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Operationalizing local ecological knowledge in climate change research: Challenges and opportunities of citizen science

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Abstract Current research on the local impacts of climate change is based on contrasting results from the simulation of historical trends in climatic variables produced with global models against climate data from independent observations. To date, these observations have mostly consisted on weather data from standardized meteorological stations. Given that the spatial distribution of weather stations is patchy, climate scientists have called for the exploration of new data sources. Knowledge developed by Indigenous Peoples and Local Communities with a long history of interaction with their environment has been proposed as a data source with untapped potential to contribute to our understanding of the local impacts of climate change. In this chapter, we discuss an approach that aims to bring insights from local knowledge systems to climate change research. Firstly, we present a number of theoretical arguments that give support to the stand that local knowledge systems can contribute in original ways to the endeavors of climate change research. Then, we explore the potential of using information and communication technologies to gather and share local knowledge of climate change impacts. We do so through the examination of a citizen science initiative aiming to collect local indicators of climate change: the CONECT-e platform (www.conecte.es). Our findings illustrate that citizen science can inspire new approaches to articulate the inclusion of local knowledge systems in climate change research. However, this requires outlining careful and ethical approaches towards knowledge validation and recognizing that there aspects of local ecological knowledge that are incommensurable with scientific knowledge.

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1. Introduction

While there is well-established evidence that climate is changing (IPCC 2013), we still have a poor understanding of how climate change differently impacts physical and biological systems across the globe (Stott et al. 2010). Scientists acknowledge that downscaling global models to resolutions that are relevant for policy-making is challenging. This is so because of the uncertainties introduced by both the downscaling techniques and the coarse-scale data that drive global models (Zou et al. 2010). Social scientists also argue that a better understanding of local climate change also requires a thorough analysis of its impacts on local social-ecological systems (Adger et al. 2013; Crate 2011). Local communities differently experience climate change impacts, not only because such impacts are place-specific but also because local economic systems and culture mediate climate change final impacts on social-ecological systems (Barnes et al. 2013).

In their quest to better understand local climate change impacts, both natural and social scientists are challenged by the scarcity of data. This has resulted in climate scientists calling for the exploration of new data sources (Rosenzweig and Neofotis 2013). Within this context, several authors have argued that local ecological knowledge has an untapped potential to contribute to further our understanding of local impacts of climate change (Barnes et al. 2013; Savo et al. 2016). Researchers have documented many instances in which Indigenous Peoples and Local Communities (IPLC) with a long history of interaction with their environment have developed complex knowledge systems that allow them to detect changes in local weather and climatic variability as well as the impacts of such changes in the physical and the biological systems on which they depend (Fernández-Llamazares et al. 2015; Orlove et al. 2000; Reyes-García et al. 2016). Moreover, researchers also claim that -beyond their potential to detect changes on physical and biological systems- insights from local knowledge systems can improve our understanding of how climate change impacts local socioeconomic systems and livelihoods (Ford et al. 2016; IPCC 2014; Nakashima et al. 2012). Given that the way in which people perceive changes influences how they respond to them (Weber 2011), understanding the perceived impacts of climate change on local social-ecological systems could contribute to the development of appropriate adaptation and mitigation policies (Ford et al. 2016; Tengö et al. 2014).

Despite this potential, insights from local knowledge systems continue to be largely absent from both climate change research and global climate policy fora (Ford et al. 2016; IPCC 2014). Several reasons explain this absence. Firstly, scholars have argued that it is difficult to discern whether locally reported impacts to physical and biological systems can be really attributed to climate change, as the complexity of such systems and confounding drivers of change (e.g., geological processes, land-use change, or human demography shifts) make attribution difficult (IPCC 2014; Rosenzweig and Neofotis 2013). While the problem of attribution is common to any research on climate change impacts, it seems to be aggravated when assessing localized impacts through local knowledge. Secondly, even scholars who recognize the potential value of local knowledge systems acknowledge that such knowledge systems are epistemologically different from scientific knowledge (Ford et al. 2016). Researchers working on local ecological knowledge have argued that, while this type of knowledge is based on factual and direct observations of biophysical phenomena, it is also largely perceptual, inherently tacit, and held in embodied experiential forms (i.e., not articulated in a form easily accessible to others; Garay-Barayazarra and Puri 2011; Orlove et al. 2010). Given these characteristics, it is difficult for local people to express their observations of weather changes in a way that can be compared with instrumental data (Reyes-García et al., 2018b). Such epistemological differences make it difficult to engage insights from these knowledge systems within the quantitative approach prevalent in climate change research (Adger et al. 2013). Finally, the spatial and temporal resolution of local knowledge tends to be less well defined than that of instrumental observations. For example, by nature of their mobile lifestyle, hunter-gatherers or nomadic pastoralists can gather ethnoclimatic information over areas larger than the ones covered by weather stations, which can result in a spatial mismatch between both measures (Fernández-Llamazares et al. 2017; Marin 2010).

