Eekhout *et al.,* 2018). Regarding fire risks, the agricultural use of the terraces configures areas with scarce vegetation and a marked horizontal discontinuity of fuel, thus reducing the risk of fire and its propagation (Reynes Trias, 2006). However, García-Ruiz *et al.* (2013) commented that abandoned terraces in which plant colonization has been rapid can be more prone to fires.

The importance of the regulating ES is reflected in the large volume of research highlighting the effectiveness of terraces regarding erosion and flood reduction (e.g. Beach *et al.,* 2002; Gebremichael *et al.,* 2005; Zhang & Li, 2014; Chen *et al.,* 2017). Mekonnen *et al.* (2015) identified terraces as sediment retention traps and Wheaton & Monke (1981) considered them the best measure for erosion control. In a sub-humid climate in India, Sharda *et al.* (2002) verified experimentally how terraces are very effective in reducing runoff and soil loss: by more than 80% and 90%, respectively, compared to the system without terraces. In addition, Zhang & Li (2014) noted how terraces in northeastern China reduced the rate of soil erosion by 16% for the entire slope and recommended that traditional farming practices be changed to terraced cultivation. Terraces can reduce water erosion significantly, provided they have been properly planned, constructed, and maintained; otherwise, they can cause land degradation and increase erosion (Dorren & Rey, 2004; Romero Díaz *et al.,* 2007). The important role of terraces in water regulation has been shown on numerous occasions, from

Table 3: Selected papers reporting information related to terraces and ecosystem services provision.
Tabla 3: Documentos seleccionados que contienen información relacionada con las terrazas y la provisión de servicios ecosistémicos.

PROVISIONING	
Food	Hass *et al*., 1966; Hammad *et al*., 2004; Hammad & Børresen, 2006; Wei *et al*., 2016; Rashid *et al*., 2016
Water	Hass *et al*., 1966; Thomas *et al*., 1980; Chow *et al*., 1999; Beach *et al*., 2002; Liu *et al*., 2004, 2011; Schiettecatte *et al*., 2005; Rashid *et al*., 2016; Reynes Trias, 2006; Wei *et al*., 2016
REGULATING	
Erosion	Thomas *et al*., 1980; Wheaton & Monke, 1981; Chow *et al*., 1999; Beach *et al*., 2002; Sharda *et al*., 2002; Dorren & Rey 2004; Hammad *et al*., 2004; Gebrernichael *et al*., 2005; Reynes Trias *et al*., 2006; Romero Díaz *et al*., 2007; Chen *et al*., 2012; Pietsch & Mabit, 2012; Kagabo *et al*., 2013; Dumbrovsky *et al*., 2014; Zhang & Li, 2014; Arnaez *et al*., 2015; Mekonnen *et al*., 2015; Kovár *et al*., 2016; Rashid *et al*., 2016; Wei *et al*., 2016; Arévalo *et al*., 2017; Chen *et al*., 2017
Water	Thomas *et al*., 1980; Sandor & Eash, 1995; Chow *et al*., 1999; Beach *et al*., 2002; Liu *et al*., 2004, 2011; Schiettecatte *et al*., 2005; Rashid *et al*., 2016; Reynes Trias *et al*., 2006; Wei *et al*., 2016.
Flooding	Sandor & Eash, 1995; Beach *et al*., 2002; Dumbrovsky *et al*., 2014; Kovár *et al*., 2016.
Climate	Antle *et al*., 2007; Bocco & Napoletano, 2017.
Fire risk	Reynes Trias *et al*., 2006; García-Ruíz *et al*., 2013.
HABITAT OR SUPPORTING	
Nutrient cycling	Liu *et al*., 2011; Chen *et al*., 2012; Damene *et al*., 2012; Stanchi *et al*., 2012; Kagabo *et al*., 2013; Rashid *et al*., 2016; Wei *et al*., 2016; Arévalo *et al*., 2017.
Biodiversity	Bragg *et al*., 1979; Kosulic *et al*., 2014; Tokuoka & Hashigoe, 2015; Wei *et al*., 2016; Arévalo *et al*., 2017.
CULTURAL & AMENITY	
Cultural value	Reynes Trias *et al*., 2006; UNESCO, 2008; Koohafkan & Altieri, 2011; Wei *et al*., 2016
Landscape value	Paoletti, 1999; Reynes Trias *et al*., 2006; Arévalo *et al*., 2017
Tourism & Educational resource	Reynes Trias *et al*., 2006; UNESCO, 2008; García-Ruíz *et al*., 2013; Qiu *et al*., 2014; Wei *et al*., 2016

Source: own elaboration.

the ancient Mayan terraces (Beach *et al.,* 2002) to those of Pakistan (Rashid *et al.,* 2016), China (Liu *et al.,* 2004), and Spain (Reynes Trias, 2006).

One consequence of the regulation of runoff, increased infiltration, and enhanced recharge of aquifers (Liu *et al.,* 2004) is the reduction of floods (Wei *et al.,* 2016). In fields of Bohemia, Kovár *et al.* (2016) simulated the influence of terraces on runoff using the KINFIL model and verified the effectiveness of terraced systems in flood mitigation and the resulting soil erosion. Dumbrovsky *et al.* (2014), in the Czech Republic, modeled the impacts of different terraces and performed a cost-benefit evaluation of the effect of terrace design on the sedimentation of water courses and potential damage in urban areas as a consequence of floods. They concluded that the average potential damage exceeded € 2.4/m^2. Thomas *et al.* (1980) highlighted the regulation of water by terraces. The higher carbon sequestration in terraced soils and its relevance to climate mitigation was highlighted by Antle *et al.* (2007). Bocco & Napoletano (2017) stressed the important role of terraced agriculture in climate change adaptation in Latin America.

