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Migration as a human affair: Integrating individual stress thresholds into quantitative models of climate migration

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ABSTRACT

Sea level rise will expose millions of people to increasing coastal hazards and eventual land loss. Thus, it is important to understand how residents will make decisions about whether and when to move away with increasing exposure. Historically, non-material dimensions of human decision-making have been missing from quantitative modelling of migration under environmental change. Here, we use behavioural migration theory and the concept of an inherent mobility potential to define individual stress thresholds, represented in the tension between mobility potential and residential satisfaction. We further suggest that migration as an outcome is determined by psychological propensity to move, and that levels of capital act to modulate, rather than determine, migration responses, their timing and outcome. Using the southwest coast of Bangladesh as our case study, we quantify these characteristics using the results of a 1500 household social survey and define an exposure index based on projections of sea surface height drawn from a physical model. Aggregating data to the village level, we are able to identify place-specific mobility responses; for example, locations where high mobility characteristics are associated with high exposure and thus migration may occur earlier in response to increasing coastal hazard. By advancing theory on individual thresholds and demonstrating that complex human characteristics can be usefully quantified, we further the ability of such characteristics to be included in modelling approaches. The empirical results contribute to debates on immobility under climate change, and decision-making on the most appropriate adaptive responses to protect multi-dimensional well-being of climate-vulnerable people.

1. Introduction

Sea level rise will expose millions of people to increasing coastal hazards and eventual land loss, with coastal populations growing and many valuable man-made and ecological resources centred on these regions (Martínez et al., 2007; Neumann et al., 2015). Yet, while sea level rise is incremental, we have an incomplete understanding of how coastal populations will evolve under such increasing climate stress. Our best proxies are responses to cyclonic storms and hurricanes (e.g. Paul and Routray, 2011) and to coastal erosion (e.g. Haque and Zaman, 1989; Mortreux et al., 2018). Alternatively, we rely on conceptual models that elaborate links between sea level rise and migration through drivers of migration that may be direct (e.g. risk to life from coastal flooding) or indirect (e.g. fewer work opportunities; Perch-Nielsen et al., 2008).

Increasingly, modelling approaches are used, combining exposure indices with demographic data to project migration from a coastal region (e.g. Hauer, 2017; Rigaud et al., 2018). Modelling approaches respond to a need to scale our understanding to the national or global, but in doing so can over-simplify human behaviour under change. Thus, understanding mobility responses in the period between increased exposure to coastal risk and complete inundation, at scale, requires integrating the knowledge of human responses to hazard exposure from isolated case studies into modelling approaches. Here we turn to theory on individual thresholds to fill this gap.

Individual thresholds are the building blocks of wider migration flows and thus are crucial to understand the ways in which the magnitude, direction and characteristics (e.g. changes in who migrates, the frequency of migration journeys, destination, distance and motivations) of migration may change as climate impacts intensify (Klabunde and Willekens, 2016; McLeman, 2018a, b). Knowing how depopulation may occur, for example in terms of source regions, demographic groups and timing, is useful for urban areas that receive migrants, especially cities that may already be suffering from a deficit in municipal service

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provision and rapid growth of informal settlements (Hauer, 2017; McLeman, 2018a, 2018b). Understanding thresholds is also valuable when planning appropriate interventions to protect the well-being of people at risk in sending areas, particularly in terms of understanding where eventual planned relocation may be the most appropriate response (e.g. Bronen and Chapin, 2013; Hino et al., 2017). Understanding thresholds, and who may migrate first, is important also for understanding how outmigration may change the demographics of the sending area and provide time to mitigate against migration as a maladaptive response (Jacobson et al., 2018).

Environment-migration authors have addressed thresholds in various ways. At the system level, for example, authors have identified the potential for non-linear changes in observed migration flows due to climate change (Bardsley and Hugo, 2010), or showed that changes in the nature of migration due to climate change can mean a threshold is crossed between different system states. For example, Wrathall (2012) showed that migration and remittances became an established part of the community economy in a coastal village when used as a coping strategy after flooding (Wrathall, 2012). Others have focused on the threshold effects of temperature and precipitation on the likelihood of outmigration, especially in agriculture-dependent areas, as limits to adaptation are met (Nawrotzki et al., 2017). McLeman (2018a, b) defines various conceptual thresholds. Some relate to the point at which adaptation becomes necessary and eventually fails (following Adger et al., 2009). Other thresholds relate to changes in the nature of migration as flows change from incremental to non-linear. This can be due to large-scale out-migration inducing more migration due to positive feedbacks or changes in community dynamics where the loss of keystone individuals and institutions means places lose viability McLeman (2018a).

Here we use a behavioural framework to research individual migration thresholds to climate stress. Thresholds are key to behavioural theories; the migration decision-making process is initiated by a change in circumstances that means a person experiences residential dissatisfaction (i.e. stress), and their association with place, in balance, moves from positive to negative (e.g. Brown and Moore, 1970). These theories are pertinent because they allow us to explore the psychological barriers that lead to people staying in place despite environmental stress, for example due to emotional bonds to place or perceptions of low self-efficacy (Grothmann and Patt, 2005; Martin et al., 2014). Adaptation may have taken place and failed (as in McLeman's categorisation above) or not been carried out despite capacity to do so because of these psychological barriers (discussed below). A key dimension of these theories is that of mobility potential. This term represents the concept that some people are naturally less mobile than others. This means that the attraction of the outside world is lower, or their fear of it is higher, and as such, mobility as a response to climate (or any stressor) is more psychologically demanding (Morrison, 1973). Here we operationalise mobility potential through the concepts of place attachment and rootedness. Dissatisfaction with place induced by environmental change thus exists in tension with bonds to the location that make migration an undesirable option.

