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The tea landscape of Assam: Multi-stakeholder insights into sustainable livelihoods under a changing climate

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ABSTRACT

Tea plays a pivotal role in India's national economy, with the state of Assam the world's largest regional producer of black tea. However, various socio-environmental factors are threatening tea production and the livelihoods of millions of people reliant upon the industry. Little documentation exists which provides comprehensive spatial insights into tea production practices and associated livelihoods. Additionally, vulnerability from climate change to those livelihoods dependent upon the tea landscape has received limited multi-level stakeholder qualification. Consequently, this paper goes towards addressing this knowledge deficit through adopting a sustainable livelihoods approach for investigating the tea landscape of Assam. Mixed social survey methods were used to document responses from multiple stakeholder groups representing managers of commercial plantations, smallholders and tea workers. Results provide a comprehensive insight into the livelihoods of those reliant upon tea production activities across the four major tea growing regions of Assam. Outputs indicate that varying production practices are in place to optimise yield, increase livelihood resilience and manage the landscape effectively under a changing climate, with tea workers possessing varying diversity in assets to support their livelihoods. Outcomes from this research highlight the need for adaptable and climate-smart landscape activities, with active support from expert tea advisory agencies, to promote long-term socio-environmental sustainable cultivation of tea under changing climatic conditions.

1. Introduction

India has experienced a rise in the importance of its domestic tea market with overall tea production increasing by 19% between 1997 and 2010 (Arya, 2013). Conversely, international trade has declined since the collapse of the Soviet Union in the 1980s (Lines, 2006) with falling tea auction prices since the 1990s (Mishra et al., 2011) and recent stagnation in productivity (Arya, 2013). Historically, tea has played a vital role in the national economy, providing sectoral employment in remote and poor rural areas (Lines, 2006), yet tea plantation labour wages are the lowest of the organised sector (Mishra et al., 2011). The recent closure of some tea plantations has had a detrimental impact on worker livelihoods given the limited availability of alternative livelihood strategies in the tea growing regions (Van der Wal, 2008).

Assam, a state in northeast India, is the single largest tea growing region in the world, producing approximately 57% of India's tea (Tea Board of India, 2017) and providing some of the world's finest black tea (FAO, 2016); Assamese tea is registered as a Geographical Indication tagged product signifying the quality and importance of tea produced in this region. Despite the product's importance, there is limited comprehensive empirical evidence regarding the inherent value of the tea landscape for producers and the impact production has on sustaining livelihoods, particularly under a changing climate. Research into likely future climate change projections for northeast India, which predict further increases in temperature and uncertain variation in precipitation (Dash et al., 2012), has been undertaken, but there remains a large tea-climate research deficit for the region which needs addressing, particularly in terms of enhancing evidence-based climate change adaptation of tea landscapes for sustaining livelihoods. This shortfall is echoed by a recent bibliometric review undertaken by Marx et al. (2017) which highlighted the deficit of explicit analyses of global climate warming impacts on tea production landscapes.

To help address this research deficit, this paper presents evidence to

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better understand the determinants of livelihood vulnerability to climate change in the tea landscape of Assam, through comprehensive multi-stakeholder insights into the livelihoods of those dependent on tea production. Such information provides documentation into the processes and strategies within the tea landscape which are crucial for sustaining livelihoods, and how climate change vulnerability is impacting landscape resilience and socio-environmental sustainability. This paper begins by providing a brief overview of tea production in Assam regarding landscape management, livelihood security and regional climate change pressures. To gain a greater understanding of sustainable livelihoods in Assam, multiple stakeholders (plantation managers, smallholders and tea workers) participated in this research to garner information regarding tea landscape activities and the implications of regional climate change. Our research contributes to advancing knowledge for informing tea landscape management to sustain livelihoods under a changing climate. Outcomes highlight the opportunities for advisory agencies to help communicate information around production and climate change mitigation/adaptation strategies more effectively to tea growers, and we identify the need for climate-smart measures to enhance landscape resilience.

2. Landscape management

Tea is indigenous to northeast India and large-scale commercial cultivation in the region contributes over 50% of tea to India's overall production from more than 900 estates (Dikshit and Dikshit, 2014). Approximately 1.2 million workers are employed within the tea sector in Assam (Dikshit and Dikshit, 2014), primarily by large commercial plantations which dominate around 65% of tea production; the remaining 35% is produced by smallholder farmers with cultivable plots less than 10 hectares in size (Mansingh, 2013). The Tea Board of India regulates tea cultivation with regard to tea outputs, quality and marketing (Borah, 2013). Tea producers are somewhat reliant on advice from the Tea Research Association (TRA) who provide necessary guidelines for tea cultivation to tea farmers and estates (Dikshit and Dikshit, 2014), drawing upon information in their *Tea Field Management* guidebook (Goswami, 2011). Guidance is provided on fertiliser and pesticide applications to maximise yield, as well as information on best tea garden practice such as water resources management, crop shading, soil erosion control and reducing land degradation (Goswami, 2011). However, not all tea gardens have access to this advice so land management practices can be variable across the region. The small tea grower sector (smallholders) especially lacks access to this information which not only affects their production, but also presents sustainability challenges due to limited sectoral regulation, less environmentally sustainable farming practices, low traceability, poorer quality crops, and intermittent production which threatens export-orientated supply changes (Van der Wal, 2008). Poor tea production practices can cause adverse environmental impacts through land clearance for cultivating tea crops, high energy demands for crop processing, excessive pesticide application to counteract pest attacks, reduced soil fertility (which increases agrochemical use for soil nutrient fertilisation) and increased occurrence of erosion (Van der Wal, 2008). All producers are under added pressure from increasing climate change susceptibility, but smallholders have a lower capacity to adapt to climate threats (Nair et al., 2013).

