'My new routine': Assessing the impact of citizen science on climate adaptation in Bangladesh

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Abstract:

Citizen science is put forward as a method for extending science to include communities in learning about, and adapting to, climate variability and change in the places they live. But it is difficult to find evidence of how citizen science influences climate adaptation governance. The citizen science field lacks the assessment frameworks and empirical studies for understanding impacts on citizen scientists' common adaptive capacities for supporting social processes of adaptation. In addressing this gap, this paper describes a citizen science initiative carried out with communities in northeast Bangladesh, and assesses how it contributed to local governance capacity for climate adaptation. In doing so, it develops and tests a novel framework that assesses citizen science's contributions a high-quality knowledge base, and to five different capital stocks. The assessment saw high increases in citizen scientists' human capital relative to their awareness and understanding of local rainfall; learning that they applied in adaptive practices at work and at home, and local leadership. There were also high increases in social capital among citizen scientists, but more moderate increases in technological and resource capital, and in political capital. There was some evidence of the citizen science being used to support public adaptation decision-making. The initiative had the least impact on institutional capital.

Key words: citizen science; climate adaptation; governance assessment; Bangladesh

1. Introduction

Climate adaptation governance steers the social processes by which communities adjust to actual and expected climate and its effects in the places they live (Adger et al., 2009). Adaptation governance scholars study the unique sets of resources and capacities that facilitate communities' adaptive processes, including a sound knowledge base for understanding, interpreting and anticipating climate (Armitage 2005; Folke et al. 2005; Lebel et al. 2006). But there are important epistemological challenges to knowing a climate regime that is going beyond our experience; challenges that confound disciplinary scientific enquiry alone (Bremer, 2017). There are increasing calls to 'co-produce' climate knowledge for adaptation, with affected communities (Armitage et al. 2011; Bremer & Meisch, 2017). Co-production introduces alternative epistemologies for re-learning the climate, seen in extended modes of science like 'post-normal science' (Brace & Geoghagen, 2010), 'participatory science' (Mukherjee, 1997), 'sustainability science' (Turner, 2010), 'transdisciplinary science' (Swart et al. 2014), or 'Mode 2 science' (Ison et al. 2011). It also introduces alternative sets of extended scientific methods, like 'citizen science' (as distinct from its use as an analytical concept – see Irwin, 1995) or 'Living Labs' (Ballon et al. 2018) for example. This paper is about how we implemented citizen science with communities in Bangladesh, to help them build a robust local knowledge base and climate adaptation capacity.

Citizen science, as we use the term, is "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (Oxford English Dictionary 2018). Defined this broadly, amateur scientists can concretely contribute to research at multiple stages of a scientific study, from developing the research question to designing the method, gathering and analysing data, and communicating the results. The past 20 years has seen increased applications of citizen science, but its use for studying climatic change and impacts is a more recent trend (Silvertown, 2009). Most current work seeks to build scientific understanding of climatic change, through phenological studies of climate-induced shifts in ecosystems (Cooper et al. 2014; Dickinson et al. 2012; Knudsen et al. 2011), measurements in the atmosphere (Snik et al. 2014) or classifying storms and weather reports (Gura 2013) for instance. However, there is relatively little attention to how citizen science can support society's climate mitigation or adaptation; *its community-level impacts on governance for climate change*. Some put forward citizen science as a method for building adaptive governance capacity (Spellman 2015; Wildschut 2017), but to realise this potential we need empirical evidence of precisely how this method influences governance; its impacts on political processes, institutional structures and policy tools (Lange et al. 2013). *We need comprehensive and sophisticated assessment infrastructures, built on empirical lessons, to guide and assess the worth of citizen science for climate adaptation governance*. This is a challenge because the citizen science literature focuses more on impacts on individual citizen scientists' and scientific scholarship, and less on the social structures and interactions that steer governance (Bonney et al. 2016; Conrad & Hilchey 2011).

This paper takes up this challenge, with the objective of *assessing to what extent, and in which ways, citizen science can contribute to governance capacity for climate adaptation*. It *describes* citizen science work studying climate and its effects in northeast Bangladesh, as an effort to conduct science appropriate to the local adaptation challenge and consistent with culture, expertise, knowledge and institutions in that context. The paper then *assesses* this work's impact on local climate adaptation capacity, using a novel assessment framework that looks beyond citizen science's impact on individuals to include a focus on social interactions and structures. It starts in

Section 2 by introducing the TRACKS (*'Transforming climate knowledge with and for society'*) research project, our aspirations for citizen science, and the assessment framework we designed. Section 3 describes how we implemented citizen science, and Section 4 assesses this work using the framework. Section 5 discusses the findings and offers insights for future citizen science.

2. Background: Initiating citizen science in Bangladesh

2.1 The TRACKS Project in the Sylhet Division, Bangladesh

TRACKS was a three-year (2014 – 2017) climate adaptation research project, funded by the Norwegian Research Council and carried out by an interdisciplinary group of scientists from across seven institutions in Bangladesh, Norway and the United States (www.projecttracks.net). TRACKS aspired to (i) a robust understanding of climate variability and its impacts in the Sylhet Division, (ii) co-produced with local communities via a post-normal science approach, to (iii) increase communities' capacity to use knowledge in support of their daily climate adaptation. The project focused on communities in lowland Sunamganj (Sunamganj Sadar and Jamalganj) and in the hillier Moulvibazar (Barlekha and Hakaluki Haor), which face different impacts of the local rains (see Bremer et al., 2017, for detail on site selection) (see Fig 1).

TRACKS focused on Sylhet Division because there remain significant uncertainties about the causes of the unique rainfall in the area (Stiller-Reeve et al., 2015), particularly in the pre-monsoon period. These uncertainties are compounded by rapid changes to rainfall patterns experienced by local people (Bremer et al., 2017) and corroborated by meteorological science (Bashar et al., 2017), and limitations faced by local meteorological science (Haque et al., 2017).

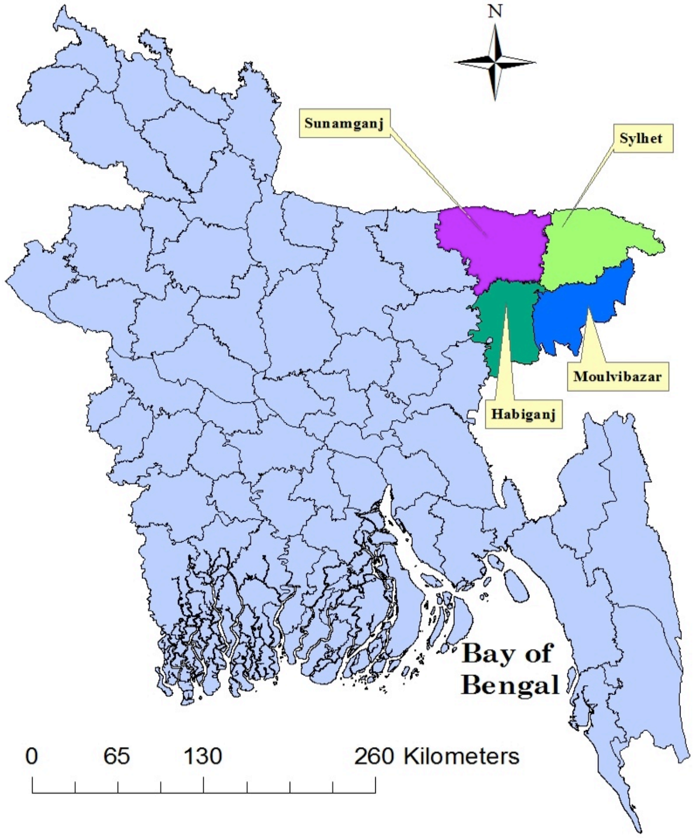

Figure 1: Map of the northeast i.e. Sylhet Division of Bangladesh.

