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

Victoria Reyes-García, Álvaro Fernández-Llamazares, David García-del-Amo, Mar Cabeza

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 of 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. First, we present a number of 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 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 LICCI project (www.licci.eu). 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 are 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 differentially 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 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 experience climate change impacts differently, 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 furthering 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. First, 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. Second, 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. First, 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 on climate change impacts around the world: the LICCI project (www.licci.eu). 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 in their own right (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 experimenting 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. 2019b). 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 standard 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 the 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).

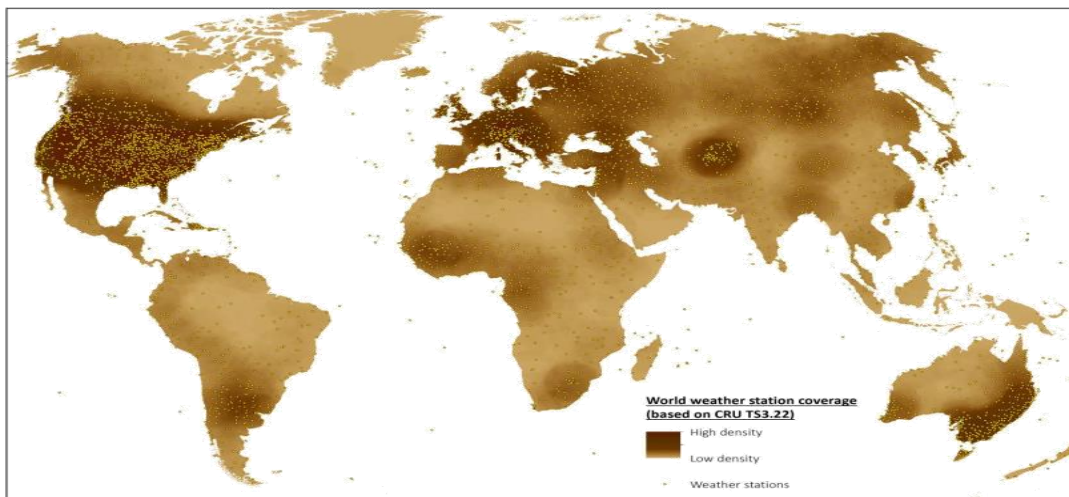


Figure 1. World distribution of weather stations. Source: Fernández-Llamazares 2015.

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 vein, 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 observations of impacts generated by climate change (Crona et al. 2013; Galloway-McLean 2010; Reyes-García et al. 2019b). The approach, while informative, is highly time-consuming and –ultimately– under the 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 appropriate (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-scientist 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 have encountered while designing a platform to collect local indicators of climate change under the framework of the LICCI project (*Local Indicators of Climate Change Impacts*, www.licci.eu).

LICCI is an ERC funded project that aims to bring insights from Indigenous and local knowledge (ILK) to climate research. The LICCI project got inspiration from CONECT-e (www.conecte.es), a citizen science initiative 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, 2019a). To document traditional knowledge, CONECT-e promotes that users contribute their own knowledge and that talk to other knowledge holders and enter their knowledge. 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 it. 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) to engage them in activities for knowledge transmission. 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), the CONECT-e platform is designed to facilitate knowledge validation within the knowledge system. Thus, all data published can be validated through a peer-to-peer validation inspired by the Wikipedia peer governance system (Kostakis 2010), and also common 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 are applying these same principles in the development of a global platform to collect information of local indicators of climate change impacts. The platform, which mostly targets IPLC whose livelihoods show direct dependence on the environment, will collect people's observations of how climate change is impacting the physical, biological, and socioeconomic systems on which they depend. The proposed design would guide users to enter information in relation to one or several elements potentially impacted by climate change (e.g., water, ice and snow, weather, seasons, birds, plants, mammals, health, transportation, etc.) in a way that the information can be compared across sites (see Reyes-García et al., 2019b). All information entered will be place-specific, but with a resolution that does not allow geographical tracking. Information will include previous reports from IPLC on climate changes impacts documented in the literature, selected case studies from the LICCI team, and information from any citizen in the world. The idea is that information could complement the information provided by instrumental data on climate change. 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 encountered two important challenges in our efforts to develop this platform: finding relevant interest groups and bridging the technology gap with local knowledge holders. First, differently than in other domains of knowledge (e.g., landraces), it is difficult to identify citizen's interest groups on climate change impacts. We have established contacts with UNESCO's Local and Indigenous Knowledge Systems programme (LINKS) as well as with the Local Communities and Indigenous Peoples Platform (LCIPP) Facilitative Working Group (FWG) of the United Nations Framework Convention on Climate Change (UNFCCC), initiatives aiming to promote ILK's inclusion in global climate science and policy processes. However, differently from the RdS, these initiatives do not directly represent the wide diversity of IPLC around the world, for which it is difficult to motivate local participation through them. Consequently, the design of the section has mainly been done by the LICCI 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; Reyes-García et al. 2019b). The approach is challenging because research suggest that not including citizens in the design of the project has important implications for the potential later use of this information by citizens themselves (Turreira-García et al. 2018). Second, targeted local knowledge holders are typically IPLCs highly dependent on the environment for subsistence, often with few skills in the use of ICTs. To bridge this technology gap, we are working with a group of trained partners (i.e., PhD students, postdocs, and practitioners), who can provide technological support to local knowledge holders. This alliance would make possible not only the gathering of local knowledge in the LICCI platform, but also the *in situ* transmission of knowledge. 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. The issue is then, whether bridging the technology gap might be prohibitive for such type of projects.