In the face of these challenges, in this chapter we discuss an approach that aims to bring insights from local knowledge systems to climate change research. Firstly, we present the theoretical arguments that give support to the idea that local knowledge systems can contribute in original ways to the endeavors of climate change research. Then, we explore the potential use of Information and Communication Technologies (ICTs) to gather and share local knowledge of climate change impacts. We do so through the examination of a citizen science initiative aimed at collecting local ecological knowledge: the CONECT-e platform (www.conecte.es). Specifically we discuss the opportunities and challenges of this approach to meaningfully gather local knowledge for understanding local climate change impacts.

2. The theory: The complementarity of local and scientific knowledge systems in climate research

Researchers have long debated the epistemological status of local knowledge systems in relation to mainstream scientific knowledge (e.g., Brokensha et al. 1980). This debate is also lively in climate change research, since some authors argue that there has been little effort to create synergies between scientific and local knowledge systems (Ford et al. 2016). On one side of the debate, many scientists consider scientific validation of local knowledge as a pre-requisite for the inclusion of such knowledge in many research frameworks (see the discussion in Agrawal 1995). Along these lines, most previous studies aiming to bring local knowledge to climate research have often attempted to compare scientific data with local observations of climate change (e.g., Chaudhary and Bawa 2011; Marin 2010). For example, the authors of a recent meta-analysis of local indicators of climate change by resource-dependent societies around the world state that the local observations included in the study had been '*verified* (…), *demonstrating that the observations from individual case studies are consistent with climate data*' (Savo et al. 2016:462). While considering both knowledge systems as valid, these studies tend to evaluate the accuracy of local knowledge systems through scientific validation, implicitly confining local and scientific knowledge to discrete categories (Simpson 2004).

On the other side of the debate, other authors argue that knowledge generated by different knowledge systems should be viewed as valid (Pyhälä et al. 2016; Sutherland et al. 2013; Tengö et al. 2014). In that view, conflicting or contradictory evidence between –or within– different knowledge systems should not be neglected, dismissed, or concealed, but rather considered as a starting point for further knowledge generation. This recognition is precisely the cornerstone of the Multiple Evidence Base (MEB) approach, which has been proposed as a mechanism to create synergies across knowledge systems in sustainability science (Sutherland et al. 2013; Tengö et al. 2014). The MEB approach attempts to bring together different knowledge systems on an equal platform where validation of knowledge occurs primarily within rather than across knowledge systems and where the knowledge generated by each system is viewed as useful in itself (Schweizer 2006; Tengö et al. 2014, 2017). This is important because, when local knowledge becomes *scientized* and assimilated within Western epistemic frameworks, it is often deprived of its local meaning (Mistry and Berardi 2016). As a result, a narrow understanding of what constitutes valid data can easily lead to the exclusion of essential insights from other knowledge systems (Klein et al. 2014; Mistry and Berardi 2016). Moreover, using the validation methods of a certain system to evaluate the reliability of knowledge from another system compromises the quality and/or integrity of the knowledge being "validated" (Berkes 2008; Nakashima and Roué 2002), which can be disempowering for local knowledge holders (Nadasdy 1999; Pyhälä et al. 2016). Alternatively, the identification of complementarities and contradictions between different knowledge systems can generate synergies that contribute to an enriched understanding of a process (Tengö et al. 2014, 2017). This approach has provided an overall framework for integrating different knowledge systems in science-policy arenas and agreements such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) or the Convention on Biological Diversity (CBD) but has yet to be integrated into climate research (Tengö et al. 2017).

