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Local indicators of climate change: The potential contribution of local knowledge to climate research

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Abstract

Local knowledge has been proposed as a place-based tool to ground-truth climate models and to narrow their geographic sensitivity. To assess the potential role of local knowledge in our quest to understand better climate change and its impacts, we first need to critically review the strengths and weaknesses of local knowledge of climate change and the potential complementarity with scientific knowledge. With this aim, we conducted a systematic, quantitative meta-analysis of published peer-reviewed documents reporting local indicators of climate change (including both local observations of climate change and observed impacts on the biophysical and the social systems). Overall, primary data on the topic are not abundant, the methodological development is incipient, and the geographical extent is unbalanced. On the 98 case studies documented, we

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recorded the mention of 746 local indicators of climate change, mostly corresponding to local observations of climate change (40%), but also to observed impacts on the physical (23%), the biological (19%), and the socioeconomic (18%) systems. Our results suggest that, even if local observations of climate change are the most frequently reported type of change, the rich and fine-grained knowledge in relation to impacts on biophysical systems could provide more original contributions to our understanding of climate change at local scale.

Introduction

Climate models are very effective at providing global information on climate change; yet, over recent years, their ability detecting impacts at the local scale has been deeply questioned.[1, 2] For this reason, global models assessing climate change are often downscaled to specific settings, to provide a more suitable resolution for adaptation planning.[3, 4] However, the myriad of uncertainties entailed by the downscaling process and techniques (e.g., climate interpolations, limited weather station coverage)[5] has evidenced the need for more detailed, fine-scale, and local observations of climate change.[2, 6, 7] In such context, some research proposes tapping into local knowledge as a place-based tool to ground-truth climate models and narrow their geographic sensitivity.[8, 9] Indeed, recent studies document that -throughout the world- people with a long history of interaction with their environment, hereafter local peoples, have developed intricate and complex systems of first-hand knowledge not only of weather and climate variability, but also of climate change.[10–13] Such observations relate to changes observed in the local climatic system, as well as in the physical, the biological, and the socioeconomic systems, all of which are directly affected by climatic changes.[14] Furthermore, at least some works integrating local knowledge with scientific information report an overlap between observations made from both knowledge systems.[15, 16] Since local peoples are increasingly being recognized as potential allies in our quest to understand better climate change and its impacts,[17–19] the need to critically review the strengths and weaknesses of local knowledge of climate change and the potential complementarity of local and scientific knowledge becomes urgent.

In this work, we conduct a meta-analysis of scientific literature reporting local indicators of climate change (Box 1). To do so, we adapt the framework proposed by Rosenzweig and Neofotis[14] which differentiates between changes in the climate itself and the impacts of climate change that can be observed in the physical, the biological, and the social systems. We follow the Framework Convention on Climate Change and use *climate change* to refer to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period.[20] We use the term *local indicator of climate change* to refer to both local observations of climate change reported by people with long histories of interaction with the environment and observed impacts on the biophysical and the social systems attributed to climate change. We then use the term *local observations of climate change* to refer to reports provided by local peoples about changes in the climatic system (i.e., temperature, precipitation and wind). We further differentiate between *observed impacts on the local 1) physical, 2) biological, and 3) socioeconomic systems*. Our literature review is structured around four questions: 1) What are the major trends in the literature on local indicators of climate change?; 2) Which indicators are more

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frequently mentioned?; 3) What is the social and geographical extent of research on the topic?; and 4) Do local and scientific indicators of climate change overlap?

Methods

Data gathering

We used two standard web-based search engines during January 2015, the Web of Science (http://science.thomsonreuters.com) and Scopus (http://www.elsevier.com/online-tools/scopus), to locate published case studies reporting local indicators of climate change. Keywords used in the search included related terms encompassing three main concepts: (i) '*indigenous knowledge',* or '*local knowledge'*, or '*traditional knowledge',* or '*traditional ecological knowledge';* (ii) '*observations'*, or '*perceptions'*, or '*indicators'*; and (iii) '*climate change',* or '*global change'*, or '*environmental change'*. We did not limit the time-span for documents published in the past, but our search only included documents published up to December 2014 (included).

Our combined search resulted in 222 documents. We reviewed the title, abstract, and content to select documents providing 1) information on local indicators of climate change (i.e., excluding indicators referring to local systems of weather forecast, unless people use them to report climate change and adaptation strategies) and 2) first-hand information (i.e., containing information reported by local people, not by the scientists conducting the research). A total of 83 documents (38%) met our criteria and were selected for detailed examination. Some documents reported data from more than one case study location,37 so we collected information separately for each case study location. Our final sample comprises 98 case studies, for which we collected information on 1) the name of the studied society and their main livelihood strategy, 2) the sampling strategy, 3) the data collection methods, 4) the local indicators of climate change reported, 5) the geographic features and location, and 6) the reported correspondence between local indicators and scientific information of climate change. We entered the data in a Microsoft Office Access 2007 database specifically designed for this work.

Data transformation

Information entered in the database was coded to allow for a quantitative exploration38 (Table 1).

Bibliography—We retained the *year* of publication and noted the type of document analyzed (journal article, book chapter, or conference proceeding). We then used the subject description in the journal's web page to classify journals according to their main subject area, ultimately differentiating between journals from the social and the natural sciences.

Studied group—We generated two non-exclusive dummy variables. The first variable classified the studied society as *indigenous* (=1) or not (=0). As the prevailing view today is that no formal universal definition of the term is needed, but rather that peoples themselves should define their own identity as indigenous (Article 33 of the United Nations Declaration on the Rights of Indigenous Peoples), we coded this variable using the information provided

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in the reviewed document or –if missing- using ethnographic literature found in the web (mainly the eHRAF). The second variable captured whether the main current livelihoods of the studied group are based on the direct use of natural resources (gathering, agriculture, fishing, pastoralism) (*rural*=1) or not (*rural*=0).

Sample—We coded information on the sampling strategy used into two non-exclusive dummy variables that capture whether the information was provided by *local experts* (e.g., elders, specialists) or by the *general population*.

Methods—We created two variables capturing whether data were collected using qualitative (e.g., participant observations, focus groups, semi-structured interviews) or quantitative (e.g., surveys) methods. Again, as some studies used a mixed approach,16, 39 the two variables are non-exclusive.