3. Livelihood security

The tea sector is labour intensive with cultivation requiring a large workforce to maintain the landscape (Dikshit and Dikshit, 2014). Under the 1951 Labour Plantation Act (PLA), the welfare schemes of tea plantations are obligated to ensure provisions for permanent workers, such as subsided rates of rations and tea, medical benefits, housing and land for private farming (Duara and Mallick, 2012; Mansingh, 2013). Casual (temporary) workers are not entitled to these benefits except rations at a nominal rate (Duara and Mallick, 2012). However, those contracted to more than 60 days per year do have entitlements, yet these are rarely enforceable (Mansingh, 2013). Despite the requirements of the PLA, many plantations in Assam fall short of fulfilling these provisions, and even with those that do, pay is often below the living wage, with most labourers classed as extremely poor (Mansingh, 2013; Nayak, 2009). Low wages are a necessity according to plantation managers to ensure tea estates remain profitable (Duara and Mallick, 2012) to offset factors such as falling market prices (Mansingh, 2013) and rising energy costs (Van der Wal, 2008).

For an already highly vulnerable work force, primarily comprised of workers who are poor and often from scheduled tribe and caste and/or migrant communities (Van der Wal, 2008), this presents severe risks to livelihood security (Mishra et al., 2011). In particular, many tea plantation workers and their families have low levels and limited access to education, and high levels of illiteracy (Duara and Mallick, 2012), which limits prospects for livelihood diversification (Mishra et al., 2011). Additional livelihood concerns stem from malnutrition due to inadequate access to basic facilities such as drinking water, sanitation and electricity (Van der Wal, 2008). Plantation work is a gendered space with females employed to pluck tea leaves, and males engaged in maintenance of estates (including pruning), factory work, pesticide application and weed removal (Duara and Mallick, 2012). Although the gender employment split in plantations is roughly equal, women are often in lower paid, irregular and informal employment (Mishra et al., 2011).

Since the 1990s, tea cultivation on smallholdings has increased in Assam with more than 270,000 small tea growers (Dikshit and Dikshit, 2014), the majority (94%) of which are located within the Upper Assam region (Borah, 2013). However, most smallholders are excluded under the PLA (holdings less than five hectares) and growers have limited access to land management information. These circumstances present livelihood challenges, particularly as smallholders have low bargaining power on the supply chain with high dependency on private 'bought leaf factories' (BLF) for selling their tea, and as the market price for tea is set by the auction houses, this places limits on the cash value of Indian tea (Lines, 2006). Low farm gate prices, poor extension services, limited market channels, poor access to credit and low levels of farmer organisation all present problems for smallholders (Van der Wal, 2008). Despite these pitfalls, smallholders have lower costs (they are not required to provide social provisions like plantations for workers) and the production model is seen as more favourable (Van der Wal, 2008). Borah (2013) recommended that smallholdings should be encouraged and supported as entrepreneurial activities as tea enterprises can play a pivotal role in reducing poverty and generating employment. However, several barriers such as land ownership, limited finance, low price of green leaf tea and unorganised cultivations practices are greatly hindering smallholder expansion in India (Borah, 2013).

4. Climate change

Climate change poses a major threat to the socio-environmental resilience of agricultural systems, which includes the tea landscape of Assam, particularly the production of premium tea products (FAO, 2016). Given that tea produced in India equates to approximately a quarter of global tea production, with around 17% exported – primarily consisting of premium products (Tea Board of India, 2017) – the economic foreign exchange earnings of tea are under threat from adverse climate impacts which threaten productivity margins. Temperatures, precipitation variability, and the frequency of extreme weather events

are likely to increase globally, including over the Indian subcontinent (Mathison et al., 2013). The relative severity of climate impacts will be greatest in regions where human-environment system dependency is high, where agricultural production is essential for securing livelihoods and promoting economic growth.

Given tea's specific enviro-climatic niche required for growth,[1] climate variability and change could be placing significant impacts upon productivity, with an ensuing requirement for more adaptive land management. For example, periods of drought can lead to reduced yield and increased susceptibility to pest attacks (Dikshit and Dikshit, 2014). Specifically for northeast India, increasing trends are apparent in maximum, minimum and mean temperatures (Dash et al., 2007; Jain et al., 2013; Jhajharia and Singh, 2011). Intra-regionally, diurnal temperature ranges are noted to have significantly decreased in South Bank and Upper Assam, yet increased in Cachar and North Bank (Jhajharia and Singh, 2011). Precipitation has a less succinct picture with uncertainty around trends high in the region (Prakash et al., 2015). Nonetheless, some research has observed significant decreasing trends in annual rainy days (Kumar et al., 2010), wet days (Das et al., 2014; Panda and Kumar, 2014), and annual and monsoon precipitation (Deka et al., 2016). Intraregional variation also exists for contrasting trends in annual (Kumar and Jain, 2011), monsoonal (Dash et al., 2007) and winter precipitation (Deka et al., 2016), with the monsoon onset date also temporally shifting earlier (Moron and Robertson, 2013). Duncan et al. (2016) showed that prolonged periods of no precipitation have been associated with reduced tea yields, and increased temperatures have been associated with increased production across the four major tea growing regions of Assam. Future climate impacts are projected to mainly affect tea production through temperature increases, whereby management practices will need to adapt to this warming (Dutta, 2014).

5. Data and methods

To gain a holistic understanding of the livelihoods of those dependent on the tea landscape of Assam, and how climate change vulnerability is affecting livelihood strategies and outcomes, we collated information from multiple stakeholders across the region. Three main groups of tea actors were selected for involvement in data collation: plantation managers of commercial tea gardens, owners of smallholdings (less than 10 hectares in size) and tea workers employed as labour in the commercial plantations. Stakeholder selection was confined to the four major tea growing regions of Assam (Cachar, North Bank, South Bank and Upper Assam) (Fig. 1). Data were collated through questionnaires and focus group discussions, and geocoded to the district level to ensure anonymity of participants.