Following this second line of thought, here we argue that climate research would benefit by focusing on bridging different knowledge systems and experiment with the co-production of knowledge in its quest to understand climate change impacts. Previous research suggests that there are two specific aspects for which local knowledge systems could complement scientific knowledge on the local impacts of climate change. First, local knowledge systems have the potential to fill spatial and temporal gaps in instrumental climatic data. And second, local knowledge systems could provide rich and fine-grained accounts of climate change impacts, beyond standard climatic measures (Reyes-García et al. 2016). We briefly discuss these two potential contributions.

2.1 Local Knowledge Systems can fill spatial and temporal gaps in instrumental observations

To date, the main tools available to project changes in climate are Global Circulation Models (GCMs), i.e., mathematical representations of atmospheric, oceanic, and biotic processes that govern the global climate system. In combination with emission scenarios, GCM are commonly used to project future climates and thus have become conductive in all IPCC assessments (e.g., IPCC 2013). However, these climate models are best used to represent global and continental processes, operating at scales that are coarser than those at which impacts are observed and managed (e.g., Giorgi et al. 2009, Rummukainen 2016). Although resolution is increasing with computer power, GCMs have limited capacity to simulate climate variability and extreme events (e.g., Huntingford et al. 2003; Schaeffer et al. 2005) or key regional or local climate aspects, a situation that led to calls for higher resolution in climate projections (Mearns et al. 2001). Consequently, the last decade has seen a burst of efforts to increase model's resolution through diverse downscaling approaches (IPCC 2007; Maraun et al. 2010, Rummukainen 2010). For example, the latest IPCC report (2013) largely took into account Regional Climate Models (RCMs), i.e., models of biophysical processes nested within GCMs but allowing for further resolution by taking into account regionally-relevant processes (e.g., orography, land-sea contrasts).

The performance of climate models (i.e., GCMs, RCMs) is often evaluated by simulating historical trends in climatic variables and then comparing them against independent observations mostly obtained from standardized weather stations. A major caveat of this approach is that instrumental data from standardized weather stations is patchy, both in space and time. Thus, there are important geographical gaps on weather station coverage, particularly in central Africa, the Amazon, Southern and Southeast Asia and the Arctic (Figure 1). Similarly, we lack historical climate records for a large part of the globe (New et al. 2002). Gaps in instrumental data can be addressed in a variety of ways. For example, climatologists have used data interpolation techniques (e.g., Hijmans et al. 2005). Such techniques, however, bring added uncertainties to modelling results (Brohan et al. 2006). An alternative approach has been to use data sources that are prior to instrumental records such as newspapers, ships' logs, weather diaries, or ancient manuscripts providing information on phenomena such as flowering and harvest dates or grain prices (Grau-Satorras et al. 2017; Lawrence 2009; Whitfield 2001).

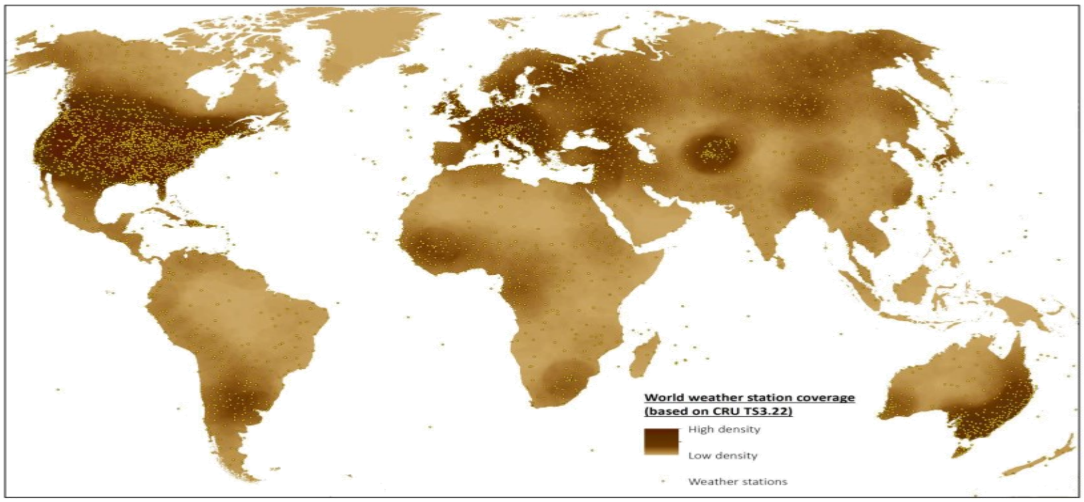

Figure 1. World distribution of weather stations. Source: Fernández-Llamazares 2015.