Local indicators of change—We noted, *verbatim,* all local indicators of climate change reported in the reviewed literature. We grouped information to generate codes containing similar information (for example "higher temperatures" and "hotter" were assigned the same code). We reached a consensus on the criteria for coding after each author had reviewed 5-6 documents (n=35). We then classified codes in four main types of indicators related to 1) local observations of climate change and its impacts on 2) the physical, 3) the biological, and 4) the socioeconomic systems. After all the data were entered, the lead author reviewed the full data set and fixed inconsistencies.

Study area—We noted the most precise geographical reference of the case study provided, notably, the geographical coordinates when available. We overlapped geographical location with climate types as defined by Koeppen-Geiger climate classification40, 41 (Figure 3).

Overlap with scientific data—We recorded whether the document compared or not local indicators of climate change with scientific information. If the document provided such comparison, we further differentiated whether the comparison was done based on scientific data found in the secondary literature in the area or based on primary data (e.g., climate records) documented by the document's authors. We then recorded whether the reports of change provided by local indicators were or not in agreement with the ones provided in the scientific literature.

Data analysis

We used descriptive and bivariate statistics to analyze data. To provide a descriptive analysis of the major features of this research body, we started by describing the temporal evolution and the scientific areas of interest on the documents reviewed. We then explored the diversity of local indicators of climate change by calculating frequency of mentions and comparing our results with trends in scientific literature on indicators of climate change. We used a chi-square test of independence to examine the relation between the type of population being studied (indigenous vs. non-indigenous, and rural vs. non-rural) and the frequency with which indicators were reported. To visualize the geographical clustering of the case studies, we performed a kernel density estimation analysis. We applied a kernel function to provide an expected number of points per unit of area in a 2000km radius around each georeferenced case study. The analysis was performed in ArcMap 10.3. Finally, we assessed whether local and scientific indicators overlap by comparing information for each case study.

The Development of Research on Local Indicators of Climate Change

The literature on local indicators of climate change has expanded rapidly since 1996, year when our search located the first article.[42] The increase has been exponential after 2010, with as much as 80 documents on the topic (36%) being published during 2013-2014 (Figure 1). While most of the documents identified (84%) correspond to journal articles, some of the literature has also appeared in conference proceedings (9%) and book chapters (7%). The identified articles have been published in journals from several fields and scientific disciplines (Figure 2), but mainly in journals classified as natural sciences and especially in journals from earth sciences (49.5%) and biology (20.4%). Less than one fifth of the articles have been published in social sciences journals (geography 8% of articles; anthropology 5%).

From the initial pool of 222 documents, only 83 (or 26.5%) contained primary data on local indicators of climate change. Of the remaining documents, some were theoretical discussions[36, 37] and some used secondary data.[43] Many documents described ways in which local people forecast weather,[44–48] focused on adaptation and coping strategies,[49, 50] or management practices[51] but did not report local indicators of climate change. It is noteworthy that the subset of documents actually containing primary data on local indicators of climate change has grown in parallel with the overall pool of articles initially retrieved in our search (Figure 1).

Of the 98 case studies documented, 49 compiled data collected from indigenous populations and almost all of them (n=87 including the previous 49) compiled data collected from rural populations (Table 2); only some works exceptionally sampled people living in urban settings.[52, 53] Arguably some research amongst Westerners might not have been captured by our keyword search, since public perceptions of climate change in urban settings are rarely termed as “local”. Methodological descriptions were often scant or inexistent, with several studies not reporting sampling strategy or sample size and many studies not mentioning study duration. From those reporting sampling criteria, 45 case studies were conducted with local experts and 66 collected data from the general population. Seventeen case studies used a more eclectic approach interviewing both local experts and the general population. Regarding the methodological approach, most studies relied on qualitative methods (n=84), including standard methods such as semi-structured interviews (n=42), focus groups (n=37), open-ended interviews (n=22), and participant observation (n=15), but also less standard methods such as participatory mapping[54] or participatory video.[55] The 29 case studies using systematic methods mostly relied on individual (n=20) or household level surveys (n=5). Nineteen case studies using systematic data collection methods used them in combination with qualitative methods.

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Local Indicators of Climate Change

In the 98 case studies analyzed, we recorded the mention of 746 indicators that fit our definition of local indicators of climate change (case study mean=10.4; SD=7.3; max=38). We grouped the registered observations in 49 indicators: 11 correspond to local observations of climate change (e.g., changes in temperature, precipitation, and wind), 14 to observed impacts on the physical systems (e.g., changes in hydrology, the cryosphere, coastal systems, soils, and geological systems), 10 to observed impacts on biological systems (e.g., changes in terrestrial, marine, freshwater, and seasonal events), and 14 to observed impacts on the socioeconomic systems (e.g., changes in agriculture, forest, fisheries, and human health) (Table 3). As much as 37 of the case studies reported at least one indicator in each of the four main types of indicators used for the analysis (i.e., 1) local observations of climate change and its impacts on 2) the physical, 3) the biological, and 4) the socioeconomic systems). Only 11 case studies reported indicators in only one of these four main types.

Local observations of climate change

Echoing the definition of climate change proposed in the scientific literature,[20] climatic variables are also the indicators more frequently reported on the literature on local indicators of climate change, representing 40% of the indicators found. Indicators mostly relate to changes in precipitation, including variations in the mean and distribution of precipitation (19.2% of all the indicators). Furthermore, as much as 76.3% of the case studies reported, at least, one indicator of change in precipitation. Reports of changes in temperature (13.0%) and wind (8.0%) were also abundant and mentioned in many studies (67.0% in the case of temperature). It is worth noting that while most indicators referred to changes in the mean temperature (7.1%), with reports of “rising temperatures”[56] or “increase in the dry season temperature” [53], there were also some reports of unexpected temperature fluctuations (2.9%).[57] Climate variables used in the scientific literature as indicators of climate change which are typically measured with long-term instrumental data, such as humidity or carbon dioxide (CO_2), did not appear in the documents reviewed.

