Front. Earth Sci. 2017, 11(3): 457–468
DOI 10.1007/s11707-017-0644-1

RESEARCH ARTICLE

Hydroclimatological data and analyses from a headwaters region of Mongolia as boundary objects in interdisciplinary climate change research

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Abstract Collaborative work on increasingly complex hydroclimatic investigations often crosses disciplinary boundaries. Elements of scientific inquiry, such as data or the results of analyses can become objectified, or capable of being adopted and/or adapted by users from multiple disciplinary realms. These objects often provide a bridge for collaborative endeavors, or are used as tools by individuals pursuing multi-disciplinary work. Boundary object terminology was first formalized and applied by social scientists. However, few examples of the application of this useful framework are found in the hydrologic literature. The construct is applied here to identify and discuss how common research products and processes are used both internally and externally through providing examples from a project examining the historical and paleo proxy-based hydroclimatology of a headwaters region of Mongolia. The boundary object concept is valuable to consider when conducting and critiquing basic research, collaborating across multiple disciplinary teams as when studying climate change issues, as an individual researcher working in a cross boundary sense using methods from differing disciplines to answer questions, and/or when one group adapts the work of another to their own research problems or interpretive needs, as occurred with selected products of this project.

Keywords Mongolia, boundary objects, climate change, hydroclimate

1 Introduction

Study of the Earth's changing climate is a complex and challenging endeavor employing a diverse and ever-broadening assemblage of disciplines to attain knowledge. Humans have impacted most Earth systems, with significant and long lasting consequences (Zalasiewicz et al., 2011). Innovative and integrative solutions are needed to manage the challenges faced by the rapidly changing socio-ecological systems of the Anthropocene (Rockstrom et al., 2009), particularly in developing regions of the world. As such, scientists are routinely performing collaborative work that crosses disciplinary boundaries to address larger and more complex problems, or are at minimum, employing the language of multi-, inter-, and transdisciplinarity in climate change related research to further their individual research goals (Rhoten and Parker, 2004; Sundberg, 2007).

In this context, this paper examines aspects of steps taken to research hydroclimatic change in a headwaters region of Mongolia through application of a boundary object construct. Boundary object terminology was first formalized and applied by social scientists. Objects can initially be described as information, such as various kinds of data collected, curated, and analyzed, or the products of analysis, created by a specific discipline or community (i.e., Star and Griesemer, 1989). The objects may occupy a shared space across social boundaries where they can be adopted and adapted for use by individuals from other disciplines/communities (Star, 2010). Few formal examples of the application of this terminology are found in the hydrologic literature, though the construct is quite applicable to modern research that spans multiple disciplines.

Star and Griesemer (1989) developed the concept of boundary objects as a way to describe how objects of scientific inquiry, such as reports, artifacts, and even data, can inhabit different intersecting social and/or disciplinary worlds. These different intersecting worlds can be portrayed as the social spheres of influence and interaction

Received August 12, 2016; accepted February 3, 2017

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of professional scientists in their own community versus those of another distinct group such administrators at a university, or even as scientists from one disciplinary realm (e.g. hydrologists) to another (e.g. ecologists). The conceptualization of climate change data and/or scientific research results as boundary objects has precedent (e.g., Lynch et al., 2008; Star, 2010; Whetton et al., 2012; van Pelt et al., 2015; Blades et al., 2016). This paper applies the boundary object concept through exploration of the process of initial hydroclimatic and dendroclimatic data acquisition and use, the development of tenable research questions, hypotheses, and analysis choices, and the final dissemination of research products such as spatial trend analysis maps. These formal devices and products [objects] of research are examined according to how these objects adapt or are adapted interpretively across boundaries or social/disciplinary divides to meet the needs of different groups. This is done both internally, through discussion of the research experiences of a multi-disciplinary scientist and externally, through brief examination of the further use of those works by others. These examples are drawn from hydroclimatic and dendroclimatic investigations (Venable, 2016) conducted as part of a larger multidisciplinary project examining the resilience of Mongolian nomadic pastoralists (herders) to climate change.

2 Study site

The Khangai Mountain region of Mongolia is an approximately 150,000 square kilometer area of mountain, forest, steppe, and desert steppe landscapes that serves as the headwaters for several river systems supplying water to local herders and to downstream population centers (Fig. 1). It is a region that not only spans different ecosystems and climate zones, but has differing hydrological regimes as well. Water originating from snowfields on the northern side of the Khangai Mountains sustains perennial rivers that flow into Lake Baikal in Russia, with the water eventually draining to the Arctic Ocean. Rivers originating in headwaters on the southern side of the mountains become increasingly intermittent before terminating in the internal drainage basins of the Gobi Desert.