4.3. Supporting Ecosystem Services

Supporting ES mainly concern the improvement of the nutrient cycle and biodiversity (Figure 4). The formation of terraces by filling and plowing also helps to form zones with a high content of nutrients (Stanchi *et al.,* 2012). Liu *et al.* (2011) demonstrated how terracing in the Loess plateau in China stores and retains large volumes of water, promoting more favorable interactions between water and fertilizers. Damene *et al.* (2012) concluded that terracing in Ethiopia reduced the loss of nutrients by erosion, but indicated that it is unlikely that terracing alone will improve soil fertility. This requires terracing combined with integrated nutrient management. In an extensive review, Stanchi *et al.* (2012) concluded that soil fertility often declines following the abandonment of terraces, if erosion processes intensify. Kagabo *et al.* (2013) analyzed the fertility of soils in terraced and non-terraced areas in Rwanda, and verified that soil fertility was higher in the lower parts of the terraces, which had a higher organic carbon content (57%) and higher phosphorus availability (31%) than the higher parts of the terraces. Arevalo *et al.* (2017) showed that the soil quality in terraced fields on the island of Lanzarote (Canary Islands) was better than in non-terraced fields. Soil conditions are often improved in consolidated terraced terrain, in comparison with recently terraced landscapes, as found in vineyards in the Northeast of Spain (Ramos *et al.,* 2006).

Regarding biodiversity, terraced cultivated landscapes often allow the conservation of varied plant and animal communities. According to Bragg & Stephens (1979) and Wei *et al.* (2016), terraces can benefit the restoration of vegetation and improve the biodiversity due to the higher soil moisture and nutrient content. Egea Fernádez & Egea Sánchez (2010) mentioned how some birds build their nests on the terraces of rainfed arboreal crops, and Kosulic *et al.* (2014) found that vineyard terraces can serve as a refuge for endangered spiders. Following abandonment, on occasions, the diversity of plants is greater and even the stone-walls themselves can house a large number of plant and animal species (Tokuoka & Hashigoe, 2015).

On the other hand, terraces can also have negative impacts, especially if poorly planned, constructed, or maintained. For example, through severe land leveling, subsoiling, and the use of heavy machinery, terracing can reduce the content of organic matter, the water retention capacity, and the stability of the aggregates. In this respect, Bazzoffi *et al.* (2006) showed that soil losses due to landslides were greater in Italian terraced vineyards, and Romero Díaz & Belmonte Serrato (2008) found that the terraces built for afforestation destroyed the original soil, leaving poor soils that lacked structure and nutrients.

4.4. Cultural Ecosystem Services

Terraces have an important cultural and ethnological value throughout the world. The transformation of the environment by the application of traditional techniques has given rise to a set of knowledge, practices, and techniques of great value. These cultural landscapes form part of the identity and cultural diversity of many regions and are worth conserving and protecting. In addition, in many cases, they can become a tourism resource, taking into account their landscape, cultural, and historical values. Among the educational and scientific ES of the terrace technologies analyzed, the better knowledge of the erosion and conservation of soils acquired by farmers stands out, as does the strengthening of the community institutions (Figure 5).

The uniqueness of terraced landscapes is recognized internationally, as reflected in some cases by their status as UNESCO World Heritage Sites. This is the case, for example, of the terraces of Machu Picchu in Peru (since 1983), the rice fields of Ifugao in the Philippines (1995), Cinque Terre in Italy (1997), the vineyards of the Douro in Portugal (2001), and the Sierra Tramuntana on the Spanish island of Mallorca (2011), among others. These areas also stand out from the landscape point of view (Paoletti, 1999), which is why they constitute a tourism resource (Qiu *et al.,* 2014). It is also worth mentioning that in November 2018 "The art of dry stone construction: knowledge and techniques", with contributions from countries such as Croatia, Cyprus, France, Greece, Italy, Slovenia, Spain, and Switzerland, was declared part of the Intangible Cultural Heritage of Humanity by UNESCO.

5. Conclusions

We have shown the importance of terraces in the functioning of agricultural landscapes and their impacts on ES. Terrace construction, sometimes going back millennia, has brought many benefits to farmers and society in general. Our assessment of different terrace techniques documented in the WOCAT database highlights their advantages, disadvantages, costs, and benefits. WOCAT proved an essential resource to review global Sustainable Land Management (SLM) practices and their effectiveness, and to facilitate the dissemination of local knowledge. From our review of the impacts, we conclude that the construction of terraces, in general, has very positive effects on socioeconomic, production, sociocultural, ecological, and off-site factors. Although, to a lesser extent, some negative impacts are reported for certain technologies as well, especially when terraces are poorly planned, constructed, or maintained.

