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Including Indigenous and local knowledge in climate research. An assessment of the opinion of Spanish climate change researchers

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Abstract

Researchers have documented that observations of climate change impacts reported by Indigenous Peoples and Local Communities coincide with scientific measurements of such impacts. However, insights from Indigenous and Local Knowledge are not yet completely included in international climate change research and policy fora. In this article, we compare observations of climate change impacts detected by Indigenous Peoples and Local Communities from around the world and collected through a literature review (n=198 case studies), with climate scientists' opinions on the relevance of such information for climate change research. Scientists' opinions were collected through a web survey among climate change researchers from universities and research centres in Spain (n=191). In the survey, we asked about the need to collect local level data regarding 68 different groups of indicators of climate change impacts to improve the current knowledge, and about the feasibility of using Indigenous and local knowledge in climate change studies. Results show consensus on the need to continue collecting local level data from all groups of indicators to get a better understanding of climate change impacts, particularly on impacts on the biological system. However, while scientists of our study considered that Indigenous and local knowledge could mostly contribute to detect climate change impacts on the biological and socioeconomic systems, the literature review shows that information on impacts on these systems is rarely collected; researchers instead have mostly documented the impacts on the climatic and physical systems reported by Indigenous and local knowledge.

Keywords

Indigenous and Local Knowledge; local indicators of climate change impacts; web survey; scientists' opinion

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1 Introduction

Climate change impacts are becoming evident in all the Earth's ecosystems (Allen et al. 2010; Cardinale et al. 2012; Hoegh-Guldberg & Bruno 2010) with measurable impacts on the physical and biological systems (Helmuth, 2009; Huey et al. 2009; Peñuelas et al. 2013; Potts et al. 2010; Rosenzweig et al. 2008; Scheffers et al. 2016). Inevitably, such impacts also affect the socio-economic and cultural systems of local communities with direct dependence on the environment (Adger et al. 2013; Wang & Cao 2015).

Most of the current knowledge on future climate change impacts transcending to the public opinion and decision makers comes from research on the natural sciences and from the use of predictive models relying on mathematical representations of large-scale records of weather variables combined with gas emission scenarios. These models describe future climate changes at global or regional levels, even in data deficient regions for which interpolation of adjacent data is used (Harris et al. 2014). While recent improvements of these tools (Pierce et al. 2009; Rummukainen 2010) have greatly expanded our understanding of climate change (Maraun et al. 2010), the scientific community recognizes that these models are still too imprecise to detect impacts produced at the local scale (Fernández-Llamazares et al. 2017; Stott et al. 2010). The mismatch between the scale at which impacts are modelled and the actual scale at which local communities will have to overcome climate change impacts inhibits local actors to get an accurate prevision of the impacts that will affect their environment and livelihood (Kolawole et al. 2016; Xu et al. 2009). For this reason, researchers and policy makers have called for the exploration of different data sources and particularly for locally grounded data that can complement the data series currently used to assess climate change impacts (Alexander et al. 2011; Berkes 2009; Ford et al. 2016; IPCC 2014; Rosenzweig & Neofotis 2013).

Along this line, a growing number of scientists argue that Indigenous and Local Knowledge (ILK) holds the potential to improve our understanding of climate change impacts and thus help in the quest to adapt to and to mitigate its effects (Barnes et al. 2013; Baul and McDonald 2015; Chanza and De Wit 2016; Reyes-García et al. 2016; Altieri and Nicholls 2017; Magni 2017; Khanal et al. 2018). Through time, Indigenous Peoples and Local Communities (IPLC) with a long history of interaction with the environment have dealt with and overcome many changes and extreme weather events, developing a knowledge system that allows them to adapt their daily activities to changing climatic conditions (Boillat & Berkes 2013; Hiwasaki et al. 2015; Turner & Spalding 2013). Indeed, since its recognition in the 1992 Convention on Biological Diversity (CBD) and the 2007 United Nation Declaration of the Rights of Indigenous Peoples, ILK has become a popular, even fashionable, topic in international spheres. For example, maintaining ILK has been one of the 2010 CBD Aichi targets; ILK has been included as a valid source of knowledge in the IPBES platform; and ILK has been considered important to achieve the Sustainable Development Goals (Buenavista et al. 2018; United Nations 2015). However, the transfer of intentions from the international spheres to the national, regional and local agendas is not so simple.

Actually, part of the climate change research community remains sceptical on the potential value of ILK. This part of the research community argues that many climate change impacts are difficult to detect without the adequate scientific instruments (Stone et al. 2013; Howe and Leiserowitz 2013; Cramer et al. 2014) and that the local nature of ILK hampers its extrapolation (Briggs 2013). Moreover, the epistemological differences between both knowledge systems, although for some are useful as they provide a greater understanding of the problem (Ford et al. 2016), for most are obstacles for the dialogue of both types of knowledge (Orlove et al. 2010; Adger et al. 2013). Finally, the different language used by scientists and IPLC to express their knowledge further prevents the equal participation of all the actors in the co-production of new knowledge (Conrad and Hilchey 2011).

Despite these critiques, other researchers have started to include ILK in climate change research. This has been done mainly in vulnerability assessments, adaptation frameworks, and action plans (Dazé et al. 2011; Pasteur 2011). However, although the inclusion of ILK in vulnerability and mitigation assessments somehow recognizes ILK ability to anticipate future negative impacts of climate change, ILK is not fully recognized as a potential data source for the collection of information on climate change impacts. Nonetheless, many authors have shown that IPLC are able to detect changes in local weather and climatic conditions and their subsequent impacts on the physical and biological systems on which their livelihoods depend (Fernández-Llamazares et al. 2015; Orlove et al. 2000; Weatherhead et al. 2010), see Reyes-Garcia et al. 2019 for a review). Moreover, numerous studies have shown the overlap between local and scientific information on a diversity of topics including temperature and rainfall trends (Klein et al. 2014; Baird et al. 2014; Da Silva et al. 2014; Oyerinde et al. 2015), fish stock declines (Brewer 2013; Gurgiser et al. 2016), or changes in vegetation index (Gamble et al. 2010), suggesting that information from both knowledge systems can be complementary. Particularly, insights from ILK would enrich the availability of data in now data-deficient regions (Belfer et al. 2017; Cai et al. 2017; Reyes-García et al. 2016; Sanchez et al. 2012; Savo et al. 2016; Wildcat 2013).

