Reg Environ Change (2014) 14:281–294
DOI 10.1007/s10113-013-0487-6

ORIGINAL ARTICLE

Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh

Md. Monirul Islam · Susannah Sallu · Klaus Hubacek · Jouni Paavola

Received: 16 November 2012 / Accepted: 18 May 2013 / Published online: 6 June 2013

Abstract Globally, fisheries support livelihoods of over half a billion people who are exposed to multiple climatic stresses and shocks that affect their capacity to subsist. Yet, only limited research exists on the vulnerability of fishery-based livelihood systems to climate change. We assess the vulnerability of fishery-based livelihoods to the impacts of climate variability and change in two coastal fishing communities in Bangladesh. We use a composite index approach to calculate livelihood vulnerability and qualitative methods to understand how exposure, sensitivity, and adaptive capacity measured by sub-indices produce vulnerability. Our results suggest that exposure to floods and cyclones, sensitivity (such as dependence on small-scale marine fisheries for livelihoods), and lack of adaptive capacity in terms of physical, natural, and financial capital and diverse livelihood strategies construe livelihood vulnerability in different ways depending on the context. The most exposed community is not necessarily the most sensitive or least able to adapt because livelihood vulnerability is a result of combined but unequal influences of bio-physical and socio-economic characteristics of communities and households. But within a fishing community, where households are similarly exposed, higher sensitivity and lower adaptive capacity combine to create higher vulnerability. Initiatives to reduce livelihood vulnerability should be correspondingly multifaceted.

Keywords Bangladesh · Climate change · Climate variability · Fisheries · Livelihoods · Vulnerability

Md. M. Islam (✉) · S. Sallu · J. Paavola
Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK
e-mail: monirulislam153@yahoo.com

Md. M. Islam
Department of Fisheries, University of Dhaka, Dhaka 1000, Bangladesh

K. Hubacek
Department of Geographical Sciences, University of Maryland, College Park, MD, USA

Introduction

Fisheries support the livelihoods of over half a billion people globally (FAO 2010). Many of the people dependent on small-scale fisheries live in developing countries and face climatic shocks and stresses such as cyclones, floods, droughts, sea-level rise, land erosion, and temperature and rainfall fluctuations (IPCC 2007). While few positive impacts on fisheries have also been reported, such as increased nutrient production in high latitude (Brander 2010), seasonal increase in growth of rainbow trout (Morgan et al. 2001), and reduced cold-water mortalities of some aquatic animals (IPCC 2007), most of the impacts of climate change are overwhelmingly negative (IPCC 2007). Climate change will tend to exacerbate non-climatic pressures on fisheries such as overfishing, pollution, and loss of habitat (Brander 2006; Sumaila et al. 2011). Increasing temperatures, altered precipitation patterns, sea-level rise, ocean acidification, and changes in dissolved oxygen concentration all affect the structure and productivity of marine and coastal ecosystems and fish populations (IPCC 2007; Cheung et al. 2009; Brander 2010; Drinkwater et al. 2010; Johannessen and Miles 2011). These impacts have already extended to fishery-dependent people in some regions (Perry et al. 2009). Extreme weather events such as cyclones and floods may further intensify these impacts by disrupting fishing operations and land-based infrastructure

(Westlund et al. 2007). The land-based assets can also be deteriorated by sea-level rise, land erosion, and variations in temperature and rainfall. These impacts may result in vulnerability of fishery-dependent livelihoods (Sarch and Allison 2000; Coulthard 2008; Iwasaki et al. 2009; Perry et al. 2009). Small-scale fishing communities are considered especially vulnerable to the negative impacts of climate variability and change (Downing et al. 1997; Dixon et al. 2003; IPCC 2007).

Examining the vulnerability of fishing communities and households to climate variability and change can help identify and characterise actions that can ameliorate adverse impacts. Despite its importance, knowledge of climate-induced impacts and vulnerability on the local scale of fishery-based livelihoods remains limited. Most studies have focused either on national scale of vulnerability of fisheries systems (e.g. Allison et al. 2009; Quest_Fish 2012) or of agricultural livelihoods (e.g. Vincent 2007; Eakin and Bojórquez-Tapia 2008; Paavola 2008; Sissoko et al. 2011).

The objective of this study was to assess the vulnerability of fishery-based livelihoods to the impacts of climate variability and change in two coastal fishing communities and their households in Bangladesh. Bangladesh is chosen because this country, including its fisheries sector, is considered a hot spot of societal vulnerability to climate change (IPCC 2007; Yu et al. 2010; Maplecroft 2011). The marine fisheries sector in Bangladesh supports livelihoods of over half a million fishers and their household members (DoF 2012).

Vulnerability to climate variability and change and fishery-based livelihoods

Vulnerability of fishery-based livelihoods to climate variability and change can be defined as the degree to which a fishery-based livelihood system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (adapted from IPCC 2007, p. 883). Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a fishery-based livelihood system is exposed, its sensitivity and its adaptive capacity (adapted from IPCC 2007, p. 883). Livelihoods can in turn be defined as “the capabilities, assets (stores, resources, claims, and access), and activities required for a means of living” (Chambers and Conway 1992: 6). Therefore, to assess livelihood vulnerability, it is necessary to understand how components of vulnerability and fishery-based livelihoods interact.

The sustainable livelihood approach (SLA) (Scoones 1998; DFID 1999) can help assess livelihood vulnerability by highlighting how climate variability and change affect the vulnerability context, the asset base, policies, institutions, and processes (Adatoh and Meinzen-Dick 2002; Elasha et al. 2005; Badjeck et al. 2010). The asset base—human, physical, natural, financial, and social capital—forms the building block of livelihoods and helps reduce vulnerability. These assets are mediated by the external vulnerability context (trends, shocks, and seasonality), and endogenous policies, institutions, and processes. The policies, institutions, or processes include markets and other institutions such as laws, social relations, and formal organisations (government agencies, NGOs, and private organisations) and related policies. Together, these factors shape access to livelihood assets, livelihood strategies, and ultimately livelihood outcomes (Bebbington 1999). Livelihood strategies include the range and combination of activities and choices made by the people in order to achieve livelihood outcomes (DFID 1999). Access in turn means “the opportunity in practice to use a resource or service or to obtain information, material, technology, employment, food or income” (Chambers and Conway 1992, p. 8). These factors determine the terms of exchange between different types of assets (DFID 1999) and therefore affect livelihood strategies and outcomes.

A combination of bio-physical and socio-economic factors shapes the vulnerability of natural resource-based livelihood systems (e.g. Paavola 2008; Sallu et al. 2010). In developing countries, rural people living in coastal zones depend on climate-sensitive occupations such as fishing, agriculture, and forestry. In a small-scale fishing community, households are involved in fishery-related activities such as fishing, post-harvest fish processing, fish trading, and making and mending of fishing materials (OECD 2001). They are served with limited physical infrastructure and often lack access to basic services such as education, health care, water, credit, and insurance (Olago et al. 2007; Iwasaki et al. 2009; MRAG 2011).

Fishing is a high-risk livelihood activity “due to the fugitive nature of the resource, the hostile environment of the seas, and perishability of the product” (MRAG 2011, p. 3). One direct impact of climatic shocks, such as cyclones and floods, is loss of life. Climatic shocks have killed several hundred thousand people in coastal Bangladesh; many of them are fishermen or their household members, friends, or relatives (IPCC 2007). Other impacts include physical injuries (Badjeck et al. 2010) and health effects (Kovats et al. 2003). Cyclones and floods also damage boats, nets, fishing gear, and fish landing centres, as well as educational, health, housing, and other community infrastructure (Jallow et al. 1999; Adger et al. 2005; Westlund et al. 2007).