At the same time, Sylhet people's livelihoods are highly vulnerable to variability in these rains, dependent mainly on haor[1] based agriculture and fisheries. A BBC Media Action project found that, across Bangladesh, Sylhet communities identified themselves as the most vulnerable to changes in climate, which they saw in reduced water, agricultural productivity and fuel availability (Mamun et al., 2013). This vulnerability was evident in April 2017, when incessant rain triggered

[1] A ***haor*** is a local term for wetland ecosystem in the northeastern part of Bangladesh, which is physically a bowl or saucer shaped shallow depression, also known as a backswamp.

flash floods in Sylhet division and adjacent districts, inundating vast areas and totally destroying the *boro* rice crop; the only crop in this area (The Daily Star, 2017). Sylhet communities are forced to reflect on their relationship to the changing rains, and how they may need to adjust agricultural and fisheries practices accordingly (Blanchard & Bremer, 2015).

Faced with uncertainties and high stakes, TRACKS adopted a post-normal science (PNS) approach for mobilising weather-related knowledge with communities at the village scale (Funtowicz & Ravetz, 1993; Bremer, 2017). Our approach was designed for ensuring the 'quality' of knowledge generated, as fit for supporting communities' daily adaptation decisions. Knowledge quality thus went beyond scientific criteria to include other considerations like practical usability, local legitimacy or cultural appropriateness. Central to quality assurance was establishing an 'extended peer community' (Funtowicz & Ravetz, 1993) that went beyond the project consortium to include a group of 48 diverse community actors, spread across the study sites in Sunamganj (21 peers) and Moulvibazar (27 peers), to work alongside scientists, peer review project findings and plan next steps. The work with the peer community progressed in three phases: (i) starting from weather understandings in local and scientific narratives (Bremer et al., 2017), before (ii) collaboratively mapping the causes and effects of rainfall and identifying knowledge gaps (Bremer et al., 2018), (iii) to be investigated using citizen science. Members of the peer communities became citizen scientists (CS) and are referred to as such.

2.2 Aspirations for the citizen science

Across the literature we saw four tightly-intertwined reasons for embarking on citizen science, which also formed the aspirations of the TRACKS citizen science phase. First, citizen science can produce information that goes beyond the current boundaries of scientific capacities (Bonney et al., 2014; Brossard et al., 2005; Conrad and Hilchey, 2011; Dickinson et al., 2010; Dickinson et al., 2012; Silvertown, 2009). TRACKS 'post-normal' citizen science generated weather information at the village resolution - something beyond current scientific capacity – and ensured its quality through place-based peer review.

Second, citizen science can improve peoples' openness toward science as one set of legitimate processes and practices for knowing the world; the epistemology of science (Bonney et al., 2014; Brossard et al., 2005; Conrad and Hilchey, 2011; Dickinson et al., 2010; Dickinson et al., 2012; Newman et al., 2012; Silvertown, 2009). But beyond passively learning within scientific frames, citizen scientists can creatively engage in scientific study and exert critical agency; re-creating scientific norms and practices that are meaningful within their own cultural frame, that help them interpret the world they face (Calabrese-Barton & Tan, 2010). TRACKS aimed to stimulate thinking among CS about how scientific methods and ways of knowing could help them learn about their local climate, as complementary to other culturally embedded information used for adapting to the climate.

Third, citizen science can increase awareness and understanding of natural phenomena and changes; presenting people with a richer picture of the place where they live (Bonney et al., 2014; Brossard et al., 2005; Conrad and Hilchey, 2011; Dickinson et al., 2010; Dickinson et al., 2012; Newman et al., 2012). That is, learning that increases *what is known* about a place - the content or 'facts' that local people learn - as distinct from *how it is known* epistemologically. TRACKS was similarly concerned with environmental learning. Several CS said that they saw a low awareness of weather and its impacts in their communities (see Section 4.3), so we sought to heighten their sensitivity to, and knowledge of, weather experienced in their place.

Fourth, citizen science can nurture participatory governance that includes citizens in decision-making and action on local issues (Bonney et al., 2014; Conrad and Hilchey, 2011; Dickinson et al., 2012; Newman et al., 2012; Silvertown, 2009). Here again agency is an important concept insofar as studies show citizen scientists can feel empowered by their scientific understanding, assume an identity as a 'local expert', and use their science as a means to act and affect change in their local place (Ballard et al., 2017; Basu et al., 2010). TRACKS too sought to engage CS in local adaptation, both through CS' individual actions, and their input to community decisions.

2.3 A framework for assessing the citizen sciences impact on local adaptive capacity

In planning the citizen science, we wanted to empirically assess scholars' claims that citizen science can build climate adaptation governance capacity (Spellman 2015; Wildschut 2016). There is growing evidence in the wider environmental governance literature (Ballard et al., 2017; Couvet et al. 2008; McGreavy et al. 2016; McKinley et al 2015) that citizen science can contribute in various ways to natural resource management, through robust monitoring and learning practices and increased stakeholder 'buy-in' for example (Aceves-Bueno et al. 2015). But thematically, we found very few publications relating to climate adaptation, and methodologically, there are few efforts to conduct comprehensive assessment of the impacts of citizen science on *governance as social interaction and structures* (see e.g. definitions by Kooiman, 2003; Lange et al., 2013). Most assessment focuses on the scientific quality of the research method (Cohn 2008; Delaney et al. 2008), its contributions to scientific scholarship (Burgess et al. 2017; Cooper et al. 2014; Theobold et al. 2015), the level of participation (Hakley 2012; Shirk et al. 2012) or educational impacts, especially on individuals' actions (Ballard et al., 2017; Brossard et al 2005; Crall et al 2012). Very few studies (see e.g. Jordan et al. 2012) extend their focus beyond individuals to consider impacts on the governing system they are part of; their social interactions, political decision-making processes, institutions and policy tools for example (Bonney et al 2016; Conrad & Hilchey 2012). Against this background, we developed our own framework for assessing the impact of citizen science on the governing system that steers citizen scientists' adaptation to climate variability relative to: (i) building a high-quality scientific knowledge base; and (ii) nurturing other resources and capacities that facilitate adaptation.