Furthermore, researchers increasingly argue that ILK could be used, in combination with scientific knowledge, in the co-production of new knowledge useful to orient more locally grounded adaptation and mitigation strategies (Huntington et al. 2004; Tengö et al. 2014; Ford et al. 2016; Berkes 2017) and to improve our understanding of climate change impacts (Savo et al. 2016; Reyes-García et al. 2019). Until recently, the comparison of information derived from different knowledge systems was used to validate ILK, so that this knowledge was acknowledged by the scientific community (Alexander et al. 2011; Panda 2016; Smith et al. 2017). However, IPLC and their advocates have argued that this process generates a situation of imbalance of power, in which the ILK has to be submitted and adapted to exogenous knowledge frameworks, often based on Western science (Berkes 2012; Cajete 2000; Johnson et al. 2016; Tengö et al. 2014). In response to this critique, many researchers advocate a respectful and inclusive knowledge integration that allows combining scientific knowledge and ILK (Agrawal 1995; Weber 2016; Berkes 2017; Turnhout et al. 2012; Watson & Huntington 2014). According to this view, each knowledge system should be evaluated and validated within their own reference frameworks (Tengö et al. 2014). This co-production of knowledge should be a collaborative process including ways to avoid power imbalances (Jasanoff 2004), a way back and forth that allows bridging a plurality of knowledge sources that are translated and assimilated by all parties and reach a common consensus of understanding and action (Armitage et al. 2011; Rathwell et al. 2015; Tengö et al. 2017). In a way, the creation of synergies for co-production of knowledge first requires that the scientific community, as a whole, recognizes the value of incorporating ILK into international agendas beyond climate change (Rigg and Mason 2018).

Within this framework, this work aims at gaining a better understanding of how scientists working on climate change value ILK. To do so, we first analysed the literature on local indicators of climate change impacts and then collected information through a web survey from 191 Spanish researchers working on climate change issues about the possibility of using information from ILK to identify climate change impacts. We analyse the match between scientists' responses and the presence of related local indicators of climate change impacts in the literature.

2 Methods

Our methodological approach compares results from a literature review documenting local observations of climate change impacts, with results from a web survey to Spanish scientists working on climate change issues.

2.1 Literature review

We reviewed articles collecting local observations of climate change impacts documented by IPLC. Following Reyes-García et al. 2016, for our search we used Scopus and Web of Science search engines and the following keywords: (i) *indigenous knowledge*, OR *local knowledge*, OR *traditional knowledge*, OR *traditional ecological knowledge*, AND (ii) *observations*, OR *perceptions*, OR *indicators*; AND (iii) *climate change*, OR *global change*, OR *environmental change*. We did not include any geographical limitations associated with our search. We obtained 273 articles from Scopus and 252 articles from Web of Science. We combined both lists and, after excluding duplicate articles, we kept 308 articles published until December 2016. Then, reading the articles in depth, we retained only 135 articles that included first-hand observations of climate change impacts documented among IPLC. Our criteria to determine whether a group could be considered as Indigenous Peoples was to follow the classification used by the authors of the article consulted. We excluded review and metadata articles (Savo et al. 2016), articles providing theoretical frameworks (Huntington et al. 2004), and articles reporting changes detected by scientific measurement devices (Ho et al. 2005). Articles were coded by a team of ten researchers following a common guideline. After each coder read and coded information from ten articles, the team discussed the coding system and solved potential discrepancies. Then the rest of the documents were analysed. The lead author conducted a final review to ensure accuracy in coding. As some papers documented impacts in different locations, from the 135 documents retained in our search, we have observations for 198 case studies.

For each document, coders noted all observations of climate change impacts reported in one location. *Verbatim* reports of observations of climate change impacts referring to the same phenomenon were grouped together (e.g., *extreme rains* and *shorter but heavier rain*). We call these aggregated observations *local indicators of climate change impacts* (LICCI) (Reyes-Garcia et al. 2016; Reyes-García et al. 2019).

Our LICCIs were classified in a hierarchical categorization of three levels. The upper level is defined by the main system in which the impact is detected. The climatic system represents changes related to atmospheric conditions and their repercussions on temperature, on the movement of air masses and on precipitation. The physical system includes changes related to the abiotic elements of the earth: hydrosphere (continental and oceanic water bodies), cryosphere and geosphere. The biological system encompasses the changes detected in wildlife, and the socioeconomic system represents the perceived impacts on agriculture, livestock, fisheries, forestry, human health and transport. The second level is formed by the sub-systems into which the four major systems are divided (e.g., the climatic system is divided into four sub-systems: temperature, rainfall, air masses and seasonal events). The third level includes LICCI groups within each sub-system (e.g., the subsystem temperature is divided into three groups: indicators related with mean temperature, indicators regarding extreme temperatures, and indicators of temperature fluctuation). Although all detected impacts depend directly or indirectly on changes in the climatic system, each observation was classified in the system and sub-system into which the change was perceived.

With this classification system, the 1357 observations documented were grouped into 75 different LICCI groups, re-grouped into 19 sub-systems, which were assigned to one of the main four systems (i.e., 4 of the sub-systems were assigned to the climatic system, 4 to the physical system, 5 to the biological system, and 6 to the socioeconomic system). This list of indicators was used to construct the web survey tool (see below). The classification of LICCI can be found in the Online Resource 1.