Our approach is quantitative. Using coastal Bangladesh as our case study, we extract data from a seasonal 1500-household survey to generate a mobility index for households living in five coastal villages on the highly-exposed southwest coast. We compare these mobility characteristics with changing exposure to coastal hazard associated with climate change up to 2100, while also taking into account levels of adaptive capacity. In doing so we advance theory on individual mobility thresholds using ideas from place attachment and subjective well-being, define a hypothetical sequence of migration away from the coast in the context of variable adaptive capacity; and highlight the potential relative timing of migration as an adaptive response to increasing coastal hazard between these coastal villages.

In the following section we justify the quantitative approach taken in this paper, discuss some of the qualitative literature around place attachment in threatened coastal locations, which informs our characterisation of mobility potential, and introduce Bangladesh as our case study. In Section 3 we present the conceptual framework which links mobility potential, adaptive capacity and exposure to hazards associated with sea level rise. In the methods (Section 4) we describe the social survey, variable creation, and generation of coastal flooding projections.

The rest of the paper presents our analysis, which has four components. First, we calculate future exposure to coastal hazards under climate change and sea level rise to 2100. We show that there are differences in expected levels of exposure and increases in exposure over time across relatively small sections of coast. Second, we examine mobility potential and adaptive capacity by village and season and show that there are significant differences between villages in mobility potential and adaptive capacity, and differences within villages between the hot summer, rainy monsoon and cool dry season. Third, we combine these indices and map villages by their mobility potential, adaptive capacity and exposure. In doing so we identify villages where high mobility is accompanied by high exposure, and as such where migration may be used as an adaptation strategy earlier. Finally, we map our results back onto the conceptual framework and argue for spatially-differentiated interventions based on the mobility, adaptation and exposure characteristics of the village. We conclude by arguing for the closer integration of individual mobility thresholds into adaptation analyses, and for the increased incorporation of the wider human experience into quantitative models.

2. Background

2.1. Integrating complex processes of human decision-making into quantitative models of climate migration

Climate is increasingly implicated as a driver of migration. As such there is a burgeoning effort to understand the ways in which climate may interact with economic, social and cultural drivers of migration. Climate and environmental data are quantitative, thus quantitative approaches to understanding human responses lend themselves to understanding climate migration, for example, demographic analyses (Fussell et al., 2014). This means that analyses are driven, to some degree, by the availability of quantitative data. Thus, economic drivers of migration dominate, usually through impacts on livelihoods, and patterns of migration are predicted through simplistic relationships such as gravity models, where levels of migration are a function of the size of the settlement and the distance between settlements (Rigaud et al., 2018).

While these dimensions are important in explaining, and going some way to predicting, migration, they are only half the story. Migration is a particularly human affair, and while humans act in a rational way, their primary motivation is not always to maximise economic benefit. Human mobility (and lack of mobility) is driven by many cultural, psycho-social and emotional factors that can present little external logic and seem to defy generalisation. However, these non-material drivers of migration are crucial to wider human well-being that extends beyond meeting material needs to a range of conditions that contribute to life satisfaction, such as good social relations, feelings of security, and an ability to self-actualise. The drivers of this multi-dimensional well-being are necessarily diverse and often specific to the individual or culture (Camfield and Esposito, 2014). However, if they are omitted from models, they are omitted from consideration in decision-making processes. Thus, the solutions generated are at risk of repeating the mistakes of other, often unsuccessful, programmes to resettle populations or 'manage' migration based on material well-being (e.g. Cernea and McDowell, 2000).

Agent-based models (ABMs; e.g. Hassani-Mahmooei and Parris, 2012; Smith, 2014) are an important way of bridging this gap and incorporating complex human behaviour into analyses of climate migration (Thober et al., 2018). However, an ABM is only as good as the assumptions that drive it (Klabunde and Willekens, 2016). In a recent review, Thober et al. (2018) found that ABMs have used characteristics such as social networks, income, behaviour of neighbours, past migration experience and gender to drive agent behaviour (Thober et al., 2018). In their review of ABMs for explaining and predicting migration, Klabunde and Willekens (2016) identify two main groups of decision theories used: microeconomic models where human behaviour is driven by maximising utility between different options and psycho-social and cognitive models – the latter dominated by the Theory of Planned Behaviour (Ajzen, 1991). Migration outcomes are defined by the way in which migrant expectations are formed, and how alternatives are evaluated (Klabunde and Willekens, 2016). Mobility potential is a characteristic of the agent that influences both these processes.

Thus, in this paper we forward the incorporation of non-material dimensions of decision-making into quantitative modelling assessments, by showing how behavioural migration theories are able to work as decision theories in models, and how readily available data can be used for model estimation and validation. We do so by testing the ability of simple proxies to represent psycho-social and cultural dimensions of migration decision-making, using readily available data, in areas vulnerable to climate change.

2.2. Migration decision-making and place attachment as a mediator of risk perception and action

In this paper, we focus on the environmental stressors associated with sea level rise: increased exposure to storm surges, salinization and erosion that will threaten coastal lives and livelihoods (e.g Chen et al., 2012; Hinkel et al., 2013). Coastal areas have highly dense populations, include many of the world's large cities, and are sites of in-migration (Neumann et al., 2015).

Coastal protection will likely be favoured in coastal cities, even though costly, due to the high economic value and concentrated nature of the activities there (Hallegatte et al., 2013). Decisions regarding protection of rural locations are more difficult; land is of low value, protection would be required over an extensive area and geographical and political marginalisation prevents populations from advocating for protection. There are some exceptions. For example, managed retreat may be a possibility depending on the ability of affected populations to lobby for such action and the presence or absence of governance structures in place to support it (Bronen and Chapin, 2013). Furthermore, this managed retreat would have well-being implications for the populations being moved, depending on who makes decisions over the relocation (Hino et al., 2017). Thus, gradual migration of residents away from areas increasingly exposed to coastal hazards may dominate as an adaptation strategy (Black et al., 2011; Hauer et al., 2016).