2.3.1 Conceptualising the assessment framework

Climate adaptation is defined broadly as *"the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities"* (IPCC 2014, p 5). Much social science research has come to conceptualise adaptation as a dynamic social process, facilitated by the unique sets of resources or capacities availing particular communities to adapt, including: (i) political leadership; (ii) institutions; (iii) natural and financial capital; (iv) science, technologies and infrastructure; (v) kinship networks and social bonds; and (vi) cultural histories and worldviews (Adger et al., 2005; Smit & Wandel 2006). This has seen various strands of literature on how to govern this social process (Adger et al., 2009; Inderberg et al., 2015; Walker & Salt, 2006), and assess 'adaptive capacities' (Grothmann et al., 2013; Gupta et al., 2010). We sought to assess citizen science's impacts on Sylhet communities' adaptive capacities but chose not to adopt an established framework. As peers we sought citizen scientists' collaboration at all research steps, including assessing impacts. We sought a framework guided top-down by theory, but populated bottom-up by citizens' concerns.

Central to the citizen science was developing a high-quality scientific knowledge base as one resource for building adaptive capacity. Assessing the quality of the science emerging from the citizen science work was conceptually less complicated. Drawing on a long tradition of knowledge quality assessment it assessed quality by three open criteria of *salience, credibility and legitimacy* (Cash et al., 2003). We did not collaborate with CS on these criteria, deeming them broad enough to capture CSs concerns. Assessing impacts on other capacities demanded more conceptual work.

The adaptive governance literature was the theoretical basis for our assessment of impact on other capacities. From this literature (see e.g. Folke et al. 2005; Olsson et al. 2006; Dietz et al. 2003; Chaffin et al. 2014; Walker and Salt 2006) we distilled key capacities seen to help communities adapt, including in established assessment frameworks (Bahadur et al., 2013; Plummer & Armitage, 2007; Trimble et al., 2015). On this theoretical basis, we designed three open interview questions for the citizen scientists, asking (i) what they expect and need to learn? (ii) what they think will ensure on-going collaboration between CS? and (iii) how they might translate learning into praxis? In March 2016 we asked these questions in semi-structured interviews with 16 of the 48 citizen scientists present at the Phase 2 workshops – eight from each study site – selected opportunistically. This yielded a list of CS' own 'indicators' of impactful citizen science that we clustered into capacities categories, which were in turn compared to key themes from the literature. CSs' indicators were therefore the result of a synthetic analysis, not group deliberation. We saw high correspondence, perhaps unsurprisingly given the literature shaped the interviews. Where there was correspondence – where citizen scientists' concerns matched the literature – we retained these indicators and crafted the wording from both sources. The resulting list of 12 indicators was both theoretically founded and meaningful for CS, but loosely structured.

We organised these indicators into a framework structured using the concept of capital; assessing the project's impact on capacities as stocks of capital availing CS to adapt, with capital defined as, "a stock that yields a flow of useful goods and services into the future" (Costanza & Daly, 1992). While other frameworks like that of Gupta and colleagues (2010) are structured by 'dimensions' of capacity, we favoured the capital concept as a way of: (i) categorising impacts; (ii) conceptually gluing together disparate indicators in an internally-consistent framework; and (iii) visualising the dynamic accruing and depleting of capacity according to certain actions and decisions. Influenced by planning (Innes & Booher, 1999) and development studies (Plummer & Armitage, 2007), capital – particularly 'human', 'social' and 'resource' capital – has long been central to assessing capacity in the adaptive governance literature, but usually as part of a mixed toolbox including other procedural and institutional measures. Essentially, capital is one way of categorising different capacities, but the capacities themselves largely remain constant across frameworks, whether labelled as capital or dimensions. For example, while we class learning, leadership and expertise under human capital, Gupta et al. (2010) split them across three dimensions, of 'resources', 'leadership' and 'learning'. Notwithstanding some important criticisms of the use of capital as a concept for explaining complex social phenomena (Bowles, 1999; Fischer, 2005; Haynes, 2009), we chose to take the capital concept to its full realisation. To the three widely used human, social and resource capitals we added both 'political capital', to capture the power dynamics of social decision-making *processes*, and 'institutional capital', to incorporate social *structures* in a governing system. In this way our 12 indicators were organised as indicating changes in the stocks of five forms of capital that support adaptive capacity (Table 1)

There is limited space here to go into detail on each indicator, how they show increases in capital stocks, and how these stocks in turn support adaptation processes. Suffice to list the definitions we used for each capital, and see how the indicators take shape in their application in Section 4:

Human capital: “the stock of education, skills, culture and knowledge stored in human beings themselves” (Costanza & Daly, 1992).

Social capital: “connections among individuals – social networks, and the norms of reciprocity and trustworthiness that arise from them” (Putnam, 2000)

Resources and technology capital: “physical, man-made stock, produced and reproduced by society” (Weisz et al., 2015).

Political capital: “the knowledge, skill, education and advantage someone has to give them status in society” (Bourdieu, 1986).

Institutional capital: “the supply of organisational ability and structures, literally the ‘capital’ of institutions that society has at its disposal” (Ostrom, 1990)

Table 1: The framework for assessing impact on adaptive capacity capital stocks

Human capital	**Social capital**	**Resources and technology capital**	**Political capital**	**Institutional capital**
Learning about the weather, its impacts and its uncertainties	Networks and interaction (formal and informal)	Scientific models	Impact on local policies and politics	Cooperation across institutions
Translating learning into practice in different vocations	Participation and sharing experiences	Weather measuring technologies		Remaining flexible to changing conditions
Leadership and clear organisation	Trust and openness	Communication infrastructure for the extended peer-community		

In sum, our full framework comprised two parallel but tightly linked assessments of impacts on CS' adaptive capacity, relative to: (i) the quality of the science CS draw in support of adaptation; and (ii) contributions to other capacities within a governing system as stocks of five capitals (Table 5). We considered reconciling these two, by conceptualising the former as scientific capital, but the concept of a stock is not directly reconcilable with concepts of quality. This noted, the two are tightly linked, with a scientific knowledge base part of 'resource and technology capital'.

2.3.2 Implementing the assessment

Continuing our commitment to the extended peer review of the project's community-level impacts, we sought CSs *self-appraisal* of impacts on the knowledge base and capital stocks within the governing systems that they themselves are part of. CSs perspectives as actors interacting in local networks within and across different social institutions, continuously drawing on knowledge, practices and resources to adapt to the changing weather and seasons. This implied two choices. First, that we delimit assessment to impacts on the citizen scientist groups and their networks and institutions. Second, following in traditions of participatory evaluation (Plottu & Plottu, 2011), we relied on CSs own subjective appraisal, rather than adopt an objective position that we argue is unrealistic in deeply social and political interventions like citizen science. We argue that with this approach we can: (i) observe clearer signals of how citizen science changes adaptive attitudes and practices, (ii) expressed in culturally-rich, place-specific ways best accessed through deeper qualitative analysis. The appraisal is also very personal to individuals who cannot claim an 'external' all-encompassing perspective on the whole governing system. But we can see impacts beyond individuals because the CS are members of their communities, working and living in institutions that they influence in however small or significant ways. Indeed, there are precedents to this kind of assessment (see e.g. Constant & Roberts 2017; Trimble et al., 2015).

