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A collaborative approach to bring insights from local indicators of climate change impacts into global climate change research

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Abstract

Bringing insights from Indigenous and local knowledge into climate change research requires addressing the transferability, integration, and scalability of this knowledge. Using a review of research on place-based observations of climate change impacts, we explore ways to address these challenges. Our search mostly captured scientist-led qualitative research, which -while facilitating place-based knowledge transferability to global research- did not include locally-led efforts documenting climate change impacts. We classified and organized qualitative multi-site place-based information into a hierarchical system that fosters dialogue with global research, providing an enriched picture of climate change impacts on local social-ecological systems. A network coordinating the scalability of place-based research on climate change impacts is needed to bring Indigenous and local knowledge into global research and policy agendas.

Key words: Indigenous and local knowledge; Indigenous Peoples and Local Communities; local indicators of climate change impacts.

Highlights

1. Place-based research on climate change impacts can benefit global climate change science;

2. Qualitative data can support place-based knowledge transferability to global research;

3. Local observations of climate change impacts can be organized to foster dialogue with global climate change research;

4. Research on local observations of climate change impacts is geographically biased and not universally connected;

5. A coordinated community of practice is needed to bring place-based climate knowledge into global climate change research and policy agendas.

Introduction

There is overwhelming evidence that climate change has not only direct effects on the climatic system, but also a discernible influence on physical and biological systems [1–3], with resulting impacts on local livelihoods and cultures [4]. Most of this evidence comes from research in the natural sciences relying on large-scale weather records and the use of modelling techniques to describe impacts in data deficient regions [5]. While such research has advanced our understanding of climate change's global magnitude, its methods are too coarse to detect impacts on local social-ecological systems [6] for which scientists have called for exploration of locally-grounded data sources [3].

Indigenous and Local Knowledge (ILK) has an untapped potential to contribute to research on climate change impacts on local social-ecological systems [7,8]. Indigenous Peoples and Local Communities (IPLC) with a history of interaction with the environment have developed intricate and complex knowledge systems (e.g., information, management techniques, institutions) that allow them to detect changes in local weather and climatic variability [8,9]. Attempts to bring insights from ILK into climate change research range from comparing ILK and scientific reports to validate the former [7] to encouraging synergies between both knowledge systems to obtain an enriched understanding of local climate change impacts [10]. Nevertheless, ILK continues to be largely absent in climate change impacts research [11] as epistemological [10], methodological [8], and scaling issues [12] challenge the transferability, integration, and scalability of ILK.

Bringing insights from ILK into climate change impact research would require addressing such challenges. Addressing transferability calls for bringing ILK's qualitative and interpretative nature into standardized categories while recognizing the incommensurability of some aspects [10,13,14]; addressing integration calls for combining inputs from multi-site place-based research [15]; and addressing scalability calls for the creation of a community of practice that considers both the need to effectively downscale global models to resolutions useful for local climate adaptation and the need to ensure that placed-based information is effectively upscaled to global climate models [16].

Here, we analyse the academic literature documenting observations of local climate change impacts to explore how it addresses ILK transferability, integration, and scalability. Capitalizing upon previous efforts [8], we review scholarly publications documenting first-hand IPLC observations of changes in social-ecological systems attributed to climate change. Specifically, we reviewed 135 documents reporting 1363 first-hand observations of changes locally perceived as climate-driven on 198 locations in all inhabited continents (SM1 contains a methodological description).

Transferability of observations of local climate change impacts

Observations of local climate change impacts have been mainly documented using qualitative data collection techniques, with only 64 studies reporting the use of surveys (e.g., [17]). Qualitative data collection methods include participant observation (n=15 studies e.g., [18]), open-ended (n=18, e.g., [19]) and semi-structured interviews (n=60, e.g., [20]), community gatherings (n=7, e.g., [21]), and focus group discussions (n=50, e.g., [22]). Six studies relied on participatory methods for data collection, (e.g., [23]), and only two were steered or led by IPLC ([24,25]). Finally, only 17 studies embarked on cross-cultural comparisons (e.g., [26]). In other words, the predominant approach used to document observations of local climate change impacts has relied on the collection of rich qualitative data. While not easily transferable, such work has been used in climate change research to buttress quantitative models and to assist in the triangulation and interpretation of results [9].

In response to calls to move anthropology to a "cross-scale, multi-sited research design and an interdisciplinary mix of interactive and structured tools and techniques" so "that the analytical focus is expanded to encompass local communities and their multiple action spaces as well as the higher spheres of decision-making, where policy and science are shaped" [27], researchers have recently started to look for patterns in qualitative reports from multiple sites (e.g., [6,7]). While interesting, this effort has been done *a posteriori*, without a clear *a priori* strategy that improves the prospects for comparability and transferability of qualitative observations (e.g., [28]). Examples exist of data collection methods designed to gather place-specific, yet comparable, knowledge from different locations (e.g., [29,30]). Such an approach would boost the transferability of multi-site observations of climate change impacts while valuing local ways of understanding and interacting with the environment.