We identified different provisioning, regulating, supporting, and cultural ES provided by terraces (Figure 6). Of particular importance are the regulating ES that result in the reduction of runoff and soil erosion and of natural hazards downstream (e.g. floods), which could cause damage to infrastructure. Terraces help to improve soil conditions and soil moisture and, in some cases, crop yields and/or biodiversity increase. In this way, terraces can make an important contribution to the adaptation to climate change.

With certain exceptions, the cost-benefit ratio has not been a well-developed research topic, but it is implicit in many studies. Our analysis shows that, in general, the cost-benefit ratio, in terms of both implementation and maintenance, is positive or very positive in the long term. However, the ES provided go beyond monetary costs, so the overall relationship is very positive. Nevertheless, in many areas, the maintenance of terraces is insufficient or terraces may even be eliminated to facilitate extensive mechanized monocultures. While recognizing the potential difficulties that terraces can produce in terms of access, their maintenance continues to have an incalculable value for the sustainability of agricultural lands and for society. Terraces will only fulfill their ecosystem functions when properly maintained, while their abandonment, especially in semi-arid areas, promotes soil erosion processes and other hydro-geomorphological consequences (Moreno de las Heras *et al.,* 2019). It is necessary to make the multiple benefits that terraces offer to farmers and to society more visible, since they are one of the most effective soil and water conservation measures

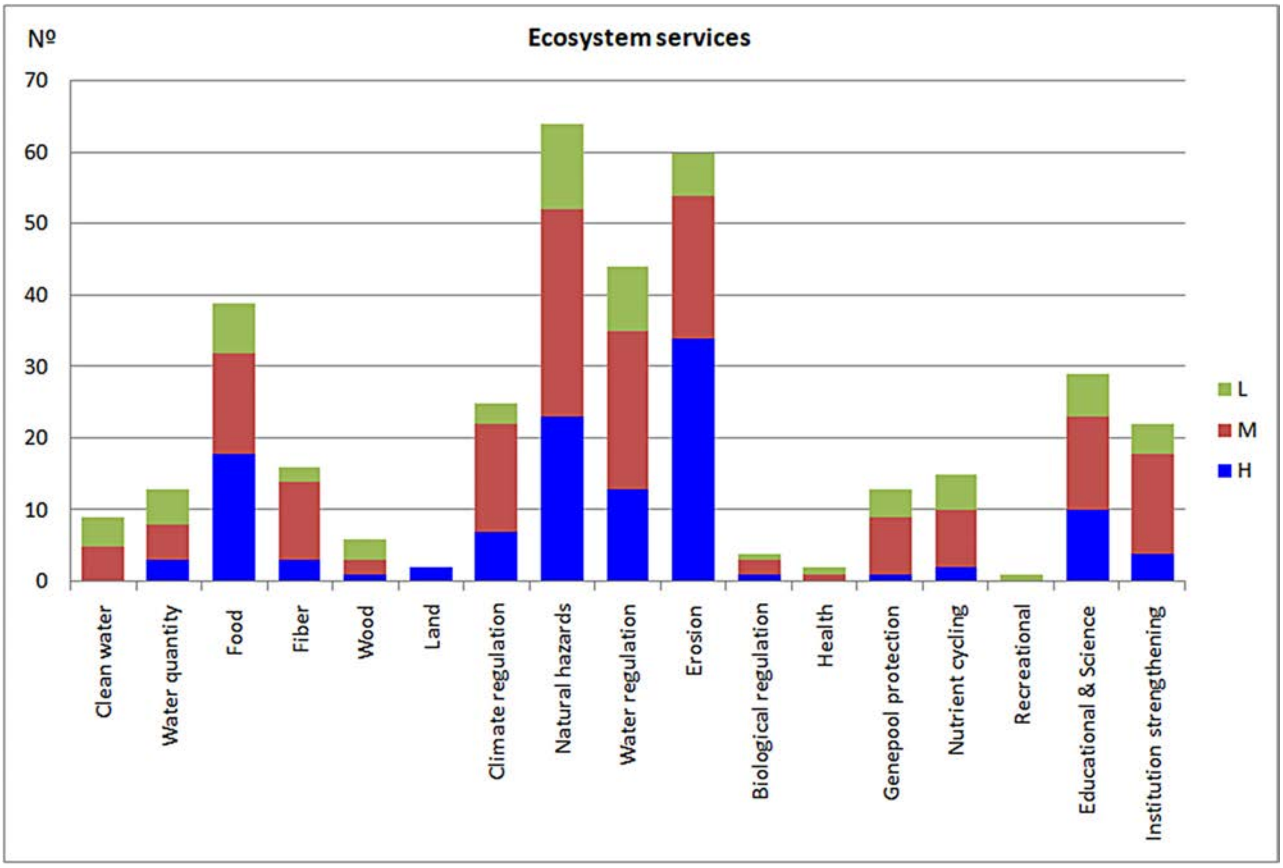

Figure 6: Main ecosystem services provided by terraces. Impact (%): H = high, M = medium, and L = low. Source: own elaboration from WOCAT database.

Figura 6: Principales servicios ecosistémicos proporcionados por las terrazas. Impacto (%) H = alto, M = medio y L = bajo. Fuente: elaboración propia a partir de la base de datos WOCAT.

on hillslopes. Economic support as part of current and new agricultural policies and sustainable development plans is necessary for the maintenance of terraces and their ES. This requires monetary and non-monetary quantification of the intrinsic and patrimonial value of terraced landscapes and the ES they provide.