Research that focuses on processes of migration decision-making, place attachment, risk perception and subjective well-being has been working to understand the lived experience of exposure to sea level rise and the reactions of coastal communities to threats to their way of life and livelihoods. A rich literature examines the role of attachment to place in mediating between risk, risk perception and action on climate risk. For example, place attachment influences levels of risk perception in exposed coastal locations. Quinn et al. (2018) show that attitudes to various adaptations on the coast vary with the strength of attachment and the kinds of meanings that residents associate with place. They also show that mobility, and the demographic changes that mobility generates, alter people's attachment to place (Ibid). Others have shown that high levels of place attachment lead to residents not acting against coastal risks, despite high levels of perception of those risks (De Dominicis et al., 2015). This research stresses the importance of emotional bonds to place in driving behaviour and the reluctance of populations to leave despite risks. Graham et al. (2014) highlight the importance of understanding the dimensions of coastal lives under threat from sea level rise in order that interventions are sensitive to different drivers of place-based well-being.

2.3. Increasing coastal risks in Bangladesh

Bangladesh has a long history of coastal flooding, from devastating storm surge events caused by tropical cyclones to regular small-scale floods. Sea level rise will lead to higher maximum sea water levels and more frequent flooding events of a given height, with the potential for great disruption to local communities (Karim and Mimura, 2008). Rising mean sea level has already been observed at monitoring stations in the North Indian Ocean (Unnikrishnan and Shankar, 2007) and projections by the Intergovernmental Panel on Climate Change suggest a further rise of 0.3-0.6 m or more by the end of this century (Church et al., 2013). Subsidence is likely to further increase the local sea level (Brown and Nicholls, 2015). These physical impacts are occurring in a region of high population density and extreme poverty.

Bangladesh offers an early warning of impacts that may soon affect other regions. Researchers have tried to understand the impact of degradation of the coastal environment on migration patterns. Riverbank erosion is a well-known driver of displacement in Bangladesh (Haque and Zaman, 1989). More recent studies have looked at the impacts of flooding versus drought-inflicted crop failure. Flooding was found to influence migration across Bangladesh. However, while migration was 'modestly affected' by flooding there was more of an effect from crop failure due to a lack of precipitation (Gray and Mueller, 2012). Lu et al. (2016) found that migration on the south coast during Cyclone Mahasan in 2013 followed usual seasonal patterns, rather than there being any direct response to exposure to the cyclone hazard. Thus, environmental factors interact with mobility through livelihoods and exposure to hazard, but without simple, direct relationships.

3. Conceptualising individual stress thresholds

3.1. Mobility: the interplay between dissatisfaction in place, and a disinclination to move

Migration is a universal coping strategy for people and households at all wealth levels. Migration can lead to increases in well-being when used as a strategy in response to degrading conditions (Nowok et al., 2013) but can also serve to undermine households if the conditions of migration are exploitative and decisions are taken under conditions of distress (Warner and Afifi, 2014; Jacobson et al., 2018). Thus, migration can both increase resilience of those affected by climate change (Black et al., 2011) and reproduce conditions of precarity (Felli, 2013).

Here, based on behavioural migration theory, we focus on mobility potential to better address the ambiguous relationship between migration and well-being into work on migration and environmental change. Mobility potential relates to how easy it is for people to move; some people are 'easily movable' while others are 'virtually immobile' (Morrison, 1973). The level of residential dissatisfaction (dissatisfaction with place; or stress) that an individual tolerates before initiating the migration decision-making process is inversely related to this characteristic (Brown and Moore, 1970; Speare, 1974). This assertion allows us to begin to investigate relative thresholds to environmental risks: the higher the emotional cost of migration, the more residential dissatisfaction a person is likely to tolerate before migrating.

Fig. 1 describes these characteristics in terms of proximity to a hypothetical, individual threshold. If someone is dissatisfied with where they live already they are closer to a migration threshold than someone who is completely satisfied with their location. Someone who is satisfied with location first must experience dissatisfaction generated by climate change impacts. Likewise, someone who is more inclined towards migration in general is closer to moving than someone who finds the idea of moving psychologically stressful.

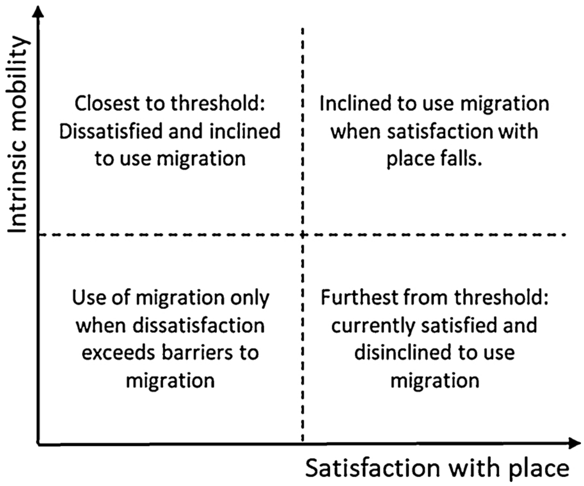

Fig. 1. Likelihood of using migration as an adaptation to environmental change based on initial levels of satisfaction with place (x-axis), and intrinsic mobility potential (y-axis). Those who are less mobile are further from their migration thresholds; conditions must worsen to induce them to overcome barriers to migration. Those with high initial levels of satisfaction are further from their threshold because they still have to experience dissatisfaction in place before action becomes necessary.