Observed impacts on the physical systems

The IPCC Fifth Assessment found that physical systems in all terrestrial and oceanographic regions respond to climate variability.[58] Climate change has been found to strongly affect the hydrological system and the cryosphere. Such impacts are locally observed, with reports of impacts on physical systems being the second most frequently documented in our analysis (23.2% of all the local indicators recorded). As for local observations of climate change, the largest focus is on water systems, with 9.5% of the observations referring to impacts on the cryosphere and 8.6% to impacts on hydrology, mentioned in 49.5% of the case studies. Local peoples provided a rich set of indicators referring to changes in snow cover, sea ice, lake ice, river ice, glaciers, ice sheets, and frozen ground (i.e., permafrost), including reports such as “snow patches not as crusty as before”[59] or “earlier slushy lakes.”[60] Some level of attention is also given to coastal systems (2.6%) and especially to sea-level rise, with some informants reporting that “islands are disappearing.”[37] Reports of impacts on the soil systems relate to soil moisture[61] or soil erosion,[62] but overall are scant.

Observed impacts on the biological systems

Temperature changes and other climatic variability strongly affect the morphology, abundance, distribution, and migration patterns of plant and animal species in terrestrial and marine systems alike,[58, 63–65] as well as seasonal patterns in several regions of the world.[14, 66] Impacts on the biological systems represent 19.0% of the local indicators documented, with a large emphasis on changes on terrestrial systems (9.0% of all reports, but cited in 40.2% of the case studies) and changes in seasonal events (6.7% of the indicators and cited in 41.2% of the case studies). As in the scientific literature on impacts of climate change on biological systems, where marine systems are generally underrepresented,[65] reports of local indicators in marine environments are meagre (2.1% of all reports). Indicators on terrestrial systems were among the most diverse in our dataset. Such indicators often refer to concrete species (e.g., "shift in heights of salmonberries and willows"[67]) or very specific behaviors (e.g., the wintering sites of whales, walruses and seals[68]). A similarly rich diversity is found in reports of changes in timing and duration of seasonal events, with some studies reporting events such as "spring has been occurring earlier in the year and at a faster rate"[69] or a "shorter first rainy season."[70] Undoubtedly, such variation reflects the specificity of the local biological systems.

Observed impacts on the socioeconomic systems

Climate change might impact socioeconomic systems both directly[71, 72] and through more indirect changes in the biophysical environment.[73] While it is assumed that impacts on socioeconomic systems should be largely perceived by indigenous and rural communities,[20] arguably because of their dependence on such activities for subsistence,[17] in our study this is the less represented cluster (17.6% of all citations). The socioeconomic systems with the highest number of reports are agriculture (6.4% of the indicators and appearing in 30.9% of the cases) and forest (3.5% of the indicators and 21.6% of the cases). The sparse number of observations on impacts of climate change on socioeconomic systems might relate to the largest visibility of other drivers of local livelihood changes, including integration into the market economies, specialization, diversification, and migration, which affect most of the studied communities.[74, 75] For example, Boissière and colleagues argue that people in Mamberano, Papua, consider that climatic changes are not as important as other issues such as mining, or political decentralization, which have a more direct and immediate impact on their lives.[75] Such findings go in line with researchers increasingly acknowledging the challenges of separating the effects of the many drivers of change in socioeconomic systems.[73]

Finally, while the scientific literature is starting to pay some attention to the effects of climate change in human health, for example highlighting the health effects of extreme heat events or the increasing prevalence of vector-borne diseases,[76] the topic represents 3.1% of all citations reported on the literature on local indicators of climate change.

The Social and Geographical Focus of Research

In the context of climate change research, reports of climate change provided by people with a long history of interaction with their environment have gained increasing recognition

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versus reports provided by populations lacking such history.[77, 78] Such recognition lays on the assumption that local knowledge of climate change reflects a depth of experience that, due to place attachment and time continuity, makes them suitable to detect changes in climate over long periods of time.[79, 80] The empirical question is whether there are differences between indicators provided by different types of populations.

Results from our analysis suggest that, compared to indigenous samples, non-indigenous samples report more observations of climate change (44.8% vs 35.4%) and more indicators of observed impacts on the socioeconomic systems, particularly the agricultural system (8.44% vs 4.36%) (Table 4). Conversely, the indigenous sample report more indicators of impacts on the physical (25.1% vs 21.4%) and biological (22.6% vs 15.6%) systems, with the largest differences relating to reports of change in the cryosphere (12.3% vs 6.9%), terrestrial systems (11.4% vs 6.6%), and seasonal changes (7.9% vs 5.5%). Overall differences in the types of indicators were statistically significant (Pearson chi^2 (17) = 32.38, p=.01). Differences in the local indicators of climate change reported were also found when dividing the sample between rural and non-rural populations (Pearson chi^2(17) =45.53 p<. 0001), with the non-rural sample significantly reporting more observations of climate change (50.0% vs 38.7%) than the rural sample.

Researchers have noticed a lack of geographical balance in the scientific data on climate change and its impacts both in natural and managed systems, with a marked underrepresentation from tropical regions and marine systems.[73] Figure 3 suggests that the literature on local indicators of climate change is also biased, but in a different direction. Most case studies on the literature on local indicators of climate changes have concentrated on African tropical regions and the Himalayan range. Polar Regions, mostly Alaska, the Northwest Territories and Nunavut, have also received a fair degree of attention. Overall, when examining the case studies by climate, the most largely represented climate is the tropical (32% case studies), followed by temperate (23%) and polar (18%). Cold and –especially- arid climates (12.8% of the case studies) –concentrate a low number of studies on local indicators of climate change. Additionally, Figure 4 suggests that while the original research on the topic was conducted in polar regions in the late 1990s, the emphasis seems to be now mostly on temperate regions.

The Overlap Between Local and Scientific Indicators of Climate Change

A little above one-third of the case studies analyzed (37) do not compare results of local indicators of climate change with scientific information, in some cases arguing that there is little scientific data on the area to compare to[85] (Table 2). Slightly below one-third (27) does compare local indicators with some sort of secondary data, typically collected at a much larger scale and often through general statements,[86] as for example “the fishers discourses align with scientific knowledge of the links between human activities, climate change and fish stock declines."[87] The remaining third (33) compares results from local indicators with primary climatic data from different sources.

