Landform Analysis, Vol. 17: 111–116 (2011)

Short to medium-term gully development: Human activity and gully erosion variability in selected Spanish gully catchments

Irene Marzolff[1], Jean Poesen[2], Johannes B. Ries[3]

[1]*Department of Physical Geography, Johann Wolfgang Goethe University Frankfurt, Germany*
[2]*Physical and Regional Geography Research Group, Department of Earth and Environmental Sciences, K.U.Leuven, Belgium*
[3]*Department of Physical Geography, Faculty of Geography and Geosciences, Trier University, Germany*
e-mail: marzolff@em.uni-frankfurt.de

Abstract: This study investigates how medium-term gully-development data differ from short-term data, and which factors are responsible for their spatial and temporal variability. Eight actively retreating bank gullies situated in Spanish basin landscapes were monitored for up to 11 years with high-resolution aerial photographs using unmanned remote-controlled platforms. The results of planimetric and volumetric change analysis using GIS and photogrammetry systems show a high variability of annual gully retreat rates both between gullies and between observation periods. The varying influences of land use and human activities with their positive or negative effects on runoff production and connectivity appears to play the most important role in these study areas, both for short-term variability and medium-term difference in gully development. The study demonstrates the importance of capturing spatially continuous, high-resolution three-dimensional data for detailed gully monitoring. It also confirms that short-term data are not representative of longer-term gully development, but they are still required to understand the processes – particularly human activity at varying time scales – causing gully-erosion variability.

Keywords: gully erosion, monitoring, small-format aerial photography, land degradation, semi-arid regions

Introduction

The evaluation of gully development rates under different climatic and land use conditions provides important data for modelling gully erosion and predicting impacts of environmental change on this major soil erosion process. Soil erosion by water has received and still receives a lot of attention from scientists, soil conservationists and policymakers. However, the main focus of investigations has been and continues to be on sheet and rill erosion rather than on gully erosion. So far, the scientific literature and internal reports have documented over 5,000 cumulative plot-year data on soil loss by sheet and rill erosion in Europe (Boardman & Poesen 2006), while gully erosion has received much less attention with assumedly less than 100 years of cumulative gully monitoring data (Poesen et al. 2006).

Among the reasons for this scarcity of data are the methodological difficulties associated with the temporal and spatial scales and variability at which gully erosion occurs. Gully erosion is usually caused by intense and hence rather infrequent rainfall events, making it difficult to capture by regular monitoring. The wide range of sizes and forms of gullies often are beyond the traditional scale for investigating soil erosion by water, and at the same time, gullies may develop in locally very restricted parts, with active retreat areas shifting irregularly between headcut, sidewalls or individually gully branches. Gullies may be subject to rapid cycles of alternating incision and infilling, and material eroded at the gully edges may be deposited within the gully, not even leaving the system during the same observation period (e.g.: Vanwalleghem et al. 2005a, Marzolff & Poesen 2009). Thus, linear, areal and volumetric retreat rates are not necessarily proportional or deductible from each other. Also, gullying involves a wide range of subprocesses related to water erosion and mass movements, such as headcut retreat, piping, fluting, tension crack development and mass wasting, and it is the complex interaction of these subprocesses on different time scales which complicates reliable measurements as well as forecasting by gully erosion models. Therefore, Poesen et al. (2003) have called for increased efforts in establishing appropriate and standardised monitoring techniques enabling the study of gully development with a higher precision than that obtained by current techniques, and for more detailed monitoring, experimental and modelling work to increase the capacity to predict impacts of environmental changes on gully erosion rates.