3.2. The role of adaptive capacity in modulating timing and outcome of mobility responses

Adaptive capacity can be defined as the potential to adjust to current or future climate and is related to levels of resources, psycho-social characteristics of the individual and institutional factors (Mortreux and Barnett, 2017). In the literature migration has generally been posited in contrast, or as an alternative, to adaptation; that is to say, one migrates when adaptation fails (McLeman and Smit, 2006; McLeman, 2018a). Others have promoted migration as an adaptation that allows individuals to act with agency (Black et al., 2011). Yet this conceptualisation of migration has been criticised for reinforcing conditions of vulnerability and precarity (Felli, 2013).

Here we conceptualise adaptation through the five capitals of the sustainable livelihoods approach: natural, financial, human, social and environmental (Scoones, 2018). This is an established way of measuring adaptative capacity (through the resources and capabilities available to the household) that, while not cutting edge and not without problems, can be represented through readily available data. One of the key problems with this definition of adaptation is that having the capital to adapt does not necessarily mean that adaptation will occur. Asset-rich households may not take adaptation action due to, for example, attachment to their dwelling, a false sense of security generated by material wealth and status, and other intervening social-psychological processes, such as risk perception, feelings of self-efficacy and trust in authorities (Mortreux and Barnett, 2017).

However, adaptive capacity represents an asset base that can be mobilised to protect well-being under change. Thus, it serves to define whether the migration that occurs as a response to environmental change builds or undermines well-being. The outcome of migration depends on resources available to a household, migrant agency, and local context for example, whether others have migrated. Households with high adaptive capacity have a choice as to whether to liquidate their capital to fund migration or to use their asset base to adapt to environmental change. We posit that this choice is made based on their mobility characteristics – their attachment to place and initial feelings of satisfaction with place before climate impacts altered where they lived.

Fig. 2 illustrates some of the ways in which mobility characteristics of the individual could interact with their adaptive capacity (levels of capital) to produce different timings and outcomes of migration. Curve 1 on Fig. 2 shows high mobility and high adaptive capacity households. Here the intervening obstacles to migration are small due to an asset base that can be liquidated and because of social capital in destination locations (McLeman et al., 2008). Furthermore, those with more assets can also be more risk averse (Halek and Eisenhauer, 2001) and thus may be inclined to move away from high risk areas early. Curve 2 on Fig. 2 shows low mobility and high adaptive capacity households. Capital-rich households can also show less propensity to migrate because of hesitancy to abandon assets and because alternative adaptive options are available such as access to credit and insurance (McLeman et al., 2008).

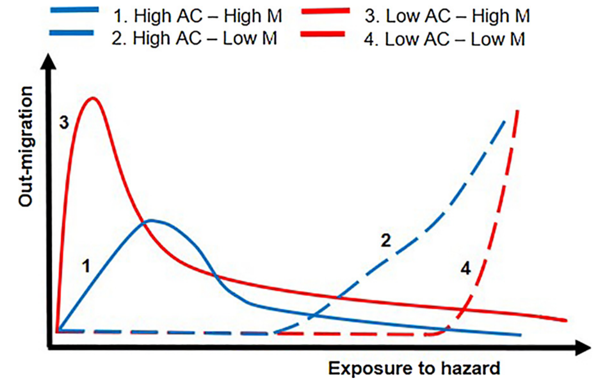

Fig. 2. Hypothetical sequence of out-migration under increased exposure to environmental hazard as stress thresholds are met.

Curve 3 on Fig. 2 shows low adaptive capacity individuals with high levels of mobility potential. Such people cannot buffer themselves and their households from environmental hazards, even under current climate variability, due to a lack of resources and capabilities. Thus, high mobility individuals may use migration as a coping strategy under relatively low levels of exposure because when assets are destroyed labour migration is the only option available to support the household (Deshingkar, 2017). Curve 4 on Fig. 2 shows households with low adaptive capacity and low mobility potential. These individuals may show some of the characteristics of trapped populations (Black et al., 2011): vulnerable to hazard, and lacking the resources, skills and desire to leave. Thus, this group may not migrate until risks are life-threatening or they are relocated with the assistance, or imposition, of an external institution (Adams, 2016).

4. Methodology

4.1. Field site

We focus on the southwest region of Bangladesh (Fig. 3). The study area is composed of nine districts, the three southernmost districts in Khulna Division (Satkhira, Bagerhat and Khulna) and all six districts of Barisal division (Pirojpur, Barisal, Jhalokati, Barguna, Patuakhali and Bhola). The total area of these districts is 18 850 km^2 with a total population of approximately 14 million (Lázár et al., 2015). The nine districts comprise 70 upazilas, themselves divided into 653 unions. In the field area, the average size of a union is 28 km^2 with an average population of 21 800 people (Ibid.). Prevalence of poverty according to the head count ratio of people below the lower poverty line (calculated using the cost of basic food requirements) is 26.7 percent and 15.4 percent for Barisal and Khulna Division respectively (Bangladesh Bureau of Statistics, 2011). In general, the region has negative population growth rates due to falling fertility rates and high levels of out-migration (Szabo et al., 2015).