Integrating observations of local climate change impacts to the global setting

Researchers [1–3], environmental agencies [31,32], and the Intergovernmental Panel on Climate Change (IPCC) [33] have proposed several categorizations of climate change impacts. Building on this, we propose a classification of qualitative place-based observations of climate change impacts. For this categorization, we specifically draw on the IPCC´s 5th Assessment Report (AR5) Working Group (WG) II´s [33]. We started creating a list of all observations of local climate change impacts documented in our search and grouping *verbatim* observations referring to the same phenomenon (e.g., "higher temperatures" and "hotter"). We then classified observations in indicators, or more general descriptions of observations; what we call 'local indicators of climate change impacts' (LICCI) (SM2). We then grouped LICCIs based on the natural element or process reportedly being impacted; and further grouped these elements in 19 sub-systems ultimately corresponding to the four main systems: climatic, physical, biological and socioeconomic (Table 1). Drawing on scientific reports [31-33], we added some categories on the "Element impacted" level to encompass impacts not reported in the documents reviewed. We differentiate between 'slow onset' impacts (i.e., gradual trends observed in long timescales) and 'rapid onset' impacts (i.e., abrupt changes and/or extreme episodic events) [34].

Our classification suggests that observations most commonly documented through qualitative research refer to impacts on the climatic system (n=609 observations, 44.7%), and particularly to changes in precipitation (n=269, 19.7%) (Table 1). Some of the impacts observed refer to very specific phenomena, such as trends in mean precipitation and extremes [35], but others refer to complex phenomena, such as changes in drought patterns [36] or seasonal events [37]. Some impacts detected with instrumental measurements (e.g., changes in atmospheric moisture) are not documented in the literature reviewed. Most observations on the climatic system refer to slow onset impacts (83.3%) (e.g., changes in the length of seasons).

IPLC also report impacts on the local physical system (n=320; 23.5%), including observations of impacts on the marine [38] and the terrestrial physical systems [39], among which observations of impacts on the freshwater (e..g, [40], 10.1%) and the cryosphere systems (e.g., [41], 7.7%) (Table 1). Impacts on some elements of the physical systems documented in the IPCC AR5 are rare in the literature (e.g., impacts on ocean salinity and currents are only mentioned once) and others (e.g., impacts related to ocean acidification, hypoxia, or soil salinization) are not documented. Almost all

Table 1
Classification and number of observations (N) of local climate change impacts on systems, sub-systems, and elements

System	Sub-system	Element	N	Onset
Climatic (n=609)	Temperature (n=102)	Mean temperature	70	S
		Temperature extremes	32	R
	Precipitation (n=269)	Mean precipitation	90	S
		Precipitation extremes	32	R
		Precipitation distribution, variability, predictability	90	S
		Drought	45	S
		Clouds and fog	12	S
	Air masses (n=78)	Wind	40	S
		Storm (hail/dust/sand)	28	R
		Cyclones, tornadoes	10	R
	Seasonal events (n=160)	Seasonal ice formation changes	26	S
		Duration and timing of seasons	68	S
		Seasonal temperature changes	42	S
		Seasonal precipitation changes	24	S
Physical system (n= 320)	Marine physical systems (ocean & sea) (n=34)	Sea temperature	3	S
		Sea level	17	S
		Coastal erosion/sedimentation	10	S
		Ocean currents	3	S
		Ocean salinity	1	S
	Freshwater physical system (continental waters) (n=138)	Mean river flow	36	S
		River and lake floods	20	S
		Fresh water availability/quality	52	S
		Water temperature of rivers and lakes	2	S
		Lake level	10	S
		Phreatic/underground water	10	S
		River bank / pond erosion/sedimentation	8	S
	Terrestrial physical system (soil & land) (n=43)	Soil erosion/landslides	27	S/R
		Soil moisture	14	S
		Soil temperature	1	S
		Edaphic properties (fertility, structure & biology)	15	S
		Earthquake and tsunamis	1	R
	Cryosphere (ice & snow) (n=105)	Snowfall and snow cover	41	S
		Ice sheet / lake and river ice	18	S
		Glaciers	21	S
		Permafrost	11	S
		Sea ice	14	S
Biological (n=224)	Marine biological system (n=46)	Marine spp abundance	16	S
		Marine spp composition	*	S
		Marine spp habitat range (distribution)	5	S
		Marine spp invasive alien species	3	S
		Marine spp disease/pest/mortality	16	S
		Marine spp phenology	2	S
		Marine spp reproduction	1	S
		Marine game spp quality	3	S
	Freshwater wild fauna (n=31)	Fresh water spp abundance	14	S
		Fresh water spp. composition	*	S
		Fresh water spp habitat range (distribution)	4	S