All plantation managers and smallholders that are TRA member gardens were contacted and invited to participate in the research. Two workshops were held for the plantation managers (one central to the three northeast contiguous regions, where 48 participants attended; the other in Cachar, with 23 participants), and four regional workshops were held (one in each tea growing region with a total of 163 participants: 50 in Cachar, 47 in North Bank, 23 in South Bank, and 43 in Upper Assam) for smallholders to attend. Fig. 1 indicates where these workshops were held and the geographical extent of tea garden locations from which participants originated (for further details see Table 3 in Biggs et al., submitted). At these workshops participants were required to complete a questionnaire whereby questions sought to ascertain information from tea producers regarding tea production processes, landscape management strategies, and climate change (see Survey 1 and Survey 2 in Biggs et al. (submitted) for questions). Separate questionnaires were developed for smallholder tea estate managers and plantation tea estate managers; this allowed for targeted matching of questions and context for the stakeholder groups. The questionnaires contained a mixture of closed- and open-ended questions; the open-ended questions allowed for capturing nuanced information which would otherwise be omitted. The plantation manager survey asked for information on tea estate and production, as well as details on social programmes and climate change. For smallholders, the sections of the survey sought to ascertain baseline information on tea estate characteristics, including details on income and production. Additionally, information on livelihoods and climate change was acquired. Specific questions under each of these topics were developed in consultation with experts from the Tocklai Tea Research Centre who have an intimate working knowledge of tea production practices in the region. Questionnaires for smallholders were translated into Assamese and subsequent responses were translated by the project researcher and transcribed into a database in English.

Following the workshops, commercial plantation managers were contacted to request permission to undertake focus group sessions with tea workers. The first five gardens per region[2] to reply were visited and two focus groups were held within each garden with workers grouped by gender. A minimum of 15 tea workers were sought for participation per focus group following Clayton's (1997) recommended panel sample size of 15–30 people. An adapted version of the Delphi technique was utilised to formulate group consensus regarding the role that tea has in sustaining tea workers' livelihoods. The Delphi method has been noted to be particularly effective in stimulating discussion and convergence towards agreement to consolidate information raised by a group (Linstone and Turoff, 2002). Biggs and Watmough (2012) found the technique to be highly beneficial for participants from illiterate populations, and suggested a necessary group gender split for research engagement with social systems in South Asia to allow all opinions to be voiced. As such, tea workers were split by gender and participants were asked to state all factors which they deemed relevant to supporting their livelihoods using the opening question 'What are the important factors of working in a tea plantation which impact life for you and your family?'; these were noted by the session moderator. Subsequently, participants were asked to formulate group consensus on the five most important factors and then assign weighting to these factors through allocation of 20 counters. A total of 36 focus group discussions were held (18 with females; 18 with males). To analyse the focus group responses, data were either categorised as assets under human-physical-social-natural-financial capitals (following consultation of DfID's (1999) sustainable livelihoods guidance sheets and discussion with a livelihoods expert independent to the project research), or as factors relating to climate change vulnerability.

6. Results

Our findings present comprehensive insights (across the four major tea growing regions of Assam) into local knowledge of climate change, important assets for sustaining livelihoods, tea landscape management structures and processes, and livelihood outcomes which are realised as important for building climate resilience and socio-environmental landscape sustainability. These are discussed here in relation to the sustainable livelihoods approach, whereby a conceptual overview of the tea landscape is provided in Fig. 2.

6.1. Climate change vulnerability

Here we report findings regarding tea producers' localised

[1] In Northeast India, tea growth occurs within an optimal ambient temperature range of 13–30 °C, with an approximate buffer of ± 5 °C from the higher end, and crop dormancy during winter when temperatures are too low for production (Eden, 1958). Sufficient and spatially homogeneous precipitation (averaging around 2100 mm annually), especially during January–March facilitates growth of the first flush and second flush (premium products), as well as during the monsoon season (Sen et al., 1966).

[2] Only three gardens in Upper Assam were visited due to a lack of response.

