

1 **A framework for identifying and selecting long term adaptation policy directions for deltas**

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Accepted Version

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54 *Abstract*

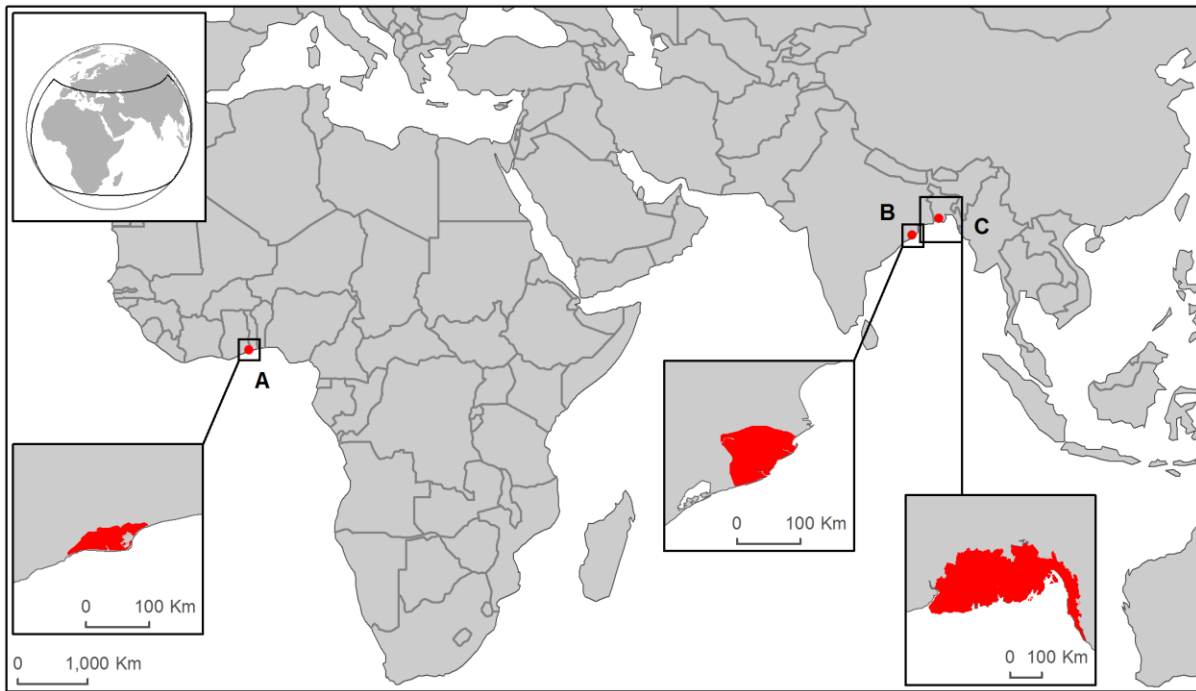
55 Deltas are precarious environments experiencing significant biophysical, and socio-economic
56 changes with the ebb and flow of seasons (including with floods and drought), with infrastructural
57 developments (such as dikes and polders), with the movement of people, and as a result of climate
58 and environmental variability and change. Decisions are being taken about the future of deltas and
59 about the provision of adaptation investment to enable people and the environment to respond to
60 the changing climate and related changes. The paper presents a framework to identify options for,
61 and trade-offs between, long term adaptation strategies in deltas. Using a three step process, we:
62 (1) identify current policy-led adaptations actions in deltas by conducting literature searches on
63 current observable adaptations, potential transformational adaptations and government policy; (2)
64 develop narratives of future adaptation policy directions that take into account investment cost of
65 adaptation and the extent to which significant policy change/ political effort is required; and (3) explore
66 trade-offs that occur within each policy direction using a subjective weighting process developed
67 during a collaborative expert workshop. We conclude that the process of developing policy
68 directions for adaptation can assist policy makers in scoping the spectrum of options that exist, while
69 enabling them to consider their own willingness to make significant policy changes within the delta
70 and to initiate transformative change.

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73 1. Introduction

74 Deltas are dynamic, stressed and often densely populated environments. They are especially
75 vulnerable to the impacts of climate change and variability, including sea-level rise, erosion, land loss,
76 increased soil salinity, and changing storms (Church et al., 2013; Collins et al., 2013). These factors
77 combined with subsidence and sediment starvation are rapidly changing the coastal landscape
78 (Brown and Nicholls, 2015; Syvitski and Saito, 2007). This has implications for deltaic populations
79 who rely on the economic activities and ecosystems services that deltas provide (Ericson et al., 2006).
80 Without adaptation measures to address these multiple stresses, deltas could struggle to attain the
81 Sustainable Development Goals (SDGs) and become unsafe locations. Human interventions have a
82 long history in deltas through efforts to enhance livelihoods and reduce hazards. Engineered
83 adaptation interventions, where they have occurred, have arguably had a major impact on delta
84 evolution (Welch et al., 2017). However, these adaptations have not been systematically planned,
85 assessed or documented to date. Consequently, there is a pressing need for information about what
86 deltaic communities and their governments can do to adapt. Drawing on evidence of policy-led
87 adaptations collected through a five year IDRC funded project ('Deltas, Vulnerability & Climate
88 Change: Migration and Adaptation' - DECCMA) this paper aims to provide policy makers with insight
89 into plausible adaptation policy directions in deltas. DECCMA's geographical focus is on three deltas
90 in Africa and Asia: the Volta in Ghana, the Mahanadi in India, and the Ganges-Brahmaputra-Meghna
91 (GBM) spanning India and Bangladesh (Figure 1). However, this paper has a wider relevance,
92 especially for large ecosystems, as we seek to generate a method for understanding adaptation in
93 complex social and physical environments.



94

95 **Figure 1: Map of the DECCMA study deltas (A: Volta Delta, Ghana; B: Mahanadi Delta, India; C:**
 96 **Ganges-Brahmaputra-Meghna (GBM), India and Bangladesh)**

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98 Adaptation policy is a newly emerging area for most countries where it is becoming an increasingly
 99 important challenge to meet. Adaptation is all the more pertinent in the context of the Paris
 100 Agreement 2015, the global agreement to address climate change, adopted under the United
 101 Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement introduces an
 102 ‘ambition mechanism’ requiring countries to strengthen their commitments to adaptation and
 103 mitigation. Many countries are grappling with the possible contents of adaptation policy, and this is
 104 especially challenging in large interconnected and transboundary ecosystems, such as deltas,
 105 mountains or coasts, where adaptation policies do not exist. Using deltas as an example, we reflect
 106 on the challenges affecting large ecosystems, that often have both upstream and downstream areas,
 107 and that may span national or regional borders. The aim of this paper is therefore to explore long
 108 term adaptation policy choices for deltas. To do this we ask: (1) what adaptations are occurring in

109 deltas?; (2) what are possible future directions for adaptation policy?; and (3) what are the trade-
110 offs associated with each policy direction?

111 This paper first reviews the theoretical literature on framing adaptation, and considers the key
112 drivers underpinning adaptation policy development (section 2). Drawing on data collected by
113 DECCMA researchers during literature searches, inventory analysis and policy analysis, we then
114 outline the planned, policy-led adaptations that are currently occurring in deltas, as well as
115 presenting a method to create and populate four discrete directions for adaptation policy, which
116 considers the trade-offs between different aspects of adaptation (section 3). Section 4 describes
117 specific adaptation actions in DECCMA's three deltas, in the context of the four directions for policy,
118 which range from a minimum intervention approach to radical transformational adaptation.

119 2. Adaptation theory

120 Broadly defined, adaptation is "an adjustment in natural or human systems in response to actual or
121 expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities"
122 (IPCC, 2007). However, debates surrounding more precise definitions as well as the content of
123 adaptation continue unabated adding to the perceived complexity of understanding adaptation
124 (Lesnikowski et al., 2016). Despite the lack of consensus in answering questions about the
125 relationship between adaptation and other variables e.g. coping and adapting, or adaptation and
126 development, progress has been made on agreeing its broad aims. It is generally agreed that
127 adaptation aims to: (1) address drivers of vulnerability; (2) reduce disaster risk (DRR); and, (3) build
128 landscape/ecosystem resilience (Eakin et al., 2009; Ensor and Berger, 2009; McGray et al., 2007).
129 These three broad aims allow a simpler categorisation of adaptation options and an easier
130 communication to stakeholders. We are thus developing and organising our policy adaptation
131 scenarios around these categories.