Citizen scientists' self-appraisal was elicited through semi-structured interviews, using questions derived from the assessment framework indicators, so interview talk was the principle source of material for the assessment. We interviewed 23 CS in all, selected according to who was active in the citizen science work, according to diversity, and who was available for interviews at the time. There were two rounds of interviews, midway and at the end of the first year of citizen science, but while this did allow some comparison of how the work evolved there were no provisions made to measure changes in capital stocks over time. Finally, interview responses were validated by focus group discussion led by TRACKS field staff in the citizen scientist meetings (see Section 3). For example, where CSs reported strengthening social cohesion this could be checked by observing CS interaction and how they helped each other, not only relative to citizen science.

Interview talk was analysed according to what CS revealed about indicators from the assessment framework. This saw transcripts first coded by indicators, before being analysed and assessed. The assessment of impact on capital stocks was, as in Gupta et al. (2010), subjective to the researchers' own reading of the transcripts, guided by the frequency with which themes were mentioned. As discussed by Grothmann et al. (2013), we chose to omit a numerical scoring system that might imply precision, instead opting for a simple high, moderate or low impact scale. We did not record negative impacts, but it might have improved the assessment. Like Gupta et al. (2010), the assessment was peer reviewed within the consortium according to a consensus model of validation.

Finally, it is important to state up front what this assessment can and cannot reveal, with three main issues. First, the research design is such that we only observe changes in the particular indicators we identify as important, which might mean overlooking other important changes.

Second, there are issues about how to elicit this self-appraisal authentically. By interviewing CS as their research partners, we may have encouraged them to inflate the impacts of our common venture, for example about how their learning translates to practice. Third, self-assessment of things like learning are very different to objective assessment of content knowledge and skills.

3 Implementation of citizen science research

The TRACKS citizen science phase was to measure rainfall and its impacts for a full Bengali calendar year from Boishak to Chaitra; that is from April 2016 to March 2017. But, due to the enthusiasm of the CSs it was extended for a second year, and funded and run independent of the TRACKS project, until May 2018. At writing, many of the CSs continue their measurements.

3.1 Citizen scientist selection

The selection of CSs began in Phase 1 of TRACKS in late 2014, when 238 people were interviewed across the study sites to elicit local narratives of climate (see Bremer et al., 2017 for detail on interviewee selection), with most interviewees voicing enthusiasm for participating further in the project. Based on the interview transcripts, a diverse selection of knowledgeable and enthusiastic interviewees were invited to collaborate on citizen science, first by attending workshops (Phase 2) to design the study, and then to carry out the measurements and analysis (Phase 3) (see Bremer et al., 2018 for detail on workshop participants). A total number of 48 CSs chose to continue working with us on a voluntary basis – 21 people in Sunamganj and 27 in Barlekha – men and women of all ages, with different education and occupations (Table 2 & 3).

Table 2: The citizen scientists of Sunamganj and the indicators they measured (citizen scientists shaded grey were interviewed for the assessment)

Occupation	Gender	Age	Education level	Indicators
Baul singer	Male	34	Primary	Mango trees budding
Businessman	Male	32	Primary	Mango trees budding
Businessman	Male	61	HSC**	Rainfall; Kalboishakhi and hailstorm damage
Day labour	Female	34	No formal education	Mango trees budding; and Frog flies and insects behavior
Day labour	Female	28	No formal education	Mango trees budding; and Frog flies and insects behavior
Employed in government livestock office	Male	54	Masters degree	Rainfall
Farmer	Male	35	SSC*	Kalboishakhi and hailstorm damage
UP member (politician)	Female	37	SSC	Kalboishakhi and hailstorm damage
UP member (politician)	Female	27	SSC	Thunderstorm casualties
UP member (politician)	Female	35	SSC	Thunderstorm casualties
UP member (politician)	Female	41	SSC	Cloud density, colour and location
Journalist	Male	47	Bachelor Degree	Rainfall; Flood level; and Wind direction and speed
Journalist	Male	48	HSC	Rainfall; Flood level; and Wind direction and speed
Poultry business	Male	25	SSC	Air temperature; and Wind direction and speed
Religious school teacher	Male	58	Masters Degree	Air temperature; Rainfall
Researcher in NGO	Male	52	Masters Degree	Kalboishakhi and hailstorm damage
Retired statistician	Male	65	Masters Degree	Thunderstorm casualties
School teacher	Male	39	Masters Degree	Student attendance; and Wind direction and speed
School teacher	Female	33	HSC	Mango trees budding
Shopkeeper	Male	27	Primary	Cloud density, colour and location
Village doctor	Male	42	HSC	Wind direction and speed; and Air temperature

* SSC-Secondary School Certificate; **HSC-Higher Secondary Certificate

Table 3: The citizen scientists of Barlekha and the indicators they measured (citizen scientists shaded grey were interviewed for the assessment)

Occupation	Gender	Age	Education level	Indicators
Baol singer (folk singer)	Male	26	SSC*	Flood level
Carpenter	Male	54	Primary	Cloud density colour and location; and Frog flies and insects behavior
Farmer	Male	28	SSC	Rainfall
Farmer	Male	55	SSC	Flood level
Farmer	Male	69	Primary	Kalboishakhi and hailstorm damage
Farmer	Male	64	HSC**	Cloud density, colour and location
Fish trader	Male	66	Primary	Thunderstorm casualties
Fisherman	Male	30	SSC	Rainfall
Fisherman	Male	28	SSC	Kalboishakhi and hailstorm damage
Fisherman	Male	59	SSC	Thunderstorm casualties
Former UP member	Male	55	SSC	Rainfall
Former village police	Male	61	SSC	Cloud density, colour and location
Government employee in social welfare	Female	58	HSC	Mango trees budding
Housewife	Female	25	SSC	Mango trees budding
Housewife	Female	31	SSC	Mango trees budding
Housewife	Female	26	SSC	Mango trees budding
Journalist	Male	53	HSC	Air temperature, wind direction and wind speed
Leader of auto rickshaws owner	Male	49	Primary	Mango trees budding instead
Mechanics	Male	54	HSC	Thunderstorm casualties
Political leader	Male	65	SSC	Flood level
Priest	Male	32	HSC	Rainfall
Religious school teacher	Male	59	Bachelor Degree	Kalboishakhi and hailstorm damage; and Air Temperature
Retired secretary of UP office	Male	62	HSC	Air temperature; and Thunderstorm casualties
School teacher	Male	51	Bachelor Degree	School attendance
Student	Male	13	SSC	Cloud density, colour and location
Tourist guide	Male	29	HSC	Kalboishakhi and hailstorm damage
Village doctor	Male	58	HSC	Frog flies and insects behavior; Kalboishakhi and hailstorm damage; Air temperature; and Wind direction and wind speed

* SSC-Secondary School Certificate; **HSC-Higher Secondary Certificate

3.2 Identifying areas for more research and crafting indicators

Phase 2 brought the CSs together with the scientific consortium in two workshops, from 9-10 March in Sunamganj and 13-14 March 2016 in Barlekha, to familiarise the CSs with the research process and to design the citizen science study (find a detailed account of the workshops in Bremer et al., 2018). The aim was to identify, through extended peer review, locally meaningful indicators of rainfall and its effects. Together, the CSs and consortium scientists generated cognitive maps of rainfall, in order to identify and prioritise knowledge gaps, and design indicators and regiments of measurement tailored to these gaps and appropriate to the local conditions. The workshops identified 10 interrelated indicators (Table 4) common to all study-sites and from across three categories: (i) indicators *predictive* of rain (clouds, insects, wind, mango buds); (ii) indicators describing *rainfall events* (rainfall, temperature); and (iii) indicators of *effects* of rainfall (river levels, school attendance, storm damage, thunderstorm casualties.