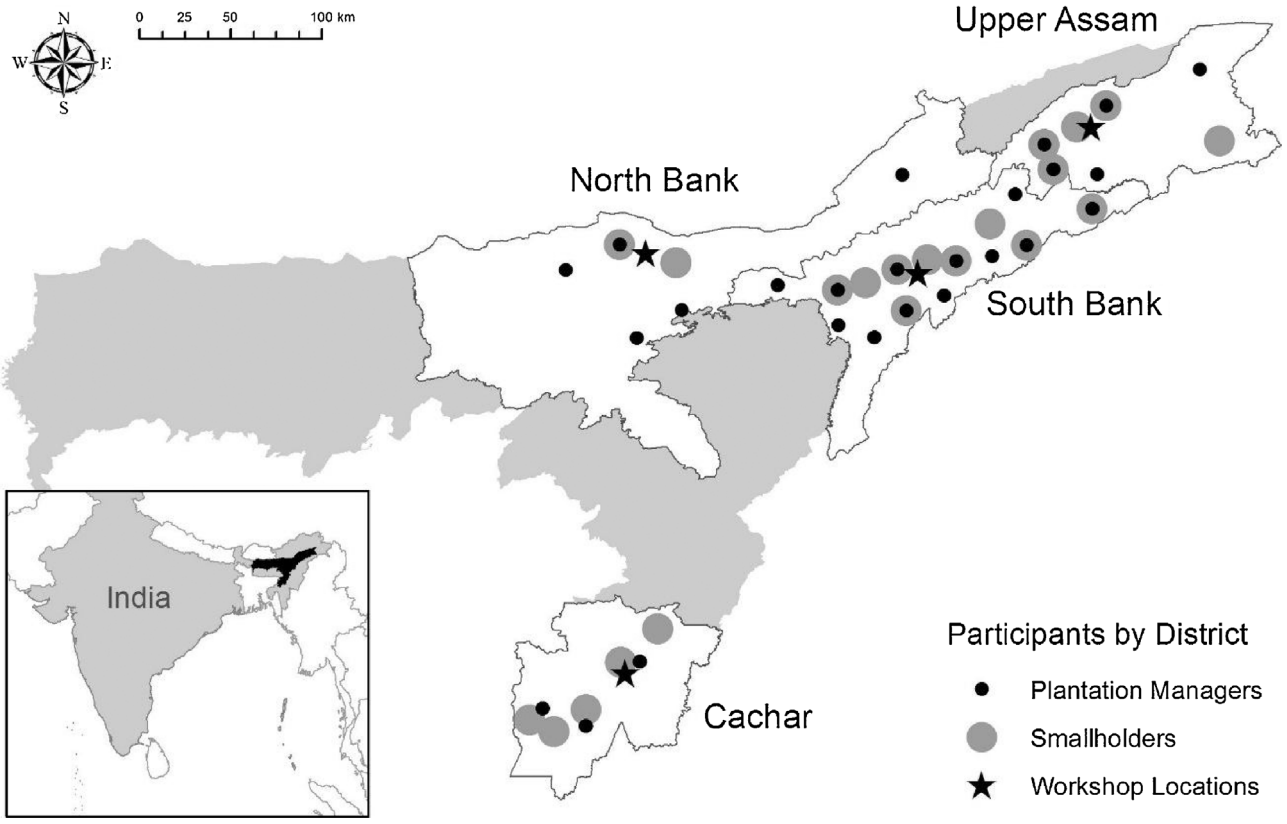

Fig. 1. The four main tea growing regions of Assam (inset: location of Assam, India) indicating the district locations of tea grower participants (plantation managers and smallholders) and workshop locations for this research (note: there were multiple participants per district location).

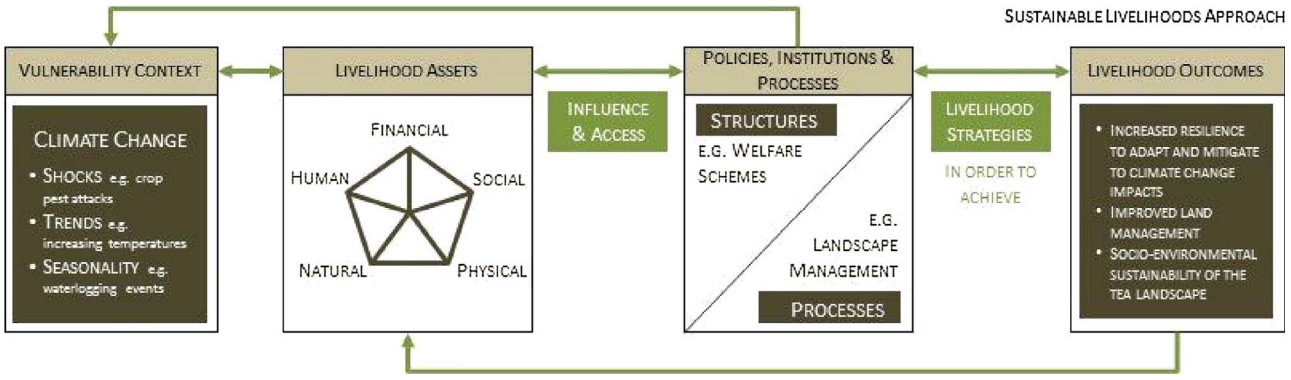

Fig. 2. A conceptual overview of a sustainable livelihoods approach for the tea landscape of Assam's major tea-producing regions, adopting a climate change vulnerability focal lens. Adapted from Donohue and Biggs (2015).

understandings of the vulnerabilities posed by climate change to the tea landscape. 88% of the plantation managers stated that climate was definitely a threat to their tea plantations, and 5% stated that a threat was possible. 97% of smallholders also noted that adverse climate conditions were definitely a threat to crop production, with noted reductions in yield quantity and quality, and in some cases plant survival being compromised. Such impacts were stated as having a detrimental impact to some growers' livelihoods, with increased financial losses. Rationale for why climate was stated as a threat to tea production reflected sub-optimal enviro-climatic growing conditions for the crop. For example, one manager (South Bank) reported extreme temperatures of up to 42 °C and temperature lows of 3 °C which are well outside the ideal tea growth range. Increased hot/warm spells were understood by plantation managers to be impacting tea yield, which has resulted in a reduced active growing period, a requirement for elevated pest management (e.g. higher incidence of termites and thrips), and impacts on the health, wellbeing and income of workers. Smallholders in Upper Assam and South Bank stated that excessive sunlight damages their crops whereby shade trees are essential to lower ambient temperatures as well as protecting tea crops from wind damage.

More erratic, reduced intensity rain events and prolonged dry spells were noted by plantation managers to be affecting already heat-stressed plants, especially those located in degraded (lacking nutrients and organic matter) and lower moisture retention soils, with resultant increases in crop mortality rates. Heavy rain events were noted as causing waterlogging and soil erosion. Changes in rainfall patterns regarding onset and increased intra-seasonal variability were stated by managers to cause (i) changes in yield with delayed growth of tea crops, particularly affecting the harvest of higher value crops (first and second flush) due to a shortened growing season, and (ii) waterlogging which