2.2 Sampling climate change scientists

We collected opinions on the potential contribution of ILK to climate research among Spanish scientists. We chose Spain as a case study for several reasons. First, we consider that the bridging between scientific knowledge and ILK should be done at the local level, for which we decide to work locally. Second, we focus on Spain because this country has a diverse geological relief that has favoured a large biological and ecological diversity that has favoured expertise diversity among climate change scientists. Moreover, the Iberian Peninsula, where Spain is found, is one of the areas of Europe where a greater increase in temperatures and drought is expected as a consequence of anthropogenic climate change (Füssel et al. 2017; Kendrovski et al. 2017). Finally, given our institutional affiliations and personal contacts, it was logistically easier for us to target this particular community of scientists.

To select scientists, we targeted university professors and members of research groups focusing on *climate change* issues, members of the Spanish *Long-Term Ecological Research* network (LTER), and researchers from the Spanish governmental research groups (CSIC) with a research line related to climate change. We also wrote personal e-mails to directors of National Parks belonging to the Spanish Global Change Monitoring Program requesting information on research groups that had performed climate change studies in their parks. Finally, we encouraged survey respondents to disseminate the survey among their contacts with related research topics.

Recruitment followed several stages. We sent an e-mail to scientists in our initial list (n=1077 contacts) explaining our goals and inviting them to voluntarily participate in our study. In the e-mail, we provided a link to the survey in Spanish and English. To encourage participation, we sent three reminders with 20 days of separation (Walston, Lissitz & Rudner 2006). As response rate was low, in a second round we reviewed the rest of the 87 recognized universities in Spain and included 1141 new contacts, for whom we followed the same procedure. In total we contacted 2218 scientists from 47 universities and 23 governmental research centers. We received 191 responses, 93 respondents from the first recruitment effort and 98 from the second, representing 8.61% of the initial sample. We received 137 answers in Spanish and 54 in the English version.

2.3 Web survey

We collected scientists' opinions on the potential contribution of ILK to climate research using a web survey, as this tool seems to efficiently capture the attention of the academic community (Kellner 2004). The survey was generated using the online application *google forms* and posted in a *WordPress* page created for this purpose (https://localindicatorsofclimatechange.wordpress.com/). The page was open to responses from February to August of 2018. The first part of the survey included respondent's sociodemographic information: gender, age, research centre, position (i.e., senior researcher, junior researcher, PhD student or technician), research topics of interest, and years of experience in the field of study.

In the second part of the survey, respondents were asked to report their opinion on the potential of including local knowledge[1] to detect indicators of climate change impacts. Overall, the survey included questions on 184 indicators identified in our literature review. We organized these indicators into 68 groups, according with the subsystem they belonged, which in turn were regrouped into 17 independent modules corresponding to 17 subsystems. We excluded two subsystems, human health and transport from our survey because the particular observations reported in the literature (i.e., increased hunger, physical injuries, insect-borne diseases or destruction of communication routes) did not seem relevant for the Spanish context. Respondents were instructed to answer only the modules for which they consider themselves as experts.

All modules were structurally identical but referred to different groups of LICCI. Thus, for each of the 68 groups of LICCI we first asked: 1) What is the need to collect more local level data on these indicators of climate change impacts? (without referring to local knowledge) and then 2) How feasible is to incorporate data from local knowledge on these indicators? For each of these questions, respondents had to give a score from 0 (i.e., no need to collect more local level data/no possibility to incorporate data from local knowledge) to 10 (i.e., great need to collect more local level data / great possibility to incorporate data from local knowledge). The third question was composed by the list of indicators related to each group and documented in the literature review. In this question, we asked respondents to

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[1] In the survey we used the term Traditional Ecological Knowledge (TEK) instead of Indigenous and Local Knowledge (ILK) because ILK is a more recent expression defined by IPBES members (www.ipbes.net) and people from outside social-interdisciplinary fields are more familiarized with the term TEK. Here we have opted to use the more generic term *local knowledge*.

evaluate, according to their perception, the potential of local knowledge to contribute with data to these indicators. Responses to this question could also range from 0 (null contribution) to 10 (great contribution). The fourth and last question in each module requested informants to list other potential indicators derived from local knowledge that could contribute to increase our current knowledge of climate change impacts at local scale.

3 Data Analysis

We first analysed results from the literature review on local indicators of climate change impacts. Particularly, we assessed the importance of the different groups of LICCI in previous literature by calculating the number of times each LICCI group appeared in the selected works and their relative frequency versus the total number of observations in our search.

We then analysed scientists' participation in our survey. To do so, we calculated participation in the different survey modules according to scientists' research area, gender, position, and years of experience in their field. After, we analysed scientists´ opinions on ILK relevance for climate change research by examining the four survey questions. Since informants' provided information on the contribution of various indicators belonging to the same group, which were often related, we created a variable that represents the average value of all indicators within a group. We called this variable *aggregated indicator*. To compare responses among systems and sub-systems, we performed Kruskal-Wallis nonparametric tests, because the sample did not meet the conditions of normality and homoscedasticity.

In our final analysis, we compared scientists´ opinions on the relevance of each indicator with the prevalence of the same indicator in the literature. Specifically, we compared the total number of LICCI documented on each sub-system with the average score obtained in the web survey on the same sub-system or module.

All statistical analyses were carried out with the SPSS program version 22 and the statistical applications of the Microsoft EXCEL program.

4 Results

4.1 Literature review

Among the 135 articles analyzed, we documented 1357 observations of climate change impacts. LICCI referring to the climatic system were mentioned in 88.89% of the articles (120 articles), LICCI referring to the physical system were mentioned in 78.52% (106 articles), LICCI referring to the biological system were mentioned in 45.93% (62 articles), and LICCI referring to impacts on the socioeconomic system were mentioned in 65.93% of the publications (89 articles). Moreover, almost half of the observations, 43.04% (584 obs.), referred to changes on the climatic system. Observations of impacts on the physical system represented 24.54% of all the observations collected, whereas only 10.83% of the observations referred to impacts on the biological systems (147 obs.). Finally, 21.59% (293 obs.) of the observations related to impacts on the socioeconomic system. A graph showing all the observations found in the literature review grouped by system and year of publication can be found in the Online Resource 2. Six of the 19 sub-systems in which we organized observations had more than 100 observations, of which three referred to the climatic system, two to the physical system, and one to the socioeconomic system (i.e., *agricultural system*). Rainfall was the sub-system with more observations (265 obs.), while the sub-systems with fewer observations was found within the biological system (Table 1, *Literature review* column).