The region is remote from the capital city Dhaka, with poor connectivity to markets, industry and other off-farm activities, and is

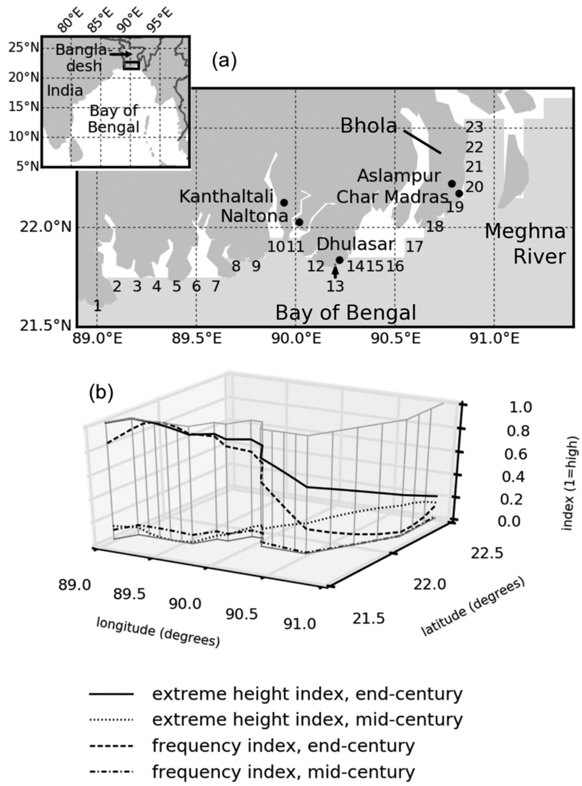

Fig. 3. (a) Overview of the study area. Numbers show the coastal cells of the physical model used to estimate sea levels; the named points are the centres of the 5 unions (administrative districts) where the study villages were located. **(b)** Comparison of the exposure to high sea water events on the delta coast. All quantities are normalised so that 1 represents the highest value found and 0 represents the lowest, and plotted for 23 points along the delta coast, shown in Fig. 3a.

subject to tropical cyclones. The recovery from cyclone Aila in 2009 is still ongoing in some places. Poverty varies across the region (Johnson et al., 2016) with poverty most prevalent to the west of the study area in saltwater shrimp areas and in the east of the study area on, or adjacent to, the island of Bhola. Villages are spread throughout this ecologically-diverse part of the delta (Adams et al., 2018) with the coastal villages examined in this study situated adjacent to the Sundarban mangrove forests, the coast of the Bay of Bengal and the banks of the Meghna River.

4.2. Household survey

We operationalise these ideas using household survey data (Adams et al., 2016) and projections of coastal sea levels (Kay et al., 2015) to create three indices: mobility potential, adaptive capacity and exposure.

We use data from a seasonal household livelihood survey carried out in the southwest and southcentral coastal regions of Bangladesh during 2013 and 2014 to build the adaptive capacity and mobility indices. The questionnaire collected information on a wide range of material and subjective measures of well-being and we defined the initial level of stratification using social-ecological system to take into account different human-environment interactions based on the ecosystem services available. This classification involved mapping the field area using satellite imagery and geographic information systems. Based on qualitative fieldwork seven different systems were identified within the field area – each with different bundles of ecosystem services and distinct access mechanisms and management systems (Raudsepp-Hearne et al., 2010; Adams et al., 2018). Four of these systems were defined based on dominant land use: irrigated agriculture, rain-fed agriculture, saltwater prawn production and freshwater shrimp production. Three systems were identified by their proximity to a particular environmental feature: Sundarban mangrove forests, the coast of the Bay of Bengal and the banks of the Meghna River. This analysis uses data from these last three social-ecological systems since they are proximate to the coast and exposed to coastal hazard. Adams et al. (2016) contains a full description of the sampling strategy with links to the full dataset, which is available as an open-source download, and accompanying documentation.

We extract data for administrative regions (unions) that bordered the Bay of Bengal. Thus, 377 households were sampled from 15 villages (mouzas), three from each of the five unions. Stratified random sampling ensured that villages were randomly selected in unions and households were randomly selected in villages. Fig. 3a shows the location of the Bangladesh delta area within the Bay of Bengal, and the location of the selected unions along the coast. The survey was carried out three times over a year to capture seasonal differences in poverty and access to natural resources. Thus, all analyses are repeated for each of the seasons in each of the 15 locations.

Our first survey took place during the monsoon period and the recall period incorporates the hot, humid summer period leading up to the monsoon rains. This recall period includes harvesting of crops grown through the cool winter season (cultivated from November to March) and those grown in the hot summer period (cultivated from March to June). The second survey took place in October and covers the monsoon. The third survey took place in February, when the climate is cool and dry, and the recall period includes the harvesting of crops grown during the rainy season (cultivated from June to November). The first survey period took place during June, so all recall periods span half-months (i.e. the first recall period spans mid-February to mid-June).

4.3. Creating the proxies

A single survey question was used as a proxy for each of the dimensions of mobility potential. We used a question on universal satisfaction with life, as a proxy for place utility. Household heads were asked: “On a scale from 1 to 10, how satisfied with your life are you at the moment?” Subjective well-being is a measure of how people cognitively assess their lives against their own objectives (OECD, 2013; p.10). There were no follow up questions regarding which dimensions of the person’s life were most important in generating satisfaction, so unfortunately the contribution of place to this assessment remains unknown. However, the question provides an indication of dissatisfaction and strength of existing push factors, and, thus, relative proximity to stress thresholds.

Intrinsic mobility potential was measured through a five-point Likert scale response to the question: “Your roots are here” by the household head. Thus, rooted is used as a proxy for intrinsic mobility potential (or lack thereof), with the scale reversed so that a higher score represents a higher likelihood of mobility. Rootedness is one of the strongest and most subconscious forms of emotional attachment to place and someone strongly rooted can lack interest in alternative ways of life or locations (Fried, 2000). The costs of breaking such emotional bonds, especially when there is an element of coercion or force, are always high (Fullilove, 2001). Place attachment and rootedness are measurable and quantifiable, usually through various Likert scale type questions such as this (see Lewicka, 2011 for a review).