Fish productivity, abundance, and distribution are also likely to be impacted by climate change (IPCC 2007;

Cheung et al. 2009; Brander 2010; Drinkwater et al. 2010), which may increase the cost of accessing fish catch (Badjeck et al. 2010). Fish processing costs may also increase; traditional fish drying is sensitive to variations in temperature and rainfall. Impacts on catch and processing will ultimately influence employment, income, and nutrition of fishery-dependent households and communities through changes in local institutions and resource management (Badjeck et al. 2010).

For the above discussed reasons, climate variability and change importantly influences economic return from livelihood strategies. This in turn can impact on the vulnerability and adaptive capacity of households and communities. But all households within a community are not equally vulnerable; they may be differentially affected by climate variability and change on the basis of their level of adaptive capacity (Adger 2003; Smit and Wandel 2006) and sensitivity, which relates to their livelihood assets and strategies. Roncoli et al. (2001) found that poorer households are often less able to adapt. Coulthard (2008), however, considers in her study in a South-Indian lagoon, that fishers which have become locked into an overly specialised fishery are less able to adapt than the poorest.

Since climate change will impact on fishery-based livelihood systems in different ways, it is necessary to conduct more in-depth studies on vulnerability. While a number of studies have investigated the impact of climate change on the vulnerability and adaptive capacity of the fisheries sector at the national scale (e.g. Allison et al. 2009; Quest_Fish 2012), little research has examined the impacts of climate variability and change on the livelihoods of small-scale fishing communities and households in developing countries, particularly in Bangladesh. National scale studies cannot provide specific enough findings applicable to the household or community scale (Hahn et al. 2009), and at the local scale, vulnerability assessments of agricultural livelihood systems dominate (e.g. Vincent 2007; Eakin and Bojórquez-Tapia 2008; Paavola 2008; Sissoko et al. 2011). As the vulnerability of an agricultural livelihood system is different from that of fishery-based one, implications for vulnerability of one livelihood system to another is not necessarily transferable; more work is required in fishery-based systems. This study aims to fulfil this gap in understanding one highly vulnerable region of the world.

Study sites, indicators of vulnerability, and the design of a composite vulnerability index

Study sites

We assessed livelihood vulnerability to climate variability and change in the fishing communities of Padma, Barguna District, and Kutubdia Para, Cox's Bazar District in southern coastal Bangladesh (Fig. 1). These two districts are more affected by climatic phenomena such as cyclones, tidal fluctuation, and salinity intrusion than other coastal areas of Bangladesh (Agrawala et al. 2003). The two communities share some characteristics but also have different physiographic contexts and livelihood portfolios.

Padma is home to 4,204 people in 908 households. Most household heads are male with limited formal education. Most households (89 %) directly depend on fisheries; small-scale fishing in the Bay of Bengal is their main livelihood activity. Some households are involved in other livelihood activities such as fish drying, fish trading, net making and/or mending, boat making and repairs, shrimp post-larvae collection, daily labouring, firewood selling, grocery shop keeping, cattle rearing, investing money in informal loan systems, motorcycle driving, fish culture, and agriculture. Most men work as crews in small mechanised fishing boats. The fishing season runs from July to October (first season, within which a few days are excluded from fishing) and December to April (second season). Most fishing is done during the first season. A crew of 3–18 people work during a fishing operation that lasts 6–15 days.

Padma's physical infrastructure is poor. Dirt roads become muddy during the rainy season and are dusty when it does not rain. Two cyclone shelters have a joint capacity of 3,000 people. One of the cyclone shelters serves as a primary school, the only formal education institution in Padma. There is no hospital or clinic but 2 pharmacies dispense medicines. People with medical needs visit the sub-district health complex in Patharghata about 8 km away. There is no access to the electricity grid or piped water supply. Filtered and alum-treated pond water of uncertain quality is used by households.

Livelihoods in Padma have been influenced by storm surge-induced flooding (hereafter refer to as flood), cyclones, sea-level rise, salinity intrusion, and land erosion (Table 1). The most devastating climatic shock in the past 40 years was the super cyclone *Sidr* (wind speed 230–270 km/h, surge height 20–25 feet) in 2007. A strong cyclone in the sea in 2005 and a flood caused by cyclone *Aila* in 2009 also had disastrous impacts on the community. Padma is <1 metre above the sea level and does not have a protective dike around it.

Kutubdia Para is home to 12,815 people in 2,015 households. Most households are climate disaster-driven migrants from the Kutubdia Island in the same district. The village came into existence in 1986 as an isolated neighbourhood, but it is now a ward in the district of Cox's Bazar. Most household heads are male with little formal education.

Livelihoods in Kutubdia Para depend on fishery-related activities such as fishing in the sea, fish drying, fish

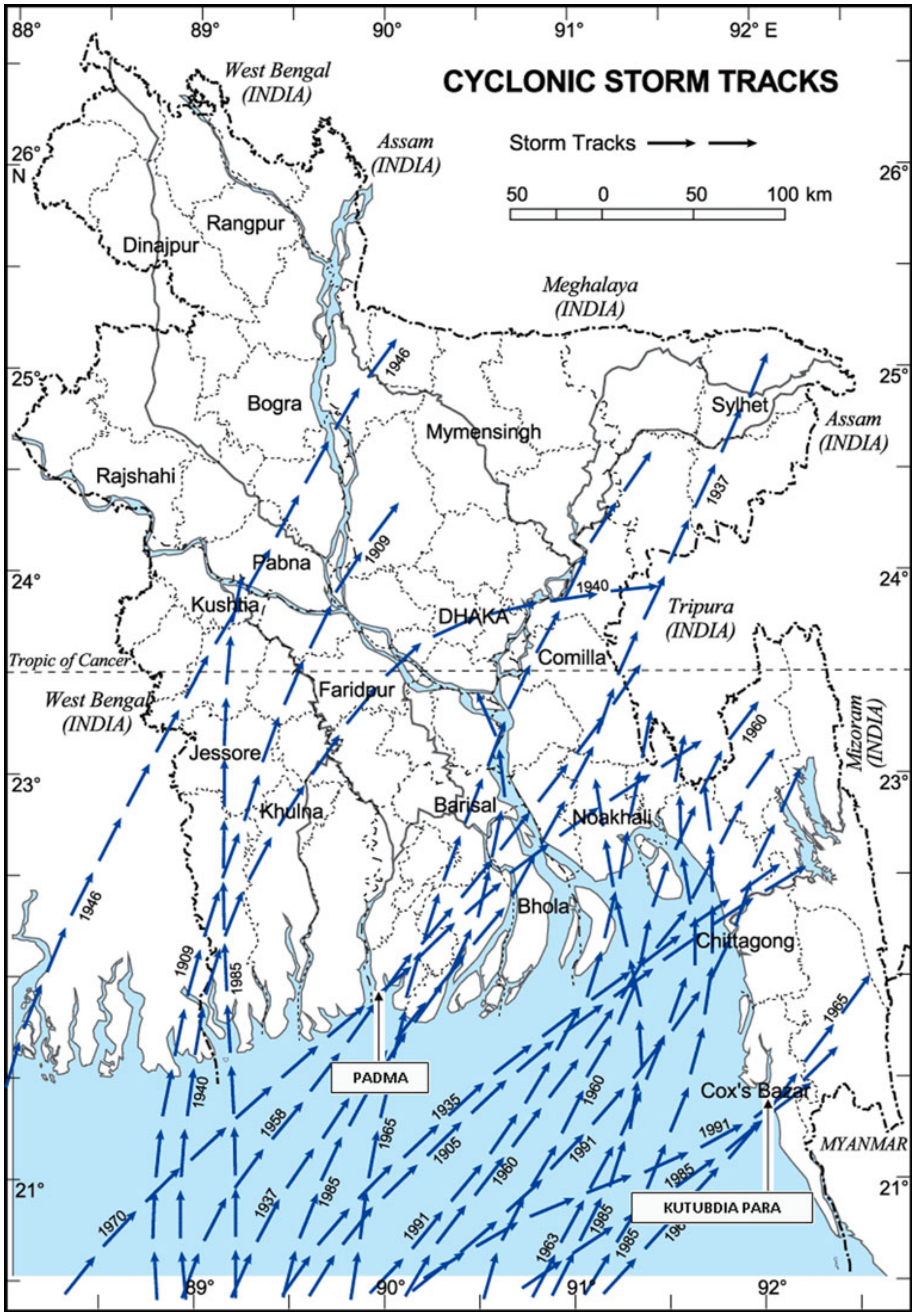

Fig. 1 Bangladesh study site locations and cyclone tracts (modified from Banglapedia 2006)

transportation, and net mending. Fishing and fish drying support the livelihoods of about 92 % of the households. A few households depend on tailoring, grocery sales, and daily labouring in building construction for their livelihoods. Kutubdia Para's physical infrastructure is poor and very similar to that of Padma, apart from all households have access to pure drinking water and electricity. It is 3 km from Cox's Bazar airport and 6 km from Cox's Bazar town.

