Cuadernos de Investigación Geográfica *Geographical Research Letters*	2019	Nº 45 (1)	pp. 5-18	eISSN 1697-9540

DOI: http://doi.org/10.18172/cig.3876

GEO-ECOLOGY IN THE ANTHROPOCENE

E. NADAL-ROMERO[1]*, E. CAMMERAAT[2]

[1]Instituto Pirenaico de Ecología, Consejo Superior de Investigaciones Científicas (IPE-CSIC), Campus de Aula Dei, P.O. Box 13.034, 50080, Zaragoza, Spain.
[2]Institute for Biodiversity and Ecosystem Dynamics, Ecosystem and Landscape Dynamics Department, University of Amsterdam, Netherlands.

ABSTRACT. *Human activities have left signatures on the Earth for millennials, and these impacts are growing in the last decades. As a consequence, recent global change suggests that Earth may have entered a new human-dominated geological epoch. In the last years, much scientific debate has focused on the definition, stratigraphic signatures and timing of the Anthropocene. However, there is no a geological evidence, because these changes must be recorded in geologic stratigraphic material. Consequently, the definition of Anthropocene is controversial and the International Union of Geological Sciences (IUGS) has not provided a formal and official definition.*

Regardless of whether one is concerned with the proposed new Anthropogenic geologic epoch, it is evident that humans have significantly altered vegetation patterns and land cover (i.e. agriculture and subsequent land abandonment, conversion of forest to grasslands for pastoral use), water dynamics and distribution of fresh water (i.e. construction of dams), biogeochemical cycles (such as the carbon cycle), soil formation and soil erosion processes. Likewise, human have created and modified new landscapes (defined as anthropogenic landscapes).

This special issue includes 11 contributions concerning studies about the definition and timing of the Anthropocene as a new geological era, and showing some of the most important human impacts on the Earth.

Geoecología en el Antropoceno

RESUMEN. *Existen evidencias de la acción humana sobre la tierra en los últimos milenios, aunque este impacto se ha visto incrementado en las últimas décadas. El aceleramiento de estos cambios sugiere el inicio de una nueva época o edad geológica dominada por los humanos.*

En los últimos años, gran parte del debate científico se ha centrado en la definición, búsqueda de señales estratigráficas y delimitación temporal del Antropoceno. Sin embargo, no hay consenso, y no existen evidencias geológicas *reales del inicio de esta nueva época. En consecuencia, la definición oficial de Antropoceno es controvertida, y la Unión Internacional de Ciencias Geológicas (IUGS) no ha proporcionado una definición formal y oficial de una nueva época o edad geológica.*

Independientemente de la definición formal y el acuerdo global sobre la existencia de una nueva época geológica (Antropoceno), lo que es evidente es que los seres humanos han alterado significativamente los patrones de vegetación y las cubiertas vegetales (actividades agrícolas y su posterior abandono, la conversión de bosques a pastizales para uso pastoral en el piso subalpino), la dinámica del agua y la distribución de agua dulce en el planeta (p.e. construcción de presas y embalses), los ciclos biogeoquímicos (como el ciclo del carbono), la formación de suelos y los procesos de erosión del suelo, creando y modificando nuevos paisajes (definidos como paisajes antrópicos).

Este volumen incluye 11 contribuciones sobre la definición de una nueva época geológica denominada Antropoceno y su delimitación en el tiempo. Además, se presentan algunos de los impactos humanos más importantes sobre la Tierra.

Key words: Anthropocene, human impact, biodiversity, hydrology, erosion, land use changes.

Palabras clave: Antropoceno, impacto humano, biodiversidad, hidrología, erosión, cambios de usos de suelo.

Received: 14 November 2018
Accepted: 2 December 2018

*Corresponding author: Estela Nadal-Romero, Instituto Pirenaico de Ecología, Consejo Superior de Investigaciones Científicas (IPE-CSIC), Campus de Aula Dei, P.O. Box 13.034, 50080 Zaragoza, Spain. E-mail address: estelanr@ipe.csic.es

1. Introduction

The concept of Anthropocene is widely accepted by the scientific community, although the definition as a new era is still pending on a formal definition by the International Union of Geological Sciences (IUGS). Many authors have discussed the formalization of the Anthropocene over the last decade (i.e. Finney and Edward, 2006; Brown *et al.*, 2013; Zalasiewicz *et al.*, 2017). Two influential papers were published at the beginning of the 21^{st} century; Crutzen and Stoemer (2000) and Crutzen (2002) proposed that we live in the Anthropocene, a time, in which "humans have replaced nature as the dominant environmental force on Earth" proposing the term "Anthropocene". Nevertheless, other authors as Lewis and Macklin (2014) and McGregor and Houston (2018) only recognized the value of the Anthropocene as an informal and useful concept to stimulate political, social and public awareness of past and present human impacts, indicating that "a formal definition presents some disadvantages". Likewise, other authors suggest that there was a previous and significant influence of man on the Earth (with less relevance and local impacts) (Peña-Monné and Sampietro, 2019). It is called the Early Anthropogenic Era and some authors use the term PaleoAnthropocene (Foley *et al.*, 2005; Ruddiman and Thomson, 2001). González-Álvarez (2019) indicated that anthropogenic impacts with different intensities on landscapes occur since prehistory. This author analyzes the long-term anthropization of alpine and subalpine areas in the northwestern area of the Iberian Peninsula and highlights the potential of landscape archaeology (cultural and environmental traits of landscapes) to analyze the Anthropocene. Nevertheless, according to the International Union of Geological Sciences (IUGS) (announcement made on July 2018) the Holocene has been subdivided in three ages, and we are now living in the "Meghalayan Age", but the Anthropocene remains undefined (Valladares *et al.*, 2019). The Meghalayan Age defines the "late Holocene" and the present day, but makes no mention of the human impact on the environment.