From the case studies comparing local observations of climate change with scientific data, few[88] do not report –at least partial – agreement between the two bodies of knowledge, although many do report only partial overlap (Box 2). We argue that such result should be taken with caution for at least three reasons. First, as mentioned, comparisons of local and scientific indicators are often done based on different metrics and/or matching data with different spatial resolution. For example, some authors compare local indicators of climate change with information collected in local meteorological stations,86, 87 other authors compare them with records aggregated at the national level, 61 and still others with simulations and projections of the IPCC AR4 for the region. 89 In some cases, it is not even clear the type of scientific indicators being used. Second, in most case studies there is no detail on how much agreement there was on the local indicator reported. We have found cases where different groups of informants reported opposite trends, in which instance the comparison loses relevance. Third, local indicators of climate change often lack temporal resolution. Although local knowledge, through cumulative experience and oral narratives, can provide a historical perspective on past climatic changes or climate baselines,90 in most cases it was impossible to associate a period or a date with the information provided without incurring high uncertainty. It is important to note that many local societies do not frame time in the same metrics as scientific knowledge, thus hampering further possible comparisons of local knowledge with data-series of scientific records.

Conclusion

Although the analysis of local indicators of climate change seems to growingly attract the interest of the scientific community, especially in the natural sciences, the field suffers important weaknesses: primary data on the topic are not abundant, the methodological development is incipient, and the geographical extent is unbalanced. Furthermore, there have been very few previous attempts to classify local indicators of climate change, all of them using data from a single case study.43, 62, 91 The field could, therefore, benefit from ***i)*** building more closely on the experience of social scientists working with local peoples, ***ii)*** homogenizing the methodological approach, and ***iii)*** covering previously neglected geographic areas or climatic regions. As a starting point, the classification system proposed here (Table 3) might constitute a first step towards the development of a more systematic and critical analysis.

Our review highlights that *local observations of climate change* typically relate to variables 1) typically reflecting unusual rather than average patterns and occurrences and 2) potentially affecting a wide range of biophysical and socioeconomic systems, as suggested by the important frequency of reports of observations on precipitation and hydrological systems. Researchers have previously argued that such local observations are of limited help to identify causal interactions between impacts of climate change in different systems73 or at large scales.14

While local observations of climate change are the most frequently reported type of change, our results provide two reasons why indicators of *observed impacts on physical and biological systems* deserve attention. First, we found that *local observations of climate change* are more frequently reported in studies conducted among non-indigenous and non-rural populations than among indigenous and rural populations. Considering that non-indigenous and non-rural populations have most probably better access to information (i.e.,

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because of higher levels of literacy, fluency in national languages, better physical infrastructure), their reports might be relatively more influenced by the scientific discourse on climate change presented in the mass media.[12, 17, 92] If this is the case, our finding might indeed be signaling that reported local indicators are not necessarily "locally observed." Second, we also found higher diversity in indicators related to impact on the biological and physical systems, which reflects the rich and detailed knowledge in relation to these systems. The rich and fine-grained knowledge in relation to impacts on biophysical systems, and the potential interactions between them, provides insights that are qualitatively different to those offered by scientific information on climate change. Such bodies of information could –therefore- be combined to generate synergies for the governance of natural resources under climate change.

We conclude by highlighting two venues in which the study of local indicators of climate change can contribute to broaden the scope of our understanding of the local manifestations of complex changes in the climate system. First, having emphasized that local indicators of climate change can indeed contribute to a better understanding of climate change at the local scale, it is important to explore how this integration should take place in the research process itself.[83] Future research should explicitly attempt at linking social and climate data in a single operational framework in order to improve models assessing climate change.[93, 94] The keystone feature of such an approach could be to overlay indigenous observations with instrumentally-measured climatic changes, particularly in data-deficient regions. Second, owing to the fact that local indicators of climate change are mostly based on experiential knowledge acquired through continued observation, they offer interesting opportunities for developing and informing effective adaptation strategies that are finely attuned to the specific characteristics of particular local environments and contexts.[13, 95, 96] Moreover, local indicators provide an intuitive way to get climate messages across, potentially offering a new rationale for climate change communication to local peoples.

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Box 1

Can local people observe climate change?

No small amount of ink has been spilled over the topic of local observations of climate change.[21] There is a long debate between '*invisibilist*' scholars assuming climate change to be inherently undetectable to the naked eye[22, 23] and '*visibilist*' researchers claiming that the effects of climate change are visible and can be tracked based on personal experience.[24, 25] In this context, a great deal of work in experimental psychology has evidenced that the ability of local people to reliably perceive climatic changes can be indeed biased. For example, research suggests that local people evaluate global climate change mostly in terms of extreme events[26, 27], and that local people's perceptions of climate change can be shaped by personal experience of recent increases in local temperatures,[28] actual outdoor temperature at the moment of elicitation,[29, 30] or other short-term weather fluctuations,[31, 32] rather than long-term trends of global climate change. [33, 34]

Authors have argued that it is indeed difficult to experience global climate change and that what most local people detect are changes in local weather patterns, which might not always reflect long-term global climatic trends.[31, 35] Moreover, whether observable climatic impacts create opportunities for local people to become more aware of global climate change, or alternatively, whether prior knowledge of –or belief on– climate change shapes people's perceptions through a process of 'motivated reasoning' is still contested.[26, 33, 36] Yet, most of these studies have been conducted with societies in which access to the scientific construct of climate change is guaranteed (mostly through reports in the mass media). This situation, however, might be different in many indigenous and rural societies worldwide.[12] Our literature review focuses on documents exploring knowledge provided by populations arguably less familiar with the scientific construct of climate change, offering views that could be critical to answer what Myers and colleagues[26] named the 'chicken-or-egg question' on the relation between perceived personal experience of climate change and belief certainty that climate change is happening.

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Box 2

Towards '*hybrid*' knowledge of climate change?