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 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 connect global discourses of climate change with local contexts, contributing to bringing to daylight the knowledge, perspectives and voices of local people on 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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References

- Adger, W., Barnett, J., Brown, K., Marshall, N., & O'Brien, K. (2013). Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change*, 3, 112-117.
- Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Development and Change*, 26(3), 413-439, doi: 10.1111/j.1467-7660.1995.tb00560.x
- Alessa, L.N., Kliskey, A.A., Williams, P., & Barton, M. (2008). Perception of change in freshwater in remote resource-dependent Arctic communities. *Global Environmental Change*, 18(1):153-164.
- Barnes, J., Dove, M., Lahsen, M., Mathews, A., McElwee, P., McIntosh, R., et al. (2013). Contribution of anthropology to the study of climate change. *Nature Climate Change*, 3, 541-544.
- Berkes, F. (2008). *Sacred ecology*. New York: Routledge.
- Berkes, F. (2017). Environmental Governance for the Anthropocene? Social-Ecological Systems, Resilience, and Collaborative Learning. *Sustainability*, 9(7), 1232, doi:10.3390/su9071232
- Boillat, S., & Berkes, F. (2013). Perception and Interpretation of Climate Change among Quechua Farmers of Bolivia: Indigenous Knowledge as a Resource for Adaptive Capacity. *Ecology and Society*, 18(4), doi:Unsp 2110.5751/es-05894-180421.
- Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D. (2006). Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. *Journal of Geophysical Research*, 111: D12106, DOI: 10.1029/2005JD00654.
- Brokensha, D., Warren, D., & Werner, O. (1980). *Indigenous Knowledge Systems and Development*. University Press of America, Lanham, Maryland, United States.
- Calvet-Mir, L., P. Benyei, L. Aceituno-Mata, M. Pardo de Santayana, D. López-García, M. Carrascosa, et al. (2018). Contributions of traditional agroecological knowledge as a digital commons to agroecological transitions. The case of the CONECT-e platform. *Sustainability*, SI "Agroecology for the Transition towards Social-Ecological Sustainability". 10, 3214. Doi:10.3390/su10093214
- Chaudhary, P., & Bawa, K.S. (2011). Local perceptions of climate change validated by scientific evidence in the Himalayas. *Biology Letters* 11(8): 767-770.
- Crate, S. A. (2011). Climate and Culture: Anthropology in the Era of Contemporary Climate Change. *Annual Review of Anthropology*, 40 (40):175-194, doi:10.1146/annurev.anthro.012809.104925.
- Crona, B., Wutich, A., Brewis, A., & Gartin, M. (2013). Perceptions of climate change: Linking local and global perceptions through a cultural knowledge approach. *Climatic Change*, 119(2), 519-531, doi:10.1007/s10584-013-0708-5.
- Devictor, V., Whittaker, R. J., & Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Diversity and Distributions*, 16: 354–362. doi:10.1111/j.1472-4642.2009.00615.x
- Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., et al. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, 10(6), 291-297, doi: 10.1890/110236.
- Eisner, W. R., Hinkel, K. M., Cuomo, C. J., & Beck, R. A. (2013). Environmental, cultural, and social change in Arctic Alaska as observed by Iñupiat elders over their lifetimes: a GIS synthesis. *Polar Geography*, 36, 1-11.