Adaptive capacity is often characterised through the five capitals of the livelihoods approach (physical, financial, natural, social and human; e.g. Vincent, 2007). We take this approach here. Each of the five capitals used in the calculation of adaptive capacity is represented in the analysis by a single variable taken from the questionnaire: Physical capital by total value of household assets; Financial capital by total household income for the four-month recall period of survey; Social capital using the 5-point Likert scale answer to the question “I want to

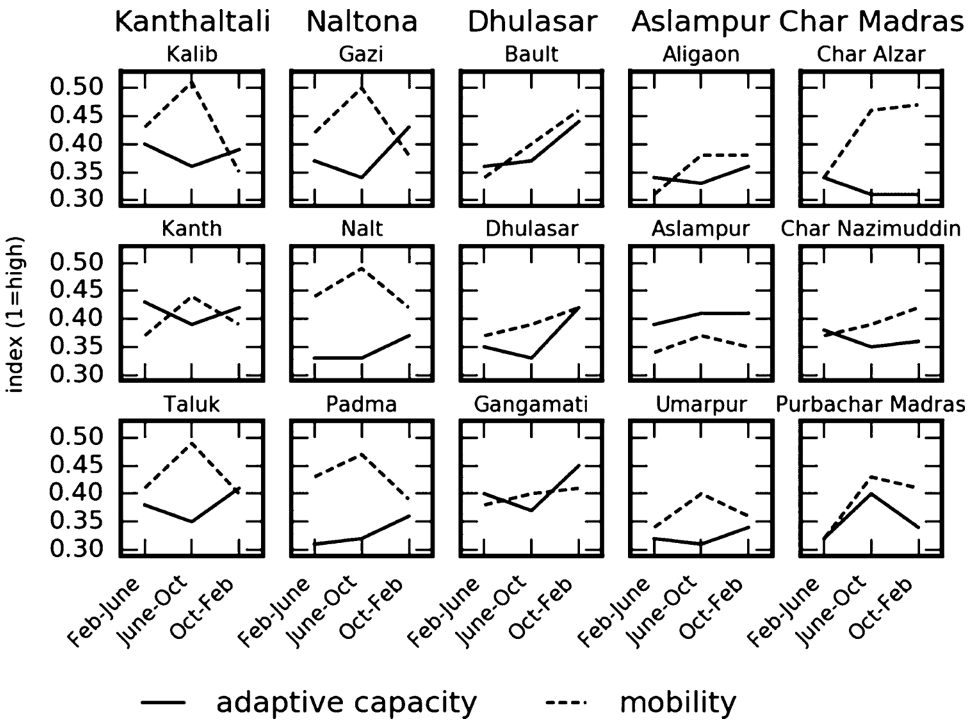

Fig. 4. Adaptive capacity and mobility potential scores, based on current socio-economic and behavioural characteristics, for each village by season. Column headings are the union names; see Fig. 3a for locations. There are statistically significant differences between villages in mobility potential that hold in all seasons, but villages cannot not be distinguished by their adaptive capacity. Within villages, adaptive capacity and mobility each varied with season in six out of the 15 villages. Three villages showed significant differences in both these dimensions.

be involved in village activities" by household head; Human capital by education level of the household head; and Natural capital by total area of cultivatable land in household. Whilst reductive, this approach has advantages since the data to create quantitative indices on these capitals is available in many social surveys. The social capital answer in particular is not ideal. Preferably we would have used a variable that asked about involvement in village activities, but such responses were not available in the survey.

Exposure of coastal Bangladesh to high sea level events was assessed by using outputs from a model that simulated hourly sea level height in the Bay of Bengal for the 21 st century (Fig. 3a) (Kay et al., 2015). This used the hydrodynamic model POLCOMS (Holt and James, 2001) and was driven at the air-sea boundary by data from a regional climate model (Caesar et al., 2015). The projections were based on the medium-emissions SRES A1B scenario (Nakićenović et al., 2000), and the results shown here are the mean for an ensemble of three runs. Scenarios of higher or lower greenhouse-gas emissions are likely to lead to similar results but on a shorter or longer timescale. Sea level rise was imposed at the model boundary using projections for the northern Bay of Bengal produced for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Church et al., 2013), adjusted to be consistent with the A1B scenario. This gave 0.25 m in 2050 and 0.54 m in 2100, compared to a baseline in 2000. These values do not include a contribution from the melting of the West Antarctic ice sheet, which may occur in the 21st century and could add a further 0.5 m (Levermann et al., 2014). The model also takes account of river flow and projections, taken from a hydrological model driven by the same climate projections (Whitehead et al., 2015). The model outputs thus combine the effects of mean sea level rise, change in storms and change in river inputs.

The maximum water height and frequency of high water level events was assessed from time series data at 23 points on the delta coast, with "high water" defined as a level that occurs once per decade in current conditions (Fig. 3b). Since maximum height and event frequency represent independent aspects of the hazard from high sea levels, a hazard exposure index was defined by adding the normalised values of these two indicators.

5. Results

5.1. Future exposure to coastal hazards under climate change and sea level rise to 2100

We used projections of high sea level events to quantify exposure to coastal hazard for 15 villages from 5 administrative districts (unions) (Fig. 3a). In the west of the region the height of extreme events is projected to increase by about 0.28-0.30 m between present-day and mid-century, with a slightly smaller increase in the second half of the century. Points in the east of the region, on the river mouth, show an increase of 0.33-0.35 m in the first half of the century, but very little further increase by end-century. The east of the region currently experiences higher peak events than the west, so its exposure index is lower. Thus, although the absolute sea level rise is higher here, it makes less difference when compared to the already high base level.

East-west differences also occur in the frequency of high water events. In the western part of the field area, heights that are reached once per decade in present-day conditions are projected to occur about seven times per decade at mid-century and several times a year by mid-century. The increases are much smaller in the east: three times per decade at mid-century, eight per decade at end-century. Thus, exposure to coastal hazard is uneven along short lengths of coastline, and the increase in hazard is non-uniform, meaning the hazard landscape changes as the century progresses.