System	Sub-system	Element	N	Onset
		Fresh water spp invasive alien species	1	S
		Fresh water spp disease/pest/mortality	1	S
		Fresh water spp phenology	10	S
		Fresh water spp reproduction	1	S
		Fresh water spp quality	*	S
	Terrestrial wild fauna (n=56)	Terrestrial fauna abundance	16	S
		Terrestrial fauna composition	*	S
		Terrestrial fauna habitat range (distribution)	12	S
		Terrestrial fauna invasive alien species	5	S
		Terrestrial fauna disease/pest/mortality	13	S
		Terrestrial fauna phenology	10	S
		Terrestrial fauna reproduction	*	S
		Terrestrial game spp quality	*	S
	Terrestrial wild flora (fungi-plants-shrubs-trees) (n=73)	Wild flora abundance (excluding timber & NTFP)	14	S
		Wild flora composition	*	S
		Wild flora habitat range (distribution)	2	S
		Wild flora invasive alien species	2	S
		Wild flora disease/pest/mortality	5	S
		Wild flora phenology	13	S
		Wild flora productivity and quality	6	S
		Timber forest sp. composition and structure	12	S
		Timber forest sp. availability and quality	7	S
		Non-timber forest products availability and quality	12	S
	Land cover change (n=18)	Habitat degradation	11	S
		Forest fires	7	R
Human (n=210)	Aquaculture (marine & fresh water)	Aquaculture productivity and quality	*	S
		Aquaculture disease/pest/mortality	*	S
		Aquaculture phenology and reproduction	*	S
	Cultivated plant spp (crops, orchards) (n=103)	Cultivated spp productivity and quality	43	S
		Seed or propagule availability or quality	*	S
		Disease/pest/mortality of crops	37	S
		Crop weeds (invasive alien species)	4	S
		Phenology and reproduction	19	S
	Pastures & grassland (n=28)	Pasture availability and productivity	17	S
		Pasture spp composition, distribution & quality	7	S
		Pasture disease/pest/mortality	*	S
		Pasture weeds (invasive alien species)	3	S
		Pasture phenology and reproduction	1	S
	Livestock (n=29)	Livestock productivity and quality	7	S
		Livestock spp. composition	*	S
		Livestock disease/pest/mortality	20	S
		Livestock phenology and reproduction	2	S
	Human health (n=47)	Diseases	19	S
		Health injuries, physical affection	9	S
		Hunger	11	S
		Conflicts	*	S
		Cultural/spiritual/ identity values	8	S
	Infrastructure(n=3)	Transport (e.g. trails)	3	S

[S] slow onset impacts;[R] rapid onset impacts.
* we did not find observations corresponding to these LICCIs in the literature, but it is possible that these LICCIs were overlooked in our search as they are not evident in the papers.

observations of impacts on elements of the physical system (91%) correspond to slow onset impacts (e.g., permafrost).

IPLC also observe impacts on the biological system (n=224, 14.6%), and particularly changes in terrestrial wild flora (n=73, 5.4%, such as changes in abundance of species [22] or phenology [26]) (Table 1). There are several differences between observations of impacts on elements of the biological systems reported in our search and in the IPCC report. For example, local observations of climate change impacts on forests focus on changes in vegetation cover or height (e.g., [23]), whereas the IPCC report emphasizes forests' productivity. Similarly, the IPCC report mentions impacts on the extent of agricultural areas and provides indicators of impacts on marine and freshwater species, while these are not reported on documents in our search. Inversely, the IPCC report points at an information gap regarding impacts on hunting and wild food collection, but such impacts are documented by IPLC (e.g., [42]). Only 3.1% of the local observations of impact on elements of the biological system are rapid onset impacts, mostly corresponding to forest fires.

Finally, 210 (15.4%) documented observations refer to impacts on elements of the human system, of which 103 (7.6%) correspond to impacts on the agricultural system (Table 1). The literature includes few mentions of impacts on health and nutrition (3.4%) or infrastructure (0.3%), probably reflecting sampling biases (see SM1). As for impacts on the biological system, the IPCC report lists impacts on health, nutrition, and agricultural infrastructures not reported in the reviewed literature. All impacts documented in the human system are slow onset impacts.

The categorization of local climate change impact observations provides several insights. First, in all inhabited continents, IPLC observe slow onset climate change impacts on multiple elements of their social-ecological system. While IPLC might not detect some impacts (e.g., soil salinization), they seem to observe changes on the biological system resulting from them (e.g., changes in wild flora). Second, local observations can be organized in a way that fosters dialogue with global climate change research, including the IPCC. Categorization, however, is dependent on the existence of qualitative data that permits the correct interpretation of information. And third, the literature reviewed suggests that, to detect change, IPLC use multiple elements of their knowledge system simultaneously. While this highlights IPLC´s understanding of complex interactions in social-ecological systems, it also adds an unsolved layer of complexity on the integration of this body of knowledge to global climate research.

Scalability of local climate change impacts observations

To explore the scalability potential of observations of local climate change impacts to global research, we analyse document's spatial distribution and connectivity. The analysis of the 198 locations documented shows an unbalanced geographical distribution (Fig. 1; SM3). Most locations concentrate on tropical regions (n=65), and particularly on the Congo Basin and the East African Mountains. Locations in the temperate climate (n=49) concentrate in the Himalayan range. Polar Regions (n=33), cold (n=29), and arid climates (n=22) have drawn less scholarly attention (SM4). The higher diversity of LICCI has been documented in Polar Regions (n=69) and the lowest in arid regions (n=39). A similar number of LICCI has been documented in tropical (n=62), temperate (n=62), and cold regions (n=59).