- Fernández-Llamazares, Á. (2015). *Indigenous knowledge of a changing environment: an ethnoecological perspective from Bolivian Amazonia*. PhD Thesis, Autonomous University of Barcelona.
- Fernández-Llamazares, Á., & Cabeza, M. (2017). Rediscovering the Potential of Indigenous Storytelling for Conservation Practice. *Conservation Letters*. doi: 10.1111/conl.12398
- Fernandez-Llamazares, A., García, R., Díaz-Reviriego, I., Cabeza, M., Pyhälä, A., & Reyes-García, V. (2017). An empirically-tested overlap between local and scientific knowledge of a changing climate. *Regional Environmental Change*. 17(6): 1673-1685. 2017. DOI 10.1007/s10113-017-1125-5.
- Fernández-Llamazares, Á., Méndez-López, E., Díaz-Reviriego, I., McBride, M., Pyhälä, A., Rosell-Melé, A., & Reyes-García, V. (2015). Links between media communication and local perceptions of climate change in an indigenous society. *Climatic Change*, 131(2), 307-320, doi:10.1007/s10584-015-1381-7.
- Ford, J. D. (2012). Indigenous health and climate change. *American journal of public health*, 102(7), 1260-1266. doi: 10.2105/AJPH.2012.300752
- Ford, J. D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Willox, A. C., et al. (2016). Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, 6(4), 349-353, doi:10.1038/nclimate2954.
- Galloway-McLean, K. (2010). *Advance Guard: Climate Change Impacts, Adaptation, Mitigation and Indigenous Peoples—A Compendium of Case Studies*. United Nations University. Institute for Advanced Studies (UNU-IAS), Traditional Knowledge Initiative, Darwin, NT, Australia.
- Garay-Barayazarra, G., & Puri, R. K. (2011). Smelling the monsoon: Senses and traditional weather forecasting knowledge among the Kenyah Badeng farmers of Sarawak, Malaysia. *Indian Journal of Traditional Knowledge*, 10, 21-30.
- Gearheard, S., Aporta, C., Aipellee, G., & O'Keefe, K. (2011). The Igliniit project: Inuit hunters document life on the trail to map and monitor arctic change. *Canadian Geographer-Geographe Canadien*, 55(1), 42-55, doi:10.1111/j.1541-0064.2010.00344.x.
- Gearheard, S., Matumeak, W., Angutikjuaq, I., Maslanik, J., Huntington, H. P., Leavitt, J., et al. (2006). "It's Not that Simple": A Collaborative Comparison of Sea Ice Environments, Their Uses, Observed Changes, and Adaptations in Barrow, Alaska, USA, and Clyde River, Nunavut, Canada. *Ambio* 35(4): 204-212.
- Giorgi, F., Jones, C. and Asrar, G.R. (2009). Addressing climate information needs at the regional level: the CORDEX framework. *World Meteorological Organization Bulletin*, Vol. 58 (3), pp. 175-183
- Grainger, A. (2017). Citizen Observatories and the New Earth Observation Science. *Remote Sensing*, 9(2), 153. doi:10.3390/rs9020153
- Grau-Satorras, M., I. Otero, E. Gómez-Baggethun, V. Reyes-García (In press). Prudent peasantries: multilevel adaptation to drought in NE Spain (1600-1715). *Environment and History*.
- Green, D., Billy, J., & Tapim, A. (2010). Indigenous Australians' knowledge of weather and climate. *Climate Change*. doi: 10.1007/s10584-010-9803-z
- Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25:1965–1978.