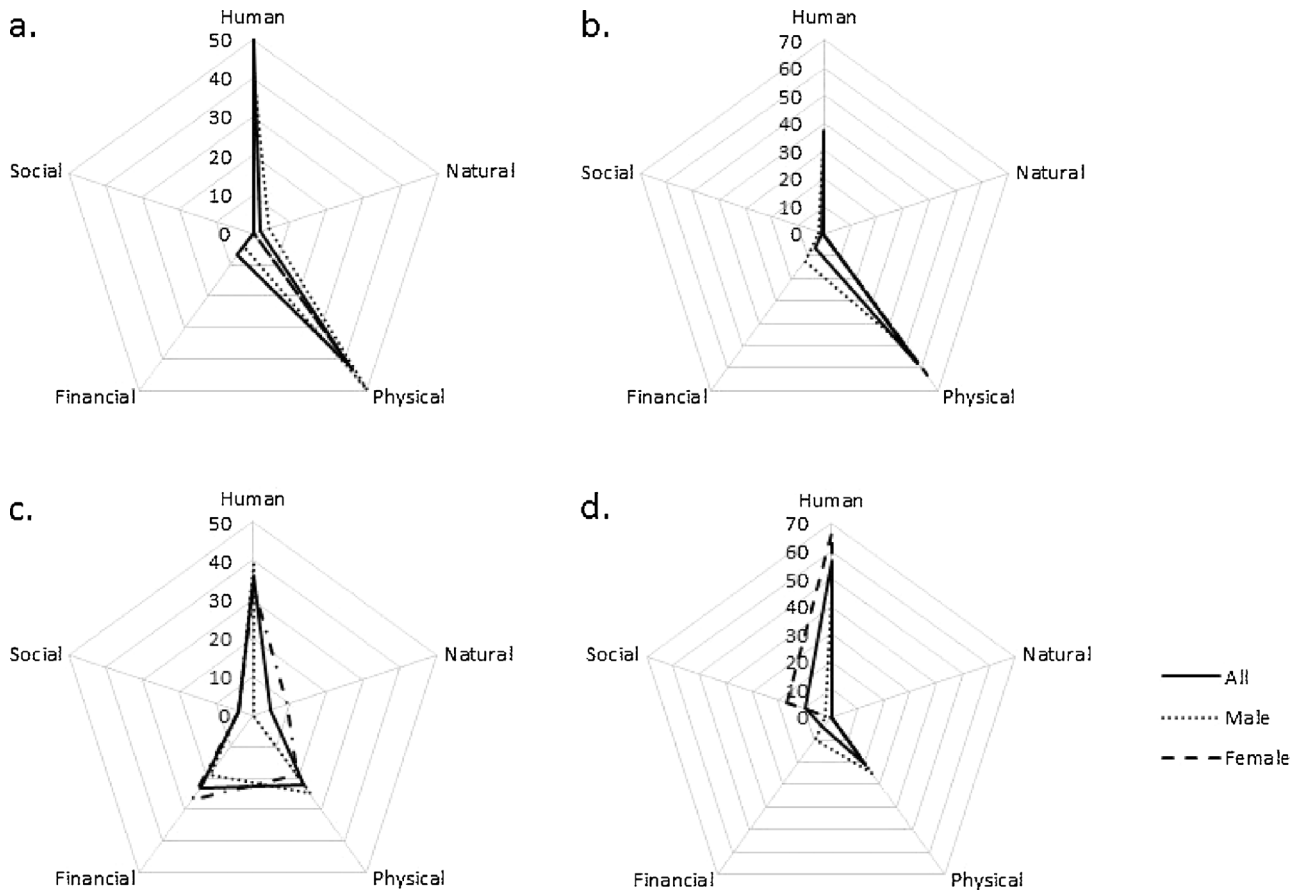

Fig. 3. Weighted assets identified by communities as most important for sustaining livelihoods grouped and averaged by region and gender for (a) Cachar (b) North Bank (c) South Bank and (d) Upper Assam.

hampers root development (resulting in reduced drought tolerance of plants) and increased soil erosion. Increased crop stress from changes in rainfall and temperature conditions was noted to result in poor and late recovery of tea leaf development following the pruning of sections, affecting harvest quality and timing.

Many tea workers also identified vulnerability issues which are threatening their ability to adequately sustain their livelihoods. These were not exclusively climate stresses (e.g. reduced rainfall and soil moisture; increase in occurrence of drought), but also associated increases in pest attacks to both crops (e.g. looper; trampling or consumption by wildlife) and human security (e.g. wildlife attacks on population), an increase in the prevalence of plant disease, and a biodiversity threat from deforestation.

6.2. Livelihood assets

Multiple assets were stated by tea workers as being important to sustaining their livelihoods within the tea landscape (see Fig. 3 in Biggs et al., submitted). All regions identified human and physical assets as important for supporting livelihoods, with the five most important factors also primarily falling into these categories (Figs. 3 and 4). Most factors raised relating to human capital reflected the quality of education, health facilities, sanitation, nutrition levels from rations, work pressure and job security. Physical factors primarily attributed importance to access to [safe] drinking water, housing facilities, road and irrigation infrastructure, access to energy supplies (electricity, firewood and kerosene), landscape adequacy of management practices within the

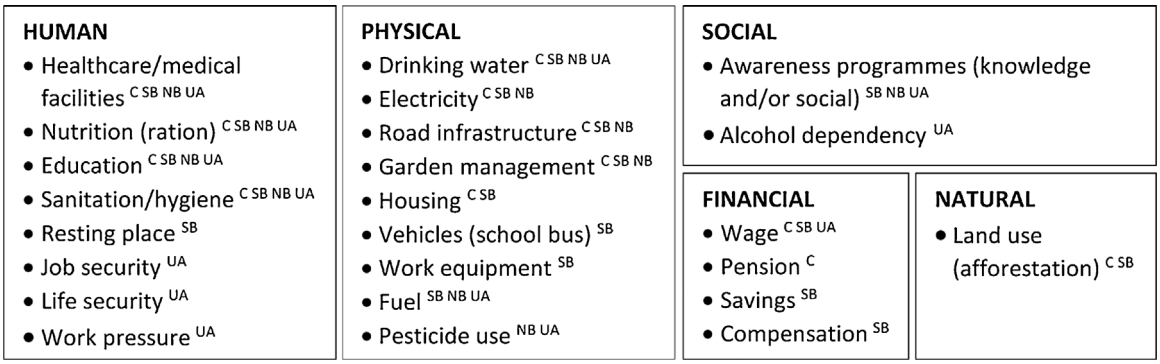

Fig. 4. The five factors across the four tea growing regions as identified from tea workers in all focus group sessions as being the most important to impact either positively or negatively upon their livelihoods (C = Cachar, SB = South Bank, NB = North Bank, UA = Upper Assam).

gardens and worker clothing provisions. Financial assets were also raised as important but at a lower frequency, and included factors such as adequacy of wages (particularly for allowing savings to accrue), access to pension, monetary investment in garden development, bonuses and [often limited] alternative sources of income to support livelihoods.