Despite, the refusal of the IUGS to define the Anthropocene, a second issue that should be addressed, in the case of the official definition of a new era, is its beginning: When did the Anthropocene start? There is some controversy about the start of Anthropocene and a large number of possible dates, varying from early in the Holocene (Smith and Zeder, 2013), to the rise of Anthropocene methane from rice and livestock production (5000 years ago) (Ruddiman, 2013), to the Columbian Exchange (Crosby, 1972), the Industrial Revolution (Crutzen, 2002), to the World War II (Zalasiewicz *et al.*, 2010), or to the radionuclide events in 1960. Most of the authors recognize that the second half of the 20^{th} century is a time of major anthropogenic global environmental changes. In that sense, Zalasiewicz *et al.* (2015, 2017) proposed to use radionuclide deposits from atomic bombs as a potential Anthropocene Global Boundary Stratotype Sections and Points (GSSPs). Some geologists argued against its establishment as a formal period of geologic time (Ruddiman *et al.*, 2015). Others, as the subdivision of Quaternary Stratigraphy of the Geological Society of London, (preliminary) dated in 16 July 1945 (the first atomic bomb) the beginning of the Anthropocene. To sum up, there is not a consensus yet about definition and time.

Even though the Anthropocene concept is still unapproved and controversial, in the last decade scientific research related to the Anthropocene is increasing. The term Anthropocene has already produced thousands of publications. At the end of October 2018, Scopus includes 2,850 sources containing the term Anthropocene (showing an exponential trend) with about 30,500 citations (h-index 71) (Fig. 1).

Moreover, scientific journals focusing on the topic have appeared in the last decades: e.g. *The Anthropocene*, *The Anthropocene Review*, *Elementa-Science of the Anthropocene*. Furthermore, the increasing scientific interest in the Anthropocene is reflected in the many reviews, special issues, meetings and monographs devoted to the Anthropocene research during the last two decades. For example, special issues were produced in high impact journals: (i) Landscapes in the Anthropocene: State of the art and future directions (*Anthropocene*, volume 6, 2014), (ii) Predictions under change: water, earth, and biota in the Anthropocene (*Hydrology and Earth System Science*, 2015), (iii) Challenges of the "Anthropocene" (*Anthropocene*, volume 20, 2017), (iv) Remote Sensing of Anthropocene (*Remote Sensing*, 2019); and review (invited) papers were published: (i) *Soil erosion in the Anthropocene: Research needs* (Poesen, 2017, *Earth Surface Processes and Landforms*), (ii) *Physical geography in the Anthropocene* (Ellis, 2017, *Progress in Physical Geography*), (iii) *Impact of historical land use and soil management change on soil erosion and agricultural sustainability during the Anthropocene* (Vanwalleghem *et al*., 2017, *Anthropocene*), (iv) *The geomorphology of the Anthropocene: emergence, status and implications* (Brown *et al*., 2017, *Earth Surface Processes and Landforms*).

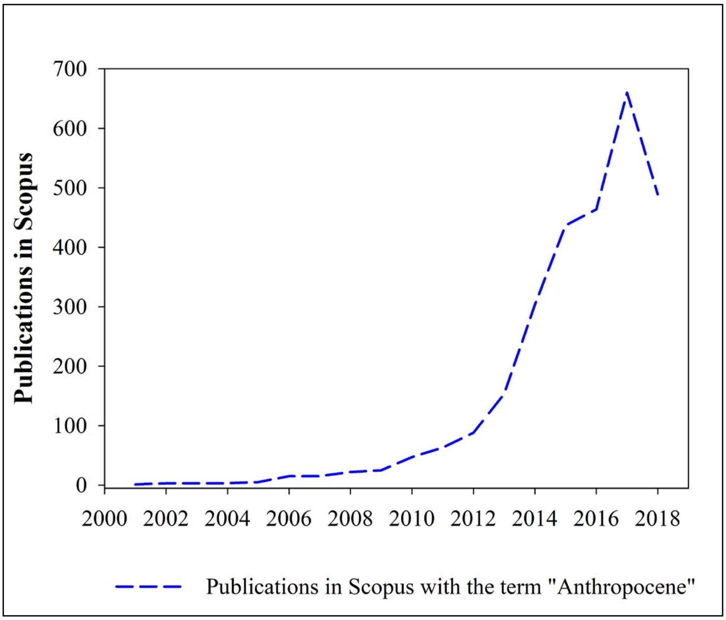

Figure 1. Number of publications in Scopus database with the term "Anthropocene" (October, 2018).