At a theoretical level, a large body of literature has focused on comparing scientific and local knowledge.[81, 82] When so doing, the goal has not generally been to assert that one type of knowledge is more valid than another[15] but rather to understand the critical differences with regard to their spatial and temporal scales of observation.[17, 82] In this context, some researchers propose exploring the apparent discrepancies between −and within– scientific and local knowledge with the goal to generate new knowledge about climate change.[19, 83]

Many studies suggest that both local and scientific knowledge have many points of overlap. On the one hand, critical work in anthropology has shown that scientific knowledge can also be 'local' in important ways.[84] For example, the scientific records of a single weather station can capture the local idiosyncrasies of a very specific micro-climate in a particular locality. On the other hand, local knowledge is also intrinsically similar to scientific knowledge in that it has an empirical component, derived from the longstanding association of people with their environment.[19] As empirical tests of such overlaps become available to the scientific community, the gaps between scientific and local knowledge of climate change might gradually become bridged.[59, 81] Future climate research will benefit by moving beyond simple comparisons of local *vs*. scientific knowledge and focusing on their complementary engagement in '*hybrid*' knowledge frameworks.[17]

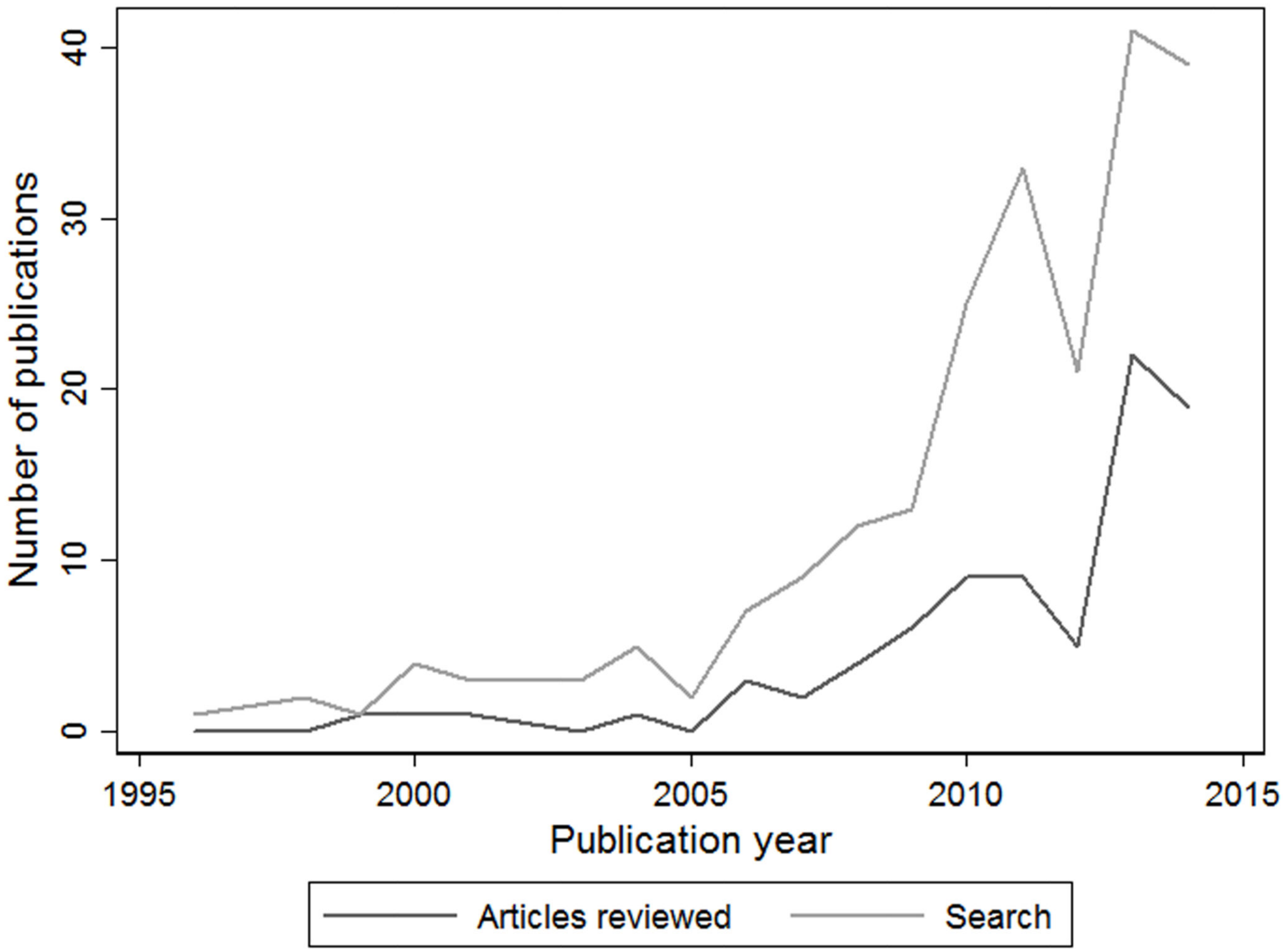

Figure 1.
Number of publications on local indicators of climate change, by year.