Fishing practices in Kutubdia Para are similar to those of Padma, except that the second fishing season is extended for two more months and more fish is caught in this season. Fish are dried by traditional open-air method mainly (80 %) between November and February. The remaining 20 % of fish are dried in September, October, March, April, and May (extended drying period).

Since settling in Kutubdia Para, households have experienced two major cyclones and associated floods in

Table 1 Community exposure to climatic shocks and stresses

Climatic shocks and stresses	Padma		Kutubdia Para		Sources of data
	Mean	Standard deviation	Mean	Standard deviation	
Number of past floods[a]	4	N/A	2	N/A	Focus group discussions (FGDs)[b]
Number of past cyclones[a]	3	N/A	4	N/A	FGDs[b]
Past land erosion (metre/year)[a]	16.67	N/A	0.67	N/A	FGDs[b]
Past sea-level changes (mm/year)	2.9[c]	N/A	1.4[d]	N/A	BWDB, CEGIS (2006; cited in Yu et al. 2010)
Variation in past maximum temperature (°C)[e]	1.61	0.46	1.61	0.47	BMD (2011)
Variation in past minimum temperature (°C)[e]	1.81	0.70	1.44	0.63	BMD (2011)
Variation in past rainfall (mm)[e]	13.86	14.01	16.4	15.77	BMD (2011)

[a] Period discussed with respondents 1981–2011

[b] Refer to data collection and analysis section

[c] Mean change 1959–1986, Khepupara measurement station (20 km east of Padma)

[d] Mean change 1968–1991, Cox's Bazar station

[e] Standard deviations of daily maximum temperature (°C), daily minimum temperature (°C), and daily total rainfall (mm) by month, between January 1981-May/June 2011, averaged. Data from: Khepupara station (Padma) and Cox's Bazar station (Kutubdia Para)

1991 (named *Gorki*) and 1997 (Table 1). They are also exposed to sea-level rise, temperature and rainfall variations, and little land erosion. Kutubdia Para is <1 m above sea level and <1 km away from the sea, and it does not have a protective dike around it. Its fish-drying field is close to sea and only a few centimetres above sea level.

The coastal region in which both communities lie will likely experience climate change impacts as predicted for Bangladesh as a whole, including increases in floods (Mirza 2003, 2011), temperature (MoEF 2005) and wind speed (Emanuel 1987), sea-level rise (MoEF 2005), and seasonal changes in rainfall (Agrawala et al. 2003). These impacts will have predominantly negative consequences for case study communities unless they adapt.

Indicators of vulnerability

Exposure, sensitivity, and adaptive capacity are the key factors that determine the vulnerability of households and communities to the impacts of climate variability and change (IPCC 2007). Indicators for each of these factors are therefore essential elements of a comprehensive vulnerability assessment. However, "many of these indicators cannot be quantified, and many of the component functions can only be qualitatively described" (Yohe and Tol 2002, p. 27). For instance, effective governance is important for adaptive capacity (Paavola 2008), but it is difficult to capture in an indicator (Vincent 2007). The most useful indicators of vulnerability have construct validity, are sensitive enough to capture variation, and broad enough to be transferable (Vincent 2007).

Exposure in the context of this study is the nature and degree to which a fishery-based livelihood system is exposed to significant climatic variations (modified from IPCC 2001, p. 987). Exposure indicators selected for this region characterise the frequency of extreme events, rate of land erosion and sea-level rise, and variations in temperature and rainfall (Tables 1, 2). The two communities have experienced similar variations in maximum temperature (Table 1) so no indicator on it was included in index calculation. Only retrospective data on indicator values were used; no future projections were attempted due to unavailability at community scale. This is sufficient for the purposes of this study, because the greater the level of exposure to climate variability (and change), the greater the relative propensity for communities and households to be impacted.

Sensitivity in this context is the degree to which a fishery-based livelihood system is affected by or responsive to climate stimuli (note that sensitivity includes responsiveness to both problematic stimuli and beneficial stimuli) (adapted from IPCC 2007, p. 881). Sensitivity indicators characterise the first-order effects of stresses (IPCC 2001; Polsky et al. 2007). At the local level, exposure and sensitivity are almost inseparable, and it is challenging to characterise them (Smit and Wandel 2006). Sensitivity indicators include livelihood characteristics such as dependence of livelihoods on climate-sensitive activities and patterns of resource use (Smit and Wandel 2006; Eakin and Bojórquez-Tapia 2008). But many indicators of

Table 2 Indicators used to determine fishery-based livelihood vulnerability

Indicators	Explanation of the indicators	Sources of data
Indicators of Exposure		
Refer to Table 1 "Study sites" Section	Refer to Table 1	Refer to Table 1
Indicators of Sensitivity		
Employment from fisheries	Number of days a household is involved with fisheries in last year	Household questionnaires (HQs)
Income from fisheries	Percentage of household income from fisheries sector in last year	HQs
Nutrients uptake from fisheries	Amount (per capita) of fish and seafood a household consumed in last year (kg/month)	HQs
Indicators of Adaptive Capacity		HQs
Adult workforce	Number of individuals aged 14–60 in household	HQs
Presence of non-elderly household head	Whether household head is <50 years old or not	HQs
Experience	Experience of household head in fisheries-related activities (years)	HQs
Education	Highest years of schooling of any member of household	HQs
Health	Number of days a year household head remains physically fit to carry out livelihood activities	HQs
Presence of male-headed household	Whether household head is male or not	HQs
Quality of house	Aggregate index of household's quality of house[a]	HQs and FGDs
Number of fishery materials	Number of types of fisheries-related materials (boats, nets etc.) of household	HQs
Use of technology	Aggregate index of household use of technology[b]	HQs
Distance from services	Aggregate index of distance (time) of household's house from services[c]	HQs and FGDs
Natural capital	Aggregate index of natural capital[d]	HQs
Financial capital excluding income	Aggregate index of household financial capital excluding income[e]	HQs
Per capita income	Per capita income of household (Taka/year) (TK76 = US$1)	HQs
Social capital	Aggregate index of household social capital[f]	HQs
Number of income-generating activities	Number of income-generating activities per household	HQs

[a] Calculated as sum of household scores (i.e. 0 = insufficient, 1 = moderate, 2 = good), based on 4 variables: availability of rooms per adult equivalent (0 = <0.5 rooms per adult equivalent, 1 = 0.5–1 per adult equivalent, 2 = >1 per adult equivalent), quality of outside walls (0 = non-cemented material or without corrugated tin, 1 = corrugated tin, 2 = cement and brick casting/concrete), quality of roof (0 = leaves/straw/tile, 1 = corrugated tin, 2 = concrete) and quality of floor (0 = dirt, 1 = brick/wood with non-cemented material, 2 = concrete). Index ranges between 0 and 8. The scores on different variables were agreed by the household heads of this study during the FGDs