2. Human impacts on the Earth

Human activities have left signatures on the Earth for millennia and the impacts are growing in the last decades (Tarolli, 2016). Human activity is now global and induced changes to the lithosphere, hydrosphere, cryosphere, pedosphere, biosphere and atmosphere. Here we list some of the impacts associated with a high variety of anthropogenic processes: (i) land use changes and vegetation distribution, (ii) changes in biodiversity (both on land and in the sea) as a result of habitat change/

loss, predation and invasive species, (iii) changes in number, magnitude and intensity of fires, (iv) changes in the hydrological cycle, and (v) changes in soil dynamics, geomorphological and erosion processes and sediment transport dynamics. However, as stated by Lewis and Maslin (2015) these changes are spatially heterogeneous and diachronous, and probably this is one of the difficulties to officially define the Anthropocene era.

In the following paragraphs we will discuss some of the main anthropogenic changes mainly focused in 5 interrelated topics, integrating different temporal and spatial scales.

(i) Land use changes from natural vegetation to agricultural land (i.e. forest cutting and grassland conversion; deforestation and expansion of cropland) are the two largest spatial transformation of Earth's surface in human history. Montserrat and Gómez-García (2019-in this issue) discussed the variations on the forest and herbaceous domains in the landscape of the Iberian Peninsula in the last 20,000 years and questioned the importance of the effect of large herbivores (mega-herbivores) on vegetation patterns. They hypothesized that (i) mega-herbivores help structuring the landscape maintaining a high biodiversity, and (ii) the disappearance of these herbivores probably caused different ecological effects. Nevertheless, they did not find clear evidences to support or reject these hypotheses. On the other hand, González-Sampériz *et al*. (2019-current issue) indicated that the Anthropocene is the origin of current landscape transformation and presented evidences of deforestation processes in the subalpine belt in the Central Pyrenees with a high temporal and spatial variability, suggesting that during the Middle and Modern ages deforestation of the subalpine belt and the expansion of grasslands were common, coinciding with the increasing prevalence of transhumance (suggesting the onset of the Anthropocene). During the 17th century the montane belt was also deforested as a consequence of demographic growth and the expansion of cultivation. These data, which were obtained in the Pyrenees are similar to the ones obtained in other Mediterranean mountain areas (i.e. Colombaroli *et al*., 2010; Roepke and Krause, 2013; García-Ruiz *et al*., 2016). These are only two examples of scientific discussions about anthropogenic land use change and vegetation pattern dynamics. During the 20th century many land use changes occurred worldwide. Foley *et al*. (2005) suggested that land use change is one of the main factors involved in environmental change, nowadays being cropland abandonment (in mountain areas worldwide) and intensification of agriculture. Mediterranean mountain areas are a good example of cropland abandonment and revegetation processes (Molinillo *et al*., 1997), with consequences for quality and quantity of water resources, soil resources and other ecosystem functions and services (García-Ruiz and Lana-Renault, 2011). Furthermore, the intensification of agriculture, occurring in a high diversity of areas, also affects soil quality, geomorphological processes and the quality and quantity of water (i.e. Cerdà *et al*., 2012).

(ii) The anthropogenic transformation of ecosystems has serious impacts on biodiversity and has serious consequences for natural resources and land management (Hobbs *et al*., 2006). Dirzo *et al*. (2014) suggested that in the last centuries an “anthropogenic” biodiversity loss has been observed (referred to as the Anthropocene defaunation). For example: 322 species of terrestrial vertebrates have become extinct since 1,500 and a 25% decline in abundance. Similar values have been observed related to invertebrates. As well, deforestation and clear cutting activities negatively affected biodiversity. However, results of studies show a high variability. García *et al.* (2019-in this issue) analyzed land cover and landscape changes in the Ordesa and Monte Perdido National Park (OMPNP) and the effects of these changes on some endemic plants. This study concluded that: (i) the reduction of traditional land use is not threatening narrow-distributed plants, and it might even improve the situation of some plants and trees, and that (ii) landscape diversity is getting lower in the OMPNP (landscape simplification), leading to a plant diversity reduction. On the other hand, the role of biological invasions, that have recently challenged the traditional concept of biogeography in the Anthropocene, should also be highlighted. Gallardo and Vila (2019-in this issue) indicate that the geographical distribution of invasive species is dependent on human activities that promote their expansion. These authors highlight the need to apply modelling techniques in order to anticipate the potential distribution of invasive species, including climate but also human variables. The application of these models in the Iberian Peninsula indicates that minimum annual temperature was the most important variable, together with other human variables as distance to port or accessibility, underpinning the need to include anthropogenic predictors.