132 Well-developed theoretical constructs already exist to allow us to explore the three aims of
133 adaptation in more detail. To better understand the first aim, addressing the drivers of vulnerability,
134 the sustainable livelihoods approach (SLA) builds on decades of work on entitlements and
135 endowments. It has been widely used to document poverty and wellbeing in the context of shocks
136 and stresses (Carney, 1998; Chambers and Conway, 1992). The SLA offers a visual and practical
137 framework to categorise adaptations around the different forms of capitals that are used to
138 generate income and support livelihoods (DfID, 1999). The five capitals used in the SLA relate to
139 people's stocks of / access to: i) the natural environment (*natural capital*); ii) health, education and
140 physical wellbeing (*human capital*); iii) financial resources (*financial capital*); iv) physical assets and
141 infrastructure, such as houses, cars, phones (*physical capital*); and v) access to social networks and
142 community support (*social capital*).

143 The Hyogo and Sendai Frameworks (UNISDR, 2005; UNISDR, 2015) categorise actions that address
144 the second aim of adaptation, DRR. These frameworks respond to decades of research into DRR that
145 finds that disasters do not happen on their own – they are created through people's susceptibility
146 and exposure to hazards (Pelling, 2001; World Bank and United Nations, 2010). The frameworks
147 acknowledge that susceptibility and exposure arises from a lack of action in four time steps: i) *long*
148 *term risk mitigation*, such as managing land or infrastructure to reduce risk; ii) *hazard preparedness*,
149 i.e. preparing for specific hazards, for example through developing risk management plans; iii)
150 *response*, timely action taken immediately before, during or immediately after a hazardous event,
151 e.g. evacuation or going to a shelter; and iv) *recovery and rehabilitation*, i.e. returning to normality
152 after a disaster, such as search and rescue, or rebuilding post disaster.

153 A third framework, the Millennium Ecosystem Assessment (MEA 2005), categorises actions that
154 address the third aim of adaptation, building social-ecological resilience. The MEA recognises the
155 value of ecosystems and the services that they provide. Following CGIAR (2014) and Walker and Salt
156 (2012) we define ecosystems services as the combined actions of natural processes that perform

157 functions of value to society. Since the MEA, ecosystems are broadly recognised as delivering four
158 main types of services: i) provision of food, water, building materials and protection of direct use to
159 people (*provisioning services*); ii) maintenance of a diversity of species (e.g. bee and bird populations
160 to fertilise plants) to support other ecosystems (*habitat services*); iii) maintenance of healthy
161 planetary systems e.g. trees to regulate the climate and air quality (*regulating services*); and iv)
162 aesthetic, spiritual, mental health, and cognitive development services (*cultural services*). By using
163 the MEA in conjunction with the SLA, the interrelationships between natural resources and human
164 wellbeing are recognised. As such, this approach addresses criticisms of the SLA that relate to the
165 concept of 'natural capital', notably, that by suggesting ecological processes are a form of capital,
166 trading them for another form of capital, for monetary or other gain, is without consequence
167 (Sneddon, 2000).

168 Collectively, these three theoretical frameworks allow us to consider adaptation options at multiple
169 spatial scales, across multiple environments (from human to natural), and at multiple administrative
170 scales (household to national). To allow us to identify and document adaptations we use all three
171 frameworks (Figure 2), recognising 13 classes of adaptation. Although we document adaptations
172 using deltas as an example, these classes of adaptation could apply anywhere.

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Adaptation to climate variability/change and related drivers

Vulnerability Reduction

1. Human capital

2. Financial capital

3. Social capital

4. Physical capital

5. Natural capital

Disaster Risk Reduction

6. Risk mitigation

7. Hazard preparedness

8. Disaster response

9. Post disaster recovery

Social-Ecological Resilience

10. Provisioning services

11. Regulating services

12. Habitat services

13. Cultural services

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176 **Figure 2: Classes of adaptation**

177 As with any typology, there are inevitably overlaps between categories. To address this issue, we
178 have slightly modified the focus of some of the 13 classes, which are outlined in greater detail in
179 Table 1. For example, to address areas of potential duplication between 'natural capital' and
180 'provisioning services', we include 'natural capital' adaptations only where the adaptation actively
181 influences livelihoods and relates to land access and ownership. For example, natural capital
182 adaptations may include land reclamation and redistribution (to the poor or other groups) or fishing
183 zones with associated fishing rights. In contrast, adaptations included in 'provisioning services' relate
184 to the production of goods and services by the land. These adaptations may include the use of
185 climate tolerant crops or the provision of seed banks. The following section applies this framework
186 to first identify current adaptation actions in deltas, and then to create directions for policy that
187 explicitly show the trade-offs between the 13 different classes.

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191 **Table 1: Description of the 13 classes of adaptation**

Broad objective of adaptation	Class of adaptation	Description of plausible adaptations
Addressing drivers of vulnerability	1. Financial Capital	Changes in flows of money and savings that households have available, including loans and insurance
	2. Human Capital	Changes in skills, health and ability to labour of members of a household
	3. Social Capital	Changes in networks, relationships and membership of groups that households can use
	4. Natural Capital	Changes in land ownership and access to natural resources and storage facilities
	5. Physical Capital	Changes in infrastructure and goods such as tools and equipment that households can use to increase productivity and non-productive assets of the households (e.g. house material)
Disaster Risk Reduction	6. Managing long term risk	Efforts to build physical and social infrastructure that mitigate the worst impacts of an event. These can be one off activities, for example, building a sea wall, cyclone shelters, or on-going initiatives, e.g. developing flood risk management plans or relocating communities.
	7. Preparedness	Efforts to ensure communities are ready to respond to an event. These activities take place cyclically, for example, ensuring sea walls are maintained, practicing evacuation drills, or testing early warning systems.
	8. Response	Efforts to ensure affected households, communities, business and services receive appropriate assistance during and immediately following an event, e.g. evacuation support, first aid medical supplies, emergency responders
	9. Post disaster recovery and rehabilitation	Efforts to ensure affected households, communities, business and services are able to rebuild following an event, e.g. rehousing, reconstruction, etc.
Landscape/ecosystem resilience	10. Provisioning services	Changes in ecosystem goods, quality or productivity that can be directly consumed, such as food, water, raw materials (e.g. fibre, biofuel, ornamental items), but also adaptations that enhance these services such as the use of irrigation and fertiliser
	11. Regulating services	Changes in the services that keep the wider planetary systems (such as the atmosphere, cryosphere, oceans) functioning and include the regulation of climate, air, nutrient cycles and water flows; moderation of extreme events; treatment of waste – including water purification; preventing erosion; maintaining soil fertility; pollination; and biological controls, such as pests and diseases.
	12. Habitat services	Changes in the habitats that maintain the life cycles of species or maintain genetic diversity, through quality and quantity of suitable habitats. In turn, these habitats underpin the health of provisioning and regulating services.

	13. Cultural services	Changes in aesthetic, recreational and tourism, inspirational, spiritual, cognitive development and mental health services provided by ecosystems.
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193 3. Identifying long term adaptation policy directions for deltas

194 With a view to creating a set of adaptation policy directions for deltas, a three step process was
 195 adopted: i) identify current policy-led adaptation actions in deltas in Ghana, India, and Bangladesh
 196 (using the framing method in section 2); ii), create narratives of adaptation policy directions; and iii)
 197 highlight adaptation trade-offs inherent in each policy direction.

198 *3.1. Step 1: Identify current policy-led adaptation actions in deltas*

199 Adaptation actions were identified using an inventory of observed adaptations, delta-wide
 200 adaptation policy analyses, and a literature search on transformational adaptation. First, to generate
 201 evidence of observed adaptations, we conducted a keyword search using ISI Web of Science. Each
 202 delta team employed specific search terms appropriate to the type of hazard they experienced. For
 203 example, Bangladesh used terms such as “Climat*”, “Adapt*”, “Cyclon*”, “Flood*”, “Salin*”
 204 coupled with the term “Bangladesh”. Papers were deemed suitable for inclusion if they documented
 205 observed (and not theoretical) examples of adaptation, included a study area that was within the
 206 boundaries of the DECCMA deltas, had been peer-reviewed, and were published in English. To
 207 identify articles from the grey literature (e.g. NGO reports) we used a snowballing method where
 208 we discussed the findings of the peer-reviewed literature search with country experts who then
 209 sought out relevant grey literature (Hagen-Zanker and Mallett, 2013). The output of these searches
 210 generated an inventory of 122 adaptations that included strategies such as post disaster mobile
 211 water treatment plants or training on new farming methods. Of these, 93 documents relate to the
 212 GBM delta (85 from Bangladesh and 8 from the Indian Bengal Delta), 14 refer to the Mahanadi, and
 213 15 to the Volta.