Considering this variability in the spatial and temporal development of gullies, ideal gully erosion data should be spatially detailed and continuous, three-dimensional, of sufficient duration for avoiding a bias due to short-term fluctuations, and taken at frequencies that accurately capture the erosion dynamics. Obviously, such data do not exist and would require great efforts in collecting. Reported studies on gully erosion rates only partly meet these requirements. Spatially and temporally detailed studies, usually conducted by rather intensive fieldwork, rarely exceed short-term durations of 3–5 years (e.g.: Brooks et al. 2009, Hu et al. 2007, Oostwoud Wijdenes & Bryan 2001, Rodzik et al. 2009, Vandekerckhove et al. 2001, Wu et al. 2008). Medium to long-term studies (> 10 years) are more often based on existing aerial photography, analysed in retrospect, and consequently of much lower spatial and temporal resolution (e.g.: Campo et al. 2006, Martínez-Casasnovas et al. 2003, 2009, Nachtergaele & Poesen 1999, Vandekerckhove et al. 2003).

Analysis of some of the rare existing medium to long-term data on gully erosion by Vanwalleghem et al. (2005b, Fig. 4) have found that gullies show a degressive exponential increase of volume and length during their lifetime. This non-linear retreat behaviour cannot sufficiently be described by (usually highly variable) short-term data – even less so when there are no clues as to the stage of age into which the current measurements fall. Consequently, the following questions need closer examination in order to improve the value of short to medium-term monitoring data:

- Do medium-term data tell us more about the development of a gully? How do medium-term averages differ from short-term and from long-term averages of gully erosion?
- What are the causes for fluctuations in gully retreat rates a) in short term, b) in medium term? Which processes at the gully itself and within the gully catchment are responsible for the spatial and temporal variability of gully development?

Objectives and methods

The objectives of this paper are to show that spatially detailed and continuous, medium-term monitoring data on gully erosion are much superior to short-term data for capturing and interpreting the development of gullies and differentiate between the individual sub-processes involved.

For this purpose, short to medium-term gully monitoring data taken with high-resolution remote sensing and field measure-ments at selected bank gullies in North and South-East Spain was analysed for determining linear, areal and volumetric retreat rates (Table 1). Using small-format aerial photography taken from hot-air blimps, kites and autopiloted model airplanes (Aber et al. 2010), these sites have been monitored by the authors in intervals of usually 1 or 2 years beginning between 1995 and 2008 (Ries & Marzolff 2003, Marzolff & Ries 2007, Marzolff & Poesen 2009). Several gullies had earlier been subject to short-term monitoring using field methods by Vandekerckhove et al. (2001).

Table 1. Gully sites used in this study with summary of erosion parameters. Volume and area loss measured at both headcut and sidewalls. R_{max}: maximum linear retreat measured at headcut; R_{mean}: mean linear retreat measured at all active edges

Gully site	Land use/land cover	Gully catchment size [ha]	Monitoring [years]	Volume loss [m^2 yr^{-1}]	Area loss [m^2 yr^{-1}]	R_{max} [m yr^{-1}]	R_{mean} [m yr^{-1}]
Barranco Rojo	cereal fields, young fallow land	13.7	7	5.85	3.03	0.37	n/a
Salada 1	almond plantation	25.3	6/11*	108.41	21.75	0.52	0.24
Salada 3	young fallow land	1.4	11	7.26	2.07	0.15	0.05
Luchena 1	very sparse matorral	0.15	10	3.13	1.29	1.71	0.24
Freila A	rangeland, abandoned fields	4.6	7	2.90	2.97	0.62	0.02
Freila B	rangeland, abandoned fields	1.3	7	2.16	2.67	0.23	0.01
Casablanca	rangeland	3.3	7	0.49	0.84	0.07	0.01
Belerda 1	cereal fields, olive plantations	1622	1/13**	26.47	3.51	0.35	0.20

*gully head infilled after 6 years; erosion parameters taken from the first 6 years
**aerial photomonitoring started in 2008; values of previous years estimated from terrestrial photos and measurements

At all gully sites, ground control points are permanently installed with steel pipes and marked with signals for the photographic survey. From the resulting stereoscopic images with extremely high ground resolutions of 0.5–10 cm, various techniques of analysis for measuring gully development and loss of soil material have been carried out with image-processing systems, geographic information systems (GIS), and digital photogrammetry stations. The resulting change maps keep accurate records of the spatial patterns of gully development, revealing shifting zones of activity at the gully edges.