(iii) The first major human impact on the environment (although at local scale) was probable the use of fire, linked to land use changes and vegetation dynamics. Fire has been one of the main causes of disturbance of vegetation over time (i.e. Carracedo *et al.*, 2018). Although fire is not anymore part of our traditional activities, its frequency and intensity are related to human activities (Leone *et al.*, 2009; Rodrigues *et al.*, 2016). What is clear is that wildfires are a common phenomenon worldwide, increasing in frequency and magnitude as a result of environmental and climatic changes, impacting natural resources, infrastructures and millions of people every year (Bowman *et al.*, 2009).

(iv) The hydrological cycle is also increasingly affected by anthropogenic changes disturbing water dynamics, atmosphere, groundwater, lakes, rivers and oceans. These changes also modify some other Earth system components and cycles as sedimentation, nutrient and carbon balances, greenhouse emissions and aquatic biodiversity. Human activity can influence fluvial processes and water resources: indirectly through land use change or directly through river management. Some major changes are inter-basin transfers, transformations of the stream network (dams, reservoirs) (Fig. 2), deforestation and afforestation, changes in flood and drought cycles and changes in water quality regimes (i.e. Ehret *et al.*, 2014; Savenije *et al.*, 2014; Arthington *et al.*, 2018). For examples, since medieval times, floodplains were transformed (Brown *et al.*, 2018), introducing weir and mill-based systems, and during the last century the “industrialization of channels” occurred through hard-engineering. Sediment fluxes, floodplains and delta-plains are also affected by the sediment load reduction due to natural revegetation and afforestation of mountain abandoned areas (Syvitski and Kettner, 2011; Sanjuán *et al.*, 2016).

Figure 2. Dam construction in the Central Pyrenees (Yesa reservoir). Dams and reservoirs have been constructed worldwide modifying the hydrological dynamics and transforming the stream network. Photo: Estela Nadal-Romero.

(v) Human activity also influences soil formation, soil erosion processes and sediment transport. An old example is the development of agriculture that generated an anthropogenic impact replacing natural vegetation and soils. Vanwalleghem *et al*. (2017) indicated that many of the soil features are of anthropogenic origin and concluded that there are strong links between historical land uses and soil management changes, soil erosion and agriculture sustainability. Recently, it has been demonstrated that organic farming agriculture can improve soil quality and ecosystems, and transform the soils into a sink of carbon as a way to reduce global warming (i.e. Skinner *et al*., 2014). Novara *et al*. (2019-in this issue) highlighted the use or organic farming with cover crops as a significant strategy for soil organic matter restoration and climate change mitigation in long-term cultivation areas. Likewise, the European Commission (see European Commission, 2006) identified several soil threats that are a consequence of human activities such as urbanization, intensive agriculture or deforestation (Ferreira *et al*., 2018). Halifa-Marín *et al*. (2019-in this issue) investigated the effects of anthropic changes (afforestation, check-dam building, land abandonment) on erosion processes, fluvial morphology, sediment sources, and soil carbon pools. The study, carried out in SE Spain, demonstrated that fluvial morphology has changed during the last decades increasing bank erosion and gully development, and affecting inner fluvial plains or alluvial fans, and their vegetation cover. All these changes affected also the soil organic carbon reservoir stored in the fluvial sediments and soils in the catchment. Many studies have also suggested that major land use changes in the Anthropocene has increased soil erosion rates worldwide (i.e. García-Ruiz *et al*., 2017) and that agricultural activities show the highest erosion rates (Montgomery, 2007) (see Fig. 3). In that sense, Pijl *et al*. (2019-in this issue) indicated that vineyard terraces showed the highest erosion rates of all Mediterranean landscape types. Their study demonstrated that vineyard mechanization shows higher erosion rates than non-mechanization fields, concluding that anthropic mechanization and related compaction and transformation of agricultural landscapes (terraces and infrastructures) increase soil loss risk in an already erosion prone landscape type. Finally, Poesen published in 2017 the review paper titled "*Soil erosion in the Anthropocene: Research needs*" concluding that soil erosion in the Anthropocene mainly occurs as a consequence of a combination of natural and human-induced soil erosion processes, although an increasing number of studies indicates that anthropogenic soil erosion processes have become dominant.

Figure 3. Soil erosion in young vineyard fields in La Rioja (Spain). Agricultural activities modified the soil and intensified soil erosion processes. Many authors suggest that soil erosion in vineyards are the highest soil erosion rates worldwide. Photo: Luis Ortigosa.