The approximately 90,000 nomadic pastoralists of the region employ observations of seasonal and annual changes to their landscape in management of the livestock and pasture resources needed for their survival (Fernandez-Gimenez, 2000; Green and Raygorodetsky, 2010; National Statistical Office of Mongolia, 2015). Droughts, *dzuds* (winter snow and ice disasters), dust storms, the drying of lakes and springs, and lowering river flows, along with increasing temperatures are of concern to herders (Fer-

Fig. 1 Study Site. Mongolia and surrounding countries (inset) with main focus on portions of the three *aimags*, or provinces, of the Khangai Mountain region. Includes locations of four river basins of interest, meteorological stations (black squares), and stream gages (black circles). Map was created with ArcGIS software by ESRI, used under license.

nandez-Gimenez, 1993, 2000, 2012, 2015a, b; Marin, 2010; Fassnacht et al., 2011; Sukh, 2012; Venable et al., 2012; Bruegger et al., 2014; Jigjisuren et al., 2015). Abrupt changes and the perceived (or actual) increasing frequency of these events are often attributed to a changing climate, but also represent changes to socio-ecological, economic, and governmental/policy systems (Fernandez-Gimenez and Batbuyan, 2004; Regdel et al., 2012; Lkhagvadorj et al., 2013).

3 Data and methods

To study possible climatic effects, hydroclimatological (i.e., temperature, precipitation, streamflow) and dendroclimatological (tree-ring) data from the region were collected and analyzed using a variety of methods. One of the methods used was non-parametric analysis of monthly maximum and minimum temperature (Tmax and Tmin) and precipitation (P) gridded datasets from the Climatic Research Unit (CRU) Timeseries 3.21 (Harris et al., 2014) using the Mann-Kendall (Mann, 1945; Kendall and Gibbons, 1990) and Thiel-Sen (Thiel, 1950; Sen, 1968) approaches. Spatial climate variable trend maps were derived using these techniques for all of Mongolia over the period of 1963–2012 (Venable et al., 2015). Another method used was to compare herder's observations of change to hydrometeorological records from the Mongolian Institute of Meteorology, Hydrology, and the Environment. Non-parametric methods similar to those previously used were employed, only with point-based data instead of gridded data (Venable et al., 2012). Scientists working in Mongolia have collected herder's observations of change from many parts of the country, with recent surveys incorporating explicit questions regarding the hydroclimate along with other questions about their environment (e.g., Marin, 2010; Fassnacht et al., 2011). Some surveys, such as those conducted by Sukh (2012), are composed entirely of questions about hydroclimatic change. A third type of analysis examined here is the use of dendroclimatological and/or dendrohydrological methods to create tree-ring based streamflow reconstructions of time periods prior to the instrumented record. This type of analysis incorporates multi-disciplinary approaches using statistical relations between hydrometeorological variables from historical periods and data obtained from the specialized processing and analysis of tree growth rings to reconstruct past scenarios of hydrological variability over the length of the selected paleo proxy record (e.g., Fritts, 2001). The types and sources of the original data plus the research products derived from them, which are further discussed in this paper as objects, are presented in Table 1.

Disciplinary boundaries are crossed when these data objects are used to answer research questions through the generation of multiple research products that are broadly based in similar contexts of nomadic pastoralist use of natural resources, and impacts to those resources under a changing climate (Fig. 2).

As boundary objects, the results of research can be used by differing groups or disciplines for their own purposes which may differ from those purposes for which they were originally constructed. For example a map created for use by a hydroclimatologist to examine changes in precipitation seasonality may be useful to an ecologist when selecting potential study sites to explore changes in seasonality of vegetation green-up due to the strong links between spring precipitation and growth of new vegetation (e.g., Yu et al., 2003) (Fig. 3).

4 Results and discussion

4.1 Hydroclimatic data

The boundary object model can initially be established at the data level, as climate variables form the foundation of hydroclimatic change investigations. In the case of station-based Mongolian climate data there is uncertainty associated with the *delegated work* (Star, 2010) of the data collection and archiving process that cannot be

Table 1 Information about data used for hydroclimatological and dendroclimatological (dendrohydrological) analyses discussed in this work

Variable code	Data type	Period of record*	Research product	Data source
T	Point-based	1961–2010	Trend analyses	IMHE[a)]
P	Point-based	1956–2012	Trend analyses	IMHE[a)]
Q	Point-based	1971–2010	Trend analyses	IMHE[a)]
T_G	0.5° lat/long	1963–2012	Spatial climate trend maps	Harris et al., 2014
P_G	0.5° lat/long	1963–2012	Spatial climate trend maps	Harris et al., 2014
TR	Point-based	1405–2011, composite period of core records	Streamflow reconstructions	ITRDB[b)]; Leland pers.comm., 2014; Venable, 2016
HO	Social Survey	2010, 2011	Climate trend and herders' observations comparisons	Fassnacht et al., 2011; Sukh, 2012

Variable Codes: T = Temperature, P = Precipitation, Q = Streamflow, T_G= Gridded Temperature, P_G= Gridded Precipitation, TR = Tree-ring widths, HO = Herders' Obeservations. *Period of record is longest period of analysis used, records from some stations were shorter. a) IMHE is the Mongolian Institute of Meteorology, Hydrology, and the Environment. b) ITRDB is the International Tree-Ring Data Bank.