[b] Calculated as sum of household scores (no = 0, yes = 1), based on the 6 variables: sanitary toilet, phone, radio/television, solar/electricity for energy, safe drinking water source, ownership of transportation. Index ranges between 0 and 6

[c] Calculated as sum of household scores (i.e. 0 = insufficient, 1 = moderate, 2 = good), based on 7 variables: time needed to reach the nearest cyclone shelter (0 = >10 min, 1 = 3–10 min, 2 = <3 min), drinking water source (0 = >15 min, 1 = 5–15 min, 2 = <5 min), market (0 = >30 min, 1 = 10–30 min, 2 = <10 min), disaster office (0 = >45 min, 1 = 20–45 min, 2 = <20 min), government offices (0 = >45 min, 1 = 20–45 min, 2 = <20 min), hospital/clinic (0 = >30 min, 1 = 10–30 min, 2 = <10 min), and time needed to reach the nearest educational institution (0 = >20 min, 1 = 10–20 min, 2 = <10 min). Index ranges between 0 and 14. The scores on different variables were agreed by the household heads of this study during the FGDs

[d] Calculated as sum of household scores (no = 0, yes = 1), based on the 2 variables: possession of land and trees. Index ranges between 0 and 2

[e] Calculated as sum of household scores (no = 0, yes = 1), based on the 3 variables: livestock, jewellery and stored food. Index ranges between 0 and 3

[f] Calculated as sum of household scores (no = 0, yes = 1), based on 13 variables: having relatives in the village, getting support from relatives in the village, having relatives outside the village, getting support from relatives outside the village, having contacts other than relatives inside the village, getting support from contacts other than relatives inside the village, having contacts other than relatives outside the village, getting support from contacts other than relatives outside the village, having membership in community organisation, getting support from the membership of community organisation, having membership in political parties, getting support from the memberships of political parties, and ability to cast vote in elections. Index ranges between 0 and 13

sensitivity are similar to those that influence a system's adaptive capacity (Smit and Wandel 2006). In order to avoid using the same indicators for measuring sensitivity and adaptive capacity, only indicators of the dependence of livelihoods on climate-sensitive activities in the fisheries sector, for employment, income, and nutrition were used as sensitivity indicators (Macfadyen and Allison 2009; Allison et al. 2009) (Table 2). This assumes that households and communities with higher dependence on fisheries for employment, income, and nutrition are more likely to be impacted by climate variability and change (cf. Allison et al. 2009).

Adaptive capacity in the context of this study is the ability or capacity of the fishery-based livelihood systems to adjust to climate change (including variability and extremes), to take advantage of opportunities, or to cope with the consequences (modified from IPCC 2001, p. 982). However, there is little consensus about the characteristics and determinants of adaptive capacity at household, community, and national levels (Smit and Wandel 2006; Jones et al. 2010), because the exploration of adaptive capacity has only just begun (Vincent 2007). At the local level, adaptive capacity can be influenced by infrastructure, community structure and social groups, household structure and composition, knowledge, social capital (such as kinship networks and social support institutions), political influence, power relations, governance structures, managerial ability, and ability or inability to access livelihood assets, especially financial, technological, and information resources (Watts and Bohle 1993; Adams and Mortimore 1997; David 1998; Adger 1999; Handmer et al. 1999; Kelly and Adger 2000; Barnett 2001; Yohe and Tol 2002; Wisner et al. 2004; Haddad 2005; Ford et al. 2006; Smit and Wandel 2006; Tol and Yohe 2007; Vincent 2007; Paavola 2008; Sallu et al. 2010). Adaptive capacity is, however, context-specific varying across scales—countries, communities, social groups and households—and over time (Smit and Wandel 2006), and best determined by a given climatic exposure in which a particular system is exposed (Vincent 2007). Indicators of adaptive capacity for the fishery-based livelihoods should thus be developed considering the nature and type of exposure of households and communities. We chose to use adaptive capacity indicators covering a range of livelihood characteristics such as livelihood assets and strategies (Table 2), assuming that households and communities with more of these are better able to cope with and adapt to the impacts of climate variability and change.

Design of a composite livelihood vulnerability index

A composite vulnerability index approach was used in this study to assess relative exposure, sensitivity, and adaptive capacity. A composite index approach computes vulnerability indices by aggregating data for a set of indicators. An indicator represents a characteristic or a parameter of a system (Cutter et al. 2008) and it is an empirical, observable measure of a concept (Siniscalco and Auriat 2005, p. 7). The composite index approach can help to identify indicators or determinants for targeting interventions and programmes (Eakin and Bojórquez-Tapia 2008; Czúcz et al. 2009).

Using the suite of indicators described in Tables 1 and 2, we quantitatively assessed the vulnerability of fishery-based livelihood systems using the combination of individual indicators and aggregate indices shown in Table 2. Since each indicator was measured on a different scale, they were normalised (rescaled from 0 to 1) by using Eq. 1.

$$\text{index}_{\text{Si}} = \frac{S_i - S_{\min}}{S_{\max} - S_{\min}} \quad (1)$$

where index_{Si} is a normalised value of an indicator of a household; S_i is the actual value of the same indicator, and $S_{\min}$ and $S_{\max}$ are the minimum and maximum values, respectively, of the same indicator.

After normalisation the respective values were averaged to yield the three sub-indices for exposure, sensitivity, and adaptive capacity. As household scale exposure data were not available, the same exposure sub-index score was used to calculate intra-community livelihood vulnerability indices. This enabled us to gain insights into the determinants of livelihood vulnerability among similarly exposed households (Eakin and Bojórquez-Tapia 2008). The household-level sensitivity and adaptive capacity sub-indices were also normalised. The normalised adaptive capacity sub-index was inverted (1- index) for inclusion in the vulnerability index because the potential impact (which is a function of exposure and sensitivity) of climate variability and change may be offset, reduced or modified by adaptive capacity (IPCC 2007).

Sub-indices were combined to create a composite vulnerability index by using an additive (averaging) (Eq. 2) or multiplicative (Eq. 3) approach. We followed both procedures but, since they produced highly correlated vulnerability scores (Spearman's ρ 0.97 for Padma and 0.98 for Kutubdia Para; $p < 0.01$), we highlight the results of the multiplicative approach because it better reflects low and high indicator and sub-index values (Hajkowicz 2006).

$$V = (E + S + (1 - \text{AC}))/3 \quad (2)$$

$$V = E \times S \times (1 - \text{AC}) \quad (3)$$

Where V, E, S and AC represent vulnerability, exposure, sensitivity and adaptive capacity of a household, respectively.

Data collection and analysis

Within both communities we targeted fishery-dependent households, which constituted 89 % (811 households) and 83 % (994 households), respectively, of the total households in Padma and Middle and North Kutubdia Para (our research was conducted in these two sections of Kutubdia Para). The data were collected during October 2010 and between February and July 2011 using a multi-method approach. Sensitivity and adaptive capacity data were collected using household questionnaires, whereas exposure data were collected from secondary sources listed in Tables 1 and 2. A simple random sampling technique was followed to select questionnaire participants and the sample sizes were decided as 100 from each community (calculated according to procedures in UN (2005) and adjusted to take account of respective population size). Participants were typically household heads. When the household head was absent, another adult member of that household was interviewed.

The dataset from the sampled households was divided into quartiles of vulnerability (very high, high, moderate, and low), each representing a fourth of the population sampled for each indicator and index (Table 3). Z-test and ANOVA were conducted to determine significant differences, respectively, between two and more than two data sets. ANOVA was also conducted to investigate significance of an indicator in distinguishing the vulnerability classes.