In order to document and analyse environmental conditions in the gully catchment, maps of surface cover, morphological features and geomorphodynamic process activity were compiled by field survey based on aerial photography (Geißler 2007, Seeger et al. 2009). In addition, runoff coefficients, infiltration and erosion rates on typical surfaces in the headcut vicinity and throughout the catchment have been analysed with rainfall simulations and infiltration experiments (Seeger et al. 2009).

Results and discussion

Statistical analysis of average medium-term retreat rates (7–13) at the gullies confirms the general logarithmic relationship with headcut catchment size already observed by Vandekerckhove et al. (2001). However, different land use within the catchment leads to deviations of individual gully sites from the general trend, with rangeland gullies yielding much lower, and low-cover agricultural gullies yielding much higher growth rates than average. When short-term rates rather than medium-term averages are analysed, the slope and exponent of the regression lines vary considerably, with the maximum observed rate in any short-term period strongly overestimating, and the minimum observed rate in any short-term period strongly underestimating gully growth. Apart from varying precipitation amounts in the individual observation periods, the most important reasons for the high short-term variability were found to be different subprocesses involved in gully erosion – especially headcut vs. sidewall erosion – and human interference in the form of land-use change and anti-erosion measures. Details on the development of all gullies listed in Table 1 and on the role of various influence factors can be found in Marzolff et al. (2011).

The gully development maps derived from the aerial photographs demonstrate the importance of detailed, spatially continuous change measurements: A considerable, sometimes even major percentage of gully growth may occur not at the actual headcut, but along the sidewalls, where mass wasting along tension cracks may lead to sudden high retreat rates (Fig. 1). For the individual gullies, mean annual retreat values may vary substantially between the years for longer observation periods (Fig. 2). The high

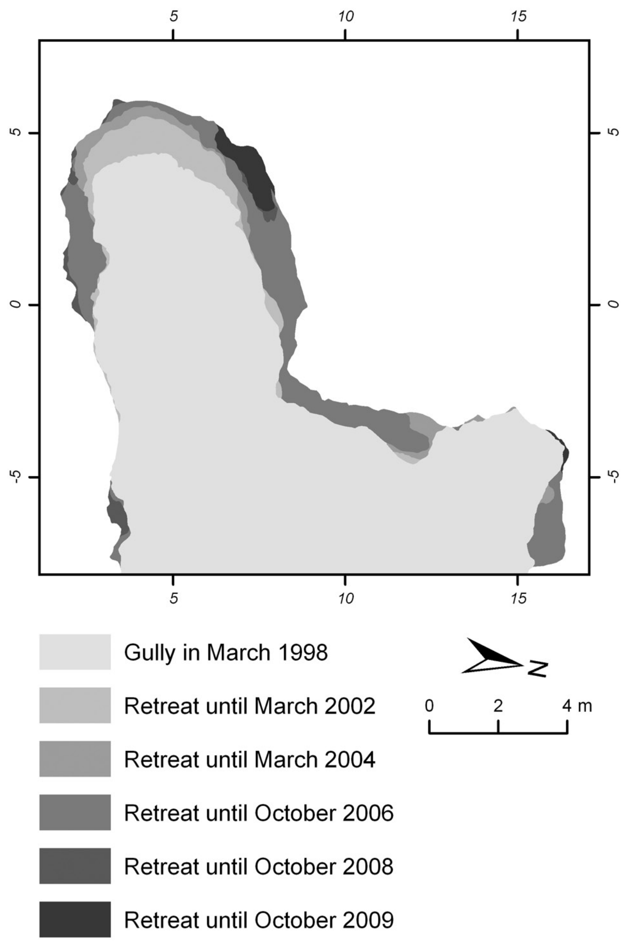

Fig. 1. Change map March 1998 – October 2009, gully head Salada 3, Province of Murcia, Spain. Local coordinate system in meters