The lowest number of factors reported by workers in the tea gardens were classed under social and natural capital. A few gardens mentioned brotherhood as an important social support factor, and others reported issues of personal identity crisis (e.g. intergenerational status from ancestors has not been retained), accessibility to job opportunities through social networks and issues of poor governance (which includes mismanagement, insufficient respect regarding any worker complaints, and cases of corruption). Many gardens indicated that an increase in alcohol dependency has led to social disruption. Some gardens highlighted that opportunities for social recreation and clubs have become more common which has increased community wellbeing; others stated that such opportunities would be desirable but currently none exist. Natural capital assets had minimal mention across all regions with only a few factors raised as important for supporting livelihoods. These included land use (competition from other agricultural sectors, afforestation schemes and intercropping), the quantity of tea planted, soil quality and land availability for livestock. No tea workers from the gardens visited in Upper Assam raised any issues of natural capital affecting their livelihoods, neither positively or negatively.

With regards to the livelihoods of smallholders, all regions reported some form of diversified incomes, with fisheries most common in Cachar and dairy/orchard more common in the other three regions (see Fig. 2 in Biggs et al., submitted). Many smallholders noted other income activities with “business” identified across all regions. Other activities included cultivation of additional crops (betel nuts/leaves, agaru, rice, pulses and vegetables), alternative employment (daily labour, teaching and insurance) and livestock farming. Rice cultivation was a common alternative strategy in North Bank. If tea production in smallholdings should fail from climate-induced shocks, then it seems that a variety of additional assets are available to some smallholders. However, North Bank has the lowest diversity of assets and multiple smallholders specifically stated that they have no alternative should tea crops fail. Conversely, in Cachar, some smallholders optimistically noted that there will be “no tea crop failure”. Other assets which were stated generally reflected engagement in alternative income-generating activities with a reliance on businesses and alternative crop cultivation. Approximately a quarter to a third of smallholders within each region stated they undertook other agricultural activities with the most common activities being fisheries across all regions (except Upper Assam), rubber plantations in Cachar and spices and orchards in South Bank and Upper Assam. Such alternative activities are important within the tea landscape of Assam as tea cropping is under increasing external pressures.

6.3. Landscape structures and processes

6.3.1. Production characteristics

Most commercial tea plantations within the four major tea growing regions are well-established with average time since establishment exceeding a century (see Table 1 in Biggs et al., submitted). However, within these landscapes, characteristics varied regionally with higher average land area under tea production in South Bank and Upper Assam, with 96–98% of all land owned or leased by the plantation producers under tea cropping in these two regions. The most common annual average yield for plantations was reported at 1500–2000 kg ha^{-1} in all regions except Cachar where production was less (< 1500 kg ha^{-1}). All regions were growing the Assam tea variety (*Camellia sinensis* var. *assamica*), with a high proportion of plantations also growing the Cambod variety (*Camellia sinensis* var. *parviflora*) in Cachar. Approximately half of the plantations had Cambod tea planted in North Bank and South Bank, with the latter also growing a similar proportion of China tea variety (*Camellia sinensis* var. *sinensis*). In terms of cropping diversity the greatest crop variation in North Bank could indicate greater resilience to potential adverse climate and crop conditions (e.g. disease or pest attacks), whilst Upper Assam lacks heterogeneity in varieties planted so could be more vulnerable (Lin, 2011). Compared to the commercial plantations, smallholdings have generally been established more recently with a maximum age of 28 years (see Table 2 in Biggs et al., submitted). Of these smallholders, most report either a static area under tea cultivation or an increase since they began production. Cachar and North Bank smallholders had a large proportion reporting increased yields. This may correspond to the higher reported levels of irrigation and cooperative membership in these regions compared to South Bank and Upper Assam; both are strategies which can increase climate resilience for smallholders within the tea landscape.

6.3.2. Land conditioning

Fertilisers were used within commercial plantations to maximise yields. Nearly all plantations used high amounts of inorganic fertiliser, yet many were also using organic fertiliser, mainly from plant and/or animal waste, and/or VermiCompost/Wash. Managers were asked to select the category range of chemical compound relative to their application within their estate, and these responses were compared against the advised TRA industry recommendations (see Table A1). In general, fertiliser was being applied as recommended or below advised standards. Nearly all smallholders reported use of inorganic fertilisers with only 5 out of the 163 smallholders having any form of growing certification status. Certification within regions was fairly low in terms of proportion of commercial plantations certified with organic or Fairtrade classifications. However, ISO (International Organization for Standardization) certified plantations were more common with all estates in Upper Assam stating they were certified (this is discussed further in Section 7.2). In terms of smallholder land management practices for increasing production – particularly from the impacts of adverse climate conditions – shade tree planting and fertiliser access were stated as the most common methods, with water storage and drainage channels more commonly used in Cachar and South Bank (see Fig. 2 in Biggs et al., submitted).

6.3.3. Social provisioning

Provisioning for tea workers onsite within the plantations indicated varying levels of healthcare and education facilities (see Fig. 4 in Biggs et al., submitted). Multi-level healthcare[3] was most common amongst tea estates in North Bank. Conversely, healthcare was limited to primary provisions in Upper Assam with no immunisation programmes, which may reflect the high level of human capital ranked as important by tea workers in this region (Fig. 2). Primary-level education provisions were fairly high across all tea plantations. Adult education (night schooling) was stated as present in every tea region except Cachar. Social awareness programmes offered to the tea workers provided a variety of schemes offered across gardens within the region (Table 1). The most common programme types related to human capital (e.g. healthcare, hygiene, sanitation), with some reflecting building social and natural (environmental) capital. Social grievance forums, should workers wish to voice their opinion about problems with working conditions, were more common in North Bank, South Bank and Upper Assam (86%, 72% and 67%, respectively), with only 38% of estates stating they provided such forums in Cachar.