4.2 Respondents' profile

Survey participants belong to 40 universities and 26 research centres in Spain. Scientists with more than 20 years of experience had a higher percentage of participation in the survey, accounting for 38.2% of all respondents (Table 2). Indeed, most survey respondents were senior researchers (70.2%) and 77.5% of participants had at least one decade of experience in their current field of research. Survey respondents varied in their research interests, which spanned across 43 different research lines. Most researchers (41.06%) focused on one of the branches of ecology, with only a few scientists (13.5%) coming from the socio-environmental perspective (see Online Resource 3). Overall, more participants considered themselves experts on the biological system (47.9%) (Table 2). More than half of the respondents (61.26%) answered only one module of the survey and 21.99 % two survey modules, representing 83.25% of the entire sample.

4.3 Spanish scientists´ opinions regarding the potential contribution of local knowledge to climate change research

A different number of participants answered each of the 17 survey modules. The module of *wild flora* was the most popular, being answered by 45 participants, followed by the modules of *temperature* (n=32), *continental waters* (n=29), and *agriculture* (n=29) (Table 1). On the other extreme, the modules on *air masses* and *ice-snow* were the modules answered by fewest participants, five each.

Responses to the question on the need to continue collecting local level data varied from one system to another. Thus, scores to the question on the need to collect local level data were higher for modules on the biological than on the other systems (^{2}= 12.92; p-value= 0.005). Additionally, respondents also considered that the incorporation of local knowledge into climate change studies was less feasible when referring to indicators on the climatic and the physical systems than when referring to indicators on the biological and the socioeconomic systems. Along the same line, results from the analysis of the variable *aggregated indicator* also showed statistically significant differences in scientists' opinion on the potential of local knowledge to contribute through specific indicators, with scientists reporting that local knowledge could be particularly relevant to measure climate change impacts on the socioeconomic system (^{2}= 30.78; p-value= 0.000).

Scientists generally agreed on the need to collect more local level data for most of the groups of indicators, although there were some statistically significant differences between groups (^{2}= 96.66; p-value= 0.010). Overall, respondents considered that the need to collect additional local level data was highest for the module *air masses* (average score 9.40 out of

10, where 10 indicates the maximum need to collect local data, Table 1). In contrast, scientists considered that the need to collect additional local level data on indicators of *ocean salinity* was lowest (average score of 6.79 out of 10). Scientists gave high scores to the question on the need to collect additional local level data to all groups of indicators in the biological system, as well as to several groups of indicators in the socioeconomic system, and particularly to the *availability of pasture* and *livestock productivity* or *phenological changes on crops*. Overall, 50 of the 68 groups of indicators (73.53%) got an average score ≥ 8.5 out of 10 on the need to collect more local level data.

Results to the question on the feasibility of incorporating data from local knowledge into current indicators of climate change impacts vary across systems. The average of scientists' scores regarding the possibility of incorporating local knowledge data into climate change research was higher than 8.5 (out of 10) for only seven groups (10.29%; Table 1), with statistically significant differences between groups (^{2}= 148.26; p-value= 0.000). Thus, participants saw more opportunities for the inclusion of local knowledge data into for groups of indicators of climate change impacts in the biological and socioeconomic systems than in the climatic and physical systems. Six of the 15 groups in the socioeconomic system had an average score over 8.5 points. The variable *aggregated indicator,* merging specific indicators collected from the literature also showed statistically significant differences among groups of indicators (^{2}= 150.66; p-value= 0.000). *Aggregated indicator* related with *fisheries, livestock and pasture,* and *agriculture* obtained the highest scores.

4.5 LICCI reported in the literature versus Spanish scientists' perceptions

In our final analysis, we compare results from the literature review with scientists' responses to our survey (Fig. 1). Overall, we find an important mismatch between LICCI documented in the literature and scientists' opinion on local knowledge potential to contribute to climate change research. According to results from our literature review, most studies documenting LICCI have reported impacts on the climatic and the physical systems (n= 917 obs.; 67.58%). Moreover, apart from impacts on the agricultural sub-system (n=110 obs.), the literature reports relatively few impacts on the biological and socioeconomic systems. Conversely, although researchers argue that it is important to collect more local level data for all the systems, results suggest that researchers consider that such data collection is more relevant for impacts on the biological system (^{2}= 12.92; p-value= 0.005). Interestingly, researchers also considered that incorporating local knowledge on climate change research had a higher potential when data referred to the biological and socioeconomic systems than to the climatic and physical systems (^{2}= 56.61; p-value= 0.000). Specifically, surveyed scientists considered that local information could best help to detect climate change impacts on agriculture, livestock and pastures, and fisheries, questions that had an average score of 8.3, 8.7 and 8.3 points out of 10 respectively (Table 1).

Finally, we examined the list of LICCI proposed by respondents in response to the last question, on other possible indicators to be included. We documented 157 comments, of which only 64 were new indicators. The remaining comments included indicators already proposed in other modules, indicators that require the use of scientific measurement devices, and other type of comments. The most abundant new indicators proposed related to agriculture, followed by indicators on continental waters, with a clear predominance of indicators related to the socioeconomic system. This list can be found in the Online Resource 4.

5 Discussion

This work assesses Spanish scientists' opinion on the importance and feasibility of including local knowledge on climate change impacts research. Before we discuss the main findings of this work, we point at some methodological limitations that should be considered when interpreting our results.