Thus, spatial gaps in instrumental observations could be complemented with information from local knowledge systems as 1) such gaps do overlap with areas inhabited by IPLC with a long history of interaction with their environment and 2) the proxies used from data prior to instrumental records resemble closely the information encoded in local knowledge systems (Green et al. 2010; Turner and Clifton 2009). Indeed, the first studies on this line have already contributed to climate research in several ways. For example, in the Arctic, Inuit reports of changes in weather predictability (based on linkages among winds, animal behavior, and ice conditions) led scientists to examine the particularities of the local climatic system finding evidence of a strong drop in temperature in the local spring afternoons, somewhat at odds with changes on a larger scale (Weatherhead et al. 2010). In the same line, research among the Tsimane', an Amazonian hunter-horticultural society, shows that Tsimane' observations of climatic variability, although at odds with predictions from global models, were congruent with predictions from local meteorological stations (Fernández-Llamazares et al. 2017), suggesting that local knowledge can be instrumental to enhance our understanding of local climate in regions for which climate station data are meagre, at best. In sum, collective memory encoded in local knowledge systems could be an alternative data source when evaluating climate models, downscaling projections, and/or interpolating gridded climate data.

2.2 Local Knowledge Systems can inform on impacts on biophysical systems

A recent review of local indicators of climate change has found that most previous research has focused on reports of local indicators of changes in the climatic system (i.e., temperature and precipitation) (Savo et al. 2016). While there are instances in which IPLC present accurate perceptions and documentation of change in the climatic system, research also shows that, often, climate change is better perceived and described through its impacts on the physical and the biological systems (Reyes-García et al. 2016).

People with a long history of resource dependence seem to be in a unique position to provide first-hand descriptions of the complex responses to climate change of physical and biological systems (Gearheard et al. 2011; Krupnik et al. 2009; Moller et al. 2004). Indeed, previous work has already documented the richness of local knowledge systems regarding changes in local physical and biological systems (see Reyes-García et al. 2016 for a review). For instance, IPLC can provide a rich set of indicators referring to changes in the hydrological system and the cryosphere, including changes in snow cover, sea ice, lake ice, river ice, glaciers, ice sheets, and permafrost (e.g., Alessa et al. 2008; Gearheard et al. 2006; Laidler 2006; Nichols et al. 2004; Pearce et al. 2010; Riseth et al. 2011). Local observations of climate change impacts have also reported changes on coastal systems and particularly in relation to sea-level rise (Crona et al. 2013). Reports of impacts on the soil systems include changes in soil moisture (Kassie et al. 2013) or soil erosion (Boillat and Berkes 2013). Similarly, IPLC have reported many changes in biological systems, with a large emphasis on changes in terrestrial systems –often referring to specific species– and in seasonal events (e.g., Eisner et al. 2013; Krupnik 2009; Lantz and Turner 2003; Mallory et al. 2003; Prober et al. 2011; Tam et al. 2013).

This potential contribution of local knowledge systems to climate research seems even more important after the IPCC Fifth Assessment stressed that climate research should go beyond the climatic and also include the biophysical system (IPCC 2013). Considering a general lack of scientific documentation on how temperature changes and other climatic variability affect many of the biophysical systems of the world, local knowledge systems could become an alternative data source.

3. Challenges and opportunities of Citizen Science

While theoretical arguments could give support to the idea that bringing insights from local knowledge systems into climate research could result in the generation of new knowledge, few empirical examples exist aiming to materialize this theoretical approach. In this section, we explore the potential of one of them, citizen science, to bring insights from local knowledge systems into climate research. We discuss both opportunities and challenges of the approach based on ongoing efforts to operationalize it.