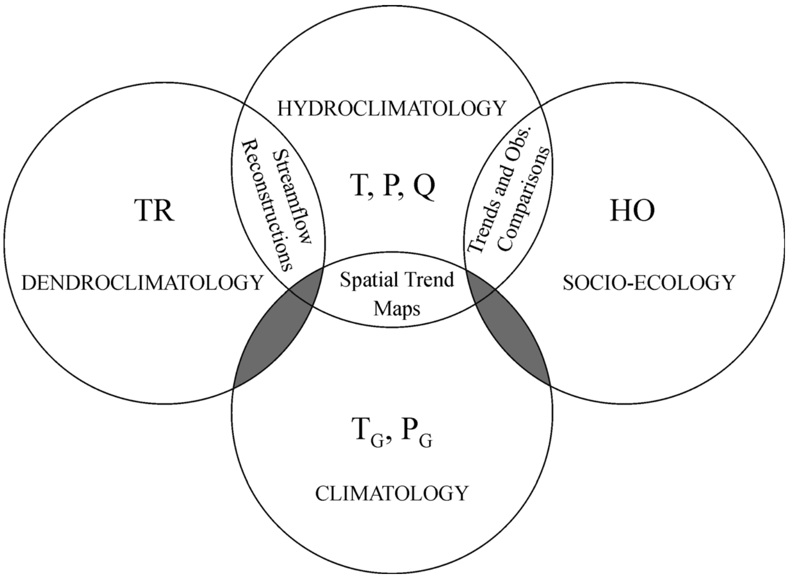

Fig. 2 Coincident boundary map of the data and analyses. Gray areas denote possible future transdisiplinary uses of boundary objects not explicitly discussed in this work. Refer to Table 1 for further description of data types and research products. Variables on map: T = Temperature, P = Precipitation, Q = Streamflow, T_G = Gridded Temperature, P_G = Gridded Precipitation, TR = Tree-Ring Widths, HO = Herders' Observations.

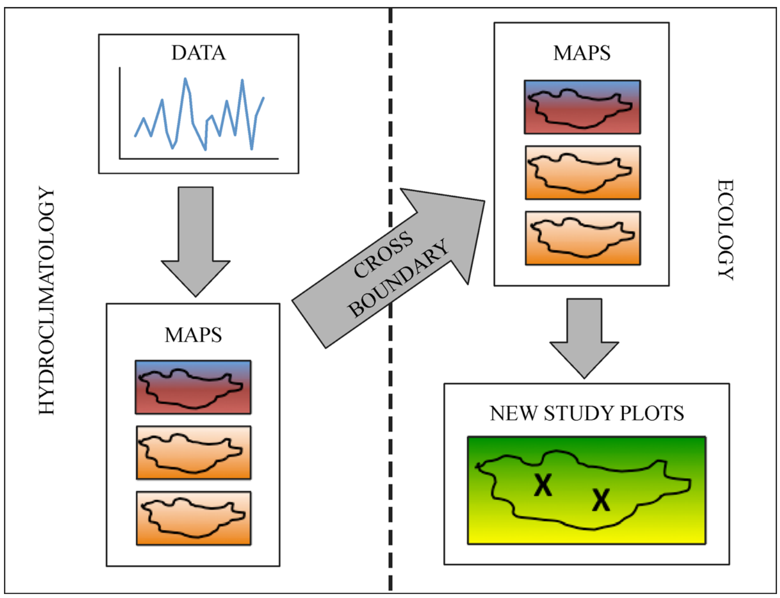

Fig. 3 Use of a boundary object by differing disciplines. Maps created by hydroclimatologists derived from climate data can be used interpretively by ecologists in planning their work.

controlled by end-users. One way this work done by others that may have different needs than end-users manifests is in the question of if missing [specifically precipitation] data represents a zero measurement or was actually missing, as in not recorded (Fig. 4). The designation of data points as missing rather than zero values has strong effects on the results of trend analyses, likely more so than the other issues such as the presence of a trend in the data prior to statistical analysis, or due to the presence of autocorrelation or persistence between observations.