The main limitations of our work relate to sampling and survey design. First, while our literature review included works from around the world, our survey sample was limited to Spanish scientists. Although Spanish scientists work in many geographical areas of the world, we did not collect information on scientists' geographical focus, for which we cannot test for potential geographical biases in answers. Moreover, as participation was voluntary, our sample might suffer from self-selection bias, for example related to disciplines or geographical areas, for which we do not know whether the sample is representative of the entire Spanish scientific community. Considering those potential biases and the fact that ours is the first survey of this kind, the extrapolation of our results beyond our sample should be made with caution. Second, issues related to survey design and the classification of indicators proposed should also be taken into account in the interpretation of results. Thus, although we instructed respondents to focus on indicators related to their field of expertise, we cannot check whether this instruction was followed. Moreover, our survey included questions on indicators from the literature whose temporal validity was not checked, whereas the survey focused on contemporary information. Finally, some of the survey questions were too vague and general, while the incorporation of local knowledge is often context-dependant. These issues related to the design of our survey call for caution when interpreting results but are also important to notice for future work on this line.

Keeping these limitations in mind, we now discuss the four main findings of this work. The first finding of this work relates to results from the literature review showing that researchers documenting LICCI have mainly focused on changes in rainfall, continental waters, and temperature, although there are also many observations of change on ice-snow, seasonal events, and agriculture. Indeed, these six sub-systems represent 64,21% of all observations documented. The prevalence of reports related to the climatic system might relate to the fact that climate change affects firstly this system, with cascading impacts on other systems (Johnson et al. 2011; Xu et al. 2009). However, the finding might also reflect pressures of the scientific community to validate ILK comparing local perceptions with scientific knowledge (Johnson et al. 2016). As the scientific community has longer and more complete time series of changes on the climatic and physical systems than on the biological system, researchers working on local observations of climate change impacts might find it difficult to compare their results with data from the biological system, which still has many information gaps (McRae et al. 2017).

The second important finding from this work is that Spanish scientists working on climate change generally agree on the need to continue collecting more local level data to monitor climate change impacts, particularly on the biological system. While climatic models have improved through the exponential increase of weather stations (Pierce et al. 2009; Rummukainen 2010), they do not yet allow one to predict climate change impacts on the local biological systems. Earth system models are increasingly including interactions between the climatic and biophysical systems like the carbon cycle, terrestrial and marine biochemistry and ecosystems and natural and human impacts (Bonan and Doney 2018), but they continue to be imprecise (Pearson and Dawson 2003; Getz et al. 2018). Lack of or deficient information on species presence, species vulnerability, species geographical distribution, or interspecies relation makes difficult the transferability of models (McMahon et al. 2011; Pimm et al. 2014; Yates et al. 2018). Such paucity of data on biological systems might be one of the reasons why researchers insisted on the need to continue collecting local level data from the biological systems to monitor climate change impacts.

Related to this, the third finding of this work is that some modules of the socioeconomic system (*livestock and pastures´ productivity and quality, fish´s invasive alien species or crop ´s phenology and growing* patterns) were the ones that, according to Spanish scientists, offered highest potential to incorporate data from local knowledge detecting climate change impacts. Additionally, survey respondents saw a large potential for local observations to contribute to detect impacts on a few modules of the biological system, particularly on *terrestrial vertebrates' diseases*, *marine invasive alien species*, or *bird phenological and reproduction patterns*. Interestingly, these results are in line with the current increase in citizen science projects. A potential explanation for the fact that participants saw more opportunities for the inclusion of local knowledge into climate change research for LICCI groups in the biological and socioeconomic system is the fact that many participants had expertise in those topics. However, a large part of the scientific community recognizes that lay citizens can be a great help to increase the number of records of animal and plant species that can contribute to improve our knowledge about the state of conservation, distribution and evolution of species (Silvertown 2009; Dickinson et al. 2012), and some countries have already taken the initiative in this task, including the voice and perspective of indigenous communities in climate change research, such as New Zealand or the Artic councils (ACIA 2005). Results from our survey suggest that more work on this line would be useful.

It is worth mentioning that Spanish scientists found scarce potential to incorporate data from local observations of impacts on the climatic and the physical systems, and particularly on the *air masses*, *ocean and seas* and *soil*. While these results may be due to the different number of participants who answered the different modules of the survey, they might also reflect the view of experts on this particular field. Indeed, as mentioned above, some climate researchers have argued that local knowledge has difficulties to contribute to climate research because this type of knowledge cannot accurately perceive changes without using scientific devices (Howe & Leiserowitz 2013). The groups of indicators considered less suitable to incorporate local knowledge are, precisely, the ones for which scientists typically rely on measuring devices such as weather stations or CTD (conductivity, temperature, and depth) to measure marine salinity. Overall, this finding suggests that, while there is a large agreement on the need to collect more local level data, sectors of the scientific community still have issues on the feasibility to incorporate inputs from local knowledge into climate change research.

The last finding of this work relates to the mismatch between the most frequent indicators of climate change impacts found in the literature review and the indicators considered by researchers as the most suitable to incorporate inputs from local knowledge into climate change studies. While the LICCI most often documented in the literature relate to rainfall, temperatures, or continental waters, Spanish climate change scientists identified LICCI related to agriculture, livestock and pastures and fisheries as the ones with highest potential to contribute to climate change studies. Indeed, local knowledge on those topics could reduce the difficulties of attribution of drivers of change that climate change scientists face when analysing impacts in the biological and socioeconomic systems (Cramer et al. 2014). The continuous modifications of human-managed systems generate a lack of long-time series on stable managed systems. However, IPLC that have preserved traditional agricultural, shepherd, hunting or fishing practices for centuries could help scientists discern the unprecedented impacts generated by climate change without the influence of other drivers.