214 Second, each DECCMA country team conducted a review of current and proposed adaptation policy
215 in the study areas (Dey et al., 2016.; Ghosh et al., 2016; Haq et al., 2015; Hazra et al., 2016; Mensah
216 et al., 2016). Thirty-one policy documents from the GBM were included in the review (21 from
217 Bangladesh and 10 from the Indian Bengal Delta); 21 policy documents from the Mahanadi were
218 included; and 18 from Ghana. Third, a literature search was undertaken on transformative
219 adaptation to document the types of adaptations that could be considered radical, new and of a
220 scale or intensity so the whole deltaic system is transformed, either socially, physically, or both
221 (Kates et al., 2012; Vincent, 2017).

222 All data were analysed consistently within the three DECCMA deltas using a data collection and
223 analysis template, developed by Tompkins et al. (2010) and described in Tompkins et al. (2017). For
224 each adaptation found in the literature, information categorised based on five core questions asked
225 by (Smit and Pilifosova, 2001): Form: what does the adaptation look like?; Purposefulness: why is
226 the adaptation being undertaken?; Provider /beneficiary: who is providing the adaptation and who
227 is benefiting from it?; Timing: is the adaptation occurring in response to or in anticipation of climate
228 change?; Function / effects: what is the broad aim of in terms of addressing drivers of vulnerability,
229 reduce disaster risk, and/or building landscape/ecosystem resilience. As with all methods, this
230 approach has its limitations, notably, only published works are included and as such, adaptations
231 that have not been reported in the literature may have been missed. The list of adaptation
232 interventions therefore may not reflect all the adaptations that are currently happening in deltas.

233 The adaptations identified included actions undertaken autonomously by households, non-
234 governmental organisations (NGOs) and governments. As the focus of this method is on policy-led
235 adaptation the household adaptations were removed, and the remaining government and NGO-led
236 adaptations were grouped into 67 discrete types, using the high level categorisation of adaptations
237 set out in Table 2. The next step describes the four different policy directions that policymakers may

238 choose to follow. For each of the four policy directions, the adaptations in Table 2 are either
 239 more/less important, or do not feature at all.

240

241 **Table 2: Current or planned policy-led adaptations in DECCMA deltas**

Broad objective of adaptation	Adaptation actions
Addressing drivers of vulnerability	<ol style="list-style-type: none"> 1. Promote livelihood diversification (farming) 2. Switch livelihoods (from farming to off-farm) and develop non-farm industry 3. Promote livelihood diversification (fishing) 4. Promote livelihood diversification - off-farm activity 5. Livelihood diversification – fishing 6. Education for non-farm livelihoods, based within the delta (e.g. STEM livelihoods) 7. Education for non-farm livelihoods, based outside the delta (e.g. STEM livelihoods) 8. Agricultural extension to provide training on how to increase income at the household level, e.g. by providing new farming or fishing techniques. 9. Availability of business and household loans at government level 10. Incentives for migration to economic expansion areas 11. Financial incentives to relocate outside of the worst affected parts of the delta 12. Promote private sector investments in eco-tourism through economic incentives 13. Establish agriculture and fisheries based insurance schemes 14. Post-harvest production and storage at local level (e.g. farmer level) 15. Develop and use open spaces, green belts and other ecologically sensitive areas for alternative livelihoods such as urban farming 16. Use of climate resilient farming techniques 17. Farmer led cooperatives that reduce the cost of production/distribution 18. Improving access to markets for all, including infrastructure and training 19. Fishing zones/rights for small-scale fishers 20. Land reclamation and redistribution (to the poor or other groups)
Disaster Risk Reduction	<ol style="list-style-type: none"> 21. All-Risk-changing-modifications to homes (e.g., height of foundations/walls/floors, climate resilient cluster housing) and local facilities (e.g., raise water sources and sanitation facilities above flood levels) through funding, loans and new building standards and codes 22. Raise land using controlled sedimentation 23. Beach nourishment 24. Land zoning, including no build zones 25. Education at school level re. responsibilities for DRR management e.g. evacuation training 26. Active stakeholder engagement in design and delivery of DRR 27. Communication and information re. individual roles and responsibilities re DRR 28. Readiness of emergency services to distribute medicines, food and potable water 29. Availability of DRR insurance 30. Rehabilitation and upgrading of reservoirs for water storage (e.g. dredging, raising spillway levels) 31. Funding to reduce risks to agriculture (Government-run Agriculture Disaster

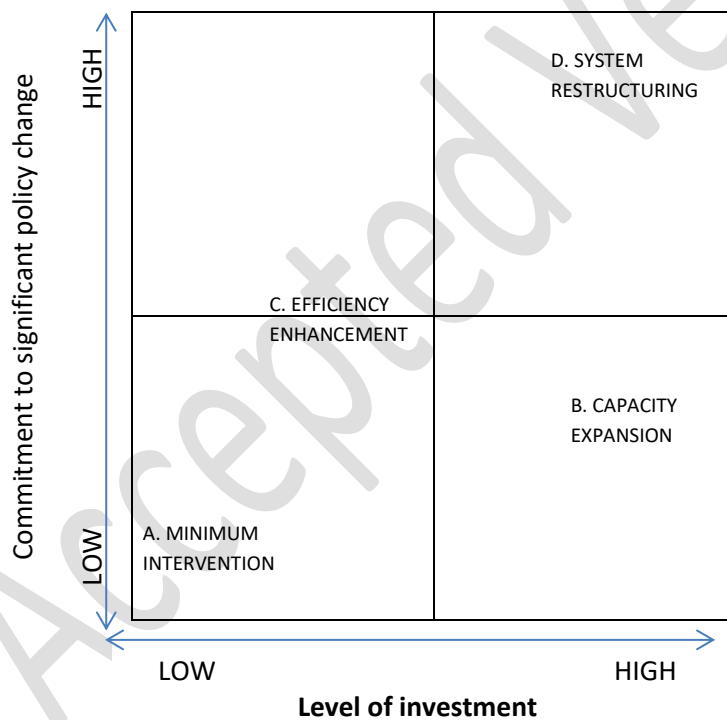
	<p>Mitigation Fund)</p> <p>32. Multipurpose shelters including flood and cyclone shelters used in conjunction with early warning systems</p> <p>33. River/coastal management defence infrastructure (including sea walls, groynes, dikes and polders)</p> <p>34. Climate-proof grain silos/storage (at national and local level)</p> <p>35. Ensure food availability during floods (e.g. Floating gardens and hanging vegetable garden)</p> <p>36. Train community in DRR management</p> <p>37. Train community in water management</p> <p>38. Maintain existing infrastructure</p> <p>39. Initiatives to promote economy recovery, e.g. funding to rebuild damaged economic assets such as ports, roads and grain stores</p> <p>40. Temporary evacuation</p> <p>41. Use of emergency responders</p> <p>42. Secondment of army or national resources</p> <p>43. Post disaster mobile water treatment plants</p> <p>44. Post disaster house construction</p> <p>45. Managed/forced relocation of households from disaster-affected areas</p>
Landscape/ ecosystem resilience	<p>46. Climate tolerant crops</p> <p>47. Changing crop varieties</p> <p>48. Seed bank for crop diversification</p> <p>49. Climate tolerant aquaculture (e.g. brackish shrimp)</p> <p>50. Alternative climate proof grasses for cattle</p> <p>51. Mixed land use (e.g. polder and freshwater shrimp farm with rice)</p> <p>52. Changing irrigation and water level management practices to improve agriculture</p> <p>53. Potable water management</p> <p>54. Promote saline tolerant trees to prevent erosion around farms and homes</p> <p>55. Use of agro-chemicals to boost agricultural productivity and treat salinity</p> <p>56. River course management</p> <p>57. Mangrove forest planting</p> <p>58. Agroforestry</p> <p>59. Afforestation - Promote ecological restoration of degraded and poorly stocked forests</p> <p>60. Tree planting in public areas</p> <p>61. Create incentives for investor in tree crops and plantation (tax relief for private sector investment in research and development)</p> <p>62. Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy</p> <p>63. No commercial mining in forested areas</p> <p>64. Afforestation – climate tolerant bamboo</p> <p>65. Create biological corridors between existing conservation areas to maintain gene flows</p> <p>66. Promote establishment of protected green spaces with native grass along waterways</p> <p>67. Conserve wildlife and biodiversity in natural heritage sites including sacred groves, protected areas</p>

242

243

244 3.2 Step 2: Creating narratives of the adaptation policy directions

245 In creating the directions for policy, we note two key limiting variables that influence adaptation
246 policy choice: the investment cost of the adaptation, and the extent to which significant policy
247 change, and hence political effort, is required (Klein et al., 2014; Mimura et al., 2014; Smit et al.,
248 2001). The adaptations in Table 2 reflect a diversity of costs and effort required. They range from
249 minimal to high cost, and from requiring a small or incremental change to a significant change from
250 the status quo. This spectrum of cost, and willingness to commit to substantial change from the
251 status quo have been recognised in earlier research on infrastructure systems (Hall et al., 2016;
252 Hickford et al., 2015) and the same approach was used here to consider what might drive
253 governments to adopt different adaptation actions (Figure 3).