3.3 Assigning indicators to the CSs

The CS could not all measure such a long list of different indicators, so each was assigned one or more indicators based on three considerations (Tables 2 and 3). First, how many and which indicators were individual CSs most interested in measuring? And which were most relevant to their purposes? For example, flood levels are important for fishermen so they were interested in this measure. Second, which CSs have education commensurate to measuring certain indicators? Some technical measures demanded extensive written notes and reading of devices (e.g. anemometer), and were less well suited to illiterate CS. Third, which indicators are conveniently measured by which CSs? Obviously, schoolteachers are best placed to record school attendance.

Table 4: Indicators and their regiments of measurement, and ways that CSs use the information

Indicators	Means of measurement	Frequency of measurement	Means of recording data	Unit of measurement	Quality control	Example applications in daily adaptation
Air temperature	A mercury thermometer, hung on the wall of CSs houses or workplaces.	Three times a day, early morning, early afternoon and late afternoon	Thermometer reading recorded daily in the logbook.	Degree centigrade (^{o}C)	CSs were given tuition initially, later discussing and sharing knowledge among themselves in bi-monthly meeting. Regular monitoring by TRACKS field staff to identify error and replace thermometers in some cases.	Temperature used to predict rainfall, in poultry farm management, and reorganise temperature sensitive drugs in pharmacies.
Cloud density, colour and location	Observed and measured using an Okta scale. Okta ranges from 0 to 8 where 0 means no cloud and 8 means whole sky is covered by cloud.	Once a day before evening	Okta were recorded daily in the logbook, with space for comment on cloud colour, or accompanying weather	Okta (0-8)	Detailed instructions of cloud observation with pictorial illustration as per WMO were given in logbook in Bengali. Observation practice of CSs was monitored directly and ensured that they were properly observing and recording data.	Used in predicting rain and applied in daily life for preparing to work in the fields or travel to the marketplace.
River level	River-gauges based on the standard scale set in consultation with the Bangladesh Water Development Board (BWDB)	Once a day, in the morning	River-gauge data recorded in the logbook daily.	Changes of water level (mm)	CSs were monitored regularly, and data were cross-checked with local staff of the BWDB	Used for predicting floods. Sand businesses piled up sand higher on the river bank when the see the river level rises
Frogs, flies and insect behavior	Observed frogs croaking, grasshopper flying close to the ground and beetles and termites' emerging.	As and when these phenomena are observed	The date and time of phenomena were recorded in the log book.	Time, date and type of animal behaviors	Data recording was checked regularly and the process discussed at bi-monthly meetings.	Used for predicting rain in order to plan work in the fields.
Kalboishakhi (nor'wester) and hailstorm damage	(i) human casualties, (ii) number of livestock killed, (iii) number of house damaged, (iv) area of crops damaged, and (v) volume of crops damaged, after these events, in a defined village space.	Following these storms, as and when they occur	Following the storms, CSs surveyed their defined village space, and consulted with others like local government officers, before recording data in the logbook. Crop damage records were estimates.	No. of human casualties; No. of livestock killed, No. of houses damaged; Area of crop damaged (acre); Amount of crop damaged (maund = 40kg)	Data checked by the research team immediately after the incidents and cross checked with other villagers.	One CS working at the local government used the information for relief distribution to the affected households

Indicators	Means of measurement	Frequency of measurement	Means of recording data	Unit of measurement	Quality control	Example applications in daily adaptation
Mango trees budding	The density of mango tree budding as high, medium or low density.	From late December to February	Recorded once each year in the logbook, when the trees are in full bud.	Percentage (%) of mango trees with buds in a village; Density of buds (high, medium, low)	Direct observation on the mango trees by the research team and checking recorded data of CSs. Photos used in the logbook to distinguish the three density categories.	Although this indicator was identified to predict hailstorm and flash flood however, this did not work accordingly.
Rainfall	Standard rain gauge	Every day in the morning between 9-10 am	Measuring the amount of rain in ml by 100 milliliter cylinder than converted into millimeters	Millimeter (mm)	CSs were trained how to measure rain with the rain gauge, regular monitoring on data recording and discussion in the bi-monthly meetings	CSs increased their understanding of rainfall patterns in their localities
School attendance	Daily student attendance at school, taken from the official register.	Once a day in the afternoon.	Students attendance data from the official register were recorded to logbook	Percent (%) of students attending class/ day	Data recording was monitored regularly	In two schools (Sunamganj and Barlekha), weather stations were installed. CSs studied the relationship between the rainfall and students attendance
Thunderstorm casualties	Human causalities, and number of livestock killed, per village, after a thunderstorm	Following thunderstorms as and when they occurred (mainly during April-June)	CSs conducted inquiries in their village and recorded casualties in logbook	No. of human casualties; No. of livestock killed	Data were checked regularly during the season of thunderstorm	CSs built up awareness of thunderstorm casualties
Wind direction and wind speed	Anemometer, at daytime when CSs observed strong winds.	As and when the CSs observed strong winds	Recording windspeed in the logbook following strong winds	Km per hour	Data were checked regularly by the research team	CSs could relate wind speed and direction to rainfall prediction

3.4 Resourcing and training the CSs

CSs were provided with resources and training for their respective indicators before they started measurement at the beginning of the Bengali year, in April 2016. Some were provided with measurement devices, specifically thermometers (for temperature), anemometers (for wind direction and speed), rain gauges (for rainfall), and river gauges (river level). Under the supervision of TRACKS scientists, these devices were set up at CSs' homes or workplaces in locations that complied with WMO guidelines while also making them practical to read. All CSs were given a logbook to record their data, tailored to their indicators and structured around an integrated Bengali and Gregorian calendar. When distributing the devices and logbooks, CSs were given individual training for measuring and recording their indicators, and there were group training sessions and discussions on method at the bi-monthly citizen science meetings. In addition, all CSs were gifted a digital bedside clock that also displays temperature and humidity to motivate their participation. These digital clocks also had important impacts (see Section 4).

3.5 Facilitating communication among citizen scientists

CSs were brought together in bi-monthly meetings, organised at a local venue (a CS's home, the local school or a restaurant) and followed by lunch. These meetings stimulated discussion among CSs, with the aims of (i) peer reviewing measurement practices, and (ii) discussing the findings, and (iii) inquiring into how CSs used this information. From the first to the second meeting we saw demonstrably improved measurements that we attributed to this extended peer review; CSs shared experiences and advice, and group training sessions held by TRACKS scientists. These experiences and lessons were recorded and helped assess the impact of the citizen science. The bi-monthly meetings also provided an arena where TRACKS scientists could present science for feedback. For instance, TRACKS worked with a professional artist to paint a representation of

CSs weather stories, and this artwork was presented to them for feedback (Stiller-Reeve & Naznin, 2018). We ensured regular contact between TRACKS scientists and CSs by topping up CSs mobile phone accounts and visiting them in their homes or workplaces every two months.