6 Conclusion

During several decades a growing number of works, sometimes in partnership with IPLC, have examined ILK contributions to climate change research. Most of this work points at the overlap of ILK and scientific data. Moreover, recent work suggests that combining knowledge from different knowledge systems is not only possible, but also desirable, as it can contribute to improve our understanding of pressing issues, like climate change (Tengö et al. 2014). In this sense, results from this work suggest that for local knowledge to contribute to climate change research, researchers need to leave behind the need to demonstrate the overlap of scientific data and local observations of impacts on the climatic system and, focus on impacts on the biological and socioeconomic systems, which can contribute better to increase our current knowledge on climate change effects. In other words, researchers should seek collaboration with IPLC to co-produce knowledge that helps us to better understand how climate change is particularly affecting them. For this purpose, it is necessary to create an interdisciplinary collaborators network at different scales, which includes IPLC, climate change researchers, researchers working with IPLC and the administrations of those specific geographic regions to achieve a real inclusion of ILK into climate change studies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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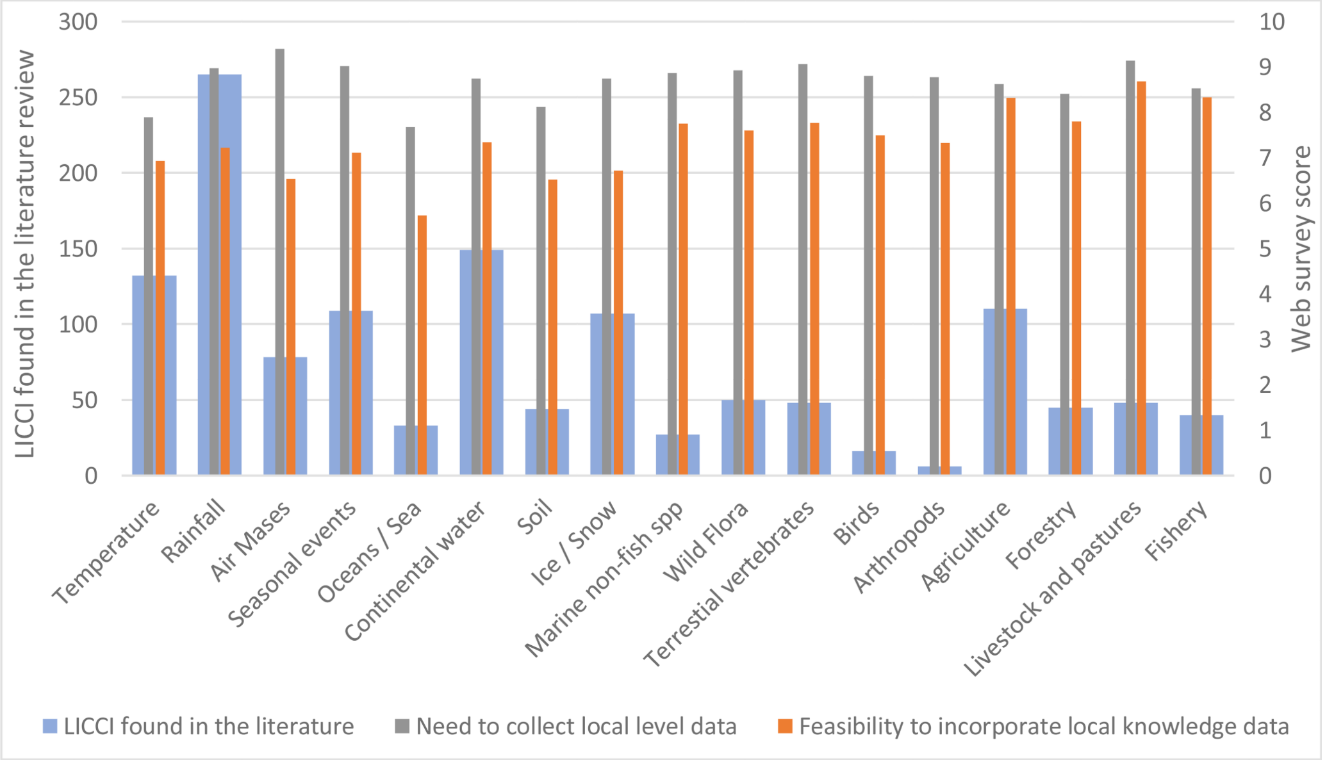

Fig. 1.

Number of observations reporting Local Indicators of Climate Change Impacts (LICCI) found in the literature review compared with scientists´ opinion collected through a web survey about 1) the need to collect more local level data and 2) the feasibility to incorporate data from local knowledge on the different sub-systems

Table 1

Comparison of information on groups of Local Indicators of Climate Change Impacts (LICCI): results from literature review compared with Spanish scientists' opinions. Comparison of 1) number and frequency of observations reporting Local Indicators of Climate Change Impacts (LICCI) found in the literature review. Average score out of 10 points on the web survey to questions on 2) the need to collect more local level data from indicators of climate change impacts, 3) the feasibility of incorporating data from local knowledge on climate change indicators, and 4) the potential of Indigenous and Local Knowledge (ILK) indicators found in the literature review, clustered in the variable *aggregated indicator*

			Literature review		**Web Survey**			
System	**Sub-system**	**Group of LICCI**	**Reports in the literature**		**Scientists answered the module**	**Need to collect local level data**	**Feasibility to incorporate local knowledge data**	**Potential of ILK indicators found in the literature *Aggregated indicator***
			n	**%**	**n**	**Avg. score**	**Avg. score**	**Avg. score**
Climatic system	Temperature	Mean temperature	93	6.85%	32	7.72	6.88	5.91^2
		Extreme temperature	33	2.43%	32	8.25	7.19	6.37^4
		Temperature fluctuations	6	0.44%	32	7.72	6.72	6.50^2
		Total / (average score)	*132*	*9.73%*	32	(7.90)	(6.93)	(6.26)
	Rainfalls	Clouds and fog	12	0.88%	18	8.28	6.33	5.61^5
		Mean rainfalls	90	6.63%	19	**8.74**	7.32	6.84^3
		Extreme rainfalls	29	2.14%	19	**9.32**	7.37	7.17^4
		Rainfall fluctuation/unpredictable precipitation	90	6.63%	19	**9.16**	6.84	7.02^3
		Drought	44	3.24%	19	**9.37**	8.21	7.68^2
		Total / (average score)	*265*	*19.53%*	19	**(8.97)**	(7.21)	(6.87)
	Air Masses	Wind	40	2.95%	5	**9.40**	6.20	5.90^4
		Storm (hail storm/dust storm/ sandstorm)	28	2.06%	5	**9.40**	6.60	6.25^4
		Cyclones & tornadoes	10	0.74%	5	**9.40**	6.80	6.65^4
		Total / (average score)	*78*	*5.75%*	5	**(9.40)**	(6.53)	(6.27)
	Seasonal events	Shifts in seasonal patterns	44	3,24%	26	**9.08**	7.08	6.90^2
		Duration and timing of seasons	65	4,79%	26	**8.96**	7.15	6.75^3
		Total / (average score)	*109*	*8.03%*	26	**(9.02)**	(7.12)	(6.83)