[3] Healthcare levels refer to the levels of specialism offered for treatment: primary equates to general practice, secondary to minor surgery, and tertiary to major surgery. The national immunisation programme provides vaccination against multiple preventable diseases.

Table 1
Social awareness programmes offered across commercial tea plantations by region.

	Cachar	North Bank	South Bank	Upper Assam
Health, sanitation and hygiene	✓	✓	✓	✓
Family planning	✓	✓	✓	
Disease awareness (malaria, TB, fever, HIVAIDS)	✓		✓	
Maternal group	✓	✓	✓	✓
Youth group	✓			
Financial awareness (savings)	✓	✓	✓	
Alcohol awareness	✓	✓	✓	✓
Waste disposal		✓	✓	
Environmental conservation		✓	✓	✓
Child trafficking		✓		✓
Safety (personal)		✓		
Sexual harrassment		✓	✓	✓
Child labour and arranged marriage			✓	
Water management			✓	✓
Women's rights			✓	
Disability group			✓	
Noise pollution				✓
Education rights		✓	✓	✓

Table 2
Smallholder suggestions for responding to climate change.

	Cachar	North Bank	South Bank	Upper Assam
Water conservation and storage through rain water harvesting using ponds	✓	✓	✓	✓
Irrigation of crops using water from rain storage, dams, bore holes, tube wells or water pumps	✓	✓	✓	✓
Prevent deforestation and encourage afforestation to provide shade and restore/conserve landscape	✓	✓	✓	✓
Reduce air pollution from industries such as controlling emissions from factories	✓	✓	✓	
Need for climate change awareness programmes and/or scientific advice and techniques		✓	✓	✓
Tighter control on pesticide and inorganic fertiliser use (encourage use of bio -fertilisers) and more timely applications of fertilisers	✓	✓	✓	✓
Reduce soil pollution and ensure conservation	✓	✓		
Adequate drainage within tea gardens		✓		
Mulching to conserve soil moisture	✓			
Introduction of climate -resilient clones			✓	

6.4. Livelihood outcomes

To build climate resilience and environmental sustainability multiple strategies were noted by tea producers in the region to be conducive to supporting favourable tea landscape livelihood outcomes. Plantation managers are aware that water conservation is important under a changing climate and as such take measured efforts to store and conserve water, particularly given the temporal heterogeneity of water provisions (driven by monsoon recharge) in Assam. Water within commercial plantations is primarily sourced from rainfall, rivers or ponds in Cachar with one estate using borehole water. In North Bank and South Bank there was a predominant mix of water sourced from boreholes, rainfall and rivers. In Upper Assam reliance was on rainfall or borehole water. Proportions of plantations using irrigation in Cachar (100%), North Bank (86%) and South Bank (78%) were quite high, all reporting a use of sprinkler systems (no drip irrigation). In Upper Assam only one garden stated they had irrigation infrastructure (sprinkler) in place. The most common water conservation methods reported by plantation managers were check dams and ponds in Cachar, North Bank and South Bank. In Cachar one manager also stated they use rainwater harvesting. One estate in North Bank had a water recharge project, and in South Bank, three gardens are using rainwater harvesting. Strategies were limited in Upper Assam with only ponds stated. Soil conservation was high in all regions with 82–100% of plantations engaged in rehabilitation activities across the four regions. To conserve soil characteristics the most common practices across all regions were mulching (greatest proportion of gardens in all regions), contour drains and planting, proper shade, infilling bare ground, and afforestation (the latter to a lesser extent in Cachar).

Smallholders stated multiple options for adapting to climate impacts

(Table 2). All of these observations were also made by plantation managers across the regions, with additional suggestions to move tea production in Assam towards climate-smart and sustainable agricultural practices, with a need for increased multi-stakeholder knowledge and awareness to make more informed decisions for long-term adaptation planning.

7. A sustainable tea landscape under climate change

The results from this research present detailed socio-environmental insights important for managing the tea landscape of Assam, highlighting the value of the tea to sustaining livelihoods and local knowledge of climate change on production, which have not previously been collated to such a detailed extent. Key recommendations emerge from the data which can provide potential avenues for enhancing tea landscape socio-environmental sustainability under the uncertainty of climate change, for all stakeholder groups producing tea within northeast India.

7.1. Environmental sustainability

Advisory bodies such as the TRA who provide guidance on best practice are operationally very important for the region. However, only member gardens have access to this information and more effort could be made to engage the wider tea growing community in best practice. This is particularly important to address issues of mal-management and mal-adaptation by smallholders who have lower environmental awareness due to reduced access to knowledge. To emphasise this point, 95% of smallholders across all four regions indicated that they would likely follow the TRA advised management practices in view of changing climate, which demonstrates the leverage that this institution can have on good decision-making. Recently some steps have been made to provide open access information to help growers mitigate for potential yield impacts of a changing climate. For example, a basic web spatial climate advisory tool (TeaCAT[4]) was developed in collaboration between TRA and the University of Southampton to disseminate research findings to farmers. This research adopted the concepts of climate-smart agriculture (CSA), which has been effectively used to improve food security and rural livelihoods, increase agricultural productivity, facilitate climate change adaptation and provide mitigation benefits, for other crops worldwide (Scherr et al., 2012). Within tea landscapes CSA could enable an increase of productivity by altering management practices such as integrated pest management, vulnerability mapping, introducing land and water conservation technologies and providing adaptation options or introducing new techniques of tea plantation management which are suitable for the changing climate scenario of northeast India. For example, landscape resilience could be enhanced through intercropping (e.g. ensuring crop diversity and shade trees for tea), natural control measures for pests and diseases, organic farming methods, and mulching for better water management (i.e. reduces soil temperature, conserves moisture and controls runoff).