We calculated vulnerability indices using equal weightings for each indicator (Sullivan et al. 2002), due to the absence of any robust weighting method for this region. The currently used weighting methods are either considered as subjective (e.g. expert judgement) or statistically biased (e.g. principal component analysis and regression analysis). As an alternative, we discuss the role of each

Table 3 Vulnerability classification of households in Padma (exposure index reflects community scale, while sensitivity and adaptive capacity indicators represent household scale)

Indicators	Very highly vulnerable	Highly vulnerable	Moderately vulnerable	Low vulnerable	Mean	Standard deviation
Number of households	25	25	25	25	25	0
Sub-Index of exposure	0.67	0.67	0.67	0.67	0.67	0.52
Indicators of sensitivity						
Employment from fisheries (days/year)***	220	199	205	165	197	40
Income from fisheries (%)***	98	93	94	67	88	19
Nutrients uptake from fisheries (kg/month)***	2.22	1.49	1.97	2.56	2.06	1.14
Sub-Index of sensitivity***	0.67	0.52	0.59	0.38	0.54	0.20
Indicators of adaptive capacity						
Number of adult workforce**	2.16	2.92	3.20	3	2.82	1.01
Presence of non-elderly household head	1	0.92	0.88	0.96	0.94	0.24
Experience (years)*	9.84	14.48	17.08	17.12	14.63	9.33
Education (years)	6.56	6.24	7.04	7.12	6.74	2.18
Health (days)	317	313	324	336	323	47
Presence of male-headed household	1	0.96	0.96	1	0.98	0.14
Quality of house**	2.52	2.36	3.36	3.44	2.92	1.32
Number of fishery materials*	0.28	0.28	0.84	0.84	0.56	0.87
Use of technology***	1.40	1.84	2.60	2.56	2.10	1.24
Distance from services (unit)	6.76	6.40	5.88	6.40	6.36	1.35
Natural capital***	0.64	1.00	1.32	1.24	1.05	0.64
Financial capital excluding income***	1.80	1.76	2.24	2.44	2.06	0.68
Per capita income (Taka)*	13,052	11,312	25,644	33,004	20,753	28,652
Social capital***	7.32	6.72	8.84	7.80	7.67	1.94
Number of income-generating activities**	2.08	2.40	2.60	3.28	2.59	1.16
Sub-index of adaptive capacity***	0.34	0.39	0.60	0.65	0.49	0.21
Index of livelihood vulnerability***	0.29	0.20	0.15	0.05	0.17	0.09

* Indicates significant difference (normalised values were used) between vulnerability classes in ANOVA test; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

component after calculating vulnerability, using qualitative data collected during oral history interviews, vulnerability matrices (adapted from CARE 2009), and focus group discussions (FGDs). This also served as a means to validate the vulnerability index.

To ensure representative sampling of qualitative data in each community, cluster analysis of household sensitivity and adaptive capacity data was conducted (see Islam 2013) which produced five and four clusters, respectively, for Padma and Kutubdia Para. We followed a purposive sampling strategy for choosing household heads to participate in qualitative data collection tools. A total of 22 and 21 oral history interviews (2–5 from each cluster depending on the number of households in each cluster) were conducted in Padma and Kutubdia Para, respectively. Single vulnerability matrix and FGD were conducted from each cluster in each community. A group of 6–10 household heads participated in each vulnerability matrix and FGD activity. The qualitative data were transcribed in Bengali and analysed using coding techniques (Miles and Huberman 1994) before translation.

Results

Vulnerability

Padma's households experience significantly higher ($p < 0.01$) livelihood vulnerability than Kutubdia Para's households (Tables 3, 4). Vulnerability also differs significantly ($p < 0.01$) between the household classes (very high, high, moderate and low) within each community. Our results highlight that the highest livelihood vulnerability to climate variability and change does not coincide with highest sensitivity and lowest adaptive capacity. Padma's households are less sensitive and have more adaptive capacity than those of Kutubdia Para's, but are nevertheless more vulnerable because of their heightened exposure. But when we look into classes of differently vulnerable households within a community (where all households are similarly exposed) higher sensitivity and lower adaptive capacity typically combine to create higher livelihood vulnerability.

Exposure

Padma is more exposed to climate variability and change than Kutubdia Para (Tables 1, 3, 4). Although it was not possible to distinguish exposure between the classes of households in a community, vulnerability matrices identify floods and cyclones are the main determinants of livelihood vulnerability in the two communities but how exposure creates livelihood vulnerability depends on the context of each community. According to almost all the participants, floods are the most important determinant of vulnerability inland, while at sea it is cyclones. Padma is more exposed to floods whereas Kutubdia Para is more exposed to cyclones (Table 1). In both communities cyclones are typically followed by surges (floods) and together they cause vastly adverse impacts on household livelihood assets, strategies and outcomes. As an extreme case, one of the participants from Padma stated during oral history interview "*during Sidr, water [surge] suddenly came and washed away not only my three family members but also my house…*". In addition to impacting land-based assets, cyclones also cause loss of life and fishing materials in the sea. One FGD participant from Padma for example stated "*he who can die, can catch fish from the sea*".

Other exposures have little or no impact on livelihoods. Land erosion and sea-level rise have resulted in the displacement (and resettlement in nearby areas) of about 5 % of the households (estimated from qualitative data) in Padma over the past three decades but none in Kutubdia Para. While variations in maximum temperature and rainfall have impacted <20 % of fish-drying process in Kutubdia Para in some years, no effects were reported in Padma. Variation in past minimum temperature has not found to pose any considerable negative impacts on livelihoods in either community.

Sensitivity

Sensitivity to climate variability and change is influenced by conditions at the community and household level. As a whole, the sensitivity is significantly higher among Kutubdia Para's households ($p < 0.01$) than among those of Padma (Tables 3, 4). The higher sensitivity of livelihoods in Kutubdia Para is due to their high dependence on climate-sensitive fisheries activities for employment, income, and nutrition (Table 4). Oral history interviews and FGDs reveal that over the past two and half decades the households in Kutubdia Para have progressively increasing access to facilities that have enabled their level of involvement in fisheries. Some of the households have extensified their livelihood strategies by fishing and drying fish outside the normal seasons when climatic stresses and shocks are more pronounced. This extensification has increased their dependency on fisheries and is the potential source of increased vulnerability.

Sensitivity varies significantly between the household vulnerability classes in each community ($p < 0.01$) (Tables 3, 4). All three indicators of sensitivity are significant ($p < 0.001$ for most indicators) in distinguishing vulnerability classes in both communities. Therefore, instead of selecting a specific indicator of sensitivity as a determinant of livelihood vulnerability, it is better to treat

Table 4 Vulnerability classification of households in Kutubdia Para (exposure index reflects community scale, while sensitivity and adaptive capacity indicators represent household scale)

Indicators	Very highly vulnerable	Highly vulnerable	Moderately vulnerable	Low vulnerable	Mean	Standard deviation
Number of households	25	25	25	25	25	0
Sub-Index of exposure	0.33	0.33	0.33	0.33	0.33	0.52
Indicators of sensitivity						
Employment from fisheries (days/year)***	228	220	215	200	216	25
Income from fisheries (%)***	99	97	95	79	92	16
Nutrients uptake from fisheries (kg/month)**	3.69	2.65	2.43	2.81	2.89	1.32
Sub-Index of sensitivity***	0.76	0.63	0.59	0.47	0.61	0.19
Indicators of adaptive capacity						
Number of adult workforce***	2.84	3.12	3.44	4.88	3.57	1.92
Presence of non-elderly household head	0.88	0.88	0.88	0.96	0.90	0.30
Experience (years)	15.72	15.56	15.76	18.20	16.31	9.00
Education (years)***	4.68	5.76	7.44	9.48	6.84	3.04
Health (days)	338	340	352	339	342	33
Presence of male-headed household*	0.88	1.00	1.00	1.00	0.97	0.17
Quality of house***	1.28	1.68	2.04	3.18	2.04	1.53
Number of fishery materials**	0.04	0.24	0.44	0.52	0.31	0.49
Use of technology***	1.84	2.60	2.88	4.08	2.85	1.46
Distance from services**	5.20	5.68	7.08	6.68	6.16	2.10
Natural capital **	0.80	1.00	1.04	1.12	0.99	0.33
Financial capital excluding income***	1.36	1.60	1.72	2.24	1.73	0.65
Per capita income (Taka)**	18,406	18,043	41,647	59,398	34,374	46,875
Social capital ***	8.32	9.00	10.24	9.96	9.38	1.70
Number of income-generating activities**	1.56	1.48	1.56	2.32	1.73	0.93
Sub-index of adaptive capacity***	0.27	0.38	0.49	0.64	0.45	0.19
Index of livelihood vulnerability***	0.18	0.13	0.10	0.05	0.11	0.05

* Indicates significant difference (normalised values were used) between vulnerability classes in ANOVA test; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

them together as dependence on small-scale marine fisheries.