Previous studies aiming to generate synergies between local and scientific knowledge on climate change have mostly relied on ethnographic fieldwork to identify local indicators of impacts generated by climate change (Crona et al. 2013; Galloway-McLean 2010). The approach, while informative, is highly time-consuming and –ultimately– under researcher's control. To achieve a more faithful representation of local knowledge, methodologies based on the sharing of information by knowledge holders themselves would be more adequate (Berkes 2017; Ford 2012; Ludwig 2001). In that sense, the use of citizen science provides an alternative to the standard ethnographic fieldwork, as this tool holds the potential both to promote the exchange of knowledge among an extended community of users and to make available local knowledge to the society at large, including climate researchers.

Citizen science was born at the beginning of the twentieth century and has flourished since then (Shirk et al. 2012). Citizen science has evolved from the use of non-scientists participants to conduct specific scientific tasks, like reporting abundance and species distribution, to citizens' participation in the design of scientific projects (Devictor et al. 2010; Dickinson et al. 2012), and recently to the creation of *citizen observatories* (Grainger 2017). Some citizen science projects have aimed at collecting local knowledge on climate change. For example, the Australian Government Bureau of Meteorology built a web-based project where Aboriginal communities can enter their weather calendars (http://www.bom.gov.au/iwk/; Lefale 2010). Some of these initiatives have tried to create bridges between different knowledge systems contributing information on climate change. One of such initiatives is a project by the National Institute of Water and Atmospheric Research of New Zealand (NIWA) which aims to bring together Māori ecological knowledge and practices with Western scientific methodologies of climate observations, research, assessment and response to human-induced climate change (https://www.niwa.co.nz/te-kūwaha; King et al. 2008). Similarly, the Alaska Native Tribal Health Consortium (ANTHC) has developed an online platform where scientists and Alaskan Indigenous Peoples submit and share observations about unusual environmental and weather events (Local Environmental Observers (LEO) Network: https://www.leonetwork.org). While citizen science initiatives might offer the potential to create synergies between local knowledge holders and climate change researchers, they are not free from challenges. In what comes, we explore some of the challenges we encountered while designing the section on local indicators of climate change of the platform: CONECT-e (*Compartiendo el CONocimiento ECologico Tradicional*[1], www.conecte.es).

CONECT-e is a citizen science initiative funded by Spanish public institutions aiming to bring local knowledge systems into efforts to document, protect, and share Spanish traditional ecological knowledge and practices (Calvet-Mir et al. 2018; Reyes-García et al. 2018a, 2018 in press). The pilot version of the platform, launched publicly in February 2017, focused on knowledge regarding plants, landraces, and ecosystems. To document knowledge, CONECT-e promotes that users contribute their own knowledge but also that they act as citizen scientists, interviewing other knowledge holders and entering data for them. To protect knowledge, a Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0) protects all the content of CONECT-e platform, so no patents can be issued on knowledge published in CONECT-e. To share knowledge, the CONECT-e team works with different groups of interest (e.g., technical and primary education students, elders in rural adult schools, farmers and home gardeners, members of seed network associations, amateur ethnobotanists and folklorists) to engage them in activities for knowledge transmission.

In the sections already operating, the CONECT-e team has tried to bridge the gap between knowledge systems in very specific ways. For example, in the design of the section on landraces, we have closely worked with the Spanish Seed Network, Red de Semillas "Resembrando e Intercambiando" (RdS; http://www.redsemillas.info/), a civil society organization that promotes the commons management of landraces and farmer's varieties in the agri-food system. This alliance brings interested groups of citizens to the design of the project, resulting in a data collection tool tailored to the needs of the participating groups. Following Tengö et al. (2014), we also designed the platform to facilitate knowledge validation within the knowledge system. Thus, although all data entered in the CONECT-e platform is first reviewed

[1] *Sharing Traditional Ecological Knowledge*, from its Spanish initials.

by the CONECT-e team (who ensures that data entered relates to traditional ecological knowledge), all data published can then be validated through a peer-to-peer validation inspired by the Wikipedia peer governance system (Kostakis 2010). This peer-to-peer technique involving users is a common practice in other citizen science websites like Encyclopedia of life (https://eol.org) or Natusfera (https://natusfera.gbif.es/). Specifically, the platform is designed in a way that registered users can "like" or "agree" with information posted in the platform, thus generating a type of review among peers holding similar knowledge.