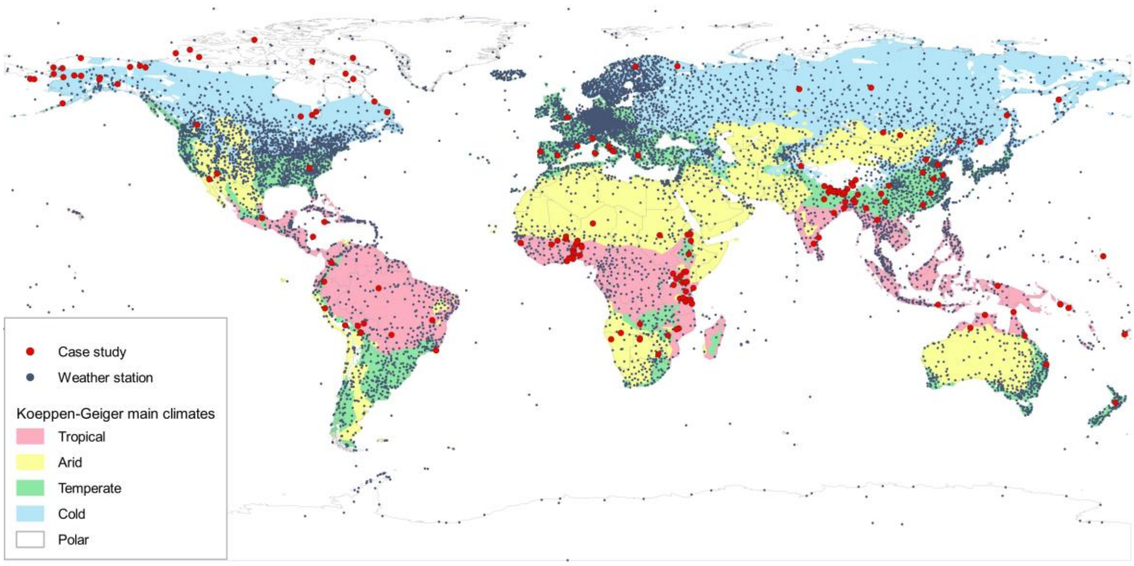

Fig. 1: Distribution of world meteorological stations based on the CRUTEM.4.6.0.0 dataset [43] and locations of the reviewed case studies along with the main climates according to the Koeppen-Geiger classification [47,48].

An important characteristic of the locations where observations of climate change impacts were documented is their distance to weather stations whose data is included in the datasets CRUTEM4 used for assessing anthropogenic climate change [43]. Thus, half of the locations documented are in areas with <6 and <27 weather stations within a 200km and a 500km radius (compared to a maximum of 61 and 346 weather stations for a case study in Italy) (SM5). Given the deficient weather station coverage, observations of local climate change impacts could become an alternative data source to evaluate the performance of climate models in these areas.

We also explored the potential for scalability by analysing the connectivity through time within the literature reviewed, measured through a bibliometric direct citation network using CitNetExplorer (SM1). We found that 36.0% of the documents analysed had no citation relations with the other publications, indicating minimal integration of more than a third of the literature surveyed. The remaining publications formed two interconnected components. Our clustering analysis produced seven clusters and indicated some degree of regional patterning, suggesting a citation pattern based on geographical criteria. For example, 71.4% of the publications in the blue cluster focused on Asia, with 52.4% centred around the Himalayas; similarly 94.4% of publications in the green cluster focused on Arctic regions. Thus, while incipient regional networks seem to be emerging, much of the literature is not integrated nor in communication with global research efforts.