3.7 Open source data: logging measurements on the 'online lab'

TRACKS developed an 'on-line lab' that was linked to its website and openly displayed most of the data collected, and linked it to the CSs by name. Given the poor local Internet coverage, a TRACKS field assistant collected data from CSs logbooks, and uploaded it to the on-line lab. These data were recorded in tables and could also be visually analysed using graphs. A visitor to the website could generate a graph that visualised two or more indicators relative to each other, to interrogate relationships between indicators. This allowed visitors to pose questions of the data, like does heavy rainfall really follow the croaking of frogs? The online lab was used to facilitate analysis with CSs in the bi-monthly meetings, with CSs asked whether different relationships between indicators were meaningful from their perspective.

3.8 Evaluating impacts of citizen science research on CSs

We assessed the impact of the citizen science on local adaptive capacity by interviewing CSs. The indicators of the assessment framework (see Section 2.3) were crafted into a semi-structured, qualitative interview script, and interviews conducted with a total of 23 CSs in two rounds: (i) twelve interviews in November 2016 in Sunamganj, and (ii) three further interviews in Sunamganj and eight interviews in Berlekha, in May 2017. These interviews, together with notes taken at bi-monthly meetings, are the principal basis for the assessment (Section 4).

One major impact was that the citizen science continued for another year, until May 2018, independently of the TRACKS project. But the study did change in various ways. Some CSs dropped away, but the study continued with 15 CSs each in Sunamganj and Barlekha. The portfolio of indicators changed too, according to those indicators CSs found most interesting and useful from the first year. Seven indicators were dropped (those on wind, clouds, storm damage, thunderstorm casualties, school attendance, animal behavior and mango budding), and two new indicators added; humidity (as measured by the digital clock) and fish colour (some fish change colour before rainfall). Otherwise, the approach is mainly unchanged. The CSs continue to meet every two months and record data in logbooks, but technical challenges meant the on-line lab could not be updated with the second year's data.

4. Assessing the impact of citizen science on local adaptive capacities

Our assessment of the TRACKS citizen science provided evidence of impacts on the CS groups' capacities for coping with climate variability and change, and some weaker signals of wider impacts on their communities' adaptive governance (see Table 5).

Table 5: Summarising impacts on adaptive capacity as a knowledge base and capital stocks

Category/capacity	Indicator/criteria	Impact	Overall impact
High-quality scientific knowledge base	Credibility	High	High
	Legitimacy	High	
	Salience	Moderate	
Human capital	Learning about the weather, impacts and uncertainties	High	High
	Translating learning into practice in different vocations	High	
	Leadership and clear organisation	Moderate	
Social capital	Networks and interaction (formal and informal)	High	High
	Participation and sharing experiences	High	
	Trust and openness	Moderate	
Resources and technology capital	Scientific models	Moderate	Moderate
	Weather measuring technologies	High	
	Communication infrastructure	Low	
Political capital	Impacts on local policies and politics	Moderate	Moderate
Institutional capital	Cooperation across institutions	Low	Low
	Remaining flexible to changing conditions	Low	

4.1 Developing a high-quality scientific knowledgebase for supporting local adaptation

Ensuring scientific quality is an ongoing challenge for citizen science (Tregidgo et al., 2013), where we understood quality broadly as *scientific robustness (credibility), usefulness (salience)* and *social legitimacy* (Cash et al., 2003). Scientific quality is largely concerned with methods of data collection and there is a significant body of work reconciling citizen science with 'normal' scientific procedural standards (see e.g. Tweddle et al., 2012). We ensured trustworthy and legitimate data with careful attention to method, in five ways.

First, for some indicators (e.g. temperature or rainfall) we employed standard meteorological measures in accordance with globally-accepted standards, like those published by the World Meteorological Organisation and the GLOBE network. These standards guided the placement of measurement instruments, individual and group training, and instructions in CSs logbooks. We also drew on other locally-accepted institutional standards. The river-level gauges were designed and installed as per the standard elevation points of the Bangladesh Water Development Board (BWDB), under direct instruction by their local staff. But sometimes, local conditions demanded creative solutions that went beyond standardized practices. Rainfall in the study area is extreme, such that daily rainfall regularly exceeds the 100 ml capacity of the standard rain gauge. On some days, CSs recorded more than 500 ml of rainfall over 24 hours. With CSs, we replaced the measuring flask with a one litre plastic bottle inside the rain gauge. CSs measured rainfall by emptying the plastic bottles contents into the 100 ml measuring flask.

Second, where indicators fell outside regular scientific measurement (e.g. mango buds), we developed robust scientific methods for collecting these measurements with the CSs, validated by the project's interdisciplinary consortium and scientific advisory board. We developed training manuals and tuition for these 'local' indicators, using photos to distinguish what constitutes high-, medium- and low-density mango buds for example. *Third*, CSs had the full-time support of a research assistant, trained in agriculture and aquaculture science, who regularly visited them to monitor their measurements, detect and correct any errors in the equipment or ways of reading them.

Fourth, the CSs peer reviewed each other's work at the bi-monthly meetings convened by the research assistant, where they discussed experiences, challenges, shared advice and interrogated the measurements. This interaction built a close-knit group of peers that identified and corrected their own errors, building trust in their peer group and the quality of their data, and lending the research social legitimacy (see Section 4.2). At times peer review extended beyond the CSs groups. The river-level data was validated with readings from the BWDBs own river-gauge. The storm damage indicators were cross-checked with data collected by other organisations like local government, and further validated in discussion with members of the local community.

Fifth, we sought an inclusive and transparent scientific study that further built social legitimacy. CSs participation was informed by a clear motivation, to learn more about local rainfall, and all willingly consented to participate on those terms. CSs participated in every stage of the study; from study framing at the beginning to communicating the findings at the end. We kept the process *open* to local communities by opening the bi-monthly meetings to all-comers, and through the 'on-line lab' that presented all data and let users graph this themselves. Among the CSs themselves, we encouraged a *diversity* of participants, reflective (if not representative) of the local communities. Finally, we sought the transparent allocation of resources, with open discussion between the TRACKS research team and CSs about the expenditure of project resources, with some CSs provided in-kind contributions.

What quality did the indicators have for helping CSs understand and anticipate local rainfall – how *useful* were they? Some proved better at representing local conditions than others and one unexpected outcome was that the digital clock, initially a simple gift, ended up providing some of the most useful and interesting information. In the bi-monthly meetings, the CSs agreed that where these clocks showed temperature above 34^{O}C and humidity above 84%, this reliably predicted rainfall and they could plan accordingly; i.e. whether to work in distant rice fields. And by measuring rainfall too, CSs came to better understand the relationship between temperature, humidity and rainfall. Another important relationship for CSs was between rainfall and river levels; by interpreting both they could anticipate floods. As Respondent 20 noted:

"I've learned a lot from my measurement of water levels in a nearby canal, and from the digital clock we've been given. Looking at the water level helps me predict floods [...] and I also use the

clock […]. When humidity and temperature readings are high, this can be a good predictor of rain; especially when this coincides with a northeast wind." (Respondent 20).