Acknowledgments

We acknowledge the support received from the Spanish Ministry of Science and Innovation, through the ADAPT project (CGL2013-42009-R), and the Seneca Foundation, through the project CAMBIO (118933/JLI/13). We thank Dr. David J. Walker for his revision of the written English in the manuscript.

References

Agnoletti, M., Errico, A., Santoro, A., Dani, A., & Preti, F., 2019. Terraced Landscapes and Hydrogeological Risk. Effects of Land Abandonment in Cinque Terre (Italy) during Severe Rainfall Events. *Sustainability,* 11, 235. https://doi.org/10.3390/su11010235

Antle, J.M., Stoorvogel, J.J. & Valdivia, R.O., 2007. Assessing the economic impacts of agricultural carbon sequestration: terraces and agroforestry in the Peruvian Andes. *Agriculture, Ecosystems and Environ*onment, 122 (4): 435-445. https://doi.org/10.1016/j.agee.2007.02.003

Arévalo, J.R., Fernández-Lugo, S., Reyes-Betancort, J.A., Tejedor, M., Jiménez, C. & Díaz, F.J., 2017. Relationships between soil parameters and vegetation in abandoned terrace fields vs. non-terraced fields in arid lands (Lanzarote, Spain): An opportunity for restoration. *Acta Oecologica,* 85: 77-84. https://doi.org/10.1016/j.actao.2017.09.014

Arnáez, J., Lana-Renault, N., Lasanta, T., Ruiz-Flaño, P. & Castroviejo Arnáez, J., 2015. Effects of farming terraces on hydrological and geomorphological processes. A review. *Catena,* 128: 122-134. https://doi.org/10.1016/j.catena.2015.01.021

Asins, S., 2006. Abandono de terrazas agrícolas: procesos de erosión y desorganización del paisaje. In: *Jornades sobre terrasses i prevenció de riscos naturals*. Consell de Mallorca. Mallorca, 289-301.

Asins, S., 2009. *El paisaje agrario aterrazado. Dialogo entre el hombre y el medio en Petrer (Alicante)*. Publicacions de la Universitat de València. Serie Estudios y Documentos 5. Valencia, 359 pp.

Ažman Momirski, A. & Berčič, T., 2016. Ignored Regions: Slovenian Terraced Landscapes. ANNALES · *Ser. hist. sociol.* 26 (3): 399-419.

Bantayan, N.C., Calderon, M.M., Dizon, J.T., Sajise, A.J.U. & Salvador, M., 2012. Estimating the extent and damage of the UNESCO World Heritage Sites of the Ifugao Rice Terraces, Philippines. *Journal of Environmental Science and Management,* 15 (1): 1-5.

Balbo, A. & Puy, A., 2017. Terrace landscapes. Editorial to the special issue. J. Environ. Manag. 202: 495-499. https://doi.org/10.1016/j.jenvman.2017.02.001

Barker, G., Gilbertson, D. & Mattingly, D., (eds.) 2007. *Archaeology and Desertification—The Wadi Faynan Landscape Survey, Southern Jordan*. Council for British Research in the Levant and Oxbow Books, Oxford.

Bazzoffi, P., Abbattista, F., Vanino, S. & Pellegrini, S., 2006. Impact of land levelling for vineyard plantation on soil degradation in Italy. *Bolletino della Società Geologica Italiana,* 125 (3): 191-199.

Beach, T., Luzzadder-Beach, S., Dunning, N., Hageman, J. & Lohse, J., 2002. Upland agriculture in the Maya Lowlands: ancient Maya soil conservation in Northwestern Belize. *Geographical Review,* 92 (3): 372-397. https://doi.org/10.1111/j.1931-0846.2002.tb00149.x

Bocco, G. & Napoletano, B., 2017. The prospects of terrace agriculture as an adaptation to climate change in Latin America. *Geography Compass,* 11 (10): 13 pp. https://doi.org/10.1111/gec3.12330

Borisov, A.V., Korobov, D.S., Simakova, A.N., Zanina, O.G., Bukhonov, A.V. & Demidov, V.V., 2012. Ancient agricultural terraces in the Kislovodsk Depression: history and modern state of the soils. *Eurasian Soil Science,* 45 (6): 561-577. https://doi.org/10.1134/S1064229312060038

Brandolini, P., Cevasco, A., Capolongo, D., Pepe, G., Lovergine, F. & Del Monte, M., 2018. Response of terraced slopes to a very intense rainfall event and relationship with land abandonment: a case study from Cinque Terre (Italy). *Land Degradation & Development,* 29 (3): 630-642. https://doi.org/10.1002/ldr.2672

Bragg, T.B. & Stephens, L.J., 1979. Effects of agricultural terraces on the reestablishment of bluestem grasslands. *Journal Range Management,* 32 (6): 437-441. https://doi.org/10.2307/3898554

Camacho Valdez, V. & Ruiz Luna, A., 2012. Conceptual framework and classification of Ecosystem Services. *Biociencias,* 1 (4): 3-15.