- Huntingford, C., Jones, R.G., Prudhomme, C., Lamb, R., Gash, J.H., & Jones, D.A. (2003). Regional climate-model predictions of extreme rainfall for a changing climate. *Quarterly Journal of the Royal Meteorological Society*, 129: 1607–1621.
- IPCC (2007). *Climate Change 2007: The Physical Science Basis—Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)] Cambridge Univ. Press, Cambridge, U.K.
- IPCC (2013). *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.
- IPCC. (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
- Iseke, J. & Moore, S. (2011). Community-based indigenous digital storytelling with elders and youth. *American Indian Culture and Research Journal*, 35, 19-38.
- Johnson, J. T., Howitt, R., Cajete, G., Berkes, F., Louis, R. P., & Kliskey, A. (2016). Weaving Indigenous and sustainability sciences to diversify our methods. *Sustainability Science*, 11(1), 1-11, doi: 10.1007/s11625-015-0349-x.
- Kassie, B. T., Hengsdijk, H., Rotter, R., Kahiluoto, H., Asseng, S., & Van Ittersum, M. (2013). Adapting to Climate Variability and Change: Experiences from Cereal-Based Farming in the Central Rift and Kobo Valleys, Ethiopia. *Environmental Management*, 52(5), 1115-1131, doi:10.1007/s00267-013-0145-2.
- Klein, J., Hopping, K.A., Yeh, E.T., Nyima, Y., Boone, R.B., & Galvin, K.A. (2014). Unexpected climate impacts on the Tibetan Plateau: local and scientific knowledge in findings of delayed summer. *Global Environmental Change* 28(1): 141-152.
- King, D. N. T., Skipper, A., & Tawhai, W. B. (2008). Māori environmental knowledge of local weather and climate change in Aotearoa–New Zealand. *Climatic Change*, 90(4), 385, doi: 10.1007/s10584-007-9372-y.
- Kostakis, V. 2010. Identifying and understanding the problems of Wikipedia’s peer governance: The case of inclusionists versus deletionists. *First Monday* 15:1-11.
- Krupnik, I. (2009). *"The Way We See It Coming": Building the Legacy of Indigenous Observations in IPY 2007-2008*. Smithsonian at the Poles: Contributions to International Polar Year Science.
- Laidler, G. J. (2006) Inuit and scientific perspectives on the relationship between sea ice and climate change: the ideal complement? *Climatic Change*, 78:407–444.
- Lantz, T.C. & Turner, N.J. (2003). Traditional Phenological Knowledge (TPK) of Aboriginal Peoples in British Columbia. *Journal of Ethnobiology* 23(2): 263-286.

- Lawrence, A. (2009). The first cuckoo in winter: phenology, recoding, credibility and meaning in Britain. *Global Environmental Change* 19:173–179, doi: 10.1016/J.GLOENVCHA.2009.01.006
- Lefale, P. F. (2010). Ua ‘afa le Aso Stormy weather today: traditional ecological knowledge of weather and climate. The Samoa experience. *Climatic Change*, 100(2), 317-335, doi: 10.1007/s10584-009-9722-z.
- Ludwig, D. (2001). The era of management is over. *Ecosystems*, 4(8), 758-764, doi: 10.1007/s10021-001-0044-x
- Mallory, M. L., Gilchrist, H.G., Fontaine, A.J., Akearok, J.A. (2003). Local ecological knowledge of Ivory Gull decline in Arctic Canada. *Arctic* 56(3): 293-298.
- Maraun, D., Wetterhall, F., Ireson, A.M., Chandler, R.E., Kendon, E.J., Widmann, M., et al. (2010). Precipitation downscaling under climate change: recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics*, 48, p. RG3003 <http://dx.doi.org/10.1029/2009RG000314>
- Marin, A. (2010). Riders under storms: Contributions of nomadic herders’ observations to analysing climate change in Mongolia. *Global Environmental Change*, 20(1): 162-176.
- Mearns, L. O., Hulme, M., Carter, T. R., Leemans, R., Lal M., and Whetton, P. (2001). Climate Scenario Development, Chapter 13 in Houghton et al., *IPCC Third Assessment Report. The Science of Climate Change*, Cambridge University Press: Cambridge, pp. 739–768.
- Mistry, J. & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, 352, 1274-1275.
- Moller, H., Berkes, F., Lyver, P. O., & Kislalioglu, M. (2004). Combining science and traditional ecological knowledge: Monitoring Populations for co-management. *Ecology and Society*, 9(3).
- Nadasdy, P. (1999). The politics of TEK: Power and the “integration” of knowledge. *Arctic Anthropology* 36: 1–18.
- Nakashima, D. J., Galloway-McLean, K., Thulstrup, H.D., Ramos Castillo, A., & Rubis, J. (2012). *Weathering Uncertainty: Traditional Knowledge for Climate Change Assessment and Adaptation*. UNESCO, Paris, France.
- Nakashima, D. J., & Roué, M. (2002). Indigenous knowledge, peoples and sustainable practice. In *Encyclopedia of global environmental change*, ed. T. Munn, 314–324. Chichester: Wiley.
- New, M., Lister, D., Hulme, M., & Makin, I. (2002). A high-resolution data set of surface climate over global land areas. *Climate Research* 21:1-25.
- Nichols, T., Berkes, F., Jolly, D., & Snow, N. B. (2004). Climate Change and Sea Ice: Local Observations from the Canadian Western Arctic. *Arctic* 57(1):68-79.
- Orlove, B., Chiang, J., & Cane, M. (2000). Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. *Nature*, 403: 68-71.
- Orlove, B., Roncoli, C., Kabugo, M., & Majugu, A. (2010). Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. *Climatic Change*, 100 (2), 243-265.
- Pearce, T., Smit, B., Duerden, F., Ford, J. D., Goose, A., & Kataoyak, F. (2010). Inuit vulnerability and adaptive capacity to climate change in Ulukhaktok, Northwest Territories, Canada. *Polar Record*, 46(237), 157-177, doi:10.1017/s0032247409008602.