			Literature review		Web Survey			
System	Sub-system	Group of LICCI	Reports in the literature		Scientists answered the module	Need to collect local level data	Feasibility to incorporate local knowledge data	Potential of ILK indicators found in the literature *Aggregated indicator*
			n	**%**	**n**	**Avg. score**	**Avg. score**	**Avg. score**
Physical system	Ocean / Sea	Sea temperature	3	0.22%	15	7.73	4.93	4.73^1
		Sea-level rise	17	1.25%	15	7.67	6.27	5.71^3
		Coastal erosion/sedimentation	9	0.66%	14	8.21	6.85	6.32^2
		Ocean Currents	3	0.22%	14	8	6.36	5.46^2
		Ocean Salinity	1	0.07%	14	6.79	4.21	3.79^1
		Total / (average score)	*33*	*2.43%*	15	(7.68)	(5.73)	(5.20)
	Continental waters	Mean river flow	36	2.65%	28	**8.82**	7.71	7.61^2
		Change in river floods	30	2.21%	28	8.46	7.86	7.29^3
		Water temperature of rivers and lakes	2	0.15%	29	**8.76**	6.07	5.45^1
		Lake level	10	0.74%	27	**8.67**	7.78	7.28^2
		Fresh water availability/quality	52	3.83%	28	**8.64**	7.79	7.31^4
		Phreatic/Underground water	11	0.81%	27	**9.19**	7.74	7.58^3
		River bank erosion/sedimentation	8	0.59%	28	**8.61**	6.43	5.68^3
		Total / (average score)	*149*	*10.98%*	29	**(8.74)**	(7.34)	(6.88)
	Soil	Soil erosion/landslides	27	1.99%	19	**8.84**	7.58	6.26^2
		Soil moisture	14	1.03%	18	**8.72**	6.89	6.19^3
		Soil temperature	2	0.15%	18	7.67	5.50	5.03^2
		Earthquake and tsunamis	1	0.07%	12	7.25	6.08	5.29^2
		Total / (average score)	*44*	*3.24%*	19	(8.12)	(6.51)	(5.69)
	Ice / Snow	Snow cover	41	3.02%	5	**9.00**	7.40	6.87^3
		Ice sheet / Lake and rive ice	21	1.55%	5	**8.80**	7.20	6.93^3
		Glaciers	20	1.47%	5	**9.40**	7.00	7.20^2
		Permafrost	10	0.74%	4	7.75	5.25	6.25^1
		Ice-sea	15	1.11%	-	-	-	.

			Literature review		Web Survey			
System	**Sub-system**	**Group of LICCI**	**Reports in the literature**		**Scientists answered the module**	**Need to collect local level data**	**Feasibility to incorporate local knowledge data**	**Potential of ILK indicators found in the literature *Aggregated indicator***
			n	**%**	**n**	**Avg. score**	**Avg. score**	**Avg. score**
		Total / (average score)	*107*	*7.89%*	5	**(8.74)**	(6.71)	(6.81)
Biological system	Marine non-fish species (spp)	Marine non-fish spp´s abundance	10	0.74%	13	**9.00**	7.77	6.74^{3}
		Marine non-fish spp´s invasive alien species (IAS)	0	0.00%	13	**9.00**	**8.62**	7.23^{1}
		Marine non-fish spp´s Diseases / pest & mortality	14	1.03%	13	**8.54**	7.00	6.13^{3}
		Marine non-fish spp´s Phenology / Distribution & reproduction	3	0.22%	13	**8.92**	7.62	6.49^{3}
		Total / (average score)	*27*	*1.99%*	13	**(8.87)**	(7.75)	(6.65)
	Wild flora	Wild plants & fungi´s abundance	14	1.03%	45	**8.80**	7.29	7.07^{2}
		Wild plants & Fungi´s IAS	3	0.22%	43	**8.98**	7.42	7.12^{2}
		Wild plants/Fungi´s Disease-pest & mortality	2	0.15%	40	**8.93**	7.75	7.74^{1}
		Wild plant & Fungi´s Phenology / Distribution & reproduction	20	1.47%	44	**9.00**	7.93	7.48^{5}
		Natural habitat degradation & disappearance	11	0.81%	-	-	-	-
		Total / (average score)	*50*	*3.68%*	45	**(8.93)**	(7.60)	(7.35)
	Terrestrial vertebrates	Terrestrial vertebrates’ abundance	17	1.25%	20	**8.95**	7.85	7.21^{4}
		Terrestrial vertebrates´ IAS	5	0.37%	19	**9.21**	8.42	7.58^{1}
		Terrestrial vertebrates´ Disease- pest & mortality	13	0.96%	19	**8.74**	6.79	5.70^{3}
		Terrestrial vertebrates´ Phenology / Distribution & reproduction	13	0.96%	19	**9.37**	8.00	6.75^{5}
		Total / (average score)	*48*	*3.54%*	20	**(9.07)**	(7.77)	(6.81)
	Birds	Birds´ abundance	7	0.52%	15	**8.87**	7.80	7.60^{4}
		Birds´ IAS	0	0.00%	14	**9.00**	7.57	7.79^{1}
		Birds´ Disease-pest & mortality	1	0.07%	14	8.21	6.36	5.75^{2}