On the other hand, some indicators proved less useful. Mango bud clusters have long been used locally to anticipate summer rainfall, with denser clusters signifying more rainfall, flashfloods and hail. But in the citizen science study this indicator performed poorly; while buds were quite sparse in spring 2017, summer brought intense rainfall and flooding. This saw CSs discard less well performing indicators going into Year 2 of the citizen science study (Section 3.8); retaining temperature, rainfall and river-levels, and including humidity as one of the indicators recorded.

4.2 Impacts on adaptive capacity seen in capital stocks

As described in section 2.3, we developed a capital-based framework (Table 1) to assess the impacts on CSs adaptive capacity. Our findings are presented according to the framework's twelve indicators, categorised under each of the five capitals.

4.2.1 Human capital

TRACKS' citizen science highly strengthened human capital in the CSs groups. All CSs interviewed (23) stated that in participating they had learned much about local climate variability; mostly relative to the indicators they measured, but also how to better anticipate the weather and its impacts. Most (19) said that this learning was their main motivation. Learning was often accompanied by an increased attentiveness to the weather, as Respondent 22 noted:

"Before TRACKS I didn't really think about the weather, but now I do. I did know about local weather patterns before, but now I'm more conscious and knowledgeable of signs of the weather.

I use this information more and share it with others. I can better predict the weather myself, and not only rely on the TV forecast." – Respondent 22

Most (17) respondents provided concrete examples of how they used the things they learned in their occupational lives, demonstrating how the knowledge and expertise developed through citizen science can translate into adaptive practices in different institutional spheres. Respondent 5, who raises chickens in sheds, explained how by measuring and anticipating temperatures he has changed his farm management practices; opening the shed to air flow on hot days to keep the chickens from dehydrating. He has linked his understanding of temperature to his knowledge of chickens' stress levels and developed an adaptation strategy. The village doctor in Sunamganj, also measuring temperature, changed how he arranged medicines and products on his shelves, with attention to those that are most heat sensitive. Similarly, Respondent 10 explained how he uses the citizen science learning in his sand business:

"When the sand is delivered by boats to my business, if I know there will be rain or storms, I place the sand in a higher place, otherwise its gets washed away." – Respondent 10

Other respondents discussed how the things they learned helped them outside of work. Several gave examples of smaller daily adaptive practices and routines, such as knowing how to dress children and sick family members according to the weather or when to bring an umbrella, and many planned their movements (i.e. to work in the fields) by the citizen science indicators. Respondent 16 said: *"My temperature and humidity readings are a new daily habit for me".*

Our findings also showed a clear impact on building local climate adaptation leadership. This leadership and organisation can be seen in: (i) the work of the TRACKS researchers, but also (ii) the leadership shown by the CSs themselves, in their wider communities. To the former, 12 of the respondents stated that the leadership and organisation of meetings, especially by the full-time field assistant, has been important for creating a network, and 9 noting that it was because of this organisation they could speak openly in the meetings. A number of respondents (8) said they would like even more interaction among CSs, and gave suggestions for other kinds of meetings. To the latter, all respondents reported sharing knowledge with other people, and some convinced others to measure indicators. Several said that people trust the information they provide, making them adaptation leaders in their communities:

"… I speak to others in the village about what I'm measuring and my predictions. I warn people of rain after reading the digital clock and observing the sky, talking to them as we work together in the haor. I feel that people respect and trust me as a source of information […] and do actually follow my advice." – Respondent 16.

4.2.2 Social capital

TRACKS' citizen science had a high impact on social capital in the CSs groups. A network was created, with almost all respondents (21) reporting that they had also come to regularly interact with other CSs outside of the organised meetings; in the market, on the roadside or at each other's houses. Five of the respondents referred to this network as a 'family'.

There was strong on-going participation in the citizen science and sharing of its findings. The research assistant reporting high attendance at bi-monthly meetings, and that most CSs kept to their measurement regime, at least over the first year. Further, all respondents (23) provided examples of how they share the knowledge they have gained through TRACKS with people outside the CS groups; from family, to friends, neighbours, colleagues, customers and students. For example, Respondent 4 is a teacher and said that he shares what he has learned with students in his class, but also with people who come by his office or who he meets at the mosque.

Relative to 'trust and openness', almost all respondents (21) stated that they could speak and participate openly in all facets of the citizen science, including at the bi-monthly meetings:

Everyone speaks in the meetings – it's not like a formal meeting with a government representative or anything like that. [Why?] *Because we are almost all poor and less educated, so we feel motivated to learn from each other. – Respondent 20*

The youngest CS, a ten-year old in Barlekha, did note that "It's harder for me to talk with the others, who are adults, or understand all that they talk about" (Respondent 19). Further, there was some evidence (from 2 interviewees in Sunamganj) that not all CSs trusted their colleagues. They suspected other CSs of wanting some 'benefit' from participating (perhaps financial, or local influence), beyond pure curiosity. Another respondent felt that some of the CSs were less capable than others, and their measurements less trustworthy. The TRACKS research was designed to bracket some of the power dynamics that characterise these contexts, and did create a space where all people could speak, but deeply-rooted village hierarchies found their way into the study, with women or young people not extended the same legitimacy for scientific work.

4.2.3 Resources and technology capital

Resources and technology capital saw a moderate increase, mainly due to the supply of ‘weather measuring technologies’, assembled by the project and the CSs themselves, which seventeen respondents said had helped them understand the local weather. Regarding scientific information, 18 respondents said that they trusted the scientific information presented to them in the bi-monthly meetings as being of high quality, and tried to use it to inform their daily adaptations. However, in interviews in May 2017, several respondents said that they would have been better served by long-term forecasts that could have predicted the flash flooding early enough to allow preparations. There almost no increase in ‘communication infrastructure’, with most CSs continuing to meet in person, and only two using other platforms like Facebook.

4.2.4 Political capital

We saw a moderate increase in political capital; where the citizen science is used to support public decision-making. There is evidence of citizen science findings being shared with politicians and in political arenas. Two of the respondents in Sunamganj are local politicians and another two formally held political posts, while one Hakaluki Haor respondent is an active politician. These five CSs all said that they share the things they have learned within their political networks, and in political discussions. Another four respondents in Sunamganj said that they have shared lessons in political meetings, and Barlekha respondent said, “Local politicians are aware that this kind of information is being collected by TRACKS” (Respondent 16). Furthermore, in May 2017, at the end of the first year of the citizen science, we presented key findings to central government and NGO decision-makers in Dhaka.

There were fewer examples of where this knowledge was visibly taken up and used for public decision-making, but it does tentatively suggest that the citizen science had legitimacy in local political decision-making. One CS in Sunamganj was able to anticipate the 2017 flash floods and warn local politicians, who acted on his warning. The politician in Hakaluki Haor also spoke about how he employed this knowledge in the aftermath of the 2017 floods:

"I use my learning and experience from TRACKS in political discussions, like those about the recent flash flooding. I talk about my river level measurements in discussions around this flooding and I can compare what I measure to what others claim. It's first-hand knowledge to back up my arguments, which gives me a strong voice. […] Based on my work with TRACKS, I argued for relief for my village, and my community received 5kg of rice/day for 200 families." – Respondent 17.