Adaptive capacity

Adaptive capacity depends on the context of each household and community, but some indicators appear to be general determinants of livelihood vulnerability in the two communities. Unlike sensitivity, the sub-index of adaptive capacity does not differ significantly ($p > 0.05$) between the two communities (Tables 3, 4). However, significant differences ($p < 0.01$) exist in adaptive capacity between the household vulnerability classes of each community. A range of indicators such as the number of adult workforce, quality of house, number of fishery materials, natural capital, financial capital excluding income, per capita income, social capital, and number of income-generating activities are significant ($p < 0.001$–$p < 0.05$) in distinguishing vulnerability classes of households in both communities.

Among the six human capital indicators only the "number of adult workforce" in a household is significant (Tables 3, 4). According to FGD participants, the lack of adult workforce increases livelihood vulnerability by limiting the household's ability to tackle emergencies during extreme weather events, as well as its access to livelihood assets and strategies. For instance, during cyclone *Sidr* some of the household heads of Padma remained at sea or otherwise outside of their home, and due to lack of adults the households were less able to move their members and assets in a timely way.

The "quality of house" was identified as an important adaptive capacity indicator in the vulnerability matrices. The quality of house improved as the level of vulnerability decreased (Tables 3, 4). Most houses in the two communities have dirt walls and thatched straw or weak corrugated tin roofs, and they are usually destroyed by extreme weather events. For example, according to vulnerability matrix participants, *Sidr* destroyed most houses in Padma and *Gorki* destroyed half of the houses in Kutubdia Para.

Boats and nets were also identified as important indicators of adaptive capacity—less vulnerable households had more of them than more vulnerable households (Tables 3, 4). The lack of boats and nets limits a household's choice and, in some cases, requires a household to adopt more climate-sensitive strategies. For example, offshore fishing during cyclones is regarded as dangerous. But in Padma, some household heads (boat crews) without a boat of their own were coerced to catch fish in cyclonic seas by those (boat owners) who do own boats.

Lack and loss of natural capital increase livelihood vulnerability by reducing the number of livelihood activities and capacity to cope with climatic stresses and shocks. Past floods have also reduced the size of fish-drying fields in Kutubdia Para and the number of fish that can be dried there. Lack of other natural capital such as trees and agricultural land also reduces adaptive capacity. For example, according to oral history interviews, not having coconut or palm trees in or near the homestead restricts the ability of some households of Padma to take shelter during a flood.

Financial capital, particularly income, is also an important indicator of adaptive capacity. Lack of income increases livelihood vulnerability by reducing both coping and adaptive capacity. The most vulnerable classes of households are not able to augment their livelihood assets and, sometimes, not even access these assets due to their low incomes, which in turn increase their vulnerability. Lack of other financial capital such as livestock, jewellery, and stored food can limit a household's coping mechanisms. For example, according to oral history interviews and FGDs, not having stored food forced some households, especially in Padma, to sell valuable items at low prices during past extreme weather events.

Social capital such as access to relatives and friends helped households to cope. However, their ability to cope and adapt was constrained because of the absence of community organisations. The most vulnerable households had the least social capital while moderately vulnerable households had most of it (Tables 3, 4). That is, social capital is not the sole determinant of vulnerability among households.

A household's involvement in a diverse set of income-generating livelihood activities or strategies reduces the vulnerability of the household, more clearly so in Padma than in Kutubdia Para (Tables 3, 4). Without livelihood diversification, dependency on fisheries becomes pronounced and so does livelihood vulnerability because fishing and fish processing have high exposure to cyclones, floods, and variations in maximum temperature and rainfall.

Discussion

We assessed the vulnerability of fishery-based livelihoods to the impacts of climate variability and change using locally relevant indicators of exposure, sensitivity, and adaptive capacity. Understanding how these components and indicators influence the vulnerability of livelihoods provides an important starting point for directing future research and climate change coping and adaptation initiatives in developing countries, particularly those with fishery systems that are similar to those of Bangladesh.

Fishery-based livelihoods in households of Padma and Kutubdia Para have high exposure to climate-related shocks and stresses, especially floods and cyclones, because the communities are located near the coastline and livelihoods are dependent upon marine fishing from small vessels. Sensitivity of livelihoods to climate variability and change is determined by dependency on marine fisheries for livelihood because of unavailability of alternative livelihoods, lack of financial capital to invest in alternative livelihoods, lack of institutional support for livelihood diversification, and lack of human capital to engage in alternative livelihood strategies. Adaptive capacity of households is limited because of the lack of physical, natural, and financial capital and limited diversification of livelihoods. These factors are interrelated. Because of the lack of financial capital (i.e. income or access to credit), households cannot augment their physical capital (i.e. boats or nets) or diversify their livelihoods. These results resonate with research that has found that the most vulnerable households and communities are usually also poor (e.g. Paavola 2008; Black et al. 2011; Deressa et al. 2011).

Exposure, sensitivity, and adaptive capacity influence the vulnerability of fishery-based livelihoods in varied ways. Those who are most exposed are not necessarily the most sensitive or least able to adapt. That means the climatic stresses and shocks have unequal impacts in different fishery-dependent communities. This aligns with research on the vulnerability of agriculture-based livelihoods that has also found the most exposed regions are not necessarily most sensitive (Gbetibouo et al. 2010). Also, having the least adaptive capacity does not necessarily make a household or a community most vulnerable because of its lower sensitivity and/or exposure. But within a fishing community, where households are similarly exposed, higher sensitivity and lower adaptive capacity combine to create higher vulnerability (for similar results in agricultural communities, see (Eakin and Bojórquez-Tapia 2008). These findings highlight how socio-economic inequalities can underpin livelihood vulnerability (Dyson 2006; Laska and Morrow 2006).

These results are in line with arguments contending that vulnerability to climate change varies between places, communities, and social classes (Adger 2003; Smit and Wandel 2006). Our findings are important because the differential level of vulnerability found between communities and households within each community will help develop adaptation strategies for them (Smit and Wandel 2006).

The contextual nature of livelihood vulnerability and considerations of spatial and temporal scale make it challenging to develop robust indicators. The selection of indicators often involves a trade-off between specificity, transferability, accuracy, and certainty (Vincent 2007). There is room for refining indicator-based approaches to vulnerability assessment as better indicators, models, and data become available. Particular consideration of system dynamics is required in future. For example, we ranked households in each community into different livelihood vulnerability classes. However, no classification will prevail over the long term because micro-scale (household) livelihoods are more dynamic than the macro-economy (Alwang et al. 2001). Also, future vulnerability will be shaped not only by climate change but also by adopted development pathways (IPCC 2007).

In the coming decades, the vulnerability of fishery-based livelihoods may substantially increase because of climate change. In the absence of adaptation, increased frequency and intensity of cyclones and floods would result in greater loss of life at sea and in the coastal zone, greater damage to fishing materials and household assets, and a loss of fishery-related income. If sea-level rise accelerates as projected during this century (IPCC 2007), coastal Bangladesh will experience permanent inundation and accelerated erosion of the land base of its coastal communities. Changes in temperature and rainfall can have unique and direct impacts on the capacity for fish drying, which is the most common fish processing activity in this region. But the future livelihood vulnerability is also intimately linked with technological, demographic, and socioeconomic trends and how they influence the ability of fishery-dependent households and communities to adapt.