- Prober, S.M., O'Connor, M.H., & Walsh, F.J. (2011). Australian Aboriginal Peoples' Seasonal Knowledge: a Potential Basis for Shared Understanding in Environmental Management. *Ecology and Society* 16(2): 12.
- Pyhälä, A., Fernández-Llamazares, A., Lehvävirta, H., Byg, A., Ruiz-Mallén, I., Salpeteur, M. & Thornton, T. F. (2016). Global environmental change: local perceptions, understandings, and explanations. *Ecology and Society* 21(3):25. <http://dx.doi.org/10.5751/ES-08482-210325>
- Reyes-García, V., Fernández-Llamazares, A., Gueze, M., Garces, A., Mallo, M., Vila-Gomez, M., et al. (2016). Local indicators of climate change: the potential contribution of local knowledge to climate research. *Wiley Interdisciplinary Reviews-Climate Change*, 7(1), 109-124, doi:10.1002/wcc.374.
- Reyes-García, V., L. Aceituno-Mata, P. Benyei, L. Calvet-Mir, M. Carrascosa, M. Pardo-de-Santayana, J. Tardío for CONECT-e, IECTBA and Red de Semillas. (2018a). Governing landraces and associated knowledge as commons. From theory to practice. In F. Girard and C. Frison, *The Commons, Plant Breeding and Agricultural Research. Challenges for Food Security, Agrobiodiversity and Law*. Routledge "Earthscan Food and Agriculture" series. Chapter 12, 197-209.
- Reyes-García, V., P. Benyei, L. Calvet-Mir, (2019a). *Traditional Agricultural knowledge as commons*. In J. L. Vivero-Pol, T. Ferrando, O. de Schutter and U. Mattei (Eds). Routledge Handbook of Food as a Commons. Routledge. Chapter 11, 173-185.
- Reyes-García, V., Á. Fernández-Llamazares, M. Guèze, S. Gallois. (2018b). Does weather forecasting relate to foraging efforts? An empirical test among three hunter-gatherer societies. *Weather, Climate, and Society*. 10, 163–177. DOI: <https://doi.org/10.1175/WCAS-D-17-0064.1>
- Reyes-García, V., D. García-del-Amo, P. Benyei, Á. Fernández-Llamazares, K. Gravani, AB. Junqueira, V Labeyrie, X Li, DM. Matias, A McAlvay, PG Mortyn, A Porcuna-Ferrer, A Schlingmann, R Soleymani-Fard. A collaborative approach to bring insights from local observations of climate change impacts into global climate change research. *Current Opinion in Environmental Sustainability*. 39: 1-8. 2019b.
- Riseth, J. A., Tommervik, H., Helander-Renvall, E., Labba, N., Johansson, C., Malnes, E., et al. (2011). Sami traditional ecological knowledge as a guide to science: snow, ice and reindeer pasture facing climate change. *Polar Record*, 47(242), 202-217, doi:10.1017/s0032247410000434.
- Rosenzweig, C., & Neofotis, P. (2013). Detection and attribution of anthropogenic climate change impacts. *Wiley Interdisciplinary Reviews-Climate Change*, 4(2), 121-150, doi:10.1002/wcc.209.
- Rummukainen, M. (2010). State-of-the-art with regional climate models, *Wiley Interdisciplinary Reviews-Climate Change*, 1, 82–96, doi:10.1002/wcc.8.
- Rummukainen, M. (2016). Added value in regional climate modeling, *Wiley Interdisciplinary Reviews-Climate Change* 7 (1), 145-159
- Ryan, J.C. (2015). The virtual and the vegetal: creating a 'living' biocultural heritage archive through digital storytelling approaches. *Global Media Journal*, 9(1).
- Savo, V., Lepofsky, D., Benner, J. P., Kohfeld, K. E., Bailey, J., & Lertzman, K. (2016). Observations of climate change among subsistence-oriented communities around the world. *Nature Climate Change*, 6(5), 462-473, doi:10.1038/nclimate2958.