4.2 Trend analyses

The idea of trend analyses, a subset of broader climate change research results, as boundary objects informing further interdisciplinary work, is a means of scaling the

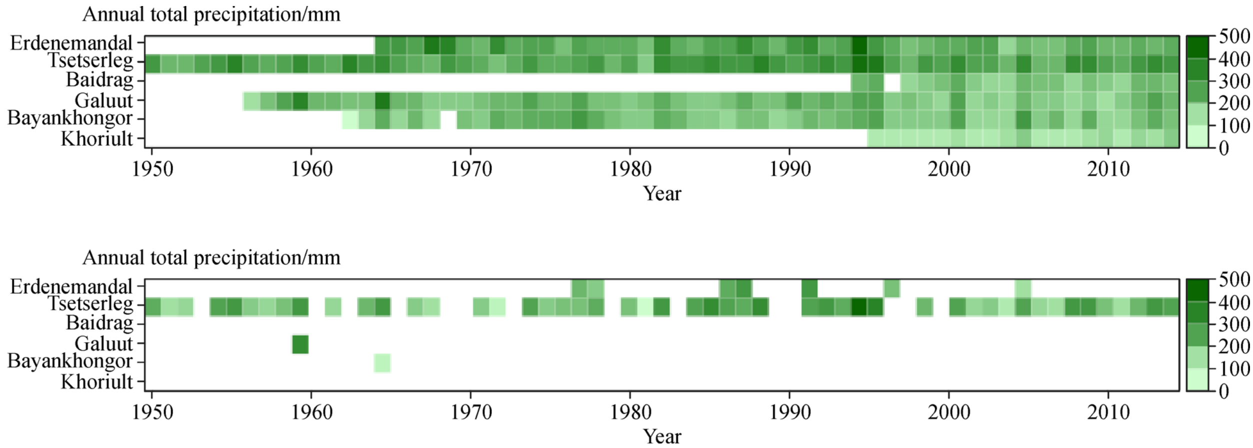

Fig. 4 Data from six meteorological stations are plotted showing the distribution of data through time with shading denoting amount of total precipitation per year in millimeters. Distribution of aggregate annual precipitation data assuming blank values equal zero (top plot). Distribution of data assuming blank values do not equal zero and are considered missing. Annual aggregation is only shown if values are recorded for every month of the year (bottom plot).

concept that has limited coverage in the climate literature. For a conceptually related example see Sundberg (2007), where the parameterization of climate models is discussed as a boundary object that both climate modelers and experimentalists connect to across occupational and epistemic boundaries. Hydroclimatological analyses can become boundary objects when interpreted through *efforts of translation* [finding shared meaning and/or reconciliation of a diversity of definitions or understandings] between different groups or worlds (Akkerman and Bakker, 2011). As more than just static research products, they are capable of stimulating communication between disciplinary communities through the creation of compatible conceptual frameworks (Lynch et al., 2008). Ideally, shared meaning would result in agreement, but in some cases it serves to highlight further distinctions between closely related groups.

An anonymous external review of hydroclimatic trend analysis results conducted with Mongolian climate data reinforced the importance of this issue. Specifically, a scientist in the climatological community, which is known for its rigorous treatment of meteorological data collection and processing methods, raised concerns that the methods employed in the trend analyses of Mongolian data may not be optimal due to data quality (see Fig. 4). The Mann-Kendall (Mann, 1945; Kendall and Gibbons, 1990) and Thiel-Sen (Thiel, 1950; Sen, 1968) approaches used for analysis however, are considered robust non-parametric methods for analyzing datasets with missing values and are widely accepted and employed by the hydrological and environmental monitoring communities (e.g., Gilbert, 1987; Helsel and Hirsch, 2002). The reviewer's comments transformed the data from a scientific product, a *thing*, to an object capable of initiating a *reflective* process highlighting differences between treatments of the data by what are perceived to be closely related disciplinary communities (Akkerman and Bakker, 2011). This example serves to reinforce disciplinary disparities, while also allowing the boundary between those disciplines to work as a means to "*look at oneself through the eyes of other worlds*" (Akkerman and Bakker, 2011, p.145) when considering future analyses and revisions of the work. Ironically, the reviewer's comments further reinforced one of the original intents of the trend analyses, specifically, to inform groups outside of the climatological community of the caveats of using data with many missing values (Venable and Fassnacht, 2015).

4.3 Data, trends, and disciplinary realms

Boundary objects maintain a common identity, but individually, or within a particular group they may have a strong structure or tailored use, a specific identity or definition. In common use by different groups, they may have a weaker interpretation or structural function allowing interpretive flexibility (Star and Griesemer, 1989; Star, 2010). A further comparative example of this difference in data use between the meteorological and/or climatological research community and the broader scientific community is related to the use of climate grids. Climate grids for Mongolia provide information that would not be otherwise available in the public domain due to proprietary use restrictions, as is the case with data from many stations there (e.g., Becker et al., 2013; Laituri et al., 2015).