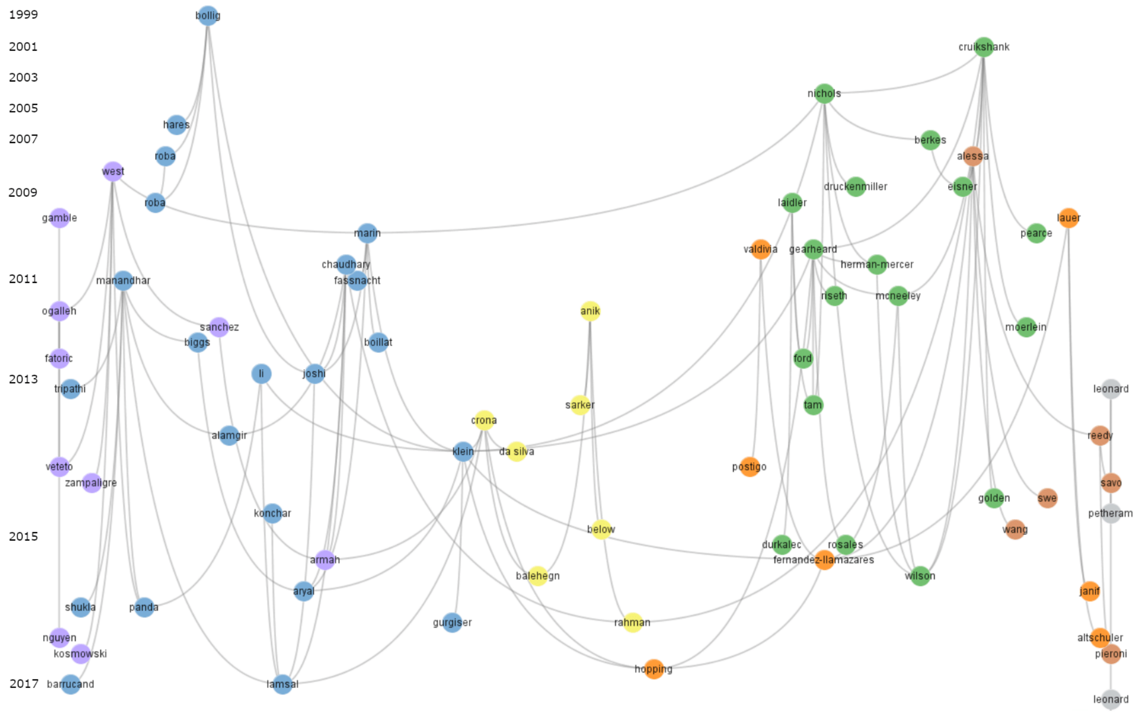

Figure 2: Citation network of publications reviewed. Circles represent publications and are labeled with the first author's surname. The position of the publication on the y-axis indicates time of publication. Lines indicate citation relations between publications.

Conclusion

The review of research documenting ILK-based observations of local climate change impacts provides three important insights that should guide future efforts to bring ILK into global climate change impacts research. First, the use of qualitative methodologies for data collection might facilitate the transferability of local observations into global research by providing the context needed to bring into standardized categories ILK interpretative nature. However, ensuring that holistic observations of complex social-ecological processes are meaningfully captured remains a challenge. Future strategies to improve transferability should include a conscious focus on the web of relations between elements of the social-ecological systems and how climate change impacts on them are captured through ILK holistic view. Future strategies should also foster continuous dialogue with ILK-holders to ensure that ILK historical and contextual complexities are not overlooked [10,11,44].

Second, multi-site qualitative place-based information can be integrated in a way that provides an enriched picture of climate change impacts on local social-ecological systems (see also [16]). Given IPLC increasing global interest to build cross-cultural narratives around climate change impacts and to connect their local realities to global climate change discourses (e.g., [45]), the classification proposed here might allow synergies across different knowledge systems documenting climate change impacts.

Finally, while the literature used illustrates ILK potential to become an alternative data source to evaluate the performance of global climate models, it also shows important geographical gaps and insufficient coordinating efforts to reach that potential. Thus, despite research increase, we still lack a community of practice (i.e., researchers, IPLC, practitioners, decision-makers) committed to upscaling ILK-based observations of climate change impacts in a coordinated way. Such strategy is common in research collecting large volumes of social-ecological data (e.g., [46]) and is increasingly combined with citizen science and community-based environmental monitoring initiatives gathering multi-site grounded data (e.g., [15]). Creating such community of practice is a necessary step to bring place-based climate knowledge into resolutions that can influence climate change-related research and policy agendas.

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Supplementary Materials

Subsystem	Impacted Element	LICCI
Temperature	Mean temperature	Changes in mean temperature
		Changes in the frequency of warm days
		Changes in the frequency of cold days
		Changes in the frequency of sunny days
		Changes in sunshine intensity
		Changes in the temperature during the night
		Changes in the temperature during the day
		Changes in temperature associated with elevation
	Temperature extremes	Changes in the frequency of heat waves
		Changes in the frequency of cold waves
		Changes in the intensity of frost
		Changes in the frequency of days with extreme temperatures
		Changes in the duration of heat waves
		Changes in the strength of heat waves
		Changes in the length of cold waves
		Changes in the frequency of frost days
Precipitation	Mean precipitation	Changes in mean rainfall
		Changes in number of rainy days
		Changes in the number of dry days
	Precipitation extremes	Changes in the intensity of heavy rainfall events
		Changes in the frequency of heavy rainfall events
		Changes in the frequency of flash floods
		Changes in the frequency of natural disasters related with rainfall
	Precipitation distribution, variability and predictability	Changes in the frequency of patchy rains
		Changes in the frequency of dry spells
		Changes in the predictability of rainfall
		Changes in variability of rainfall
		Changes in the duration of rainfall events
	Drought	Changes in the frequency of drought events
		Changes in the intensity of drought
		Changes in the length of drought
		Changes in the frequency of years without any rainfall
	Clouds and fog	Changes in cloud size
		Changes in cloud thickness
		Changes in the number of clouds
		Changes in the frequency of fog or misty days
		Changes in the frequency of cloudy days
		Changes in the duration of fog
		Changes in the colour of clouds
Air masses	Wind	Changes in wind strength or speed
		Changes in the number of windy days
		Changes in wind direction
		Changes in wind temperature
		Changes in the frequency of wind storms
		Changes in the intensity of wind storms
	Storm (hail storm/dust storm/sandstorm)	Changes in the frequency of lightning and thundering
		Changes in the frequency of hail storms
		Changes in the frequency of sand or dust storms