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257 **Figure 3: Drivers of government-led adaptation policy choice**

258

259 Drawing on this four quadrant categorisation, a set of distinctly different cost and effort sets of
260 plausible adaptation directions are developed for deltas.

- 261 A. *Minimum Intervention (low investment/low commitment to policy change)* is a no-regrets
262 strategy where the lowest cost adaptation policies are pursued to protect citizens from some
263 climate impacts. This strategy addresses those areas where maximum impact can be achieved
264 for the lowest cost, requires low levels of commitment to policy change and promotes
265 adaptations that require little investment. This direction reflects either a fundamental
266 preference for a non-interventionist government, or a government lacking ambition or the
267 capacity to act. It may also reflect the position of a government that feels that no further action
268 is required. There is little planning for climate events, instead, the government provides a basic
269 emergency response.
- 270 B. *Capacity Expansion (high investment/low commitment to policy change)* encourages climate-
271 proof economic growth, but does not seek to make significant change to the current structure of
272 the economy. A high level of investment is required to prepare the economy for future change,
273 but adaptation policy does not aim to reorient the economy, or create significant change.
274 Instead, the focus is on climate proofing industry and enhancing ability to adapt to changes.
- 275 C. *Efficiency Enhancement (medium investment/medium commitment to policy change)* is an
276 ambitious strategy that promotes adaptation consistent with the most efficient management
277 and exploitation of the current system, looking at ways of distributing labour, balancing
278 livelihood choices, and best utilising ecosystem services to enhance livelihoods and wellbeing
279 under climate change. As this policy direction is about efficiency, it requires less investment than
280 other interventionist approaches (i.e. capacity enhancement and system restructuring).
281 However, there is a reasonable commitment to significant policy change as the system moves
282 toward supporting people to adapt to long term change.
- 283 D. *System Restructuring (high investment/high commitment to change)* embraces pre-emptive
284 fundamental change at every level in order to completely transform the current social and
285 ecological system, and change the social and physical functioning of the delta system. There is a

286 guiding belief that significant/radical landscape modifications are justified to create long term
287 system restructuring despite the short term costs that may be accrued, among some social
288 groups, or economic sectors. Within this broad policy direction are three possible sub-directions
289 which each seek a different end goal. The first is *'protect'*, broadly following the Dutch model
290 with use of extensive protective infrastructure and significant landscape changes to protect the
291 current status quo in terms of livelihoods (VanKoningsveld et al., 2008). Under this policy, land is
292 protected from any further change so that communities can continue to maintain traditional
293 livelihoods such as farming or fishing. The second is *'accommodate'*, as is evolving in the
294 Mississippi delta where livelihoods have significantly changed in order to *'live with nature'* and
295 there is an aspiration to *'work with nature'* to adapt to changes to the natural environment (Day
296 et al., 2014). The third is *'retreat'* or abandonment of the delta in terms of population, for
297 example, through a policy of population and infrastructural relocation (Dun, 2011). All three
298 restructuring policies require a high level of investment and a high commitment to significant
299 policy change.

300 3.3 Step 3: Exploring adaptation trade-offs

301 Having developed a conceptualisation of adaptation, collated evidence of adaptation, and designed
302 a contrasting set of adaptation policy directions, the next step is to allocate specific adaptation
303 measures to each direction. To do this, a more nuanced understanding of each policy direction is
304 required where each of the 13 adaptation classes are given relative weights to reflect the relative
305 levels of investment, and political willingness to change. In the context of finite resources, this
306 approach also identifies the trade-offs that occur between the 13 adaptation classes. Due to the
307 complexity of the task, and following Brooks et al. (2005), an expert interdisciplinary group of eight
308 delta research scientists (in the fields of climate change adaptation, engineering, systems modelling,
309 population and development, and geography) were asked to deliberate on the relative investment
310 availability under each policy direction, and to assign weights to reflect this investment (Table 3).
311 Low, medium and high levels of investment were represented by three weights allocated out of 40.

312 Hence direction A (the least costly) is weighted 20; B is weighted 40; C is weighted 30; and, D is
 313 weighted 40. These weights constrain the quantities and focus of adaptation under each direction,
 314 thus highlighting the investment directions under each scenario. This however, also means that
 315 some adaptation measures may be ignored altogether.

316

317 **Table 3: Weights assigned to policy directions**

Broad objective of adaptation	Class of adaptation	Policy direction					
		A. Minimum intervention	B. Capacity expansion	C. System efficiency	D. System restructuring		
					Protect	Accommo- date	Retreat
Addressing drivers of vulnerability	1. Financial capital	0	8	0	3	15	10
	2. Human capital	5	7	6	3	15	10
	3. Social capital	0	0	6	0	0	0
	4. Natural capital	0	0	4	3	0	0
	5. Physical capital	0	5	0	0	0	0
DRR	6. Managing long term risk	1	4	4	20	10	0
	7. Preparedness	0	2	3	0	0	0
	8. Response	4	2	0	0	0	0
	9. Post disaster recovery and rehabilitation	4	2	0	0	0	20
Landscape/ ecosystem resilience	10. Provisioning	6	5	3	10	0	0
	11. Regulating	0	5	1	1	0	0
	12. Habitat	0	0	1	0	0	0
	13. Cultural	0	0	2	0	0	0
	Total investment	20	40	30	40	40	40

318

319 The expert group also determined how 'significant policy change' could be represented by allocating
 320 the points within each policy direction across the 13 adaptation classes. The points within each
 321 adaptation class were allocated using a two stage subjective weighting process. First, for each
 322 policy direction, each expert was asked to rank the 13 classes in order of importance. Then, in a
 323 collaborative workshop, the experts deliberated on the order of the classes for each policy direction
 324 until consensus was achieved. Second, the experts were asked to assign the points available under

325 each policy direction to each of the classes based on their importance. Again, this was done through
326 an open process of deliberation until consensus was achieved. As with any subjective decision
327 making process, the outcome is informed by the knowledge, perceptions and experience of the
328 decision makers. Thus a potential limitation arises.

329 Using this approach, the least costly policy direction, Minimum Intervention spreads limited
330 resources across six of the 13 classes of adaptation. However, one of the three most ambitious
331 directions, System Restructuring (Retreat) divides more substantial resources across just three
332 classes of adaptation and uses half of its significant resources on post disaster recovery and
333 rehabilitation alone. Using this weighting system it is possible to constrain the relative scope and
334 types of adaptation present in each policy direction to understand where trade-offs occur.

335

336 4. Understanding adaptation policy choices in deltas

337 Using the methods described in section three, this section explores more deeply the nature and
338 structure of the adaptation policy directions. The policy directions offer a vision of some of the
339 feasible adaptation futures within deltas, taking into account the main objectives of adaptation, and
340 the adaptation actions that currently occur in deltas. The impacts of each direction can only be
341 understood through an analysis of the specific adaptation choices that it promotes. To populate the
342 four policy directions, the 67 adaptation types in Table 2 were categorised using the 13 classes of
343 adaptation (see Tables 4-7). Each adaptation can appear in more than one of the policy directions.
344 For example, the adaptation intervention to 'promote private sector investments in eco-tourism
345 through economic incentives', was categorised under "*1. Financial capital – addressing drivers of*
346 *vulnerability*". It was then assigned to the Capacity Expansion policy direction as it offers a non-farm
347 income generating activity, which sits alongside traditional farm based livelihoods. It was also
348 assigned to the System Restructuring (Accommodate) policy direction as it may enable a complete

349 shift from farm-based to non-farm-based livelihood activities that are more suited to a changed
350 environment. For each of the four policy directions, we detail the adaptation options that might
351 occur within them, highlighting areas that are less important, or that are ignored all together.

352

353 4.1. *The Minimum Intervention adaptation choices*

354 *Vulnerability* is reduced through investing in human capital. There is little or no investment in other
355 forms of capital. Investment in *human capital* may include basic training on how to increase income
356 at the household level, such as learning new farming or fishing techniques. For example, India's
357 Central Rice Research Institute (CRRI) provide support and training to farmers to develop integrated
358 rice-fish farming systems on flood prone land in Odisha (RCDC, 2011) The CRRI also provide training
359 so farmers can grow new varieties of fruit, vegetables and trees. Other similar schemes were
360 reported (see: Ahmed and Garnett, 2011; Sattar and Abedin, 2012; Sterrett, 2011).