Finally, human activities have modified more than half of the Earth's land area (forms and landscapes) (Hooke *et al*., 2012), the Mediterranean region probably being the best-known man-made landscape (García-Ruiz *et al*., 2017). To conclude, some anthropogenic landforms should be highlighted. One of the best examples of human landscapes is the creation of agricultural terraces (Tarolli *et al*., 2014, 2018). Terracing of hillslopes and mountain sides for agricultural use is certainly one of the largest anthropogenic geomorphic processes in many mountain worldwide areas (Arnáez *et al*., 2017; Camera *et al*., 2018; Calsamiglia *et al*., 2018) (Fig. 4). Tarolli (2016) highlighted other examples as urban development, urban growth, embankments for railways, roads, canals, irrigation networks, open mining or below ground mining, land levelling and soil quarrying. In that sense, the paper written by Raczkowska (2019-in this issue) presents a good example of human impacts in the Tatra Mountains including mining and metallurgy, wood exploitation and oil extraction, as well as tourism activities.

Figure 4. Terraces around Bestué (Pyrenees, Spain). Terraced slopes were built to cultivate steep slopes in mountain areas, creating complex anthropogenic landscapes. Nowadays, most of the terraced systems are abandoned and revegetation processes occur. Photo: Estela Nadal-Romero.

Nonetheless, at present, the human population becomes more urban and for this reason it is necessary to promote social involvement and proactive behavior towards nature and environment. Puigdefábregas and Pérez-García (2019-in this issue) discussed about the psychological processes involved in the interaction between human and their environment highlighting the need to recover empathy with the natural environment and to draw guidelines to improve people´s concern to care for the environment.

3. Final Remarks

The articles of this special issue cover a broad range of topics related to the Anthropocene and demonstrate that many research topics related to the Anthropocene are still open for debate. The discussion to establish a formal definition of the Anthropocene is still an open question that has not been yet solved by the working group of the ICS Subcomission on Quaternary Stratigraphy or by the International Union of Geological Sciences (IUGS). A second debate is about where to place the Anthropocene's chronological boundaries, although the mid-twentieth or late eighteenth centuries are the most commonly proposed dates.

Regardless of whether one is concerned with the proposed new Anthropogenic geologic epoch or the general concept of accelerating human influences on Earth, it is evident that human activity affects lithosphere, hydrosphere, cryosphere, pedosphere, biosphere and atmosphere, modifying all major biogeochemical cycles of the Earth and creating new landscapes and landforms.

Acknowledgements

This research was supported by the ESPAS project (CGL2015-65569-R, funded by the MINECO-FEDER).

References

Arnáez, J., Lana-Renault, N., Ruiz-Flaño, P., Pascual, N., Lasanta, T. 2017. Mass soil movement on terraced landscapes of the Mediterranean mountain areas: A case study in the Iberian range, Spain. *Cuadernos de Investigación Geográfica* 43 (1), 83-100. https://doi.org/10.18172/cig.3211.

Arthington, A.H., Kennen, J.G., Stein, E.D., Webb, J.A. 2018. Recent advances in environmental flows science and water management – Innovation in the Anthropocene. *Freshwater Biology* 63, 1022-1034. https://doi.org/10.1111/fwb.13108.

Bowman, D.M., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Doyle, J.C., Harrison, S.P., Johnston, F.H. 2009. Fire in the Earth system. *Science* 324 (5926), 481-484. https://doi.org/10.1126/science.1163886.

Brown, A., Toms, P., Carey, C., Rhodes, E., 2013. Geomorphology of the Anthropocene: Time-transgressive discontinuities of human-induced alluviation. *Anthropocene* 1, 3-13. https://doi.org/10.1016/j.ancene.2013.06.002.

Brown, A.G., Lespez, L., Sear, D.A., Macaire, J., Houben, P., Klimek, K., Brazier, R.E., Van Oost, K., Pears, B. 2018. Natural vs anthropogenic streams in Europe: history, ecology and implications for restoration, river-rewilding and riverine ecosystem services. *Earth-Science Reviews* 180, 185-205. https://doi.org/10.1016/j.earscirev.2018.02.001.

Brown, A.G., Tooth, S., Bullard, J., Thomas, D., Chiverrell, R.C., Plater, A.J., Murton, J., Thorndycraft, V.R., Tarolli, P., Rose, J., Wainwright, J., Down, P., Aalto, R. 2017. The geomorphology of the Anthropocene: emergence, status and implications. *Earth Surface Processes and Landforms* 42, 71-90. https://doi.org/10.1002/esp.3943.

Calsamiglia, A., Fortesa, J., García-Comendador, J., Lucas-Borja, M.E., Calvo-Cases, A., Estrany, J. 2018. Spatial patterns of sediment connectivity in terraced lands: Anthropogenic controls of catchment sensitivity. *Land Degradation & Development* 29 (4), 1198-1210. https://doi.org/10.1002/ldr.2840.

Camera, C., Djuma, H., Bruggeman, A., Zoumides, C., Eliades, M., Charalambous, K., Abate, D., Faka, M. 2018. Quantifying the effectiveness of mountain terraces on soil erosion protection with sediment traps and dry-stone wall laser scans. *Catena* 171, 251-264. https://doi.org/10.1016/j.catena.2018.07.017.