We tried to apply these same principles to develop a section on local indicators of climate change. The goal of the section is that citizens enter observations of how climate change is impacting the physical, biological, and socioeconomic systems on which they depend. The proposed design would allow information to be entered in relation to one or several topics (e.g., water, ice and snow, weather, seasons, birds, plants, mammals, health, transportation, etc.) or through a map to help citizens to locate observations. All information entered will be place-specific (i.e., georeferenced). Citizens will also be able to enter information describing the local measures that they are taking to adapt to such changes or to check information entered by other users. The idea is that information could complement the information provided by instrumental data on climate change. Spain has a network of over 3500 weather stations integrated in different networks. Official stations belonging to the national weather agency (AEMET) and agroclimatic information system for irrigation (SIAR) represent only one third of them, and more than 2300 are from non-professional and external collaborators of AEMET, including lay citizens. Nonetheless, not all the geographical areas are equally covered (de Castro et al. 2005; Gonzalez-Hidalgo et al 2009; Río et al. 2011). Moreover, Spanish Global Change Tracking Network is constituted only by eight observatories located in National Parks, which make reports based on data from weather stations, water analysis stations, particle pickups, buoys and photometers (Ministerio para la Transición Ecológica, 2018). In such context, local knowledge of climate change impacts would provide an alternative source of data, which could be particularly relevant in areas with scant data. Moreover, this information would cover not only impacts on biophysical systems, but also the social perception of such changes, i.e., how rural communities perceive climate change impacts in physical, biological, and sociocultural systems.

Despite the potential, we have encounter two important challenges in our efforts to develop this section: finding relevant interest groups and achieving local knowledge holders' participation. First, differently than in other domains of knowledge (e.g., landraces), in Spain there are no citizen's interest groups on climate change impacts. Consequently, the design of the section has being mainly done by CONECT-e team, who based the selection of groups of impacts on a literature review of previous impacts reported by IPLC around the world (Reyes-García et al. 2016). The approach is challenging because research suggest that not including citizen's on the design of the project has important implications for the potential posterior use of this information by citizen's themselves (Turreira-García et al. 2018). Second, in the Spanish context, local knowledge holders are typically elderly people or people with few skills in the use of ICTs. While younger generations are much at ease with such technologies, in contrast they do not hold much local knowledge even in the more remote rural areas. A potential way to defeat this challenge to participation will be to organize activities that connect the two generations so to match the technological expertise of the younger generation with the local knowledge of the elders. This alliance would make it possible not only the gathering of local knowledge in CONECT-e, but also *in situ* intergenerational knowledge transmission. Such an approach is being increasingly applied to revitalize traditional oral narratives amongst Indigenous Peoples

(Fernández-Llamazares and Cabeza 2017; Iseke and Moore 2011; Ryan 2015), but again poses the challenge that it requires intensive fieldwork.

4. Conclusion

The speed and magnitude of current global changes make standard scientific approaches ineffective to properly grasp the local impacts of climate change. The time needed to collect ground data on climate change impacts on all physical, biological and socioeconomic variables would be so long that, by the time data collection is finished, the system might have changed completely. In the quest to bring alternative data sources to the table, in this chapter, we have presented the theoretical arguments that support the idea that local knowledge systems can contribute in original ways to the endeavors of climate change research and then explored the potential of using ICTs to gather and share local knowledge of climate change impacts. Specifically, we have examined the opportunities and challenges of citizen-science initiatives to bridge scientific and local knowledge on the local impacts of climate change.

From our examination, we argue that while citizen science platforms might facilitate the co-production of new knowledge articulating communication between users, reducing time in fieldwork, and allowing simultaneous data collection in different geographical locations. Moreover, these initiatives can help connecting global discourses of climate change with local contexts, contributing to bring to daylight the knowledge, perspectives and voices of local people in the frontlines of climate change. The approach, however, is not without challenges as citizen science projects are inherently empirical and applying them in relation to local knowledge systems can incur in several epistemic, normative, methodological and ethical pitfalls that require careful attention. Such challenges need to be consciously addressed from project's initial stages to generate knowledge that is useful and legitimate for a broad range of actors across different knowledge systems.

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