361 *DRR* is delivered in three ways. First, through simple measures to *address long term risk*, such as
362 training farmers to create floating gardens on flooded land (Practical Action, 2011). Second,
363 through *disaster response* such as temporary evacuation, emergency responders and the
364 secondment of the army or national resources. For example, WWF-India has helped train disaster
365 management teams in West Bengal who receive state support to help the community during
366 extreme events (Danda, 2010). Third, basic services are provided during post *disaster recovery and*
367 *rehabilitation*, such as post disaster mobile water treatment plants and post disaster house
368 construction for the worst affected households. For example, following Cyclone Komen (2015) the
369 Bangladesh Red Crescent Society (BDRCS) distributed cash grants, 3,000 tarpaulins, 30,000 packets
370 of oral rehydration solution and installed two mobile water treatment plants in the worst affected
371 areas (IFRC, 2015).

372 *Ecosystem resilience* is delivered through some basic *provisioning services*, which are partially
373 supported through training services such as potable water management. For example, in Bangladesh,

374 UNICEF and the Department of Public Health have introduced pond sand filters (PSFs) along the
375 coastal belt (Ahmed, 2010). There is no support for other ecosystem services. See Table 4, for
376 details of the specific adaptation interventions.

377 4.2 *The Capacity Expansion adaptation choices*

378 *Vulnerability* reduction is the main focus of this policy direction with the prime focus is on improving
379 *financial capital*. This is done at the household level, for example training on post-harvest production
380 and storage (Chowdhury et al., 2011) and government and NGO provided loans (Aveh et al., 2013;
381 Nukpezah and Blankson, 2017). For example, micro-credit based by the World Health Organization
382 (WHO) in the Volta have shown a reduction in poverty among women farmer-entrepreneurs.

383 Vulnerability reduction is also done at the government level, for example, by encouraging private
384 sector investment in ecotourism, which is a policy goal in Ghana (Government of the Republic of
385 Ghana, 2013). There is also an emphasis on *human capital* as the government invests in training that
386 in turn will ensure households are able to better participate in the non-farm economy (Haggblade et
387 al., 2010) and on *physical capital* by ensuring that appropriate infrastructure exists to support
388 economic growth e.g. roads, storage, rural electricity (Deichmann et al., 2009; Sharma, 2007).

389 *DRR* focuses on *long term risk mitigation* through hard and soft measures. For hard DRR there might
390 be a focus on the provision of river/coastal infrastructure to protect economically important areas,
391 for example, the World Bank recently invested USD 400 million to improve polder embankments in
392 economically important areas of Bangladesh (World Bank, 2013). For soft DRR, preparedness and
393 risk mitigation, for example through agriculture and fisheries based insurance schemes (Government
394 of the People's Republic of Bangladesh, 2009); *Post-disaster recovery* efforts focus on getting the
395 economy functioning quickly after disasters and reducing the impact of natural hazards on economic
396 sectors. For example, rapidly releasing funds to rebuild damaged economic resources such as ports,
397 roads and key grain stores.

398 *Ecosystem resilience* is delivered through investment in *provisioning services*. This is to enable
399 income from food and water production under future climate change, for example, by using saline
400 tolerant crops that can withstand coastal flooding (Islam et al., 2016). There is also a focus on
401 *regulating services*, for example, the use of agro-chemicals or creation of private sector incentives
402 for tree planting. See Table 5, for more details of the specific adaptation interventions.

403

404 4.3 *The Efficiency Enhancement adaptation choices*

405 *Vulnerability* is reduced by focusing on human and social capital at the household and community
406 level. In terms of *human capital*, livelihood diversification in farming is promoted as is the teaching
407 of climate resilient farming and post-harvest production methods (White et al., 2016). In terms of
408 *social capital*, local farming and fishing cooperatives ensure maximum production benefits. Finally,
409 by improving access to *natural capital*, for example through fishing permits, households are able to
410 make the most efficient use of income generating resources (Monirul Islam et al., 2014).

411 *DRR* is provided through investments in long term risk management using relatively low cost
412 interventions such as early warning systems and cyclone shelters (Danda, 2010; Roy et al., 2015) ,
413 development of building codes for buildings in at risk areas and no build zones and government
414 funds to reduce risks to agriculture, such as government run Agriculture Disaster Mitigation Funds.
415 There is also a focus on *preparedness*. Communities are trained to prepare for events through
416 relatively low cost initiative, such as DRR education at school evacuation training and stakeholder
417 engagement in DRR plans (Sunderban Social Development Centre, 2012; WWF-India, 2010). There is
418 little emphasis on *response* or *recovery*.

419 *Ecosystem resilience* is a priority as it supports efficient management and exploitation of the delta
420 system. All four ecosystem services are recognised as contributing to wider system efficiency and all
421 are the focus of government interventions. The focus is on low cost interventions. In terms of

422 *provisioning*, mixed land use and irrigation are promoted (UNDP Bangladesh, 2011). In terms of
423 *regulating*, tree planting, including mangroves, is the main focus (APOWA, 2012; DasGupta and Shaw,
424 2013; Iftekhar and Takama, 2008; Kinney et al., 2012). In terms of *habitat*, biological corridors are
425 created, as are green spaces with native grass along waterways. Finally, in terms of *cultural services*
426 the conservation of wildlife and biodiversity including sacred groves is promoted. See Table 6, for
427 more details of the specific adaptation interventions.

428

429 4.4. *The System Restructuring adaptation choices*

430 4.4.1 *System restructuring – Protect*

431 This policy direction aims to significantly change the natural system to make sure that traditional,
432 agricultural based livelihoods are protected from climate impacts. *Vulnerability* is reduced by
433 focusing on financial, human and natural capital. In terms of *financial capital* the green belt is used
434 for farming so productivity can be maximised. In terms of *human capital*, climate resilient farming
435 techniques are promoted, and in terms of *natural capital*, land is redistributed to poorer farmers
436 (Devine, 2002) and small-scale fishers receive fishing rights. *DRR* is the main focus with all emphasis
437 on managing *long term risk* through, for example, raising of land elevation using controlled
438 sedimentation (Schiermeier, 2014), the creation of dikes to manage flood water, no build zones, land
439 zoning and massive investment in river/coastal defence infrastructure. Specifically, there is
440 significant investment in river/coastal defence infrastructure to protect the built environment
441 including industry. This would attempt to replicate the success of the Delta Project in the
442 Netherlands (VanKoningsveld et al., 2008) *Ecosystem resilience* is a priority as the aim of this policy
443 direction is to allow traditionally based agricultural livelihoods to continue. In terms of *provisioning*,
444 significant land use changes and use of climate tolerant crops allow farming to continue. In terms of
445 *regulating*, river course management and strict rules around forest use also allow farming to

446 continue. See Table 7, for more details of the specific adaptation interventions in the three sub
447 directions.

448 4.4.2 System restructuring – Accommodate

449 This policy direction aims to significantly change livelihoods (i.e. move away from traditional
450 agricultural activities) to ensure the population can remain in the delta despite environmental
451 change and sudden environmental shocks. *Vulnerability* is reduced by significantly focusing on
452 financial and human capital. In terms of *financial capital*, there is an effort to promote non-farm
453 industry within the delta, such as private sector investments in eco-tourism through economic
454 incentives. *DRR* focuses on *managing long term risk*. There is also a focus on infrastructure that
455 allows people to remain in potentially dangerous locations, such as early warning systems and
456 cyclone/flood shelters (Lumbroso et al., 2017; Paul, 2009). *Ecosystem resilience* is not a priority as
457 land is not used for provisioning. There is no drive to protect current agriculture

458 4.4.3 System restructuring – Retreat

459 This policy direction aims to encourage population movement out of the more vulnerable parts of
460 the delta. *Vulnerability* is reduced by significantly focusing on *financial* and *human* capital. This may
461 include financial incentives to relocate outside of the delta and farmer investment in training for
462 new non-delta livelihoods. *DRR* focuses on *post disaster recovery and rehabilitation*, specifically, the
463 promotion of relocation outside of the delta following an event. *Ecosystem resilience* is not a
464 priority as land is not used for provisioning. However, new habitats may be created as an incidental
465 impact of the policy.

466 5. Discussion and conclusion

467 In this paper, we asked: what adaptations are currently occurring in deltas?; what are possible
468 future directions for adaptation policy?; and, what are the trade-offs associated with each policy
469 direction?

470 For the first time, we have generated a set of observed adaptations that are occurring in three
471 distinct deltas, but which are also generalizable across deltas worldwide. Adaptations are grouped
472 around three main objectives: (1) actions to reduce socio-economic vulnerability; (2) actions that
473 address disaster risk reduction; and (3) actions that affect social-ecological resilience. In this analysis,
474 we do not reflect on the 'success', 'failure' or 'desirability' of the adaptations, but simply identify
475 what is happening. However, this raises an important research question: what are the short-term
476 and long-term impacts of these adaptations on households and the wider delta? And, are
477 adaptations that we are observing today suitable for the future when climatic and other conditions
478 may be very different? Understanding these questions is recommended for future research and
479 DECCMA will also try to provide a quantitative answer.