Chen, S.K., Chen, W.L. & Chen, Y.R., 2012. Assessing soil erosion in a terraced paddy field using experimental measurements and universal soil loss equation. *Catena,* 95 (1): 131-141. https://doi.org/10.1016/j.catena.2012.02.013

Chen, D., Wei, W. & Chen, L., 2017. Effects of terracing practices on water erosion control in China: A metaanalysis. *Earth-Science Re*views, 173: 109-121. http://dx.doi.org/10.1016/j.earscirev.2017.08.007

Chow, T.L., Rees, H.W. & Daigle, J.L., 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: a field evaluation. *Journal and Soil and Water Conservation,* 54 (3): 577-583.

Costanza, R., 2008. Ecosystem services: multiple classification systems are needed. *Biological Conservation,* 141: 350-352. https://doi.org/10.1016/j.biocon.2007.12.020

Damene, S., Tamene, L. & Vlek, P.L.G., 2012. Performance of Farmland Terraces in Maintaining Soil Fertility: A Case of Lake Maybar Watershed in Wello, Northern Highlands of Ethiopia. *Journal of Life Science,* 6: 1251-1261.

De Oliveira, J.R.S., Pruski, F.F., da Silva, J.M.A. & da Silva, D.P., 2012. Comparative analysis of the performance of mixed terraces and level and graded terraces. *Acta Scientiarum Agronomy,* 34 (4): 351-357. https://doi.org/10.4025/actasciagron.v34i4.14755

Dorren L. & Rey, F., 2004. A review of the effect of terracing on erosion. In: *Briefing Papers of the 2nd SCAPE Workshop, Cinque Terre, Italy* (eds C. Boix-Fayos and A. Imeson), pp. 97–108, SCAPE, Amsterdam.

Dumbrovsky, M., Sobotkova, V., Sarapatka, B., Chlubna, L. & Vachalova, R., 2014. Cost-effectiveness evaluation of model design variants of broad-base terrace in soil erosion control. *Ecological Enginering,* 68: 260-269. https://doi.org/10.1016/j.ecoleng.2014.03.082

Eekhout, J.P.C., Hunink, J.E., Terink, W. & de Vente, J., 2018. Why increased extreme precipitation under climate change negatively affects water security. *Hydrology and Earth System Sciences,* 22: 5935-5946. https://doi.org/10.5194/hess-22-5935-2018

Egea Fernández, J.M. & Egea Sánchez, J.M., 2010. *Guía de paisajes culturales. Tierra de Iberos. Una perspectiva agroecológica*. Editorial SEAE. 420 pp.

El Atta, H.A. & Aref, I., 2010. Effect of terracing on rainwater harvesting and growth of *Juniperus procera* Hochst. ex Endlicher. *International Journal of Environmental Science & Technology,* 7 (1): 59-66. https://doi.org/10.1007/BF03326117

Ferrer, G., La Roca, F. & Gual, M., 2012. Servicios ecosistémicos: ¿una herramienta para la protección o para la mercantilización de la naturaleza? *XIII Jornadas de Economía crítica*, 291-294.

Galletti, C.S., Ridder, E., Falconer, S.E. & Fall, P.L., 2013. Maxent modeling of ancient and modern agricultural terraces in the Troodos foothills, Cyprus. *Applied Geography,* 39: 46-56. https://doi.org/10.1016/j.apgeog.2012.11.020

García-Ruiz, J.M. & Lana-Renault, N., 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region-a review. *Agriculture Ecosystem & Environment,* 140: 317-338. https://doi.org/10.1016/j.agee.2011.01.003

Garcia-Ruiz, J.M., Nadal-Romero, E., Lana-Renault, N. & Begueria, S., 2013. Erosion in Mediterranean landscapes: changes and future challenges. *Geomorphology,* 198 (17): 20-36. https://doi.org/10.1016/j.geomorph.2013.05.023

Gebrernichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G. & Moeyersons, J., 2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. *Soil Use and Management,* 21: 287-297. https://doi.org/10.1111/j.1475-2743.2005.tb00401.x

Haas, H.J., Willis, W.O. & Boatwrig, G., 1966. Moisture storage and spring wheat yields on level-bench terraces as influenced by contributing area cover and evaporation control. *Agronomy Journal,* 58 (3): 297-299. https://doi.org/10.2134/agronj1966.00021962005800030015x

Hamdan, J., Burnham, C.P. & Ruhana, B., 2000. Degradation effect of slope terracing on soil quality for *Elaeis guineensis* Jacq. (oil palm) cultivation. *Land Degradation & Development,* 11 (2): 181-193. https://doi.org/10.1002/(SICI)1099-145X(200003/04)11:2%3C181::AID-LDR377%3E3.0.CO;2-U

Hammad, A., Haugen, L.E. & Børresen, T., 2004. Effects of stonewalled terracing techniques on soil-water conservation and wheat production under Mediterranean conditions. *Environmental Management,* 34 (5): 701-710. https://doi.org/10.1007/s00267-003-0278-9

Hammad, A. & Børresen, T., 2006. Socioeconomic factors affecting farmers' perceptions of land degradation and stonewall terraces in Central Palestine. *Environmental Manag*ement, 37 (3): 380-394. https://doi.org/10.1007/s00267-004-0195-6

Kagabo, D.M., Stroosnijder, L., Visser, S.M. & Moore, D., 2013. Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. *Soil and Tillage Research,* 128: 23-29. https://doi.org/10.1016/j.still.2012.11.002

Kladnik, D., Ciglič, R., Geršič, M., Komac, B., Perko, D. & Zorn, M., 2016. Diversity of Terraced Landscapes in Slovenia. *ANNALES Series Historia et Sociologia,* 26(3): 469-487. https://doi.org/10.19233/ASHS.2016.38

Koohafkan, P. & Altieri, M.A., 2011. *Globally Important Agricultural Heritage Systems A Legacy for the Future*. Food and Agriculture Organization of the United Nations, Rome.