Subsystem	Impacted Element	LICCI
		Changes in the intensity of hail storms
		Changes in the intensity of sand or dust storms
		Changes in the frequency of storms
	Cyclones, tornadoes	Changes in the frequency of cyclones and tornados
		Changes in the intensity of cyclones and tornados
Seasonal events	Seasonal ice formation changes	Changes in the speed of ice melting or break-up
		Changes in the speed of ice formation
		Changes in the timing of ice melting or break-up
		Changes in the timing of ice formation
		Changes in the frequency of freeze events
		Changes in the duration of ice
		Changes in ice stability
	Duration and timing of seasons	Changes in the length of seasons
		Changes in the duration of seasonal events (eg. Monsoon)
		Changes in the timing (onset or end) of seasons
		Disappearance of one or more seasons
	Seasonal temperature changes	Changes in the frequency of unusual temperatures in a given season
		Changes in the mean temperature in a given season
		Changes in the frequency of extreme winters
		Changes in the intensity of extreme winters
	Seasonal precipitation changes	Changes in the amount of rainfall in a given season
		Changes in the intensity of rainfall in a given season
		Changes in the variation of rainfall in a given season
		Changes in the timing of rainfall season (onset, end)
		Changes in the duration of rainfall season
		Changes in the timing of dry season (onset, end)
		Changes in the duration of dry season
Marine physical systems (ocean & sea)	Sea temperature	Changes in the sea surface temperature
		Changes in the sea temperature in a given season
	Sea-level rise	Changes in the sea level
		Changes in the size of waves
		Changes in the level of tides
		Changes in the frequency of coastal flooding
		Islands disappearing
	Coastal erosion/sedimentation	Changes in coastline surface, loss or appearance of beaches
		Changes in the structure of beach soil
		Changes in the erosion of shoreline
		Changes in the depth of water in bays
	Ocean Currents	Changes in the speed or strength of ocean currents
		Changes in the direction of ocean currents
	Ocean Salinity	Changes in ocean water salinity
Freshwater physical systems (continental waters)	Mean river flow	Changes in river water flow and volume
		Changes in river water level
		Changes in the number of river pools
		Changes in river water depth

Subsystem	Impacted Element	LICCI
		Changes in the frequency of dying rivers
	River and lake floods	Changes in the extension of the area flooded by rivers
		Changes in the frequency of river floods
		Changes in the intensity of river floods
		Changes in the extension of the area flooded by lakes
		Changes in wetland surface
	Fresh water availability/quality	Changes in freshwater quality
		Changes in freshwater availability
		Changes in freshwater pollution
		Changes in freshwater transparency / concentration of dissolved particles
		Changes in freshwater salinity
		Changes in taste of snow and freshwater
		Changes in the number of natural freshwater springs
		Changes in number of freshwater ponds
	Water temperature of rivers and lakes	Changes in temperature of river water
		Changes in temperature of lake water
	Lake level	Changes in level of lake water
		Changes in the duration of temporary lakes
		Lakes disappearing
	Phreating/Underground water	Changes in the phreatic level
		Changes in the speed of aquifer recharge
	River bank / pond erosion and sedimentation	Changes in the frequency of river or pond bank erosion
		Changes in the intensity of river or pond bank erosion
		Changes in the frequency of river or pond sedimentation
		Changes in the intensity of river or pond sedimentation
		Changes in the location of river or pond sedimentation
Terrestrial physical systems (Soil & Land)	Soil erosion/landslides	Changes in rain-induced soil erosion and soil loss
		Changes in soil sedimentation
		Changes in wind-induced soil erosion and soil loss
		Changes in the frequency of landslides
		Changes in the intensity of landslides
		Changes in soil texture
		Changes in soil desertification
	Soil moisture	Changes in soil humidity, dryness
		Changes in soil evaporation
		Changes in soil water infiltration
	Soil temperature	Changes in soil temperature
	Edaphic properties (fertility, structure and biology)	Changes leading to soil degradation
		Changes in soil fertility
		Changes in soil productivity
		Changes in soil biota
	Earthquake and tsunamis	Changes in the frequency of earthquakes and tsunamis
		Changes in the intensity of earthquakes and tsunamis
Cryosphere (Ice & Snow)	Snowfall and snow cover	Changes in the amount of snowfall
		Changes in variability of snowfall