480 Adaptation actions rarely occur in isolation. More often packages of adaptation measures developed,
481 implemented and evaluated in response to different needs and priorities of nations (EEA, 2014), and
482 these packages of adaptations are likely to reflect policymakers' commitment to both investment
483 and significant change. In this paper, we have developed a method to identify suites of adaptation
484 policies. By recognising both the drivers and constraints on the development of policy (levels of
485 investment and political will to implement change), we have been able to define seven alternative
486 sets of adaptation policy choices that cover a range of possible future states in many deltas. These
487 seven futures also make explicit the trade-offs that occur when policymakers prioritise different
488 aspects of adaptation. As with any work that attempts to identify plausible and realistic bundles of
489 future choices, this research is constrained by current thinking about the nature and scope of
490 adaptation present in deltas today. Indeed, by basing the future policy directions on current and

491 planned adaptation choices we limit the adaptation set to what is known. However, we start to
492 move beyond this by exploring what transformative adaptation might look like in deltas. As a next
493 step in this research, these options can be taken to a range of delta stakeholders combined with
494 other analysis of the future. This will promote further insight on adaptation choices and their
495 implications and refine the choices presented here. This includes application to specific deltas and
496 comparison with the policy process where possible. For instance, the first Bangladesh Delta Plan
497 2100 (BDP2100) is under preparation and the draft is now in circulation for expert comments (GEC,
498 2017). As a living plan, the methods described here can potentially provide a reflective approach to
499 develop the BDP2100 into the future.

500 In answering these questions, we are able to reflect on the implications of adaptation policy choices
501 for deltas where there are uncertain future socio-economic development trajectories, to support
502 policymakers' decisions on the trade-offs necessary to follow their normative goals. This method
503 represents a possible way forward for the global stocktake of adaptation under the Paris Agreement,
504 as it identifies an approach to documenting observed adaptation, as well as giving a vision of
505 possible sets of future adaptation options. Instead of providing a silver bullet this is a way that
506 countries can consider adaptation in a way that suits their geopolitical context and can address their
507 normative goals, expressed as their development aspirations.

Table 4: Adaptation interventions under the minimum intervention direction

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	<i>Not a priority / component not active</i>
	2. Human capital	<ul style="list-style-type: none"> • Agricultural extension officer who provide basic training on how to increase income at the household level, such as learning new farming or fishing techniques.
	3. Social capital	<i>Not a priority / component not active</i>
	4. Natural capital	<i>Not a priority / component not active</i>
	5. Physical capital	<i>Not a priority / component not active</i>
DRR	6. Managing long term risk	<ul style="list-style-type: none"> • Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden)
	7. Preparedness	<i>Not a priority / component not active</i>
	8. Response	<ul style="list-style-type: none"> • Temporary evacuation • Use of emergency responders • Secondment of army or national resources
	9. Post disaster recovery and rehabilitation	<ul style="list-style-type: none"> • Post disaster mobile water treatment plants • Post disaster house construction
Landscape/ ecosystem resilience	10. Provisioning	<ul style="list-style-type: none"> • Potable water management
	11. Regulating	<i>Not a priority / component not active</i>
	12. Habitat	<i>Not a priority / component not active</i>
	13. Cultural	<i>Not a priority / component not active</i>

Table 5: Adaptation interventions under the capacity expansion direction

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	<ul style="list-style-type: none"> Promote private sector investments in eco-tourism through economic incentives Post-harvest production and storage Develop and use open spaces, green belts and other ecologically sensitive areas for alternative livelihood such as urban farming Existence of loans at government level Incentives for migration to economic expansion areas
	2. Human capital	<ul style="list-style-type: none"> Education for non-farm livelihoods, based within the delta (e.g. STEM livelihoods) Education for non-farm livelihoods, based outside the delta (e.g. STEM livelihoods)
	3. Social capital	<i>Not a priority / component not active</i>
	4. Natural capital	<i>Not a priority / component not active</i>
	5. Physical capital	<ul style="list-style-type: none"> Access to markets for all, including infrastructure, training
DRR	6. Managing long term risk	<ul style="list-style-type: none"> Government funds to reduce risks to agriculture (Government run Agriculture Disaster Mitigation Fund) Establish agriculture and fisheries based insurance schemes Cyclone/flood shelters, including early warning systems River/coastal management defence infrastructure(including sea walls, groynes, dikes and polders) Climate proof grain silos/storage Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden)
	7. Preparedness	<ul style="list-style-type: none"> Maintain existing infrastructure (e.g., coastal embankments, river embankments and drainage systems, urban drainage systems)
	8. Response	<ul style="list-style-type: none"> Emergency aid provision Provision to ensure business and economic activities that support the economy receive immediate attention Critical infrastructure protection
	9. Post disaster recovery and rehabilitation	<ul style="list-style-type: none"> Initiatives to get the economy running quickly, e.g. funds available to rebuild damaged economic resources such as ports, roads and grain stores
Landscape/ecosystem	10. Provisioning	<ul style="list-style-type: none"> Potable water management

resilience		<ul style="list-style-type: none"> • Climate tolerant crops (Saline tolerant crops; Use of drought and heat resistant crop varieties – e.g. drought tolerant peppers) • Using different crop varieties • Climate tolerant aquaculture • Promote saline tolerant trees to prevent erosion around farms and homes • Seed bank for crop diversification • Alternative climate proof grasses for cattle
	11. Regulating	<ul style="list-style-type: none"> • Use of agro-chemicals • Create incentives for investor in tree crops and plantation (tax relief for private sector investment in research and development)
	12. Habitat	<i>Not a priority / component not active</i>
	13. Cultural	<i>Not a priority / component not active</i>

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Table 6: Adaptation interventions under the efficiency enhancement direction

Broad objective of adaptation	Adaptation class	Example of adaptation intervention
Addressing drivers of vulnerability	1. Financial capital	<i>Not a priority / component not active</i>
	2. Human capital	<ul style="list-style-type: none"> • Use of climate resilient farming techniques • Livelihood diversification (farming) • Livelihood diversification (fishing) • Livelihood diversification - off-farm activity • Post-harvest production and storage at local level (e.g. farmer led)
	3. Social capital	<ul style="list-style-type: none"> • Farmer led cooperatives that reduce the cost of production/distribution
	4. Natural capital	<ul style="list-style-type: none"> • Fishing zones/rights for small-scale fishers
	5. Physical capital	<i>Not a priority / component not active</i>
DRR	6. Managing long term risk	<ul style="list-style-type: none"> • Cyclone/flood shelters, including early warning systems • All-Risk-changing-modifications to homes (walls/floors, etc.) - through funding and new building codes • Rehabilitation and upgrading of reservoirs for water (e.g. dredging, raising spillway levels) • Government funds to reduce risks to agriculture (Government run Agriculture Disaster Mitigation Fund) • Ensure food availability during flood (e.g. Floating gardens and hanging vegetable garden) • Land zoning/ no build zones
	7. Preparedness	<ul style="list-style-type: none"> • Education at school level re. responsibilities for DRR management e.g. evacuation training • Active stakeholder engagement in design and delivery of DRR • Communication and information re. individual roles and responsibilities re DRR • Readiness of emergency services to distribute medicines, food and potable water
	8. Response	<i>Not a priority / component not active</i>
	9. Post disaster recovery and rehabilitation	<i>Not a priority / component not active</i>
Landscape/ecosystem resilience	10. Provisioning	<ul style="list-style-type: none"> • Mixed land use (e.g. polder and shrimp farm with rice) • Changing irrigation and water level management practices to improve agriculture

	11.Regulating	<ul style="list-style-type: none"> • Mangrove forest planting • Promote the adoption of farm forestry practices, which include managing trees on farms, farm boundary planting and agroforestry systems (Ghana) • Promote ecological restoration of degraded and poorly stocked forests using appropriate reforestation/restoration techniques(ie enrichment planting, Assisted Natural Regeneration) • Tree planting in public areas • Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy • Afforestation – climate tolerant bamboo
	12.Habitat	<ul style="list-style-type: none"> • Create biological corridors between existing of conservation areas to maintain gene flows • Promote establishment of protected green spaces with native grass along waterways
	13.Cultural	<ul style="list-style-type: none"> • Conservation of wildlife and biodiversity in natural heritage sites including sacred groves, protected areas • Protect sacred groves

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Table 7: Adaptation interventions under the system restructuring direction