4.2.5 Institutional capital

Institutional impact was relatively low. Respondents discussed some impact on other institutions (schools, cooperatives, local government, the media) where they worked. The two respondents who are teachers both used that they've learned in their teaching, with one training his students in measuring and understanding temperature. A CS working in Barlekha local government and collecting data on thunderstorm casualties said that her work had raised awareness of the severity of this problem. In the recent years, thunderstorm casualties, particularly in Sylhet division, have increased dramatically (Suman and Islam, 2013). But 14 respondents voiced disappointment that the citizen science data were not actively disseminated to more institutions, and did not have the level of impact CS expected, particularly in support of local government decision-making:

"This information could be useful at the union level, for the administration. It could help them target specific interventions. Small interventions, like building culverts" – Respondent 22

There was a low impact on shaping institutions to 'remain flexible to changing conditions'. Most increased 'flexibility' was seen in the changed behaviour of individual CSs, rather than changed practices or policy at an institutional level. The flash floods in April 2017 showed that even where the community is better able to foresee extreme events, there is not always the institutional capacity to prepare in time. Respondent 2 explained how he had observed many weather indicators in the days before the flash flood, and that he warned local politicians. Following the respondent's warning, local politicians attempted to reinforce the embankment that protects the crops, but when the flood hit the embankment collapsed.

5. Discussion and conclusions on citizen science for climate adaptation

This assessment provides empirical evidence of how citizen science can contribute to climate adaptation governance capacity, with strong signals of impacts within the CS groups and weaker signals of impacts on the wider communities. There is, we agree, significant potential for supporting place-based climate adaptation with citizen science. But to strengthen this claim, we need a larger cadre of assessments, in other contexts, with other designs of citizen science. The TRACKS project was a unique and genuinely co-creative approach to citizen science, with participation at all steps of the research design down to the assessment of impact, to culturally embed the science in its particular context. It would be interesting to compare our assessed impacts with those of other citizen climate science studies, which may have different levels of participation or limit themselves to more universally-accepted observations for example (Shirk et al., 2012). The novel assessment framework we demonstrated here could provide a starting point for this wider assessment, though we recommend that any such assessment should be bespoke to its context, and tailored with the CSs themselves.

5.1 Reflections on the assessment framework

The assessment framework performed well in illuminating impacts on local adaptation governance that were meaningful for the CSs. Following others (Jordan et al., 2012) we grafted assessment into the citizen science work from the outset, building it on the CSs' own aspirations and criteria (Constant & Roberts 2017), which structured reflexive interviews and discussions over the length of the project. This raises two issues. Firstly, returning to the reflections in Section 2.3.2, the framework is not 'objective'. Impacts are subjectively assessed by the CSs experiencing them, and their reflecting on these impacts is influenced by other CSs and our positionality as researchers. But we argue that the co-production of assessment criteria and participatory assessment of these criteria is epistemologically and normatively consistent with the extended modes of science underpinning citizen science; particularly the notions of extended peer review and negotiated knowledge quality espoused by post-normal science. Both knowledge quality criteria and adaptive capacities are context-specific, so CSs embedded in that context are best placed to assess them.

Secondly, the framework is not highly transferable, linked to a unique approach to conducting citizen science, and comprised of indicators derived from CS's concerns within the Sylhet context. It may be less relevant to other types of citizen science studies (e.g. less participatory 'contributory' studies for example – see e.g. Shirk et al., 2012), in contexts with other modes of governance, drawing on different adaptive capacities. This noted, we argue that it does provide a basis for a variety of creative approaches. In Bangladesh, this framework could be used to re-assess these impacts several years later. In other contexts, a similar framework could be employed in a more structured pre- and post-project assessment, to better assess changes in capacities over time. In general, we think that the focus on a knowledge base and capital stocks is a good starting point for assessing impacts on adaptive capacity.

The capital framework does extend on the current assessment of citizen science. It recognises then looks beyond traditionally studied impacts on individuals' learning and expertise (human capital), and the scientific robustness of the data (resources and technology capital), to bring CSs' shared capital stocks into focus; (i) their social networks and trust (social capital), (ii) their influence on public decision-making (political capital); and (iii) the institutions that structure human interaction. This framework is not, we found, well designed to illuminate the exercise of power within a citizen science group, or CSs' different motivations. It must also be noted that this study was conducted over two years, though this is a limited period to identify pervasive social impacts. The study could be improved by longer-term data gathering.

5.2 Impacts on adaptive governance in northeast Bangladesh.

This study uniquely sought to look beyond citizen science's impacts on individuals to focus on the other adaptive capacities built up in a governing system. We made a methodological choice to have citizen scientists self-assess these impacts, which we elicited through individual interviews, providing a set of highly personal and subjective assessments. In this way the kinds of data we processed, and assessment that we conducted, ended up having much in common with the other more widespread assessment literature; closely resembling work on the individual. We argue the difference is that our assessment looks out from the individual at the social networks and structures that these individuals interact with.

Consistent with other studies (Cohn 2008; Delaney et al. 2008), TRACKS did build a high-quality scientific knowledge base about local rainfall, its predictors and its impacts, together with associated *resource and technical capital*. Our assessment showed that the citizen science *credibly* conformed to robust international scientific standards, was trusted by CSs as *legitimate*, and proved quite *useful* for guiding CSs' adaptation practices at work and in their daily lives. Many also saw the citizen science as potentially useful in other local institutions, like local government, but were disappointed when it was not taken up by these institutions; they missed more active dissemination. Other CSs stressed the need for better long-term forecasts.

In keeping with other citizen science assessments (Crall et al. 2012; Brossard et al. 2012), we found TRACKS had important impacts on individual CSs' awareness, understanding and interpretation of local climate variability; their *human capital*. We saw improved skills in critical scientific inquiry within the group, and some CSs have learned to anticipate weather events like the flooding in April 2017. We also saw changes in CSs' practices – devising their own concrete adaptation strategies to daily weather – and we saw CSs emerge as local adaptation leaders.

Going beyond other assessments (Jordan et al. 2012), we saw high impacts on the stocks of social capital that bound the CS groups together; beyond what is expected in convening a new group of commonly interested people. We created, through the collaborative project design, increasingly dense social networks, based on frequent formal and informal interactions, and very high participation at every stage of the research process (see Shirk et al. 2012). CSs also voiced, through the interviews, their 'trust' for the other participants, though the assessment failed to go deeper into what influences trust, and why some participants (i.e. the less educated) were deemed less trustworthy.

We saw moderately strong signals of impacts of TRACKS on local political decision-making; political capital. Involving politicians as CSs was an effective way of directly connecting the citizen science to public decision-making, going some way to filling the gap identified by Conrad and Hilchey (2011) and Couvet et al. (2008). Indeed, we saw instances where the citizen science was used to support political arguments, including around the April 2017 floods. But overall, the citizen science did not become integrated into regular decision-making in local institutions, and while this may not be entirely surprising over a short two-year period, it was a disappointment for the CSs. This translated to quite low impacts on institutional capital.

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