However, these continuous gridded climate surfaces that fill and smooth spatiotemporal gaps between data points are generally a product of the climatological community (e.g., Becker et al., 2013; Harris et al., 2014). Expertise has been developed to process and analyze climate data using specialized procedures (e.g., Willmott and Robeson, 1995;

Easterling et al., 1996; Mitchell and Jones, 2005; Beaulieu et al., 2007). Outside of that community however, data are frequently used “as-is” after basic quality control pre-processing, or derived products are sought that minimize discrepancies in data. The spatial trend analyses performed for this project resulted in the generation of easily interpreted composite maps. The maps, created by members of the broader scientific community, are not an exclusive product of the climatological realm. They provide climate change information for this area of sparse data coverage in a single map-style format that is a synthesis of the original 600 individual monthly climate grids (Venable et al., 2015). These derived data products, or boundary objects as described in the construct used in this paper, may be more loosely interpreted. Sometimes this interpretation occurs without due consideration that the interpolated and time gap-filled products may not adequately represent the underlying point-based records, which could significantly affect research results depending on the application (Willmott et al., 1985; Ensor and Robeson, 2008; Venable et al., 2014). In this work, care was taken to understand the limitations of the gridded products forming the basis of the climate grid analyses. However, there is a danger that biases inherent in the underlying station-based data such as missing data or station relocations, or other issues such as the short period of record analyzed could affect the derived results of this project work (Venable et al., 2015).

Exact interpretation (and full comprehension) of research results is not needed for cross-boundary conversation (Star and Griesemer, 1989). It is common for a group [discipline] to maintain a fuzzy understanding of the explicit work of another group and yet be able to use a boundary object for building their own work and contributing to a larger interdisciplinary undertaking (Star, 2010). As such, maps like the spatial climate trend maps of Venable et al. (2015) are a prime means of exemplifying the abstractions that can occur when utilizing *ideal* types of boundary objects to stimulate conversation and cooperation (Star and Griesemer, 1989).

Trends in the maps are identified by magnitude, with the depiction of significant trends focusing the user’s eye to certain parts of the map as with precipitation trends, or possibly the whole country when examining minimum temperature trends (Fig. 5). Seasonal maps generated for the project bridge other cross-boundary uses by displaying trends across the landscape in periods significant to ecological work or relevant to remote sensing analyses. For example, a seasonal map for spring (not shown) highlights spatiotemporal changes in spring precipitation averages that could be linked to changes in emergence of spring vegetation (e.g., Yu et al., 2003).

Maps easily provide information that may be difficult to determine using other formats. Where change occurs is critical to understand when extending research results, like the spatial trend analyses conducted for the Khangai Mountain region to other disciplinary spheres, such as for ecologists planning vegetation surveys, or regional and local resource managers developing long-term resource management plans for their communities (see Fig. 4 and Fig. 5). There are questions of scale however, that may prove barriers to use of this work on interdisciplinary problems at finer resolutions (Fernandez-Gimenez et al., 2015b).

The social significance of the hydroclimatic maps is interesting and important. Diverse approaches are needed to support the adaptation of governments and communities to climate change (Lynch et al., 2008). The maps are in an accessible format, easily interpreted, and much more likely to reach a broader disciplinary audience than a paper explaining the same research results. These maps [as objects] highlight the ongoing need for academics to think about how others perceive, interpret, and can use their work (Parker and Crona, 2012). The map products are more powerful than point-based analysis results (even when mapped) as there is a sense of spatial continuity across the landscape. The smoothed, black box nature of the depictions however, masks uncertainty in the analysis results, which is a common problem when communicating scientific and/or disciplinary results to others (van Pelt et al., 2015).

4.4 Herder’s surveys

The nomadic pastoralists of Mongolia live and work in a land of weather and climate extremes and must perceive and respond to ecological change to succeed economically and culturally (Fernandez-Gimenez, 2000; Bruegger et al., 2014). Historically, anthropologists and ethnographers primarily conducted studies of culture, but broader disciplinary groups like ecologists and even hydrologists are now conducting these surveys to understand herder lifestyles and their adaptation strategies to a variety of internal and external influences. Interdisciplinary scientists from Colorado State University and other institutions have been studying facets of Mongolian traditional and ecological knowledge via surveys for decades (e.g., Fernandez-Gimenez, 1993; Lkhagvadorj et al., 2013; Bruegger et al., 2014). Herder surveys can be seen as two different types of boundary objects. First, as objects sharing *coincident* boundaries (Star and Griesemer, 1989). These objects, while designed or implemented by different groups (i.e., surveys designed by ecologists or surveys designed by hydroclimatologists) are in this case, collecting information coincidently about the same place, time, or people. Each captures social, ecological, and climatic knowledge differently depending upon who designed the survey instrument and who is asking the questions. Different goals [answers to research questions] are resolved through these objects, and diverse researchers