Broad objective of adaptation	Adaptation class	Example of adaptation intervention		
		Protect	Accommodate	Retreat
Addressing drivers of vulnerability	1. Financial capital	<ul style="list-style-type: none"> Develop and use open spaces, green belts and other ecologically sensitive areas for farming 	<ul style="list-style-type: none"> Promote private sector investments in eco-tourism through economic incentives Development of non-farm industry 	<ul style="list-style-type: none"> Financial incentives to relocate outside of the delta
	2. Human capital	<ul style="list-style-type: none"> Use of climate resilient farming techniques 	<ul style="list-style-type: none"> Education for non-farm livelihoods, based within the delta 	<ul style="list-style-type: none"> Education for non-farm livelihoods, based outside the delta
	3. Social capital	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
	4. Natural capital	<ul style="list-style-type: none"> Land redistribution (to the poor or other groups) Fishing zones/rights for small-scale fishers 	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
	5. Physical capital	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
DRR	6. Managing long term risk	<ul style="list-style-type: none"> Raise land using controlled sedimentation Beach nourishment Land zoning, including no build zones River/coastal management defence infrastructure (including sea walls, groynes, dikes) 	<ul style="list-style-type: none"> Cyclone/flood shelters, including early warning systems Train community in DRR management Train community in water management All-Risk-changing-modifications to homes (e.g., height of 	<i>Not a priority / component not active</i>

		and polders)	foundations/walls/floors , climate resilient cluster housing) and local facilities (e.g., raise water sources and sanitation facilities above flood levels) through funding, loans and new building standards and codes	
	7. Preparedness	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
	8. Response	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
	9. Post disaster recovery and rehabilitation	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<ul style="list-style-type: none"> • <i>Example absent from the data but could include government supported relocation of people outside the delta following an event</i>
Landscape/ecosystem resilience	10. Provisioning	<ul style="list-style-type: none"> • Mixed land use (e.g. polder and shrimp farm with rice) • Changing irrigation and water level management practices to improve agriculture • Climate tolerant crops (Saline tolerant crops; 	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>

		<p>Use of drought and heat resistant crop varieties – e.g. drought tolerant peppers)</p> <ul style="list-style-type: none"> • Using different crop varieties • Climate tolerant aquaculture 		
	11. Regulating	<ul style="list-style-type: none"> • River course management • Reduce the pressure on forests for wood-fuels by encouraging use of renewable energy • No commercial mining in forested areas 	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>
	12. Habitat	<i>Not a priority / component not active</i>	<i>Not a priority / component not active (although new habitat may be created)</i>	<i>Not a priority / component not active(although new habitat may be created)</i>
	13. Cultural	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>	<i>Not a priority / component not active</i>

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References

- Action for Protection of Wild Animals (APOWA). Community stewardship in conservation, restoration and sustainable management of mangroves in Orissa, Available online at: <https://www.mangrovesforthefuture.org/assets/Repository/Documents/Community-Stewardship-in-Conservation-Restoration-and-Management-of-Mangroves-in-Orissa.pdf>, Last accessed on 19 December 2017, 2012.
- Ahmed A. Reducing vulnerability to climate change: the pioneering example of community based adaptation in Bangladesh, Centre for Global Change (CGC) and CARE Bangladesh, Dhaka, 2010, pp. 156.
- Ahmed N, Garnett ST. Integrated rice-fish farming in Bangladesh: meeting the challenges of food security. *Food Security* 2011; 3: 81-92.
- Aveh F, Dadzie P, Krah R. Success of microfinance institutions: the Ghanaian experience. *International Business and Management* 2013; 6: 91-97.
- Brooks N, Adger WN, Kelly PM. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change* 2005; 15: 151-163.
- Brown S, Nicholls RJ. Subsidence and human influences in mega deltas: The case of the Ganges–Brahmaputra–Meghna. *Science of The Total Environment* 2015; 527-528: 362-374.
- Carney D. Sustainable rural livelihoods: What contributions can we make? In: DFID Natural Resources Department, editor. Department for International Development (DfID), London, 1998.
- CGIAR Research Program on Water Land and Ecosystems (WLE). Ecosystem services and resilience framework. . Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 46p. doi: 10.5337/2014.229, 2014.
- Chambers R, Conway G. Sustainable rural livelihoods: practical concepts for the 21st century. Institute of Development Studies., Brighton, 1992.
- Chowdhury AH, Van Mele P, Hauser M. Contribution of Farmer-to-Farmer Video to Capital Assets Building: Evidence from Bangladesh. *Journal of Sustainable Agriculture* 2011; 35: 408-435.
- Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, et al. Sea Level Change. In: Stocker TF, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, et al., editors. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2013.
- Collins M, Knutti R, Arblaster J, Dufresne J-L, Fichet T, Friedlingstein P, et al. Long-term climate change: projections, commitments and irreversibility. 2013.
- Danda A. Sundarbans: Future Imperfect–Climate Adaptation Report. New Delhi: World Wide Fund for Nature–India. Available at [http. assets. wwfindia. org/downloads/sundarbans_future_imperfect__climate_adaptation_report. pdf](http://assets.wwfindia.org/downloads/sundarbans_future_imperfect__climate_adaptation_report.pdf) 2010.
- DasGupta R, Shaw R. Changing perspectives of mangrove management in India–An analytical overview. *Ocean & coastal management* 2013; 80: 107-118.
- Day JW, Kemp GP, Freeman AM, Muth DP. Introduction: Perspectives on the restoration of the Mississippi Delta. *Perspectives on the Restoration of the Mississippi Delta*. Springer, 2014, pp. 1-7.
- Deichmann U, Shilpi F, Vakis R. Urban proximity, agricultural potential and rural non-farm employment: Evidence from Bangladesh. *World Development* 2009; 37: 645-660.
- Devine J. Ethnography of a policy process: A case study of land redistribution in Bangladesh. *Public Administration and Development* 2002; 22: 403-414.
- Dey S, Ghosh AK, Hazra S. Review of West Bengal State Adaptation Policies, Indian Bengal Delta. DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and

- Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2016.
- DfID U. Sustainable livelihoods guidance sheets. London: DFID 1999.
- Dun O. Migration and displacement triggered by floods in the Mekong Delta. *International Migration* 2011; 49.
- Eakin H, Tompkins EL, Nelson DR, Anderies JM. Hidden costs and disparate uncertainties: Trade-offs involved in Approaches to Climate Policy. In: Adger WN, Lorenzoni I, O'Brien KL, editors. *Adapting to climate change: thresholds, values, governance*. Cambridge University Press, Cambridge, 2009, pp. 212-226.
- Ensor J, Berger R. *Understanding Climate Change Adaptation: Lessons from Community-based Approaches*. London: Practical Action, 2009.
- Ericson JP, Vörösmarty CJ, Dingman SL, Ward LG, Meybeck M. Effective sea-level rise and deltas: causes of change and human dimension implications. *Global and Planetary Change* 2006; 50: 63-82.
- European Environment Agency (EEA). *National adaptation policy processes in European countries-2014*. Luxembourg: Publications Office of the European Union, 2014.
- General Economics Division (GEC) of the Government of the People's Republic of Bangladesh. Draft Bangladesh Delta Plan 2100 Available on line at: http://www.plancomm.gov.bd/wp-content/uploads/2017/delta_plan/Bangladesh_Delta_Plan_2100_DRAFT.pdf. Last accessed 18 January 2018, 2017.
- Ghosh AK, Hazra S, Dey S. Review of national adaptation policies, India, DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2016.
- Government of the People's Republic of Bangladesh. *Crop insurance as a risk management strategy in Bangladesh*. Department of Environment. Ministry of Environment and Forests. Government of the People's Republic of Bangladesh, Dhaka, 2009.
- Government of the Republic of Ghana. *National Tourism Development Plan (2013 – 2027)*, Available online at: <http://www.ghana.travel/wp-content/uploads/2016/11/Ghana-Tourism-Development-Plan.pdf>. Last accessed 19 December 2017, 2013.
- Hagen-Zanker J, Mallett R. How to do a rigorous, evidence-focused literature review in international development, A Guidance Note. London: Overseas Development Institute 2013.
- Haggblade S, Hazell P, Reardon T. The rural non-farm economy: Prospects for growth and poverty reduction. *World Development* 2010; 38: 1429-1441.
- Hall J, Otto A, Hickford AJ, Nicholls RJ, Tran M. A framework for analysing the long-term performance of interdependent infrastructure systems. In: Hall MT, A. Hickford, R. Nicholls editors. *The future of national infrastructure: A system-of-systems approach* (p. 338), Cambridge: Cambridge University Press., 2016, pp. 12.
- Haq I, Omar MAT, Zahra QA, Jahan I. Evaluations of Adaptation Policies in GBM Delta of Bangladesh. DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2015.
- Hazra S, Dey S, Ghosh AK. Review of Odisha State Adaptation Policies, Mahanadi Delta. DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2016.
- Hickford AJ, Nicholls RJ, Otto A, Hall JW, Blainey SP, Tran M, et al. Creating an ensemble of future strategies for national infrastructure provision. *Futures* 2015; 66: 13-24.
- Iftekhar M, Takama T. Perceptions of biodiversity, environmental services, and conservation of planted mangroves: a case study on Nijhum Dwip Island, Bangladesh. *Wetlands Ecology and Management* 2008; 16: 119-137.