5.2. Mobility characteristics and adaptive capacity differentiated by location and season

Fig. 4 shows adaptive capacity and mobility by village and season, with villages arranged by union. A one-way test of variance (ANOVA) analysis reveals statistical differences between villages with respect to mobility potential, but not adaptive capacity, in all seasons (February to June $p < 0.001$; June to October $p < 0.05$; October to February $p < 0.05$). Thus, across seasons, the villages show different levels of mobility for the same levels of adaptive capacity. This indicates that mobility potential is not being directly influenced by changing levels of capital, since each variable is reacting differently to seasonal changes.

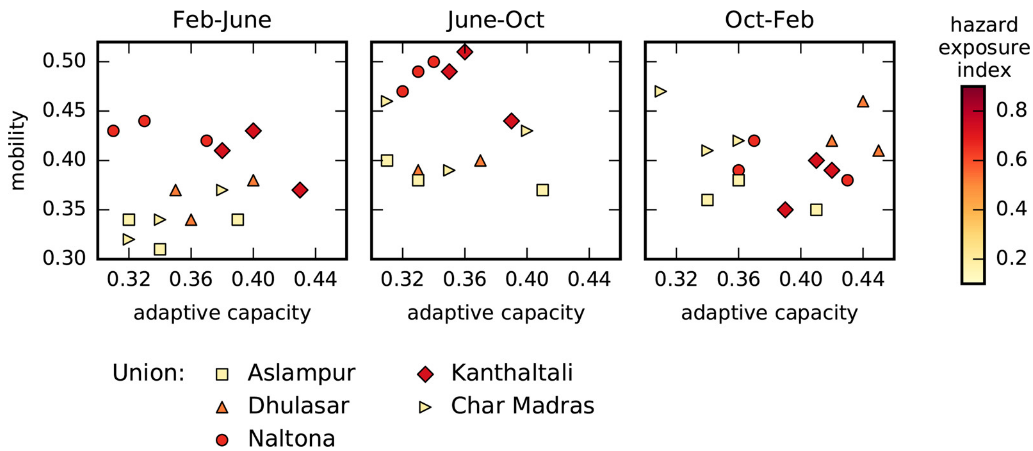

Fig. 5. Mobility and adaptive capacity by village and season for increased exposure to high sea levels at the end of the century. The results show that thresholds to migration (the point at which migration is chosen over adaptation) will vary by village, and the season in which the migration decision is made matters.

Repeated measures ANOVA shows statistically significant differences in adaptive capacity and mobility characteristics between seasons at the whole sample and union level ($p < .000$ and $p < .001$ on Greenhouse-Geisser statistic respectively). Thus, across the field area there are differences in adaptive capacity and mobility throughout the year. At the village level, adaptive capacity varied with season in six villages and mobility varied with season in six villages. Three villages showed significant differences in both these dimensions (Nalt, Bault, Umarpur). Mobility tended to be highest and adaptive capacity lowest in the June-October period (the summer monsoon).

This analysis shows that levels of mobility potential and adaptive capacity (aggregated to the village level) vary between villages. Mobility potential and adaptive capacity do not show the same seasonal patterns and do not co-vary during the year with the seasons. This starts to give us an understanding of the places that may have lower migration thresholds in response to environmental stress, that is to say, those with higher mobility potential.

5.3. Differentiated future exposure by coastal location and season

Fig. 5 plots the fifteen villages by adaptive capacity, mobility potential and exposure to hazard at the end of the century taking into account seasonal differences in mobility and adaptive capacity. Exposure is highest for Kanthantali and Naltona, in the west of the region. Villages in these unions also show high mobility, especially in the June-October period, with the Kanthaltali villages combining this with low adaptive capacity. By contrast, villages in the river mouth to the east in Char Madras and Aslampur unions, have low exposure and also relatively low mobility, Dhulasar has intermediate exposure and, unlike the other unions, shows the highest mobility, and highest adaptive capacity, in the October-February period. While there is some variability between villages, in general villages are clustered by union (e.g. Fig. 5).

6. Discussion

The results presented in the previous section can interpreted through the conceptual framework presented in Fig. 2 and described in Section 3.2. The union of Kanthaltali shows high adaptive capacity, high mobility and high end-century exposure and thus migration thresholds would be reached relatively early, and migration is more likely to produce positive well-being outcomes for the people involved, following the pattern shown in Curve 1 on Fig. 2. Naltona shows high mobility but a lower adaptive capacity combined with high exposure, thus early migration would be expected (Fig. 2, Curve 3) but it would be likely to be riskier in terms of well-being because households have fewer assets to support such migration. Dhulasar shows high adaptive capacity, a lower mobility and medium exposure. Thus, it is likely to follow Curve 2 on Fig. 2 with people within these villages only using migration as a strategy to protect well-being as their adaptive capacity becomes insufficient to counter increasingly negative impacts of coastal hazard.

In two unions, there is a lower increase in exposure to coastal hazard by the end of the century, thus migration thresholds are likely to be met later, not because of low mobility, but because residential satisfaction is not negatively affected by coastal hazards. In Char Madras, high mobility and low adaptive capacity are accompanied by low exposure. Here, migration may occur relatively later, as exposure to increased coastal hazard remains low and no additional action is required. However, when impacts become severe enough to require adaptation, migration under conditions of stress may be the only option due to the low asset base of this population. In Aslampur low adaptive capacity and low mobility are accompanied by low exposure (mapping onto Curve 4 on Fig. 2). When people within this area are affected they maybe disinclined to leave, depending on how coastal hazard affects attachments to place and satisfaction with place, but will not have the capacity to adapt and maintain well-being in situ.