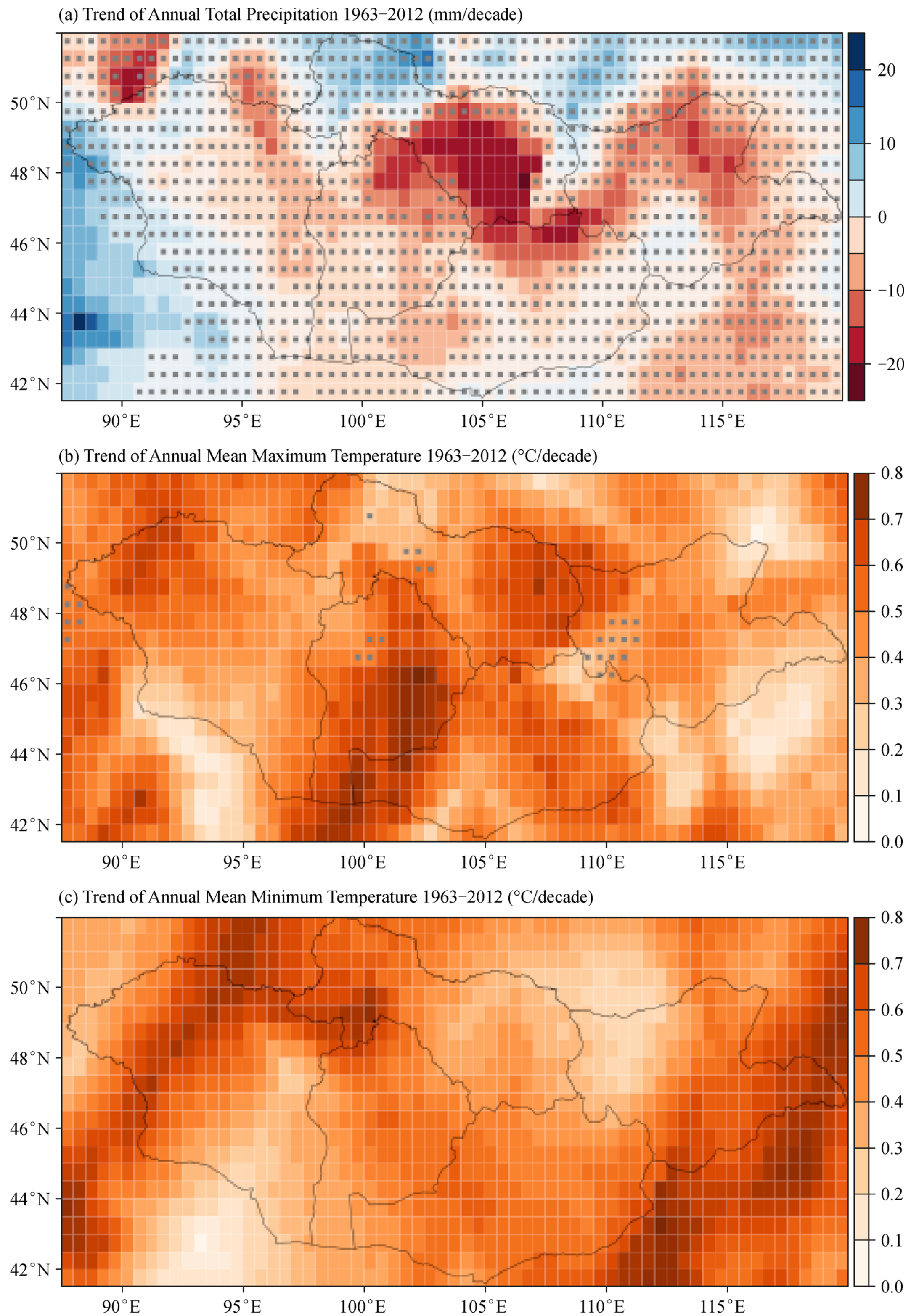

Fig. 5 Hydroclimate change trend maps. Trend per decade in the annual mean (a) total precipitation in millimeters, (b) maximum temperature in degrees Celsius, and (c) minimum temperature in degrees Celsius. Note that the small gray squares on the figures denote areas where the trend was not significant at the $p < 0.05$ level (Venable et al., 2015).

may understand and use the internal contents of each object differently (Star and Griesemer, 1989; McGreavy et al., 2013).