			Literature review		Web Survey			
System	Sub-system	Group of LICCI	Reports in the literature		Scientists answered the module	Need to collect local level data	Feasibility to incorporate local knowledge data	Potential of ILK indicators found in the literature *Aggregated indicator*
			n	**%**	**n**	**Avg. score**	**Avg. score**	**Avg. score**
		Birds´ Phenology / Distribution & reproduction	8	0.59%	15	**9.13**	8.27	7.51^{3}
		Total / (average score)	*16*	*1.18%*	15	**(8.80)**	(7.50)	(7.16)
	Arthropods	Arthropods´ abundance	2	0.15%	13	**8.77**	7.15	7.28^{3}
		Arthropods´ IAS	1	0.07%	13	**8.69**	7.54	7.80^{2}
		Arthropods´ Disease-pest & mortality	0	0.00%	13	**8.54**	7.23	7.77^{1}
		Arthropods´ Phenology / Distribution & reproduction	3	0.22%	13	**9.08**	7.38	6.82^{6}
		Total / (average score)	*6*	*0.44%*	13	**(8.77)**	(7.33)	(7.42)
Socioeconomic System	Agriculture	Crop´s productivity	42	3.10%	28	8.32	8.43	7.58^{3}
		Crop´s Disease-pests & weeds	39	2.87%	29	**8.55**	**8.52**	7.85^{4}
		Crop´s Phenology & growing patterns	14	1.03%	26	**9.08**	**8.69**	8.18^{4}
		Soil degradation & fertility	15	1.11%	26	**8.54**	7.65	6.31^{2}
		Total / (average score)	*110*	*8.11%*	29	**(8.62)**	(8.32)	(7.48)
	Forestry	Forest cover	23	1.69%	25	8.48	7.56	7.17^{5}
		Forest fires	7	0.52%	25	8.12	7.80	7.04^{1}
		No Timber Forest Products availability/quality	15	1.11%	25	**8.64**	8.04	7.36^{3}
		Total / (average score)	*45*	*3.32%*	25	(8.41)	(7.80)	(7.19)
	Livestock & pastures	Livestock productivity & quality	7	0.52%	7	**9.57**	**9.14**	7.57^{2}
		Livestock´s disease	20	1.47%	7	**8.86**	8.43	7.43^{3}
		Livestock´s phenology & reproduction	1	0.07%	7	**8.71**	8.00	7.64^{2}
		Pasture´s availability & quality	20	1.47%	7	**9.43**	**9.14**	8.14^{2}
		Total / (average score)	*48*	*3.54%*	7	**(9.14)**	**(8.68)**	(7.70)

			Literature review		Web Survey			
System	Sub-system	Group of LICCI	Reports in the literature		Scientists answered the module	Need to collect local level data	Feasibility to incorporate local knowledge data	Potential of ILK indicators found in the literature *Aggregated indicator*
			n	%	n	Avg. score	Avg. score	Avg. score
	Fisheries	Fish stock´s abundance	20	1.47%	9	**8.78**	8.44	7.28^4
		Fish´s IAS	4	0.29%	9	**8.78**	**9.11**	8.00^1
		Fish´s Disease - Mortality – Pest & Parasites	4	0.29%	9	7.89	7.00	7.00^3
		Fish´s Phenology / Distribution & reproduction	12	0.88%	9	**8.67**	**8.78**	7.67^3
		Total / (average score)	*40*	*2.95%*	9	**(8.53)**	(8.33)	(7.49)
	Human health	Diseases	19	1.40%	-	-	-	-
		Health injuries, physical affection	9	0.66%	-	-	-	-
		Hunger	11	0.81%	-	-	-	- 774
		Cultural/Spiritual & Identity values	8	0.59%	-	-	-	- 775
		Total / (average score)	*47*	*3.4%*	-	-	-	- 776
	Transport	Trails	*3*	*0.22*	-	-	-	-
		Total / (average score)	*3*	*0.22%*	-	-	-	- 777

[*] Bold values represent values ≥ 8.5.

[a] Values in parentheses represent the average score of the LICCI groups of each sub-system.

[b] Superscripts denote the number of indicators that were asked for each group of LICCI.

[c] Italic values represent the total number and frequency of observations of each subsystem found in the literature review

Table 2

Description of web survey respondents

Variable	Group	n	%	Average age	Average years of experience
Gender	Male	123	64.40 %	47.29	20.05
	Female	68	35.60 %	41.26	14.65
Years of experience	0-4 years	23	12,04 %	28.23	2.87
	5-10 years	38	19,90 %	37.02	8.39
	11-20 years	57	29,84 %	44.32	16.67
	> 20 years	73	38,22 %	55.5	29.14
Position	Senior researcher	134	70.16 %	50.08	22.68
	Junior researcher	24	12.57 %	35.54	9
	PhD student	22	11.52 %	28.77	3.72
	Technician	11	5.76 %	41.9	11.27
Reported expertise	Climatic system	54	28.27 %	46.47	18.53
	Physical system	60	31.41 %	46.30	18.67
	Biological system	91	47.64 %	46.85	20.05
	Socioeconomic system	55	28.8 %	42	14.21
Number of systems answered in the survey	1 system	136	71.02 %	45.15	18.49
	2systems	44	23.04 %	43.76	15.98
	3 systems	8	4.19 %	48.5	22
	4 systems	3	1.57 %	57.33	22.67
Number of sub-systems answered in the survey	1 sub-system	117	61.26 %	45.54	18.90
	2 sub-systems	42	21.99 %	42.08	15.05
	3 sub-systems	14	7.33 %	44.64	16.64
	4 sub-systems	12	6.28 %	47.42	20.04
	5 sub-systems	3	1.57 %	49.67	18.33
	6 sub-systems	3	1.57 %	60.67	30