- Intergovernmental Panel on Climate Change (IPCC). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007, 2007.
- International Federation of Red Cross and Red Crescent Societies (IFRC). Emergency appeal operations update Bangladesh: Cyclone Komen, Available online at https://reliefweb.int/sites/reliefweb.int/files/resources/MDRBD015_OU2%20%281%29.pdf. Last accessed 19 December 2017, 2015.
- Islam MR, Sarker MRA, Sharma N, Rahman MA, Collard BCY, Gregorio GB, et al. Assessment of adaptability of recently released salt tolerant rice varieties in coastal regions of South Bangladesh. *Field Crops Research* 2016; 190: 34-43.
- Kates RW, Travis WR, Wilbanks TJ. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences* 2012; 109: 7156-7161.
- Kinney K, Alfa B, Groen J, Hooglan M, Pauw P, Lasage R. The ADAPTS programme in Ghana Synthesis report, Available online at: <http://www.adapts.nl/perch/resources/adapts-synthesis-report-ghana.pdf>. Last accessed 19 December 2017, 2012.
- Klein RJT, Midgley GF, Preston BL, Alam M, Berkhout FGH, Dow K, et al. Adaptation opportunities, constraints, and limits. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, et al., editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2.* Cambridge University Press, Cambridge, UK and New York, NY, USA, 2014, pp. 899-943.
- Lesnikowski A, Ford J, Biesbroek R, Berrang-Ford L, Heymann SJ. National-level progress on adaptation. *Nature Clim. Change* 2016; 6: 261-264.
- Lumbroso DM, Suckall NR, Nicholls RJ, White KD. Enhancing resilience to coastal flooding from severe storms in the USA: international lessons. *Natural Hazards and Earth System Sciences* 2017; 17: 1357.
- McGray H, Hammill A, Bradley R. *Weather the storm. Options for framing adaptation and development.* World Resources Institute, Washington, 2007, pp. 57.
- MEA (Millennium Ecosystem Assessment). *Millennium ecosystem assessment. Ecosystems and human wellbeing: a framework for assessment* Washington, DC: Island Press, 2005.
- Mensah A, Anderson K, Nelson W. Review of Adaptation Related Policies in Ghana DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2016.
- Mimura N, Pulwarty R, Duc DM, Elshinnawy I, Redsteer MH, Huang H-Q, et al. Chapter 15. Adaptation Planning and Implementation In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, et al., editors. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014, pp. XXX-YYY.
- Monirul Islam M, Sallu S, Hubacek K, Paavola J. Limits and barriers to adaptation to climate variability and change in Bangladeshi coastal fishing communities. *Marine Policy* 2014; 43: 208-216.
- Nukpezah JA, Blankson C. Microfinance Intervention in Poverty Reduction: A Study of Women Farmer-Entrepreneurs in Rural Ghana. *Journal of African Business* 2017; 18: 457-475.
- Paul BK. Why relatively fewer people died? The case of Bangladesh's Cyclone Sidr. *Natural Hazards* 2009; 50: 289-304.
- Pelling M. *Natural Disasters?* In: Castree N, Braun B, editors. *Social Nature.* Blackwell, Oxford, 2001, pp. 170-188.
- Practical Action. *Floating gardens in Bangladesh*, Available online at: <http://www.fao.org/climatechange/17849-0e277b46b31f98942e6bc81bb22319243.pdf>. Last accessed 18 December 2017, 2011.

- Regional Centre for Development Cooperation (RCDC). Integrated Rice Fish Culture Climate Change Adaptation Option Paribartan Project in Kendrapara and Jagatsinghpur. Available online at <https://www.rcdcindia.org/PbDocument/995fd0d595e6ccf-173e-455b-a9f9-796e461137e6IRFC%20as%20CC%20Adaptation%20Option.pdf>. Accessed 18 December 2017, 2011.
- Roy C, Sarkar SK, Åberg J, Kovordanyi R. The current cyclone early warning system in Bangladesh: providers' and receivers' views. *International journal of disaster risk reduction* 2015; 12: 285-299.
- Sattar S, Abedin M. Options for coastal farmers of Bangladesh adapting to impacts of climate change. International Conference of Environment, Agriculture and Food sciences (ICEAFS), Phuket, Thailand, 2012.
- Schiermeier Q. Holding back the tide. *Nature* 2014; 508: 164.
- Sharma DC. Transforming rural lives through decentralized green power. *Futures* 2007; 39: 583-596.
- Smit B, Pilifosova O. Chapter 18, Adaptation to climate change in the context of sustainable development and equity. In: McCarthy JJ, Canziani O, Leary NA, Dokken DJ, White KS, editors. *Climate Change 2001: Impacts, Adaptation, Vulnerability. Contribution of Working Group II. Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 2001, pp. 877-912.
- Smit B, Pilifosova O, Burton I, Challenger B, Huq S, Klein RJT, et al. Adaptation to climate change in the context of sustainable development and equity. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS, editors. *Climate Change 2001. Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, 2001.
- Sneddon CS. 'Sustainability' in ecological economics, ecology and livelihoods: a review. *Progress in Human Geography* 2000; 24: 521-549.
- Sterrett C. Review of climate change adaptation practices in South Asia. *Oxfam Policy and Practice: Climate Change and Resilience* 2011; 7: 65-164.
- Sunderban Social Development Centre. Process Document on LEGO Risk Mapping Pilot Project (LEGO-DRR & CCA). Available online at: <http://www.ssdindia.org.in/gallery/1374828232Process%20Documentation%20of%20LEGO-DRR%20&%20CCA.pdf> Last accessed 19 December 2017, 2012.
- Syvitski JP, Saito Y. Morphodynamics of deltas under the influence of humans. *Global and Planetary Change* 2007; 57: 261-282.
- Tompkins EL, Boyd E, Nicholson-Cole S, Adger WN, Weatherhead K, Arnell NW. Observed adaptation to climate change: UK evidence of transition to a well-adapting society? *Global Environmental Change* 2010; 20: 627-635.
- Tompkins EL, Suckall N, Vincent K, Rahman R, Mensah A, Ghosh T. Observed adaptation in deltas. DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, Accessed 27 November 2017, 2017.
- UNDP Bangladesh. A New Land Use Model: Forest Fruit Fish. Available online at: http://www.bd.undp.org/content/dam/bangladesh/docs/Publications/A%20New%20Land%20Use%20Model_Forest%20Fruit%20Fish.pdf?download. Last accessed 19 December 2017, 2011.
- UNISDR. Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. 22 (International Strategy for Disaster Reduction www.unisdr.org), Geneva, 2005.
- UNISDR. Sendai Framework for Disaster Risk Reduction 2015-2030. 37 (International Strategy for Disaster Reduction www.unisdr.org), Geneva, 2015.
- VanKoningsveld M, Mulder J, Stive M, VanDerValk L, VanDerWeck A. Living with sea-level rise and climate change: a case study of the Netherlands. *Journal of Coastal Research* 2008: 367-379.

- Vincent K. Transformational adaptation: A review of examples from 4 deltas to inform the design of DECCMA's Adaptation Policy Trajectories. In: DECCMA, editor. DECCMA Working Papers. University of Southampton, Southampton, UK, 2017, pp. 18.
- Walker B, Salt D. Resilience thinking: sustaining ecosystems and people in a changing world: Island Press, 2012.
- Welch A, Nicholls R, Lázár A. Evolving deltas: Coevolution with engineered interventions. *Elem Sci Anth* 2017; 5.
- White D, Quinney M, Jarvis A. Climate-Smart Agriculture (CSA) within the Feed the Future Project Portfolio of USAID-Bangladesh: A CCAFS Deep-Dive Review. 2016.
- World Bank. Coastal Embankment Improvement Project - Phase I (CEIP-I), Available online at: <http://projects.worldbank.org/P128276/coastal-embankment-improvement-project-phase-1ceip-1?lang=en&tab=overview>. Last accessed 19 December 2017, 2013.
- World Bank, United Nations. Natural Hazards, UnNatural Disasters. The Economics of Effective Prevention. The International Bank for Reconstruction and Development / The World Bank, Washington D.C., 2010, pp. 254.
- WWF-India. Sundarbans: Future Imperfect Climate Adaptation Report. Available online at: http://awsassets.wfindia.org/downloads/sundarbans_future_imperfect_climate_adaptation_report_1.pdf. Last accessed 19 December 2017, 2010.

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