Carracedo, V., Cunill, R., García-Condron, J.C., Pèlachs, A., Pérez-Obiol, R., Soriano, J.M. 2018. History of fires and vegetation since the Neolithic in the Cantabrian Mountains (Spain). *Land Degradation & Development* 29, 2060-2072. https://doi.org/10.1002/ldr.2891.

Cerdà, A., Giménez-Morera, A., Burguet, M., Arcenegui, V., González-Peñazola, F.A., García-Orenes, F., Pereira, P. 2012. The impact of the farming, abandonment and agricultural intensification on loss of water and soil. The example of the northern slopes of the Serra Grossa, Eastern Spain. *Cuadernos de Investigación Geográfica* 38 (1), 75-94. http://doi.org/10.18172/cig.1276.

Colombaroli, D., Henne, P.D., Kaltenrieder, P., Gobet, E., Tinner, W., 2010. Species responses to fire, climate and human impact at tree line in the Alps as evidenced by palaeo-environmental records and a dynamic simulation model. *Journal of Ecology* 98, 1346-1357. https://doi.org/10.1111/j.1365-2745.2010.01723.x.

Crosby, A.W. 1972. *Columbian Exchange: The Biological and Cultural Consequences of 1492*. Praeger Publishers, Westport, CT.

Crutzen, P.J., 2002. Geology of Mankind. *Nature* 415 23. https://doi.org/10.1038/415023a.

Crutzen, P.J., Stoemer, E.F. 2000. *The "Anthropocene"*. The International Geosphere–Biosphere Programme (IGBP) 41, 17-18.

Dirzo, R., Young, H., Galetti, M., Ceballos, G., Isaac, N.J.B., Collen, B. 2014. Defaunation in the Anthropocene. *Science* 345 (6195), 401-406. https://doi.org/10.1126/science.1251817.

Ehret, U., Gupta, H.V., Sivapalan, M., Weijs, V., Schymanski, S.J., Blöschl, G., Gelfan, A.N., Harman, C., Kleidon, A., Bogaard, T.A., Wang, D., Wagener, T., Scherer, U., Zehe, E., Bierkens, M.F.P., Di Baldassarre, G., Parajka, J., van Beek, L.P.H., van Griensven, A., Westhoff, M.C., Winsemius, H.C., 2014. Advancing catchment hydrology to deal with predictions under change. *Hydrology and Earth System Sciences* 18, 649-671. https://doi.org/10.5194/hess-18-649-2014.

Ellis, E.C. 2017. Physical geography in the Anthropocene. *Progress in Physical Geography* 41 (5), 525-532. https://doi.org/10.1177/0309133317736424.

European Commission, 2006. Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of Regions. Thematic Strategy for Soil Protection (COM 2006.231). Commission of the European Communities, Brussels.

Ferreira, C.S.S., Pereira, P., Kalantari, Z., 2018. Human impacts on soil. *Science of the Total Environment* 644, 830-834.

Finney and Edward, 2006. The "Anthropocene" epoch: Scientific decision or political statement? *GSA Today* 26 (3-4), 4-10. https://doi.org/10.1130/GSATG270A.1.

Foley, j., DeFries, R., Asner, G.P., Barford, C., Bonan, G., et al. 2005. Global consequences of Land Use. *Science* 309 (5734), 570-574. https://doi.org/10.1126/science.1111772.

Gallardo, B., Vila, L., 2019. Human influence, key to understand the biogeography of invasive species in the Anthropocene. *Cuadernos de Investigación Geográfica* 45 (1), 61-86. http://doi.org/10.18172/cig.3627.

García, B., Errea, P., Gómez, D., Pizarro, M., 2019. Winners and losers of landscape changes over the last sixty years in one of the oldest and Southernmost National Parks of the European Alpine Region: Ordesa and Monte Perdido. *Cuadernos de Investigación Geográfica* 45 (1), 123-141. http://doi.org/10.18172/cig.3711.

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, Ecosystems and Environment* 140 (3-4), 317-338. https://doi.org/10.1016/j.agee.2011.01.003.

García-Ruiz, J.M., Sanjuán, Y., Arnáez, J., Beguería, S., Gómez-Villar, A., Álvarez-Martínez, J., Lana-Renault, N., Coba-Pérez, P. 2016. Evolution of the subalpine belt in the Urbión Sierra

(Iberian Range, Northern Spain): an example of the geoecology impact of human activity in the Ormazal Valley. *Pirineos* 171 e022. http://doi.org/10.3989/Pirineos.2016.171006.

García-Ruiz, J.M., Beguería, S., Lana-Renault, N., Nadal-Romero, E., Cerdà, A. 2017. Ongoing and emerging questions in water erosion studies. *Land Degradation & Development* 28, 5-21. https://doi.org/0.1002/ldr.2641.