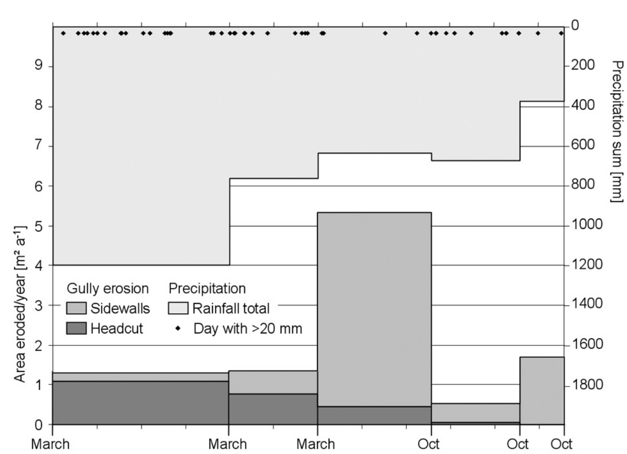

Fig. 2. Mean annual areal retreat rates, precipitation sums and possibly extreme rainfall events for 5 short-term monitoring periods at headcut and sidewalls of gully Salada 3. Mean annual retreat for complete period (March 1998 – October 2009): 0.621 $m^2 yr^{-1}$ (headcut), 1.463 $m^2 yr^{-1}$ (sidewalls), 2.084 $m^2 yr^{-1}$ (whole gully). Precipitation data from climate station La Paca (7 km distance)

variability is particularly dependent on changing local conditions in the headcut vicinity and thus strongly associated with human activities (current land use, tillage practices, erosion control measures such as earth dams, dirt-track maintenance measures, infilling of gully headcut etc.) that influence runoff behaviour and flowpaths connectivity within the catchment. The example if Gully Salada 1 (Fig. 3), which has a repeated history of human intervention, shows that such measures may influence form