Kosulic, O., Michalko, R. & Hula, V., 2014. Recent artificial vineyard terraces as a refuge for rare and endangered spiders in a modern agricultural landscape. *Ecological Engineering,* 68 (7): 133-142. https://doi.org/10.1016/j.ecoleng.2014.03.030

Koulouri, M. & Giourga, C., 2007. Land abandonment and slope gradient as key factors of soil erosion in Mediterranean terraced lands. *Catena,* 69 (3): 274-281. https://doi.org/10.1016/j.catena.2006.07.001

Kovár, P., Bacinová, H., Loula, J. & Fedorova, D., 2016. Use of terraces to mitigate the impacts of overland flow and erosion on a catchment. *Plant Soil and Environment,* 62 (4): 171-177. https://doi.org/10.17221/786/2015-PSE

LaFevor, M.C., 2014. Restoration of degraded agricultural terraces: rebuilding landscape structure and process. *Journal of Environmental Management,* 138: 32-42. https://doi.org/10.1016/j.jenvman.2013.11.019

Lasanta, T., 1990. L´agriculture en terrasse dans les Pyrénées centrales espagnoles. *Mediterranée*, 3-4: 37-41.

Lasanta, T., 2014. *El paisaje de campos abandonados en Cameros Viejo (Sistema Ibérico, La Rioja)*. Instituto de Estudios Riojanos. 305 pp., Logroño.

Lasanta, T., Arnáez, J., Oserín, M. & Ortigosa, L., 2001. Marginal lands and erosion in terraced fields in the Mediterranean mountains: A case study in the Camero Viejo (Northwestern Iberian System, Spain). *Mountain Research and Development,* 21(1): 69-76. https://doi.org/10.1659/0276-4741(2001)021[0069:MLAEIT]2.0.CO;2

Lasanta, T., Arnáez, J., Ruiz-Flaño, P. & Lana-Renault, N., 2013. Los bancales en las montañas españolas: un paisaje abandonado y un recurso potencial. *Boletín de la Asociación de Geográfos Españoles,* 63: 301-322. http://dx.doi.org/10.21138/bage.1616

Liu, C-W., Huang, H-C., Chen, S-K. & Kuo, Y-M., 2004. Subsurface return flow and ground water recharge of terrace fields in northern Taiwan. *Journal of the American Water Resources Association,* 40 (3): 603-614. https://doi.org/10.1111/j.1752-1688.2004.tb04446.x

Liu, X.H., He, B.L., Li, Z.X., Zhang, J.L., Wang, L. & Wang, Z., 2011. Influence of land terracing on agricultural and ecological environment in the loess plateau regions of China. *Environmental Earth Science,* 62 (4): 797-807. https://doi.org/10.1007/s12665-010-0567-6

Loczy, D., 1998. Man-made terraces in a German agricultural landscape. *Geografía Fisica e Dinamica Quaternaria,* 21(1): 55-59.

Luedeling, E., Nagieb, M., Wichern, F., Brandt, M., Deurer, M. & Buerkert, A., 2005. Drainage, salt leaching and physico-chemical properties of irrigated man-made terrace soils in a mountain oasis of northern Oman. *Geoderma,* 125 (3-4): 273-285. https://doi.org/10.1016/j.geoderma.2004.09.003

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamous, N., Fleury, P., Gutiérrez Lazpita, J. & Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Manag*ement, 59: 47-69. https://doi.org/10.1006/jema.1999.0335

Mai, V.T., Van Keulen, H., Hessel, R., Ritsema, C., Roetter, R. & Phien, T., 2013. Influence of paddy rice terraces on soil erosion of a small watershed in a hilly area of Northern Vietnam. *Paddy Water Environment,* 11 (1-4): 285-298. https://doi.org/10.1007/s10333-012-0318-2

Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E.M. & Maroulis, J., 2015. Soil conservation through sediment trapping: a review. *Land Degradation & Development,* 26: 544-556. https://doi.org/10.1002/ldr.2308

Millennium Ecosystem Assessment, 2003. *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press, 49-70 pp.

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis.* Washington, DC: World Resources Institute, 82.

Moreno de las Heras, M., Lindenberger, F., Latron, J., Lana-Renault, N., Llorens, P., Arnáez, J., Romero-Díaz, A., Gallart, F., 2019. Hydro-geomorphological consequences of the abandonment of agricultural terraces in the Mediterranean region: key controlling factors and landscape stability patterns. *Geomorphology,* 333: 73-91. https://doi.org/10.1016/j.geomorph.2019.02.014

Ore, G. & Bruins, H. J., 2012. Design features of ancient agricultural terrace walls in the Negev desert: human-made geodiversity. *Land Degradation & Dev*elopment, 23: 409-418. https://doi.org/10.1002/ldr.2152

Pacheco, F.A.L., Varandas, S.G.P., Fernandes, L.F.S. & Valle, R.F., 2014. Soil losses in rural watersheds with environmental land use conflicts. *Science of the Total Environment,* 485-486 (3): 110-120. https://doi.org/10.1016/j.scitotenv.2014.03.069