González-Álvarez, D., 2019. The need to understand the cultural biographies of alpine and subalpine landscapes during Later Prehistory: Upland Archaeology in the Cantabrian Mountains. *Cuadernos de Investigación Geográfica* 45 (1), 143-165. http://doi.org/10.18172/cig.3824.

González-Sampériz, P., Montes, L., Aranbarri, J., Leunda, M., Domingo, R., Laborda, R., Sanjuán, Y., Gil-Romera, G., Lasanta, T., García-Ruiz, J.M. 2019. Escenarios, tempo e indicadores paleoambientales para la identificación del antropoceno en el paisaje vegetal del Pirineo Central (NE Iberia). *Cuadernos de Investigación Geográfica* 45 (1), 167-193. http://doi.org/10.18172/cig.3691.

Halifa-Marín, A., Pérez-Cutillas, P., Almagro, M., Boix-Fayos, C., 2019. Presión antrópica sobre cuencas de drenaje en ecosistemas fráfiles: variaciones en el stock de carbon orgánico asociadas a cambios morfológicos fluviales. *Cuadernos de Investigación Geográfica* 45 (1), 245-269. http://doi.org/10.18172/cig.3690.

Hobbs, R.J., Arico, S., Aronson, J., et al. 2006. Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* 15 (1), 1-7. https://doi.org/10.1111/j.1466-822X.2006.00212.x.

Hooke, R.L., Martín-Duque, J.F., de Pedraza, J., 2012. Land transformation by humans: A review. *GSA Today* 22 (12), 4-10. https://doi.org/10.1130/GSAT151A.1.

Leone, V., Lovreglio, R., Martín, M.P., Martínez, J., Vilar, L. 2009. Human factors of fire occurrence in the Mediterranean. In: E. Chuvieco, (Ed.), *Earth Observation of Wildland Fires in Mediterranean Ecosystems*. Springer-Verlag, pp. 149-170.

Lewis, S., Macklin, M.G. 2014. Marking time in Geomorphology: should we try to formalize an Anthropocene definition? *Earth Surface Processes and Landforms* 39(1), 133-137. https://doi.org/10.1002/esp.3484.

Lewis, S., Maslin, M.A. 2015. Defining the Anthropocene. *Nature* 519, 171-180. https://doi.org/10.1038/nature14258.

McGregor, A., Houston, D., 2018. Cattle in the Anthropocene: Four propositions. *Transactions of the Institute of British Geographers* 43, 3-6. https://doi.org/10.1111/tran.12193.

Molinillo, M., Lasanta, T., García-Ruiz, J.M. 1997. Managing mountainous degraded landscapes after farmland abandonment in the Central Spanish Pyrenees. *Environmental Management* 21 (4), 587-598. https://doi.org/10.1007/s002679900051.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. *PNAS* 104 (33), 13268-13272. https://doi.org/10.1073pnas.0611508104.

Montserrat Martí, G., Gómez García, D. 2019. Variación de los dominios forestales y herbáceo en el paisaje vegetal de la península ibérica en los últimos 20000 años. Importancia del efecto de los grandes herbívoros sobre la vegetación. *Cuadernos de Investigación Geográfica* 45 (1), 87-121. http://doi.org/10.18172/cig.3659.

Novara, A., Keesstra, S., Rodrigo-Comino, J., Smith, P., Gristina, L., Cerdà, A., 2019. Long-term organic farming on a citrus plantation results in soil organic matter recovery. *Cuadernos de Investigación Geográfica* 45 (1), 271-286. http://doi.org/10.18172/cig.3794.

Peña-Monné, J.L., Sampietro-Vattuone, M.M. 2019. Late Holocene anthropic degradation records in semi-arid environmnets (NE Spain and NW Argentina. *Cuadernos de Investigación Geográfica* 45 (1), 195-217. http://doi.org/10.18172/cig.3587.

Pijl, A., Barneveld, P., Mauri, L., Borsato, E., Grigolato, S., Tarolli, P. 2019. Impact of mechanization on soil loss in vineyard terraced landscapes. *Cuadernos de Investigación Geográfica* 45 (1), 287-308. http://doi.org/10.18172/cig.3774.

Poesen, J. 2017. Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms* 43 (1), 64-84. https://doi.org/10.1002/esp.4250.

Puigdefábregas, J., Pérez-García, M., 2019. A neuro-scientific approach to environment care. *Cuadernos de Investigación Geográfica* 45 (1), 19-31. http://doi.org/10.18172/cig.3585.

Rączkowska, S., 2019. Human impact in the Tatra Mountains. *Cuadernos de Investigación Geográfica* 45 (1), 219-244. http://doi.org/10.18172/cig.3661.

Rodrigues, M., Jiménez, A., de la Riva, J. 2016. Analysis of recent spatial-temporal evolution of human driving factors of wildfires in Spain. *Natural Hazards* 84 (3), 2049-2070. https://doi.org/10.1007/s11069-016-2533-4.

Roepke, A., Krause, R., 2013. High montane-subalpine soils in the Montafon Valley (Austria, northern Alps) and their link to land-use, fire and settlement history. *Quaternary International* 308-309, 178-189. https://doi.org/10.1016/j.quaint.2013.01.022.