Based on their expertise, hydrologists/hydroclimatologists may relate changes in ecology documented in surveys to the influence of changing hydroclimatological processes, but are not necessarily concerned with the fine details of ecological change as defined and/or understood by the ecologists conducting the surveys. Herder's observations of change when used as objects, create temporary bridges to joint and future endeavors, i.e. they act as catalysts or talking points, but as objects cannot displace actual collaboration or communications by actors in differing groups (Star, 2010; Akkerman and Bakker, 2011). When exploring the length of the available hydroclimate record and herders' observations of change through time (i.e., Venable et al., 2012) the research questions considered included: *"Are the warming trends perceived [observed] by nomadic pastoralists of the Khangai Mountain region found in the results of trend analyses of observational climate records, and if so, what period of record is most statistically significant?"* The clear multidisciplinary focus of this investigation exemplified in these types of questions connects the socio-ecological world and assessments of indigenous knowledge, and the hydroclimatological realm concerned with analyzing and understanding spatiotemporal variability in station and gage-based hydrometeorological data.

As part of an iterative organic process that occurs between groups (Star, 2010), objects can provide insight to one group from another, resulting in work that bridges disciplines. This is the case of temperature analyses that were conducted in comparison to the results of herder surveys. In this example, one object [socio-ecological surveys] is used to inform the creation of another [hydroclimatological analyses] (refer to Fig. 3). Sociologists and ecologists then use the latter object synergistically in further research recognizing that an understanding of trends in hydroclimatic variables through time can contribute to the process of identifying impacts of climate change on herders (e.g., Fernandez-Gimenez et al., 2015b). Boundary objects are presentable as actionable items that become catalysts for new research ideas through collaboration (Kimble et al., 2010). Ideally, survey instruments used in this manner should be constructed to capture key relations between observations made by herders and measured climate observations to facilitate comparisons to hydrometeorological analyses. This integrative and collaborative approach was implemented with later herder surveys conducted by the project team and these were used in subsequent research (e.g., Fernandez-Gimenez et al., 2015b). This synthesis was a challenging task both from the standpoint of a need for a certain level of consensus between groups on survey design and/or implementation, and as the personal observations collected in the surveys provide a level of spatiotemporal detail that may not be compatible with coarser-scale climate products or may provide information that is difficult to support or refute as it is not measured using standard instrumented methods (e.g., Marin, 2010; Fassnacht et al., 2011; Fernandez-Gimenez et al., 2015b).

A second way of using the surveys as boundary objects is to consider them *repositories* (Star and Griesemer, 1989). In this case, portions of objects originally designed and implemented specifically for one group are extracted and used directly, or refined by a different group for their own purposes (Star and Griesemer, 1989; Star, 2010). This is functionally what the original herder surveys conducted by researchers from Colorado State University (e.g., Fassnacht et al., 2011; Sukh, 2012; Bruegger et al., 2014) became when used cross-disciplinarily. For example, when herders suggested that recent winters were cooler than those in the past, examination of the hydroclimate record revealed that indeed, winters since the 1990's were cooler on average than those prior to that time, despite warming winter trends observed over the entire period of record available for analysis (maximum 50 years, 1960–2010) (Venable et al., 2012). The hydroclimatic analyses therefore employed this object model, by extracting the results of herder surveys pertaining to temperature change and making further comparisons to the historical climate record.

4.5 Dendrohydrology

Dendrohydrology is a subset of the discipline of dendroclimatology. While the latter is focused on the study of past climatic conditions using tree-rings (i.e., Fritts, 2001), the former is focused on understanding long-term hydrologic phenomena of the past (Loaiciga et al., 1993). The practical application of the interdisciplinary field of dendrohydrology has been shaped by the intensely water-managed landscapes of the American West. Early researchers like Stockton (1971) made explicit connections between moisture-limited tree growth and variations in streamflow through time. The results of these and later investigations became boundary objects, or bridges for knowledge about the long-term variability and availability of water supplies for human use crossing from one disciplinary community (dendrohydrologists) to another (water resource managers). The crossing of interdisciplinary divides is not only driven by the desires of the hydrological and dendroclimatological scientific communities to pursue *basic research* (Parker and Crona, 2012), but also extends into the public and practitioner spheres to help water managers understand how or why this work can assist them in meeting long-term water supply needs for their constituencies (Meko and Woodhouse, 2007).