Paliaga, G., Giostrella, P. G. & Faccini, F., 2016. Terraced Landscape as Cultural and Environmental Heritage at Risk: An Example from Portofino Park (Italy). *ANNALES Series Historia et Sociologia,* 26(3): 513-522. https://doi.org/10.19233/ASHS.2016.32

Paoletti, M.G, 1999. Using bioindicators based on biodiversity to assess landscape sustainability. *Agriculture, Ecosystems & Environment,* 74 (1-3): 1-18. https://doi.org/10.1016/S0167-8809(99)00027-4

Park, J.Y., Yu, Y.S., Hwang, S.J., Kim, C. & Kim, S.J., 2014. SWAT modeling of best management practices for Chungju dam watershed in South Korea under future climate change scenarios. *Paddy and Water Environment,* 12 (1): S65-S75. https://doi.org/10.1007/s10333-014-0424-4

Pietsch, D. & Mabit, L., 2012. Terrace soils in the Yemen Highlands: using physical, chemical and radiometric data to assess their suitability for agriculture and their vulnerability to degradation. *Geoderma,* 185-186 (8): 48-60. https://doi.org/10.1016/j.geoderma.2012.03.027

Potschin, M.B. & Haines-Young, R.H., 2011. Ecosystem services: Exploring a geographical perspective. *Progress in Physical Geogaphy,* 35 (5): 575-594. https://doi.org/10.1177/0309133311423172

Price, S. & Nixon, L., 2005. Ancient Greek agricultural terraces: evidence from texts and archaeological Surrey. *American Journal of Archaeology,* 109: 665-694. https://doi.org/10.3764/aja.109.4.665

Qiu, Z.M., Chen, B.X. & Takemoto, K., 2014. Conservation of terraced paddy fields engaged with multiple stakeholders: the case of the Noto GIAHS site in Japan. *Paddy and Water Environment,* 12 (2): 275-283. https://doi.org/10.1007/s10333-013-0387-x

Quintas-Soriano, C., Brandt, J., Running, K., Baxter, C.V., Gibson, D.M., Narducci, J. & Castro, A.J., 2018. Social-ecological systems influence ecosystem service perception: a

Programme on Ecosystem Change and Society (PECS) analysis. *Ecology and Society,* 23(3): 3. https://doi.org/10.5751/ES-10226-230303

Ramos, M.C. & Martínez-Casasnovas, J.A., 2006. Impact of land levelling on soil moisture and runoff variability in vineyards under different rainfall distributions in a Mediterranean climate and its influence on crop productivity. *Journal of Hydrology,* 321: 131-146. https://doi.org/10.1016/j.jhydrol.2005.07.055

Rashid, M., ur Rehman, O., Alvi, S., Kausar, R. & Akram, M.I., 2016. The effectiveness of soil and water conservation terrace structures for improvement of crops and soil productivity in rainfed terraced system. *Pakistan Journal of Agricultural Science,* 53(1): 241-248. https://doi.org/10.21162/PAKJAS/16.1502

Reynes Trias, A., (Coord.), 2006. *Marjades i prevenció de risc naturals*. Departament de Medi Ambient. Consell de Mallorca, 144 pp.

Romero Díaz, A., Marín Sanleandro, P., Sánchez Soriano, A., Belmonte Serrato, F. & Faulkner, H., 2007. The causes of piping in a set of abandoned agricultural terraces in southeast Spain. *Catena,* 69: 282-293. https://doi.org/10.1016/j.catena.2006.07.008

Romero Díaz, A. & Belmonte Serrato, F., 2008. *Erosión en forestaciones aterrazadas en medios semiáridos: Región de Murcia.* Ediciones de la Universidad de Murcia y Real Academia Alfonso X El Sabio, 191 pp., Murcia.

Romero Díaz, A. Martínez Hernández, C. & Belmonte Serrato, F., 2016. Procesos de erosión en áreas abandonadas de la Región de Murcia. In: A. Romero Díaz (Coord.) *Abandono de cultivos en la Región de Murcia. Consecuencias Ecogeomorfológicas*. Servicio de Publicaciones de la Universidad de Murcia, 85-110, Murcia.

Romero Martin, L.E., Gonzalez Morales, A. & Ramon Ojeda, A., 2016. Towards a New Valuation of Cultural Terraced Landscapes: The Heritage of Terraces in the Canary Islands (Spain). *ANNALES Series Historia et Sociologia,* 26(3): 499-512.