Subsystem	Impacted Element	LICCI
		Changes in the frequency of snowfall
		Changes in the depth of snow
		Changes in the physical structure and texture of snow
		Changes in the length of temporary snowcover
		Changes in the extent of permanent snow
	Ice sheet / Lake and river ice	Changes in the physical structure and texture of ice in lakes or rivers
		Changes in the thickness of ice in lakes or rivers
		Changes in ice melting or breaking patterns in lakes or rivers
	Glaciers	Changes in the extension of glaciers
		Changes in the movement of glaciers
	Permafrost	Changes in the extent of permafrost surface
		Changes in the continuity of permafrost surface
		Changes in the depth of the permafrost layer
		Changes in the thawing or melting of permafrost
	Sea Ice	Changes in the extent of sea-ice surface
		Changes in the thickness of sea-ice
Marine Biological system	Marine spp Abundance	Changes in the abundance of marine animals excluding fish (mammals, birds, crustaceans, etc)
		Changes in the abundance of marine algae-seagrass
		Changes in the abundance of marine fish
		Disappearance of marine species
	Marine spp Habitat range (Distribution)	Changes in the distribution of marine species
		Changes in marine species migration areas and routes
	Marine spp Invasive Allien Species	Changes in the abundance or occurrence of marine species stated as invasive
	Marine spp Disease/pest/mortality	Changes in the size of marine animals
		Changes in the frequency of deformed marine animals and plants
		Changes in coral reef bleaching
		Changes in the frequency of parasites in marine animal species
		Changes in the mortality of marine animal species
	Marine spp Phenology	Changes in the behaviour of marine animals
		Changes in the timing of migration of marine animal species
		Changes in the timing of mating or reproduction of marine animal species
	Marine spp Reproduction	Changes in marine species´ reproduction effectiveness
		Changes in the number of eggs, pups or offspring of marine species
	Marine game spp quality	Changes in the species composition of marine fish
		Changes in the taste of marine animal species
Freshwater Wild Fauna	Fresh water spp Abundance	Changes in the abundance of freshwater animal species, excluding fish (mammals, birds, amphibians, reptiles, crustaceans, etc)
		Changes in the abundance of freshwater plant species
		Changes in the abundance of freshwater fish
		Disappearance of freshwater species
	Fresh water spp Composition	Change in the species composition of freshwater species

Subsystem	Impacted Element	LICCI
	Fresh water spp Habitat range (Distribution)	Changes in the distribution of freshwater species
		Changes in freshwater species migration areas and routes
	Fresh water spp Invasive Allien Species	Changes in the abundance or occurrence of freshwater species stated as invasive
	Fresh water spp Disease/pest/mortality	Changes in the size of freshwater animal species
		Changes in the frequency of diseases in freshwater animal species
		Changes in the frequency of malformations freshwater animal species
		Changes in the frequency of parasites in freshwater animal species
		Changes in the mortality of freshwater animal species
	Fresh water spp Phenology	Changes in the behaviour of freshwater animals
		Changes in the timing of migration of freshwater animal species
		Changes in the timing of mating or reproduction of freshwater animal species
	Fresh water spp Reproduction	Changes in freshwater species´ reproduction effectiveness
		Changes in the number of eggs, pups or offspring of freshwater species
	Fresh water game spp quality	Changes in the taste of freshwater animal species
Terrestrial Wild Fauna	Terrestrial fauna Abundance	Changes in the abundance of terrestrial animals (mammals, birds, reptiles, insects, etc)
		Disappearance of terrestrial animal species
	Terrestrial fauna Habitat range (Distribution)	Changes in the distribution of terrestrial animal species
		Changes in terrestrial animal species migration areas and routes
	Terrestrial fauna Invasive Allien Species	Changes in the abundance or occurrence of terrestrial animal species stated as invasive (cockroaches, rats, pidgeons, etc=
	Terrestrial fauna Disease/pest/mortality	Changes in the frequency of terrestrial animal diseases
		Changes in the frequency of animal pest-vector borne diseases (flies, ticks, etc)
		Changes in the frequency of malformations in terrestrial animals
		Changes in the size of terrestrial animals
		Changes in the mortality of terrestrial animals
	Terrestrial fauna Phenology	Changes in the occurrence of unusual behaviour of terrestrial animals
		Changes in the timing of migration of terrestrial animal species
		Changes in the timing of mating, reproduction or hibernation of terrestrial animal species
		Changes in the behaviour of insects
	Terrestrial fauna Reproduction	Changes in terrestrial animal species´ reproduction effectiveness
		Changes in the number of eggs, pups or offspring of terrestrial animal species
	Terrestrial game spp quality	Changes in the taste of terrestrial animal species

Subsystem	Impacted Element	LICCI
Terrestrial Wild Flora	Wild flora Abundance (excluding Timber spss and NTFP spp)	Changes in the abundance of wild plant or fungi species
		Changes in the density of wild plant or fungi species
		Changes in the type of vegetation
		Disappearance of wild plant or fungi species
		Changes in the number of species of wild plants or fungi
	Wild flora Habitat range (Distribution) (fungi-plants-shrubs-trees)	Changes in the distribution of wild plant or fungi species
	Wild flora Invasive Allien Species (fungi-plants-shrubs-trees)	Changes in the abundance or occurrence of wild plant or fungi species stated as invasive
	Wild flora Disease/pest/mortality (fungi-plants-shrubs-trees)	Changes in wild plant or fungi species mortality
	Wild flora Phenology (fungi-plants-shrubs-trees)	Changes in wild plant species flowering time
		Changes in wild plant or fungi species fruiting time
		Changes in wild plant species´ timing of leaf shedding or growing new leaves
	Wild flora Productivity and Quality	Changes in vegetation height
		Changes in wild plant species height
		Changes in the growth rate of wild plant species
		Changes in the productivity of wild plant species
		Changes in the size of wild fruits
		Changes in recruitment (younger individuals growing into large size classes)
	Timber forest sp. composition and structure	Changes in forest cover
		Changes in timber species composition
		Changes in the density of timber species
	Timber forest sp. availability and quality	Changes in the abundance of timber species
		Disappearance of timber species
		Disappearance of useful woody species
		Changes in the growth rate of timber species
	Non-timber forest Products availability and quality	Changes in the taste of wild fruits
		Changes in the abundance of wild fruits
		Changes in the abundance of other edible products
		Changes in the abundance of medicinal plants
Land cover change & land degradation	Habitat degradation	Habitat degradation
		Landscape change
		Biodiversity loss
		Landscape disappearance
		Changes in ecosystem productivity
		Loss of specific landscape elements
		Habitat fragmentation
	Forest fires	Changes in wildfire frequency