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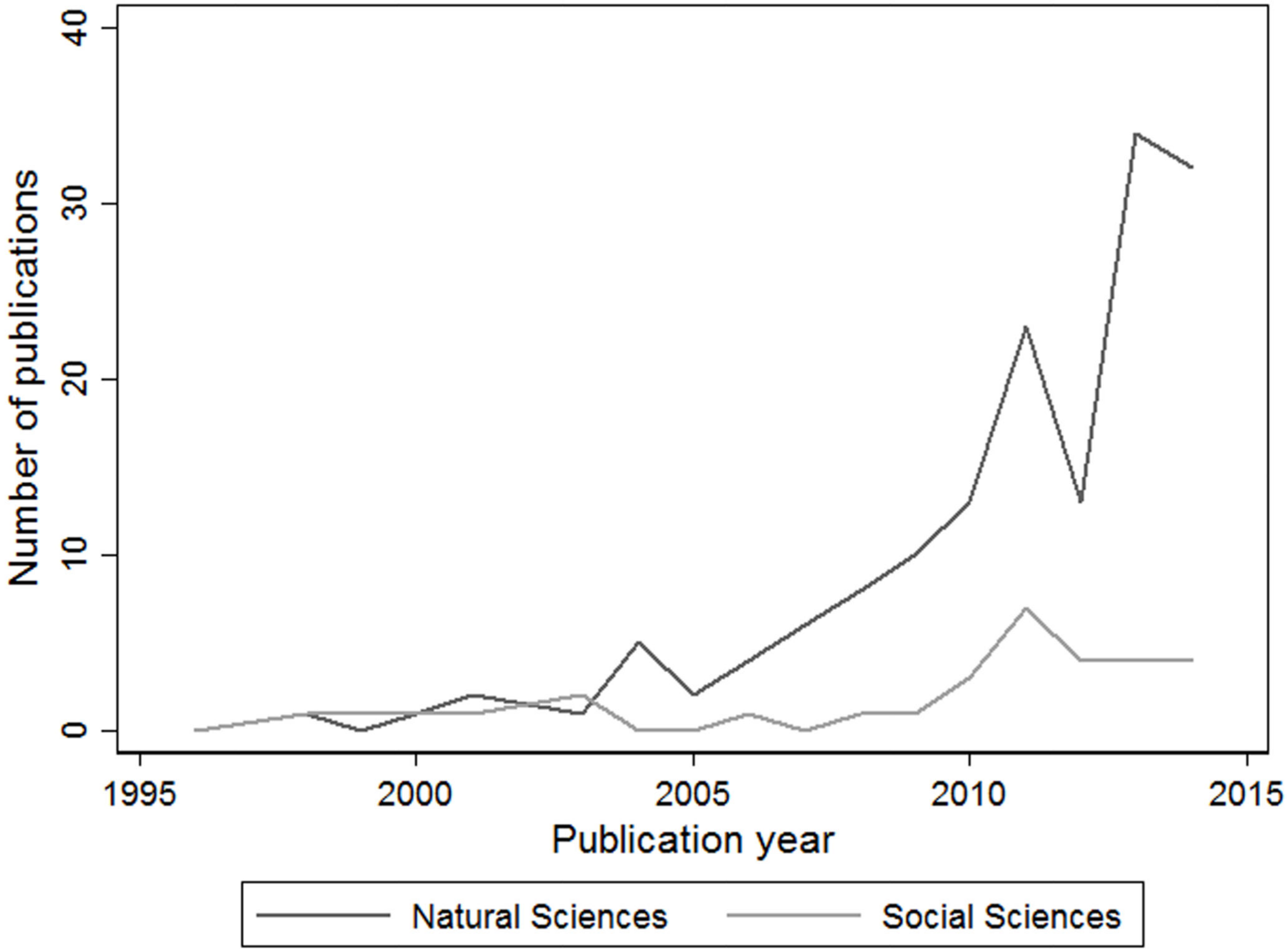

Figure 2.
Number of publications in natural and social science journals, by year.

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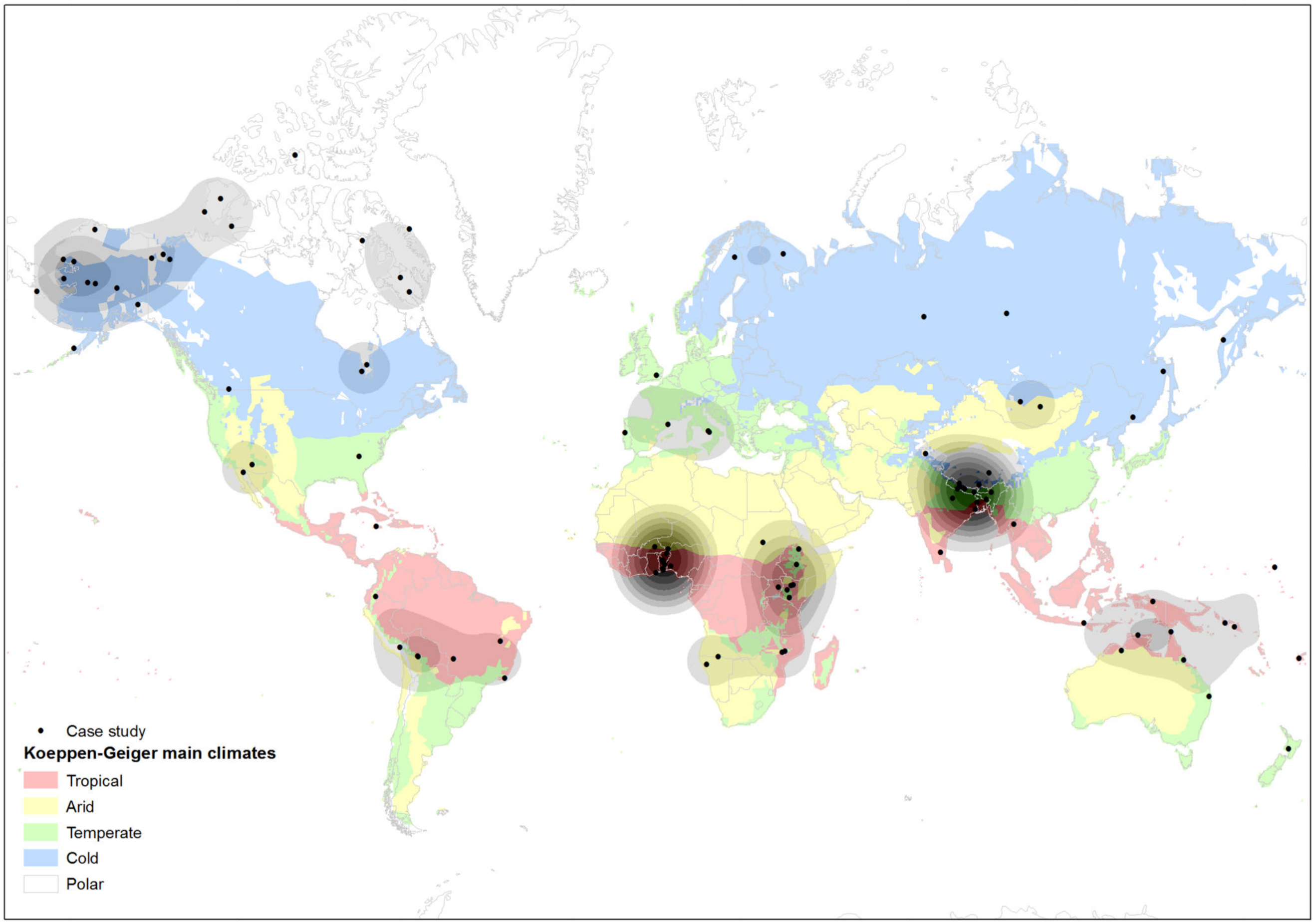

Figure 3.
Distribution map of the case studies with kernel density estimations and main climates (according to Koeppen-Geiger classification).