Conclusion

We analysed vulnerability of fishery-based livelihoods to climate variability and change using a combination of composite index and qualitative methods. Our findings suggest that different components of vulnerability affect livelihoods in varied ways. Because of the different levels of exposure, the highest sensitivity does not always lead to highest livelihood vulnerability, and the highest adaptive capacity does not always result in the lowest livelihood vulnerability. Exposure, sensitivity, and adaptive capacity are highly context dependent. A large number of factors influence livelihood vulnerability in the two communities. The most important climate-related elements of exposure are floods and cyclones, while the key factor determining sensitivity of an individual household is the dependence on marine fisheries for livelihoods. Adaptive capacity is underpinned by the combination of physical, natural, and financial capital and is influenced by the diversity of livelihood strategies.

This research provides an important starting point for directing future research into the vulnerability of fishery-based livelihood systems to climate variability and change. Further work is needed in order to move towards an improved characterisation of vulnerability and to identify most suitable means for households and communities to cope with and adapt to the impacts of climate change. Nonetheless, based on the findings of this research, it can be tentatively said that efforts to reduce livelihood vulnerability in coastal fishing communities should be multifaceted so as to simultaneously tackle exposure, sensitivity, and adaptive capacity.

Acknowledgments This paper is part of a PhD study, funded by the Commonwealth Scholarship Commission. This work also supported by the ESRC Centre for Climate Change Economics and Policy (CCCEP) and Sustainability Research Institute of the University of Leeds, Carls Wallace Trust, UK, and Annesha Group, Bangladesh. We thank the editors and 3 anonymous referees for their helpful comments and suggestions.

References

Adams WM, Mortimore MJ (1997) Agricultural intensification and flexibility in the Nigerian Sahel. Geogr J 163:150–160

Adatoh M, Meinzen-Dick R (2002) Assessing the impact of agricultural research on poverty using the sustainable livelihoods framework. International Food Policy Research Institute, Washington

Adger WN (1999) Social vulnerability to climate change and extremes in coastal Vietnam. World Dev 27:249–269

Adger WN (2003) Social aspects of adaptive capacity. In: Smith JB, Klein RJT, Huq S (eds) Climate change: adaptive capacity and development. Imperial College Press, London, pp 29–50

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309:1036–1039. doi:10.1126/science.1112122

Agrawala S, Ota T, Ahmed AU, Smith J, van Aalst M (2003) Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans. Organisation for Economic Co-operation and Development, Paris

Allison EH, Perry AL, Badjeck M-C, Adger WN, Brown K, Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish 10:173–196. doi:10.1111/j.1467-2979.2008.00310.x

Alwang J, Siegel PB, Jørgensen SL (2001) Vulnerability: a view from different disciplines. Social protection discussion paper series, Washington

Badjeck MC, Allison EH, Halls AS, Dulvy NK (2010) Impacts of climate variability and change on fishery-based livelihoods. Mar Policy 34:375–383. doi:10.1016/j.marpol.2009.08.007

Banglapedia (2006) Banglapedia—national encyclopedia of Bangladesh. Asiatic Society of Bangladesh, Dhaka

Barnett J (2001) Adapting to climate change in Pacific Island countries: the problem of uncertainty. World Dev 29:977–993. doi:10.1016/s0305-750x(01)00022-5

Bebbington A (1999) Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Dev 27 (12):2021–2044. doi:http://dx.doi.org/10.1016/S0305-750X(99)00104-7

Black R, Bennett SRG, Thomas SM, Beddington JR (2011) Climate change: migration as adaptation. Nature 478:447–449

BMD (2011) Weather data. Bangladesh Meteorological Department, Dhaka

Brander K (2006) Assessment of possible impacts of climate change on fisheries. Wissenschaftliche Beirat der Bundesregierung Globale Umweltveränderungen (WBGU), Berlin

Brander K (2010) Impacts of climate change on fisheries. J Mar Syst 79:389–402. doi:10.1016/j.jmarsys.2008.12.015

CARE (2009) Climate vulnerability and capacity analysis handbook. CARE International

Chambers R, Conway G (1992) Sustainable rural livelihoods: practical concepts for the 21st century. Institute of Development Studies (IDS), Brighton

Cheung WWL, Lam VWY, Sarmiento JL, Kearney K, Watson R, Pauly D (2009) Projecting global marine biodiversity impacts under climate change scenario. Fish Fish 10:235–251

Coulthard S (2008) Adapting to environmental change in artisanal fisheries—insights from a South Indian lagoon. Global Environ Chang 18(3):479–489. doi:10.1016/j.gloenvcha.2008.04.003

Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. Global Environ Chang 18:479–489. doi:10.1016/j.gloenvcha.2008.07.013

Czúcz B, Torda G, Molnár Z, Horváth F, Botta-Dukát Z, Kröel-Dulay G (2009) A spatially explicit, indicator-based methodology for quantifying the vulnerability and adaptability of natural ecosystems. In: Leal FW, Mannke F (eds) Interdisciplinary aspects of climate change. Peter Lang, Frankfurt am Main, pp 209–227

David S (1998) Intra-household processes and the adoption of hedgerow intercropping. Agr Hum Values 15:31–42. doi:10.1023/a:1007410716663

Deressa T, Hassan RM, Ringler C (2011) Assessing household vulnerability to climate change: the case of farmers in the Nile Basin of Ethiopia. International Food Policy Research Institute, Washington

DFID (1999) Sustainable livelihoods guidance sheets. Department for International Development, London

Dixon RK, Smith J, Guill S (2003) Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. Mitig Adapt Strat Global Chang 8:93–113. doi:10.1023/a:1026001626076

DoF (2012) National fisheries week 2012. Department of Fisheries, Government of Bangladesh, Dhaka

Downing TE, Ringius L, Hulme M, Waughray D (1997) Adapting to climate change in Africa. Mitig Adapt Strat Global Chang 2:19–44. doi:10.1023/b:miti.0000004663.31074.64

Drinkwater KF, Beaugrand G, Kaeriyama M, Kim S, Ottersen G, Perry RI, Portner HO, Polovina JJ, Takasuka A (2010) On the processes linking climate to ecosystem changes. J Mar Syst 79:374–388. doi:10.1016/j.jmarsys.2008.12.014

Dyson ME (2006) Come hell or high water: hurricane Katrina and the color of disaster. Basic Civitas Books, New York

Eakin H, Bojórquez-Tapia LA (2008) Insights into the composition of household vulnerability from multicriteria decision analysis. Global Environ Chang 18:112–127. doi:10.1016/j.gloenvcha.2007.09.001

Elasha BO, Elhassan NG, Ahmed H, Zakieldin S (2005) Sustainable livelihood approach for assessing community resilience to climate change: case studies from Sudan. AIACC Working Paper No.17, Assessments of Impacts and Adaptations to Climate Change (AIACC), Washington

Emanuel KA (1987) The dependence of hurricane intensity on climate. Nature 326:483–485

FAO (2010) The state of world fisheries and aquaculture 2010. FAO Fisheries and Aquaculture Department, Food and Agriculture Organisation of the United Nations, Rome

Ford JD, Smit B, Wandel J (2006) Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada. Global Environ Chang 16:145–160. doi:10.1016/j.gloenvcha.2005.11.007

Gbetibouo GA, Ringler C, Hassan R (2010) Vulnerability of the South African farming sector to climate change and variability: an indicator approach. Nat Resour Forum 34:175–187. doi:10.1111/j.1477-8947.2010.01302.x

Haddad BM (2005) Ranking the adaptive capacity of nations to climate change when socio-political goals are explicit. Global Environ Chang Part A 15:165–176. doi:10.1016/j.gloenvcha.2004.10.002