Salvador-Blanes, S., Cornu, S., Couturier, A., King, D. & Macaire, J.J., 2006. Morphological and geochemical properties of soil accumulated in hedge-induced terraces in the Massif Central, France. *Soil and Tillage Research,* 85 (1-2): 62-77. https://doi.org/10.1016/j.still.2004.12.008

Sang-Arun, J., Mihara, M., Horaguchi, Y. & Yamaji, E., 2006. Soil erosion and participatory remediation strategy for bench terraces in northern Thailand. *Catena,* 65 (3): 258-264. https://doi.org/10.1016/j.catena.2005.11.010

Sandor, J.A. & Eash, N.S., 1995. Ancient agricultural soils in the Andes of southern Perú. *Soil Science Society of American Journal,* 59: 170-179. https://doi.org/10.2136/sssaj1995.03615995005900010026x

Schiettecatte, W., Ouessar, M., Gabriels, D., Tanghe, S., Heirman, S. & Abdelli, F., 2005. Impact of water harvesting techniques on soil and water conservation: a case study on a micro catchment in southeastern Tunisia. *Journal of Arid Environments,* 61 (2): 297-313. https://doi.org/10.1016/j.jaridenv.2004.09.022

Sharda, V.N., Juyal, G.P. & Singh, P.N., 2002. Hydrologic and sedimentologic behavior of a conservation bench terrace system in a sub-humid climate. *Transactions of the ASAE* ,45 (5): 1433-1441. https://doi.org/10.13031/2013.11030

Sharifi, A., Gorji, M., Asadi, H. & Pourbabaee, A.A., 2014. Land leveling and changes in soil properties in paddy fields of Guilan province, Iran. *Paddy and Water Environment,* 12 (1): 139-145. https://doi.org/10.1007/s10333-013-0369-z

Siriri, D., Tenywa, M.M., Raussen, T. & Zake, J.K., 2005. Crop and soil variability on terraces in the highlands of SW Uganda. *Land Degradation and Development,* 16: 569-579. https://doi.org/10.1002/ldr.688

Spencer, J.E. & Hale, G.A., 1961. The origin, nature, and distribution of agricultural terracing. Asia *Pacific Viewpoint,* 2: 1-39. https://doi.org/10.1111/apv.21001

Stanchi, S., Freppaz, M., Agnelli, A., Reinsch, T. & Zanini, E., 2012. Properties, best management practices and conservation of terraced soils in Southern Europe (from Mediterranean areas to the Alps): a review. *Quaternary International,* 265: 90-100. https://doi.org/10.1016/j.quaint.2011.09.015

Swinton, S.M., Lupi, F., Robertson, G.P. & Hamilton, S.K., 2007. Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. *Ecological Economics,* 64(2): 245-252. https://doi.org/10.1016/j.ecolecon.2007.09.020

Tarolli, P., Preti, F. & Romano, N., 2014. Terraced landscape: from an old best practice to a potential hazard for soil degradation due to land abandonment. *Anthropocene,* 6: 10-25. https://doi.org/10.1016/j.ancene.2014.03.002

Thomas, D.B., Barber, R.G. & Moore, T.R., 1980. Terracing of cropland in low rainfall areas of Machakos District, Kenya. *Journal of Agricultural Engineering Research,* 25 (1): 57-63. https://doi.org/10.1016/0021-8634(80)90047-5

Tiwari, K.R., Sitaula, B.K., Bajracharya, R.M. & Børresen, T., 2009. Runoff and soil loss responses to rainfall, land use, terracing and management practices in the Middle Mountains of Nepal. *Acta Agriciculturae Scandinavica,* 59 (3): 197-207. https://doi.org/10.1080/09064710802006021

Tokuoka, Y. & Hashigoe, K., 2015. Effects of stone-walled terracing and historical forest disturbances on revegetation processes after the abandonment of mountain slope uses on the Yura Peninsula, southwestern Japan. *Journal of Forest Research,* 20 (1): 24-34. https://doi.org/10.1007/s10310-014-0471-0

UNESCO, 2008. *The Effects of Tourism on Culture and the Environment in Asia and the Pacific, Sustainable Tourism and the Preservation of the World Heritage Site of the Ifugao Rice Terraces, Philippines.* Bangkok: UNESCO Bangkok, viii + 90 pp.

Van Dijk, A., Bruijnzeel, L.A., Vertessy, R.A. & Ruijter, J., 2005. Runoff and sediment generation on bench-terraced hillsides: measurements and up-scaling of a field-based model. *Hydrological Processes,* 19 (8): 1667-1685. https://doi.org/10.1002/hyp.5629

Varotto, M., Bonardi, L. & Tarolli, P. (Eds.), 2019. *World Terraced Landscapes: History, Environment, Quality of Life*. Springer. New York. 1st ed. 2019, XV, 356 p.

Wei, W., Die, C., Lixin, W., Stefani, D., Liding, C., Yang, Y., Yonglong, L., Ge, S. & Tianjiao, F., 2016. Global synthesis of the classifications, distributions, benefits and issues of terracing. *Earth-Science Reviews,* 159: 388-403.

Wheaton, R.Z. & Monke, E.J., 1981. Terracing as a 'Best Management Practice' for controlling erosion and protecting water quality. *Agricultural Engineering* 114. Purdue University.

Wickama, J., Okoba, B. & Sterk, G., 2014. Effectiveness of sustainable land management measures in West Usambara highlands, Tanzania. *Catena,* 118: 91-102. https://doi.org/10.1016/j.catena.2014.01.013

Wilkinson, T.J., 2003. *Archaeological Landscapes of the Near East.* University of Arizona Press, Tucson.

WOCAT, 2016. *World Overview of Conservation Approaches and Technologies. Questionnaire on Sustainable Land Management* (SLM).

Zhang, Q.W. & Li, Y., 2014. Effectiveness assessment of soil conservation measures in reducing soil erosion in Baiquan County of Northeastern China by using Cs-137 techniques. *Environmental Science: Processes Impacts,* 16 (6): 1480-1488. https://doi.org/10.1039/C3EM00521F