In essentially unmanaged river systems such as those found across most of Mongolia, knowledge of long-term hydrologic regimes can help government officials, pastoralists, and farmers understand patterns of hydroclimatic variability over the last few centuries to place recent extreme climate conditions into a longer term context (e.g., Davi et al., 2013; Pederson et al., 2013). This is particularly important in those basins facing shifts in land use through intensification of agriculture or increases in water-intensive industries like mining (e.g., Regdel et al., 2012; Pederson et al., 2013). Dendroclimatological work using data from the Khangai Mountain region fits into this framework, filling in gaps in knowledge about long-term streamflow variability in the rivers of that area.

While the efforts of other researchers in the dendroclimatological community studying Mongolia (i.e., Leland et al., 2013) certainly inspired exploration of the dendrohydrologic relations of the Khangai Mountain region, the investigations were also a logical extension of earlier investigations of historical hydroclimatic trends across the region and in other, similar landscapes (e.g., Venable et al., 2012; Venable and Fassnacht, 2013; Venable et al., 2014; Wolf and Venable, 2015).

To conduct dendrohydrological analyses, it is necessary to work on both sides of a disciplinary line, and certain points of the process are not necessarily interdisciplinary or consensual (Star, 2010). When considering dendrohydrological research questions like: "*How does the 300+ year paleo record for the Khangai Mountain region compare to the last 50 to 35 years of station and gage-based instrumental data?*" the details of initial hydroclimatic analyses undertaken in previous work become less critical, instead providing context to the new question. The research results of previous analyses morph into a type of *ideal* boundary object that is internally useful (Star and Griesemer, 1989; Star, 2010). The transition was made from tailored and concrete use of the hydroclimatologic data in the trend and other analyses of previous project work to relatively vague use of the hydroclimatic results as contextual background when the disciplinary threshold into the tree-ring community was crossed. A sharper hydroclimatological focus was regained when connecting the results of long-term streamflow reconstructions back to historical hydroclimate trends. This iterative behavior is characteristic of the working use of boundary objects (Star, 2010).

It can be argued however, that since the hydroclimate and dendroclimatological analyses undertaken for the climate change project must adhere to the standards of the individual disciplines pursued, they do not possess true interdisciplinary characteristics. These ways of working however, are often seen as dynamic and productive tensions needed to create new knowledge (Klein, 1996). Regardless of structural terminology, these investigations generally recognize a *shared problem space* (Akkerman and Bakker, 2011), where the approaches of the differing disciplines can co-mingle to emphasize the combined disciplinary context of the work (Parker and Crona, 2012; Wyborn, 2015).

4.6 Boundary organization

The original overarching climate change resilience project that the Venable (2016) work was a part of is a type of *boundary organization* (Parker and Crona, 2012), fulfilling competing missions of creating knowledge, producing boundary objects, and collaborating with actors from universities and other places such as herders, teachers, research institutions, non-governmental organizations, and the Mongolian government. Many of these institutions and groups can be categorized as *transboundary organizations*, or organizations that transcend multiple boundaries (Sternlieb et al., 2013). The hydroclimatic and dendroclimatic research was made possible by participation in the larger project, because access was granted to proprietary hydroclimate data and other essential project information and research products.

5 Conclusions

The Mongolian hydroclimate data and resulting analyses from the Khangai Mountain region discussed here cross disciplinary boundaries and lend themselves to the boundary object role, both within the creation and interpretation of the research results, and when making connections to the broader research questions of the original multidisciplinary climate change project and other Mongolian climate change investigations. The specifics and uncertainties of the Khangai Mountain region research results may or may not be critical to some groups when used as *ideal* boundary objects as defined by Star and Griesemer (1989), or groups may criticize or question the results allowing internal re-interpretation of the work in a reflective manner. The analysis results may be used in whole or in part by other disciplinary groups as a type of repository of information, by focusing on an individual variable, or looking at a suite of variables or analysis results to paint a different and/or more cohesive picture depending on the research questions they are posing. Finally, the results may be used by the broader scientific community in terms of the original data and analyses, and the publications that are connected with them as a foundation or structure to support other investigations, or simply as talking points when translating the work to related problems of nomadic pastoralist reliance on natural resources, and impacts to those resources under a changing climate.

Acknowledgements The author would like to thank Dr. Gelegpil Adyabadam and her colleagues from the Mongolian Research and Information Institute of Meteorology, Hydrology, and Environment for providing access to the Mongolian hydroclimate data used in the original analyses. Thanks are also extended to four anonymous reviewers and the associate editor, whose comments and suggestions facilitated substantial improvements to this document. Partial support for this research was provided by the National Science Foundation Dynamics of Coupled Natural and Human Systems Program (Award BCS-1011801 entitled *Does Community-Based Rangeland Ecosystem Management Increase Coupled Systems' Resilience to Climate Change in Mongolia*?, PI Dr. Maria Fernandez-Gimenez) and by the American Center for Mongolian Studies US-Mongolia Field Research Fellowship Program.

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