Hahn MB, Riederer AM, Foster SO (2009) The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change-a case study in Mozambique. Global Environ Chang 19:74–88. doi:10.1016/j.gloenvcha.2008.11.002

Hajkowicz S (2006) Multi-attributed environmental index construction. Ecol Econ 57:122–139. doi:10.1016/j.ecolecon.2005.03.023

Handmer JW, Dovers S, Downing TE (1999) Societal vulnerability to climate change and variability. Mitig Adapt Strat Global Chang 4:267–281. doi:10.1023/a:1009611621048

IPCC (2001) Climate change 2001: impacts, adaptation and vulnerability: Contribution of working group II to the third assessment report of the Intergovernmental Panel on Climate Change. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Cambridge University Press, Cambridge

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability: Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Cambridge University Press, Cambridge

Islam MM (2013) Vulnerability and adaptation of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. Thesis, University of Leeds

Iwasaki S, Razafindrabe BHN, Shaw R (2009) Fishery livelihoods and adaptation to climate change: a case study of Chilika Lagoon, India. Mitig Adapt Strat Global Chang 14:339–355

Jallow BP, Toure S, Barrow MMK, Mathieu AA (1999) Coastal zone of the Gambia and the Abidjan region in Côte d\'Ivoire: sea level rise vulnerability, response strategies, and adaptation options. Clim Res 12:129–136. doi:10.3354/cr012129

Johannessen O, Miles M (2011) Critical vulnerabilities of marine and sea ice–based ecosystems in the high Arctic. Reg Environ Chang 11:239–248. doi:10.1007/s10113-010-0186-5

Jones L, Ludi E, Levine S (2010) Towards a characterisation of adaptive capacity: a framework for analysing adaptive capacity at the local level. Overseas Development Institute, London

Kelly PM, Adger WN (2000) Theory and practice in assessing vulnerability to climate change and facilitating adaptation. Climatic Chang 47 (4):325–352. doi:10.1023/a:1005627828199

Kovats RS, Bouma MJ, Hajat S, Worrall E, Haines A (2003) El Niño and health. Lancet 362:1481–1489. doi:10.1016/s0140-6736(03)14695-8

Laska S, Morrow BH (2006) Social vulnerabilities and hurricane Katrina: an unnatural disaster in New Orleans. Mar Technol Soc J 40:16–26. doi:10.4031/002533206787353123

Macfadyen G, Allison E (2009) Climate change, fisheries, trade and competitiveness: understanding impacts and formulating responses for Commonwealth small states. Commonwealth Secretariat, London

Maplecroft (2011) Climate change vulnerability index 2012. Maplecroft. http://maplecroft.com/themes/cc/. Accessed 30 Oct 2011

Miles MB, Huberman AM (1994) Qualitative data analysis: a sourcebook of new methods, 2nd edn. Sage Publications Inc., Thousand Oaks

Mirza MQ (2003) Three recent extreme floods in Bangladesh: a hydro-meteorological analysis. Nat Hazards 28:35–64

Mirza M (2011) Climate change, flooding in South Asia and implications. Reg Environ Chang 11:95–107. doi:10.1007/s10113-010-0184-7

MoEF (2005) National adaptation programme of action (NAPA). Ministry of Environment and Forest, Government of Bangladesh, Dhaka

Morgan IJ, McDonald DG, Wood CM (2001) The cost of living for freshwater fish in a warmer, more polluted world. Glob Chang Biol 7(4):345–355. doi:10.1046/j.1365-2486.2001.00424.x

MRAG (2011) Fisheries and livelihood. Fisheries Management Science Programme (FMSP), Marine Resources Assessment Group (MRAG), and Department for International Development (DFID), London. www.mrag.co.uk/Documents/PolicyBrief4_Livelihoods.pdf. Accessed 25 Oct 2011

OECD (2001) Glossary of statistical terms. Organisation for Economic Co-operation and Development. http://stats.oecd.org/glossary/detail.asp?ID=993. Accessed 25 Oct 2011

Olago D, Marshall M, Wandiga SO et al (2007) Climatic, socio-economic, and health factors affecting human vulnerability to cholera in the lake Victoria Basin, East Africa. Ambio 36:350–358. doi: 10.1579/0044-7447(2007)36[350:CSAHFA]2.0.CO;2

Paavola J (2008) Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. Environ Sci Policy 11:642–654. doi:10.1016/j.envsci.2008.06.002

Perry RI, Ommer RE, Allison E, Badjeck M-C, Barange M, Hamilton L, Jarre A, Quinones RA, Sumaila UR (2009) The human dimensions of marine ecosystem change: interactions between changes in marine ecosystems and human communities. In: Barange M, Field C, Harris R, Hofmann E, Perry I, Werner C (eds) Global Change and Marine Ecosystems. Oxford University Press, Oxford

Polsky C, Neff R, Yarnal B (2007) Building comparable global change vulnerability assessments: the vulnerability scoping diagram. Global Environ Chang 17:472–485. doi:10.1016/j.gloenvcha.2007.01.005

Quest_Fish (2012) Quest_Fish project. Government of UK. http://www.quest-fish.org.uk/description.html. Accessed 5 June 2012

Roncoli C, Ingram K, Kirshen P (2001) The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. Clim Res 19:119–132

Sallu SM, Twyman C, Stringer LC (2010) Resilient or vulnerable livelihoods? assessing livelihood dynamics and trajectories in rural Botswana. Ecol Soc 15(4):3

Sarch M-T, Allison EH (2000) Fluctuating fisheries in Africa's inland waters: well adapted livelihoods, maladapted management. In: Proceedings of the 10th international conference of the institute of fisheries economics and trade, Corvallis, 9–14 July 2000

Scoones I (1998) Sustainable rural livelihoods: a framework for analysis. IDS Working Paper No. 72. Institute of Development Studies (IDS), Brighton

Siniscalco MT, Auriat N (2005) Questionnaire design. In: Ross KN (ed) Quantitative research methods in educational planning. UNESCO International Institute for Educational Planning, Paris

Sissoko K, van Keulen H, Verhagen J, Tekken V, Battaglini A (2011) Agriculture, livelihoods and climate change in the West African Sahel. Reg Environ Chang 11:119–125. doi:10.1007/s10113-010-0164-y

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Global Environ Chang 16:282–292. doi:10.1016/j.gloenvcha.2006.03.008

Sullivan C, Meigh JR, Fediw TS (2002) Derivation and testing of the water poverty index phase 1 Final Report. Department for International Development and Natural Environment Research Council, London

Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S (2011) Climate change impacts on the biophysics and economics of world fisheries. Nature Clim Chang 1(9):449–456

Tol RSJ, Yohe GW (2007) The weakest link hypothesis for adaptive capacity: an empirical test. Global Environ Chang 17:218–227. doi:10.1016/j.gloenvcha.2006.08.001

UN (2005) Designing household survey samples: practical guidelines. studies in methods. Department of Economic and Social Affairs, Statistics Division, United Nations, New York

Vincent K (2007) Uncertainty in adaptive capacity and the importance of scale. Global Environ Chang 17:12–24. doi:10.1016/j.gloenvcha.2006.11.009

Watts MJ, Bohle HG (1993) The space of vulnerability: the causal structure of hunger and famine. Prog Hum Geog 17:43–67

Westlund L, Poulain F, Bage H, van Anrooy R (2007) Disaster response and risk management in the fisheries sector. Food and Agriculture Organization of the United Nations, Rome

Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, people's vulnerability, and disasters, 2nd edn. Routledge, London

Yohe G, Tol RSJ (2002) Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. Global Environ Chang 12:25–40. doi:10.1016/s0959-3780(01)00026-7

Yu W, Alam M, Hassan A, Khan AS, Ruane A, Rosenzweig C, Major D, Thurlow J (2010) Climate change risks and food security in Bangladesh. Earthscan, London