We make no claims regarding whether observed mobility potential translates into migration behaviour under future climate conditions or the form that migration will take. However, the validation of such claims is not required for the data to be useful. Our proxies are effective in that they have differentiated coastal villages based on attitudes to place (as an indicator of mobility potential) and adaptive capacity of households, and have revealed seasonal patterns in these characteristics. Combined with an understanding of how people who are place-attached react to their coastal environment, this information can usefully inform interventions and responses. For example, in some locations people who are attached (equating to low mobility potential) deny risk and are less interested in taking adaptation action (e.g. De Dominicis et al., 2015) while in other places they work to protect valued coastal locations (Amundsen, 2015). There is a positive feedback in the relationship between mobility potential and climate change. Mobility potential will likely increase as climate change negatively impacts well-being and degrades environments to the point people change their attitudes to place and push factors shift the balance towards a migration decision (Adams and Adger, 2013). On the other hand, people's bonds to place are persistent and not always climate-sensitive. Unfortunately, we were unable to model these dynamics here.

While we normalised mobility potential scores, absolute values indicate that the population had a low mobility potential overall, and this is in a population that is already exposed to difficult and worsening environmental conditions with many barriers to successful adaptation (Islam et al., 2014; Hoque et al., 2018). Thus, we could argue that still being in this location is an expression of low mobility potential. Mobility potential and adaptive capacity vary with season. This is not unexpected. Livelihoods within this region are highly seasonal (Khandker, 2012) and migration follows seasonal patterns (Lu et al., 2016) as certain members of the household access alternative labour markets during the agricultural low season or when fisheries close. However, in the context of longer term changes, it shows that out-migration from the area to destination locations may occur in seasonal waves.

We have also been able to demonstrate that exposure to coastal hazard is not uniform across the coastline and nor do rates increase uniformly into the future. Thus, exposure as a predictor of climate migration in the future is spatially and temporally heterogenous. Again, not an unexpected finding considering the dynamic nature of the biophysical system of the delta (Nicholls et al., 2018), but something missing from top-down analyses of exposure to coastal risk. Differences in exposure have implications for reaching thresholds. If people are not exposed, their adaptation and mobility characteristics are not called into play; where people are exposed, their tendency towards migration or adaptation in place can inform planning.

Based on our findings it is possible to identify place-specific mobility responses for the villages on this coast. Low mobility, low adaptive capacity groups living in exposed areas may be vulnerable but resistant to moving. Thus, resettlement may be required. Yet resettlement can be problematic for such communities on the margins. In West Bengal, non-migration of exposed groups occurs due to a lack of government policy on planned relocation, so populations are left exposed and vulnerable (Mortreux et al., 2018). Marino (2018) argues that resettlement policies are not universally appropriate and can deepen inequalities under climate change. For example, voluntary buy-out policies cannot be used in communities where market value is difficult to establish and the community wishes to relocate as a whole (Marino, 2018). For groups with low mobility but high adaptive capacity, depending on the level of exposure to environmental risk, protection for as long as possible may be an option, because this group will be resistant to moving but able to protect their own well-being (within limits). For example, in simulations residents of coastal Florida showed a willingness to pay for adaption for example through higher taxes (Treuer et al., 2018). These groups may also be well placed to mobilise to defend their rights to place due to their social and financial capital (e.g. Maldonado et al., 2013).

Where groups with high mobility potential and high adaptive capacity are exposed to climate risk, there may be benefits to helping ensure that these people are able to maximise on migration by ensuring that the right kinds of services and infrastructure are available in urban receiving areas. Martin et al. (2014) discuss the need to realign government policy to acknowledge and support rural to urban migration in Bangladesh, as remittances facilitate the sustainability of rural lifestyles. For those with high mobility and low adaptive capacity, the protection of human rights again comes to the fore, and prevention of precarious labour migration and labour exploitation of the already vulnerable (e.g. Deshingkar, 2017).

7. Conclusion

In this paper, we use behavioural migration theory and the concept of an inherent mobility potential, operationalised through place attachment and subjective well-being, to better understand how coastal populations may respond to increasing environmental stress. The sequence of depopulation from a coast, we suggest, can be approximated by understanding the migration threshold of people exposed. Here we have characterised the migration threshold as a compromise between mobility potential (an individual's interest in the outside world, operationalised in this paper as a corollary of a rooted form of place attachment) and place utility (or residential satisfaction). We argue that adaptive capacity is not a force at tension or opposing mobility, but rather modulates the timing and the well-being outcome of any migration (or staying) that occurs. Adaptive capacity, represented here by the five capitals of the livelihoods approach, allows both those who are mobile and those who are sedentary to protect their well-being.

These dimensions of human decision-making can be usefully quantified and combined with climate data (here with data on increased exposure to coastal hazard with climate change) to differentiate between communities. We have shown that increases in exposure to coastal hazard due to sea level rise occur non-uniformly on populations heterogenous with respect to their mobility potential and adaptive capacity, within a relatively small geographical area and demonstrating seasonal differences. Coastal cities are already beginning to adapt and require technical support to do so (Hayes et al., 2018); modelling projections are one way to support such activities. However, to be successful, coastal adaptation must be place-based (Islam and Nursey-Bray, 2017) and adapted to the specific trigger points of the local communities (Lawrence et al., 2018). As such, the tools we use to inform such decisions must take these characteristics into account. Here we have shown the potential to do so with readily available data.

Our research has shown the need to better integrate adaptation and migration interventions at the level of the community in climate-exposed areas. We show here that the policy objectives of adaptation and migration cannot easily be disentangled; the mobility potential of the population affects their attitudes to adaptation within place and their response to different levels of exposure. This in turn influences the most appropriate form of intervention; whether to invest in adaptation, support migration or plan resettlement.

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