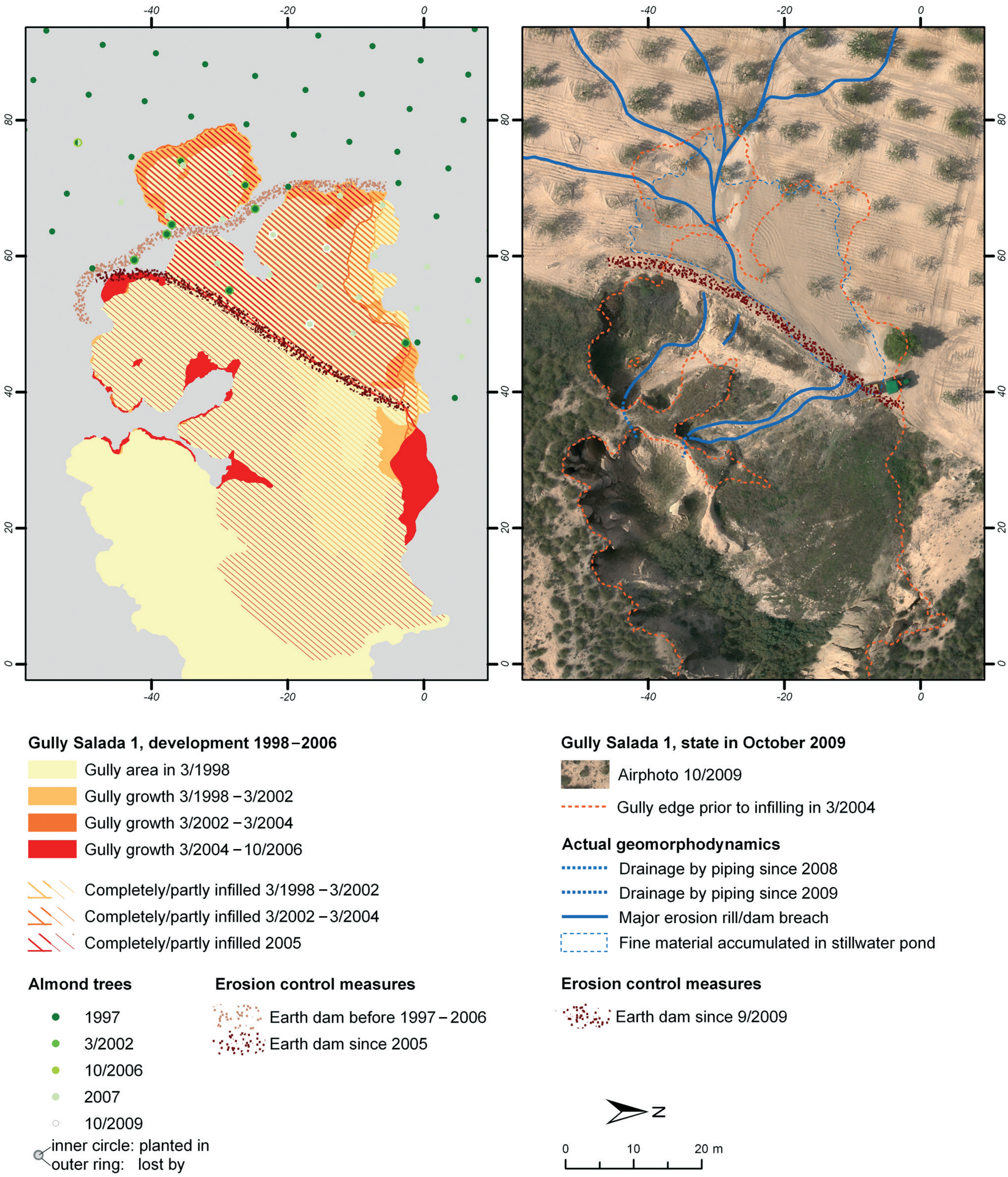

Fig. 3. Gully Salada 1, Province of Murcia, Spain. Human activities play an important role in the development of this gully head, which continues to be affected by the high runoff rates from the almond plantation and by piping processes related to earth dam construction, in spite of infilling in 2005: a) Change map March 1998 – October 2009; b) Airphoto map, October 2009. This image was taken shortly after intense rainfalls in late September and during erosion control measures carried out by the almond farmer (see tractor filling the dam breach at 0/40)

and amount of gully development for many years and even lead to "setting back of the clock" by infillings and subsequent re-incision of pipes and rills.

The study shows that short-term data, while being very valuable for analyses such as short-term sediment budgets, should not be taken as representative for the long-term development of a gully (cf. Marzolff et al. 2011). In particular, short-term retreat rates need to be used with caution when extrapolating them to longer time periods both into the future (for predicting further development) and back in time (for determining a gully's age). Medium-term averages seem to reflect gully evolution much more accurately, but even for medium- or long-term monitoring, short repeat periods are required to understand the individual reasons for gully-erosion variability.

References

Aber J.S., Marzolff I. & Ries J.B., 2010. *Small Format Aerial Photography: Principles, techniques and geoscience applications*. Elsevier, Amsterdam et al.: 256 pp.

Boardman J. & Poesen J., 2006. *Soil Erosion in Europe*. Wiley, Chichester, UK: 855 pp.

Brooks A.P., Shellberg J.G., Knight J. & Spencer J., 2009. Alluvial gully erosion: an example from the Mitchell fluvial megafan, Queensland, Australia. *Earth Surface Processes and Landforms* 34: 1951–1969.

Campo M.A., Álvarez-Mozos J., Casalí J., De Santisteban L.M., Giménez R. & Martínez-Casasnovas J.A., 2006. Long term evolution assessment of the permanent gully network in Las Bardenas Reales area (Navarre, Spain) influenced by land use change. In: Martínez-Casasnovas J.A., Pla Sentís I., Ramos M.C. & Balasch Solanes J.C. (eds.) *Soil and water conservation under changing land use*. Edicions de la Universitat de Lleida, Lleida, Spain: 147–150.

Geißler, C., 2007. *Einfluss der Landbedeckung auf die aktuelle Geomorphodynamik in Gully-Einzugsgebieten im semi-ariden Spanien.* MSc Thesis, Department of Physical Geography, Frankfurt University: 124 p.