Ruddiman, W.F. 2013. *Earth Transformed*. Freeman, New York, 400 pp.

Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q. 2015. Defining the epoch we live in. Is a formally designated "Anthropocene" a good idea? *Science* 348 (6230), 38-39. https://doi.org/10.1126/science.aab1028.

Ruddiman, W.F., Thomson, J.S. 2001. The case for human causes of increase atmospheric CH4 over the last 5000 years. Quaternary Science Reviews 20 (18), 1769-1777. https://doi.org/10.1016/S0277-3791(01)00067-1.

Sanjuán, Y., Gómez-Villar, A., Nadal-Romero, E., Álvarez-Martínez, J., Arnáez, J., Serrano-Muela, M.P., Rubiales, J.M., González-Sampériz, P., García-Ruiz, J.M. 2016. Linking land cover changes in the sub-alpine and montane belts to changes in a torrential river. *Land Degradation & Development* 27, 179-189. https://doi.org/10.1002/ldr.2294.

Savenije, H.H.G., Hoekstra, A.Y., van der Zaag, P. 2014. Evolving water science in the Anthropocene. *Hydrology and Earth System Sciences* 18, 319-332. https://doi.org/10.5194/hess-18-319-2014.

Skinner, C., Gattinger, A., Muller, A., Mäder, P., Flieβbach, A., Stolze, M., Ruser, R., Niggli, U. 2014. Greenhouse gas fluxes from agricultural soils under organic and non-organic management—a global meta-analysis. *Science of the Total Environment* 468, 553-563. https://doi.org/10.1016/j.scitotenv.2013.08.098.

Smith, B.D., Zeder, M.A. 2013. The onset of the Anthropocene. *Anthropocene* 4, 8-13. https://doi.org/10.1016/j.ancene.2013.05.001.

Syvitski, J.P.M., Kettner, A. 2011. Sediment flux and the Anthropocene. *Philosophical transactions of the Royal Society A* 369, 957-975. https://doi.org/10.1098/rsta.2010.0329.

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.

Tarolli, P. 2016. Humans and the Earth's surface. *Earth Surface Processes and Landforms* 41, 2301-2304. https://doi.org/10.1002/esp.4059.

Tarolli, P., 2018. Agricultural Terraces Species Issue Preface. *Land Degradation & Development* 29, 3544-3548. https://doi.org/10.1002/ldr.3129.

Valladares, F., Magro, S., Martín-Forés, I., 2019. Anthropocene, the Challenge for *Homo sapiens* to set its own limits. *Cuadernos de Investigación Geográfica* 45 (1), 33-59. http://doi.org/10.18172/cig.3681.

Vanwalleghem, T., Gómez, J.A., Infante Amate, J., González de Molina, M., Vaderlinden, K., Guzmán, G., Laguna, A., Giráldez, J.V. 2017. Impact of historical land use and soil management change on soil erosion and agricultural sustainability during the Anthropocene. *Anthropocene* 17, 13-29. http://doi.org/10.1016/j.ancene.2017.01.002.

Zalasiewicz, J., Williams, M., Steffen, W., Crutzen, P., 2010. Response to "the Anthropocene forces us to reconsider adaptationist models of human-environment interactions". *Environmental Science and Technology* 44(16), 6008. https://doi.org/10.1021/es102062w.

Zalasiewicz, J., Waters, C. N., Williams, M. Barnosky, A., Cearreta, A., Crutzen, P., Ellis, E., Ellis, M. A., Fairchild, I. J., Grinevald, J., Haff, P. K., Hajdas, I., Leinfelder, R., McNeill, J., Odada, E. O., Poirier, C., Richter, D., Steffen, W., Summerhayes, C., Syvitski, J. P. M., Vidas, D., Wag - reich, M., Wing, S. L., Wolfe, A. P., Zhishen, A., Oreskes, N. 2015. When did the Anthropocene begin? A mid twentieth century boundary level is stratigraphically optimal. *Quaternary International* 383, 196-203. https://doi.org/10.1016/j.quaint.2014.11.045.

Zalasiewicz, J., Waters, C.N., Wolfe, A.P., Barnosky, A.D., Cearreta, A., Edgeworth, M., Ellis, E.C., Fairchild, I.J., Gradstein, F.M., Grinevald, J., Haff, P., Head, M.J., Ivar do Sul, J.A., Jeandel, C., Leinfelder, R., Mcneill, J.R., Oreskes, N., Poirier, C., Revkin, A., Richer, D.B., Steffen, W., Summerhayes, C., Syvitski, J.P.M., Vidas, D., Wagreich, M., Wing, S., Williams, M. 2017. Making the case for a formal Anthropocene Epoch: an analysis of ongoing critiques. *Newsletters on Stratigraphy* 50 (2), 205-226. https://doi.org/10.1127/nos/2017/0385.