Subsystem	Impacted Element	LICCI
		Changes in intensity of wildfires
Aquaculture (marine and fresh water)	Aquaculture productivity and quality	Changes in productivity in aquaculture
		Changes in size of animals in aquaculture
		Changes in taste of animals in aquaculture
	Aquaculture Disease/pest/mortality	Changes in frequency of animal disease in aquaculture
		Changes in the frequency of animal malformations in aquaculture
		Changes in the frequency of parasites in aquaculture
		Changes in mortality rates in aquaculture
	Aquaculture Phenology and reproduction	Changes in the occurrence or frequency of unusual animal behavior in aquaculture
		Changes in the time of mating or reproduction in aquaculture
		Changes in the effectiveness of animal reproduction in aquaculture
		Changes in the number of eggs, pups or offspring in aquaculture
Cultivated plant spp (crops, orchards)	Cultivated spp productivity and quality	Changes in crop productivity / yield
		Changes in cultivated species´ fruit size
		Changes in the frequency of successful cropping seasons
		Changes in crop growing patterns
	Seed or propagule availability or quality	Changes in the availability of crop seeds
	Disease/pest/mortality of crops	Changes in the frequency of crop diseases (virus, fungi, bacteria, nematodes, etc)
		Changes in the frequency of crop ´pests´ (insects, birds, larvae, etc)
		Changes in crop mortality rates
	Crop Weed (IAS)	Changes in the frequency or occurrence of weed species stated as invasive
	Phenology and reproduction	Changes in crop flowering time
		Changes in crop fruiting time
		Changes in crop maturation time
		Changes in crop harvesting time
		Changes in crop sowing / planting time
		Changes in length of crop flowering time
		Changes in length of crop fruiting time
		Changes in length of crop maturation time
		Changes in length of crop harvesting time
		Changes in crop suitable cultivation areas
Pastures and grasslands	Pasture availability and productivity	Changes in pasture cover, surface or abundance
		Changes in pasture productivity
		Degradation of rangeland vegetation
		Changes in pasture species´ growth rate
	Pasture spp composition, distribution and quality	Changes in the number of pasture species
		Changes in the composition of pasture species

Subsystem	Impacted Element	LICCI
		Disappearance of pasture species
		Changes in the abundance of specific pasture species
	Pasture Disease/pest/mortality	Changes in the frequency of diseases in pasture species
		Changes in the frequency of ´pests´ in pasture species (insects, larvae, etc)
		Changes in pasture mortality rates
	Pasture weed (IAS)	Changes in the frequency or occurrence of species stated as invasive in pastures
		Changes in the abundance of plant species in pastures that are toxic or unpalatable for livestock
	Pasture Phenology and reproduction	Changes in pasture species´ timing of vegetative growth
		Changes in pasture species´ timing of reproduction
		Changes in pasture seed availability
Livestock	Livestock productivity and quality	Changes in livestock productivity (eg., milk, meat, wool)
		Changes in the milking period of livestock
	Livestock spp composition	Changes in the species composition of livestock
	Disease/pest/mortality	Changes in the frequency of livestock disease
		Changes in livestock mortality
		Changes in the frequency of livestock pest-vector borne diseases (flies, ticks, etc)
		Changes in the frequency of parasites in livestock
	Phenology and reproduction	Changes in the effectiveness of livestock reproduction
		Changes in the frequency of livestock mating
		Changes in the timing of livestock mating or reproduction
		Changes in the number of pups or offspring in livestock
		Changes in livestock behaviour
Human health	Diseases	Changes in the incidence of human diseases (eg., flu, allergies, malaria, etc)
	Heatlh injuries, physical affection	Changes in the incidence of human health injuries (eg., ice-related accidents, weather inclemency, walking longer distances to water)
	Hunger	Changes in the frequency of hunger
		Changes in the number of people affected by hunger
	Conflicts	Changes in the frequency of conflicts over pastures
	Cultural/Spiritual/ Identity values	Changes in cultural-identity-spiritual values
Infrastructure	Transport (e.g. trails)	Changes in frequency of problems with transportation
Other	Other	Changes in solar movement