Hu G., Wu Y., Liu B., Yu Z., You Z. & Zhang Y., 2007. Short-term gully retreat rates over rolling hill areas in black soil of Northeast China. *Catena* 71: 321–329.

Martínez-Casasnovas J.A., Antón-Fernándes C. & Ramos M.C., 2003. Sediment production in large gullies of the mediterranean area (NE Spain) from high-resolution digital elevation models and geographical information systems analysis. *Earth Surface Processes and Landforms* 28: 443–456.

Martínez-Casasnovas J.A., Ramos M.C. & García-Hernández D., 2009. Effects of land-use changes in vegetation cover and sidewall erosion in a gully head of the Penedès region (northeast Spain). *Earth Surface Processes and Landforms* 34: 1927–1937.

Marzolff I. & Ries J.B., 2007. Gully monitoring in semi-arid landscapes. *Zeitschrift für Geomorphologie* 51: 405–425.

Marzolff I. & Poesen J., 2009. 3D monitoring of erosion gullies with GIS using high-resolution aerial photography and a digital photogrammetry system. *Geomorphology* 111: 48–60.

Marzolff I., Ries J. B. & Poesen J., 2011. Short-term vs. medium-term monitoring for detecting gully-erosion variability in a Mediterranean environment. *Earth Surface Processes and Landforms* 36: 1604–1623.

Nachtergaele J. & Poesen J., 1999. Assessment of soil losses by ephemeral gully erosion using high-altitude (stereo) aerial photographs. *Earth Surface Processes and Landforms* 24: 693–706.

Oostwoud Wijdenes, D. & Bryan, R.B., 2001. Gully-Head erosion processes on a semi-arid valley floor in Kenya. *Earth Surface Processes and Landforms* 26: 911–933.

Poesen J., Nachtergaele J., Verstraeten G. & Valentin C., 2003. Gully erosion and environmental change: importance and research needs. *Catena* 50: 91–133.

Poesen J., Vanwalleghem T., de Vente J., Knapen A., Verstraeten, G. & Martínez-Casasnovas J.A., 2006. Gully Erosion in Europe. In: Boardman J. & Poesen J. (eds.) *Soil Erosion in Europe*. Wiley: 515–536.

Ries J.B. & Marzolff I., 2003. Monitoring of gully erosion in the central Ebro Basin by large-scale aerial photography from a remotely controlled blimp. *Catena* 50: 309–328.

Rodzik J., Furtak T. & Zglobicki W., 2009. The impact of snowmelt and heavy rainfall runoff on erosion rates in a gully system, Lublin Upland, Poland. *Earth Surface Processes and Landforms* 34: 1938–1950.

Seeger M., Marzolff I. & Ries J.B., 2009. Identification of gully-development processes in semi-arid NE Spain. Zeitschrift für Geomorphologie 53(4): 417–431.

Vandekerckhove L., Poesen J., Oostwoud Wijdenes D. & Gyssels G., 2001. Short-term gully retreat rates in Mediterranean environments. *Catena* 44: 133–161.

Vandekerckhove L., Poesen J. & Govers G., 2003. Medium-term gully headcut retreat rates in Southeast Spain determined from aerial photographs and ground measurements. *Catena* 50: 329–352.

Vanwalleghem T., Bork H.-R., Poesen J., Schmidtchen G., Dotterweich M., Nachtergaele J., Bork H., Deckers J., Brüsch, B., Bungeneers J. & De Bie M., 2005a. Rapid development and infilling of a buried gully under cropland, Central Belgium. *Catena* 63: 221–243.

Vanwalleghem T., Poesen J., Van Den Eeckhaut M., Nachtergaele J. & Deckers J., 2005b. Reconstructing rainfall and land-use conditions leading to the development of old gullies. *The Holocene* 15: 378–386.

Wu Y., Zheng Q., Zhang Y., Liu B., Cheng H. & Wang Y., 2008. Development of gullies and sediment production in the black soil region of northeastern China. *Geomorphology* 101: 683–691.