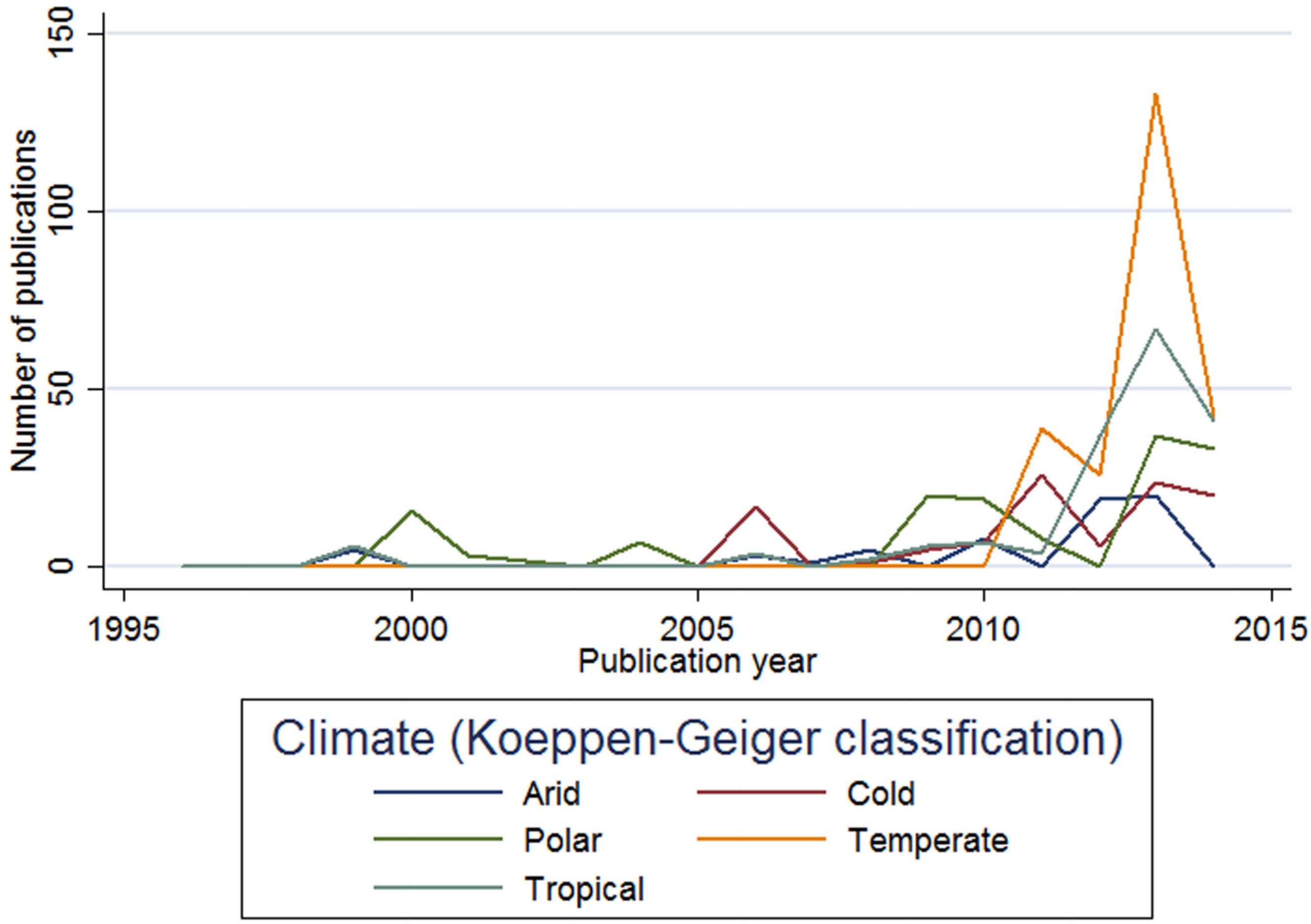

Figure 4.

Number of case studies conducted in each of the main climates, by year.

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Table 1

Definition of variables used in the meta-analysis

	Variable	**Definition**	**Format**
Bibliography	Year	Publication year	Year
	Document	Type of document analyzed	1= Journal article 2= Book chapter 3= Conference proceeding
	Subject Area	Article's main subject area	1= Social sciences 2= Natural sciences
Studied group	Indigenous	The society has a long history of interactions with the environment	0= No 1= Yes
	Rural	The main current livelihood is based on the direct use of natural resources	0= No 1= Yes
Sample	Local experts	Data were collected from local experts (e.g., elders, specialists)	1= Yes 0= No
	Lay observers	Data were collected from general population	1= Yes 0= No
Methods	Qualitative	Data collected using qualitative methods	1= Yes 0= No
	Quantitative	Data collected using quantitative methods	1= Yes 0= No
Local indicators	Local observations of climate change and observed impacts on the biophysical and the social systems attributed to climate change		49 codes (see Table 3)
Study Area	Location	Location of study area	Coordinates
	Climate	Climate types as defined by Koeppen-Geiger climate classification.33, 34	1= Tropical 2= Arid 3= Temperate 4= Cold 5= Polar
Correspondence with scientific information	Compare science	The work compares local indicators with scientific information	0= No 1= Yes, to secondary data 2= Yes, to author's data

Table 2

Description of the variables (n=98)

	Variable	Frequency
Studied group	Indigenous (=1)	49
	Rural (=1)	87
Sample	Local experts (=1)	45
	General population (=1)	66
	Both	17
Methods	Qualitative (=1)	84
	Quantitative (=1)	29
	Both	19
Climate	Tropical	35
	Arid	18
	Temperate	9
	Cold	4
	Polar	32
Compare Science	No	37
	Secondary data	27
	Primary data	33