For the commercial plantations which have access to a technical workforce there is scope to utilise climate information collected onsite more effectively to help monitor changes in key temperature and precipitation variables. Approximately two thirds of all plantation managers stated they have meteorological stations on their estates, and of these the most common variables being recorded were rainfall (96%) and temperature (49% maximum temperature, 49% minimum temperature, and 44% unspecified or ambient temperature). Other variables included relative humidity (15% of estates) and 1–2 estates stating they record sunshine hours, wind velocity and direction, and/or soil moisture. Further investigations could be undertaken to ascertain the frequency and quality of observations to better understand if these data would be of use in deciphering changes in local climate conditions to use for evidence-based spatially adaptable climate-smart solutions.

7.2. Social sustainability

Many social issues were raised by tea workers (as evidenced by the importance placed on human, physical (accessibility) and social capital – Figs. 3 and 4), with many social schemes in place across select plantations (Table 1). As commercial estates are struggling to finance their production cost-effectively, broader measures need to be considered to help support the tea industry sector to ensure long-term sustainability of both the environment and stakeholder's livelihoods. This is difficult within the organised sector as top-down governance plays a strong regulatory role. However, social enterprise schemes are present within some commercial plantations, and these can greatly enhance quality of life for workers through increased financial and social capital. One example suggested in research by Makita (2012) is that wage-fixed workers could benefit through Fairtrade certification as such practices require improved standard for social and environmental working conditions, as well as providing premiums which can be used for enhancing the livelihoods of worker communities. Maintaining adequate social provisioning will be critical under projections for increased temperatures, as operational working conditions within agriculture are likely to be adversely affected through heat-related stresses e.g. impact on worker health. Tea is a labour-intensive crop, and Burgess et al. (2014) found that one standard deviation of increase in days with high temperatures annually in India leads to a decrease in yield of (all) crops by approximately 13% and wages by 10% (due to work non-attendance on high temperature days), and an increase in mortality in rural populations by 7%.

Community-based adaptation measures are important to reduce climate change vulnerability and improve the adaptive capacity of tea worker households and communities through sectoral institutional support for long-term socio-environmental sustainability e.g. managing water supplies, income generation and landscape conservation. Capitalising on indigenous technical knowledge and the retention of traditional cultivation practices could greatly help counteract climate shocks alongside the use of novel technologies (Huq and Reid, 2007). To promote sustainable tea landscapes, Forum for the Future have suggested that market mechanisms for a more robust value chain are a necessity.[5] For smallholders, steps could be pursued to increase trading leverage within the industry. For example, Lines (2006 stated that "a well organised smallholder sector could make use of India's industrial expertise to process, package and market tea for export sales rather than relying on transnational corporation brands [to undertake this processing]". Cutting out middle processing stages (i.e. smallholders selling their produce to estate factories) could greatly enhance value attained for crops to smallholdings. India's government regulating force on tea markets prices means that the international community within the tea value chain have a strong role to play in reforming livelihoods of growers, particularly given the regional pressures facing stakeholders from climate change. The Tea2030[5] initiative is making some effort towards achieving these longer-term sustainable livelihoods goals, with some focus on climate resilience, but more needs to be achieved in Assam.

8. Conclusion

This paper has presented multi-stakeholder insights into tea production practices of the four major tea growing regions in Assam. These insights provide indicative evidence as to how growers (both plantation managers and smallholders) are attempting to sustain production of one of India's most valuable commodities. Within these regions this

[4] http://www.teacat.in/.

[5] https://www.forumforthefuture.org/project/tea-2030/overview.

research has also highlighted the impacts that climate change may be having on production through local multi-stakeholder knowledge, and the effects this is having on livelihoods. The evidence we present in the paper should be used to help make more informed future strategies regarding best practice for landscape management under a changing climate, and directing policy assistance for enhancing sustainable livelihoods within northeast India. A coordinated landscape-scale approach whereby multiple actors within the tea sector can work together to facilitate climate-smart mitigation and adaptation measures will be essential to ensure the long-term sustainability of Assamese tea production. We advocate for our findings to be used alongside other research, such as the International Trade Centre's (2014) suggested climate change indicators for assessing impacts on tea crop production, and local land management guidance (e.g. Goswami, 2011), to develop climate-smart landscape approaches for socio-environmental sustainability of Assam's tea landscape.

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Appendix A

Table A1
Application of fertilisers by the commercial plantations; a summary of inorganic compounds used by region compared to the advised recommendation standards issued by the Tea Research Association (further detail on when fertilisers are applied can be seen in Fig. 1 of Biggs et al., submitted).

Fertiliser application	*Industry recommendations*	Cachar	North Bank	South Bank	Upper Assam
Time of year fertilisers are applied	*Application during months of March-April and August–September*	Generally as advised (plus extra application(s) later in year)	As advised or later (plus extra application(s) later in year)	As advised or late (plus extra application(s) later in year)	Generally as advised or late (plus extra application(s) later in year)
Nitrogen (kg/ha)	*140–165*	Generally less	Generally less	Generally less	Generally less
Phosphate (ka/ha)	*20–50*	As advised or more	As advised	As advised	As advised
Potassium (kg/ha)	*140–165*	Generally less	Generally less	Less	Less
YTD mixture ratio for young tea	*10:5:10 to 10:5:15*	As advised	As advised	As advised	As advised
Frequency of YTD mixture	*6–8 wks*	Generally as advised or less frequent	Generally as advised	Generally as advised or more frequent	Generally as advised
Sulphur (kg/ha)	*20–40*	As advised or less	As advised or less	Generally as advised or less	As advised or less
Zinc sulphate (kg/ha)	*12–13*	Generally less	Less	Generally less	Less
Magnesium sulphate (% concentration)	*1–2 (if soil pH suitable)*	Generally as advised or more	As advised	As advised or more	As advised or more
Dolomite for low soil pH (tonnes/ha)	*2*	As advised	Generally as advised	Generally as advised	As advised
Time of year dolomite applied	*Winter*	As advised	As advised	As advised	Generally as advised

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