- Schaeffer, M., Selten, F.M., & Opsteegh, J.D. (2005). Shifts in means are not a proxy for changes in extreme winter temperatures in climate projections. *Climate Dynamics*, 25: 51–63.
- Schweizer, T. (2006). Epistemology: The nature and validation of anthropological knowledge. In *Research methods in anthropology: Qualitative and quantitative approaches*, ed. H.R. Bernard, 39–88. Altamira: Rowman.
- Shirk, J., Ballard, H., Wilderman, C., Phillips, T., Wiggins, A., Jordan, R. et al. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and Society*, 17(2), doi: 10.5751/ES-04705-170229
- Simpson, L. (2004). The colonial context for the indigenous experience of climate change. In: Helander, E., Mustonen, T. (eds) *Snowscapes, Dreamscapes: Snowchange book on community voices of change* (pp. 25-29). Tampere Polytechnic Publications, Tampere, Finland.
- Stott, P. A., Gillett, N. P., Hegerl, G. C., Karoly, D. J., Stone, D. A., Zhang, X., et al. (2010). Detection and attribution of climate change: a regional perspective. *Wiley Interdisciplinary Reviews: Climate Change*, 1(2), 192-211, doi:10.1002/wcc.34.
- Sutherland, W.J., Gardner, T.B., Haider, L.J., Dicks, L.V. (2013). How can local and traditional knowledge be effectively incorporated into international assessments? *Oryx* 48(1): 1-2.
- Tam, B. Y., Gough, W. A., Edwards, V., & Tsuji, L. J. S. (2013). The impact of climate change on the well-being and lifestyle of a First Nation community in the western James Bay region. *Canadian Geographer-Geographe Canadien*, 57(4), 441-456, doi:10.1111/j.1541-0064.2013.12033.x.
- Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting Diverse Knowledge Systems for Enhanced Ecosystem Governance: The Multiple Evidence Base Approach. [journal article]. *Ambio*, 43(5), 579-591, doi:10.1007/s13280-014-0501-3.
- Tengö M, Hill R, Malmer P, Raymond CM, Spierenburg M, Danielsen F, Elmqvist T, & Folke C. (2017). Weaving knowledge systems in IPBES, CBD and beyond – lessons learned for sustainability. *Current Opinion in Environmental Sustainability*, 26, 17-25.
- Turner, N. J., & Clifton, H. (2009). “It's so different today”: Climate change and indigenous lifeways in British Columbia, Canada. *Global Environmental Change*, 19(2), 180-190, doi: 10.1016/j.gloenvcha.2009.01.005.
- Turreira-García, N., J. F. Lund, P. Dominguez, E. Carrillo-Anglés, M. Brummer, P. Dunn, and V. Reyes-García. (2018). What's in a name? Unpacking 'participatory' environmental monitoring. *Ecology and Society*. 23 (2):24.
- Weatherhead, E., Gearheard, S., & Barry, R. (2010). Changes in weather persistence: insights from Inuit knowledge. *Global Environmental Change*, 20(3), 523-528.
- Weber, E. U. (2011). Climate change hits home. *Nature Climate Change*, 1(1), 25-26.
- Whitfield, J. (2001). The budding amateurs. *Nature*, 414(6864), 578-579, doi:10.1038/414578a
- Zou, L., Zhou, T., Li, L., & Zhang, J. (2010). East China Summer Rainfall Variability of 1958–2000: Dynamical Downscaling with a Variable-Resolution AGCM. *Journal of Climate*, 23(23), 6394-6408, doi:10.1175/2010jcli3689.1.