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Table 3

Frequency of mention of local indicators of climate change

	Local indicator	Frequency (%)	% Case studies reporting the indicator
	Local observations of climate change		
Temperature	Mean temperature	53 (7.1)	54.64
	Temperature extremes	22 (2.9)	22.68
	Temperature fluctuations/unpredictable weather	22 (2.9)	22.68
	Total	97 (13.0)	67.01
Precipitation (rainfall and snowfall)	Mean precipitation	54 (7.2)	55.67
	Precipitation extremes	17 (2.3)	17.53
	Precipitation distribution	41 (5.5)	42.27
	Drought	22 (2.9)	22.68
	Clouds and fog	9 (1.2)	9.28
	Total	143 (19.2)	76.29
Wind	Wind speed / direction /temporality	29 (3.9)	29.90
	Storm/Storm surges/Hail Storms/Dust storms	22 (2.9)	22.68
	Cyclones and tornadoes	9 (1.2)	9.28
	Total	60 (8.0)	39.18
Total		300 (40.2)	
	Observed impacts on physical systems		
Hydrology	Mean river flow/lake level	15 (2.0)	15.46
	Floods	20 (2.7)	20.62
	Fresh water (includes underground) availability/quality	25 (3.3)	25.77
	River bank erosion/sedimentation	4 (0.6)	4.12
	Total	64 (8.6)	49.48
Cryosphere	Snow cover	21 (2.8)	21.65
	Ice sheet/lake and river ice	18 (2.4)	18.56
	Glaciers	12 (1.6)	12.37
	Permafrost	7 (0.9)	7.22
	Sea ice	13 (1.7)	13.40
	Total	71 (9.5)	37.11
Coastal systems	Sealevel rise (island recede)	14 (1.9)	14.43
	Coastal erosion	5 (0.7)	5.15
	Total	19 (2.6)	17.53
Soil	Soil moisture	7(0.9)	7.22
	Soil erosion/landslides	11 (1.5)	11.34
	Total	18 (2.4)	15.46
Geological system	Earthquakes and tsunamis	1 (0.1)	1.03
	Total	1 (0.1)	1.03

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	Local indicator	Frequency (%)	% Case studies reporting the indicator
Total		173 (23.2)	
Observed impacts on biological systems			
Terrestrial	Plant and fungal phenology	14 (1.9)	14.43
	Animal phenology	10 (1.3)	10.31
	Distribution/abundance of plant species	13 (1.7)	13.40
	Distribution/abundance of animal species	21 (2.8)	21.65
	Habitat degradation (e.g. desertification)	9 (1.2)	9.28
	Total	61 (9.0)	40.20
Marine	Sea surface temperature	2 (0.3)	2.06
	Distribution of marine species	14 (1.9)	14.43
	Total	16 (2.1)	15.46
Freshwater	Change in fish behavior/migratory pattern	9 (1.2)	9.28
	Total	9 (1.2)	9.28
Seasonal events	Shifts in seasonal patterns	21 (2.8)	21.65
	Duration of seasonal events	29 (3.9)	29.90
	Total	50 (6.7)	41.24
Total		142(19.0)	
Observed Impacts on Socio-Economic Systems and Health			
Agricultural systems	Growing season for agricultural crops/phenology	11 (1.5)	11.34
	Crop productivity	17 (1.3)	17.53
	Soil degradation/fertility	5 (0.7)	5.15
	Crop diseases, pests, and weeds	15 (2.0)	15.46
	Total	48(6.4)	30.93
Forests systems	Forest cover change	9 (1.2)	9.28
	Forest fires	6 (0.8)	6.19
	Decrease in forest products availability/quality	11 (1.5)	11.34
	Total	26 (3.5)	21.65
Pastoral systems	Pasture availability	6 (0.8)	6.19
	Livestock productivity/disease/quality/behavior	13	13.40
	Total	19 (2.6)	15.46
Fisheries	Fish stock decline/ fish morphology	13 (1.7)	13.40
	Total	13 (1.7)	13.40
Human health	Diseases	16 (2.1)	16.49
	Health injuries	3 (0.4)	3.09
	Hunger	4 (0.5)	4.12
	Total	23 (3.1)	20.62
Transport	Trails	2 (0.3)	2.06
	Total	2 (0.3)	2.06
Total		131 (17.6)	

Table 4

Frequency of mention of local indicators of climate change, by studied group

	Indigenous		Rural	
	No	Yes	No	Yes
Local observations of climate change				
Temperature	50 (13.2)	47 (12.8)	16 (16.33)	81 (12.5)
Precipitation	91 (24.01)	52 (14.17)	20 (20.41)	123 (19.0)
Wind speed	29 (7.65)	31 (8.45)	13 (13.27)	47 (7.2)
Overall	170 (44.8)	130 (35.4)	49 (50.0)	251 (38.73)
Observed impacts on physical systems				
Hydrology	36 (9.50)	28 (7.63)	5 (5.10)	59 (9.1)
Cryosphere	26 (6.86)	45 (12.26)	10 (10.20)	61 (9.4)
Coastal system	10 (2.64)	9 (2.45)	7 (7.14)	12 (1.8)
Soil	9 (2.37)	9 (2.45)	0 (0.00)	18 (1.8)
Geological system	0 (0.00)	1 (0.27)	0 (0.00)	1 (0.1)
Overall	81 (21.4)	92 (25.1)	22 (22.5)	151 (23.3)
Observed impacts on biological systems				
Terrestrial	25 (6.60)	42 (11.44)	2 (2.04)	65 (10.0)
Marine	8 (2.11)	8 (2.18)	4 (4.08)	12 (1.8)
Freshwater	5 (1.32)	4 (1.09)	4 (4.08)	5 (0.8)
Seasonal events	21 (5.54)	29 (7.90)	3 (3.06)	47 (7.3)
Overall	59 (15.68)	83 (22.6)	13 (13.3)	129 (19.9)
Observed Impacts on Socio-Economic Systems and Health				
Agricultural system	32 (8.44)	16 (4.36)	9 (9.18)	39 (6.0)
Forests system	12 (3.17)	14 (3.81)	1 (1.02)	25 (3.9)
Pastoral system	7 (1.85)	12 (3.27)	0 (0.00)	19 (2.9)
Fisheries	7 (1.85)	6 (1.63)	0 (0.00)	13 (2.0)
Human health	11 (2.90)	12 (3.27)	4 (4.08)	19 (2.9)
Transport	0 (0.00)	2 (0.54)	0 (0.00)	2 (0.3)
Overall	69 (18.2)	62 (16.9)	14 (14.3)	117 (18.06)
	Pearson $chi^2(17)$ =32.38 p=.01		Pearson $chi^2(17)$ =45.53 p<.0001	