# Building adaptive capacity to climate change in tropical coastal communities

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**Preface:**

To minimize the impacts of climate change on human wellbeing, governments, development agencies, and civil society organizations have made substantial investments in improving people's capacity to adapt to change. Yet to date, these investments have

tended to focus on a very narrow understanding of adaptive capacity. Here, we propose an approach to build adaptive capacity across five domains: the assets that people can draw upon in times of need; the flexibility to change strategies; the ability to organize and act collectively; learning to recognise and respond to change; and the agency to determine whether to change or not.

**Main text:**

Tropical coastal communities that depend heavily on natural resources are on the front line of climate change. Fisheries and agricultural productivity is likely to be decreased [1, 2, 3] , and the built infrastructure that supports them will be especially vulnerable to sea level rise[4]. An increasing frequency and intensity of coral bleaching events due to global warming has already significantly affected coral-reef dependent coastal communities[5]. The human effect of such changes varies from place to place and even from person to person, depending on the local manifestations of climate change (i.e. the exposure), the degree to which people depend on affected resources (i.e. their sensitivity), and on their capacity to adapt to or take advantage of the changes they experience (i.e. their adaptive capacity)[6].

In light of profound climate change impacts that have already affected both people and the ecosystems they depend on, there is an urgent need to bolster the capacity of tropical coastal communities to adapt. Indeed, many local and national governments, development agencies, and non-governmental organizations are engaged in efforts to build adaptive capacity, yet there is little guidance on how this capacity might be developed. Adaptive capacity refers to the conditions that enable people to anticipate and respond to change, to minimize the consequences, to recover, and take advantage of new opportunities[7]. Earlier research identified key underlying determinants of adaptive capacity as the availability of capital (e.g., financial, social, human) in times of need[8, 9, 10]. Yet recent evidence suggests that adaptive capacity is not simply about having the necessary resources at hand, but also about the willingness and capability to convert resources into effective adaptive action[11, 12].

Here, we synthesize research across a range of disciplines to highlight how adaptive capacity could be built across five key domains (Fig. 1). These are: 1) the **assets** that people can draw upon in times of need; 2) the **flexibility** to change strategies; 3) the ability to **organize** and

act collectively; 4) **learning** to recognize and respond to change; and 5) the **agency** to determine whether to change or not[11, 13, 14, 15, 16, 17]. Below, we discuss these five domains of adaptive capacity and highlight strategies for their development. As a focal lens for these issues, our synthesis primarily uses examples from tropical coastal communities because they are at the coalface of significant climate change impacts, and are already receiving substantial adaptation investments. However, we believe that many of our points relate to building adaptive capacity more broadly. Although tropical coastal communities can develop capacity at multiple scales, we primarily focus on the individual, household, and community scales, which are typically the focus of many community development and aid programs that attempt to build adaptive capacity. Critically, many strategies for building adaptive capacity have the potential to interact with other social and ecological dynamics in ways that create unintended and maladaptive changes to the flow of social and ecological goods and services.

**Assets**

Assets are the financial, technological, and service (i.e. health care) resources to which people have access to, which can be individually owned or public goods. People are generally better able to adapt when they have assets to draw on during times of change[18, 19]. For example, coastal societies experiencing a shift in the ranges of important fish species[1, 2] might draw upon financial assets (savings or credit) to purchase bigger boats and freezers to store fish during longer journeys, in order to fish further afield. Likewise, fishers might adapt to altered compositions of fish assemblages by purchasing new fishing gear that selectively targets the species that have increased in abundance[20, 21].

For tropical coastal communities, building assets could involve: 1) improving productivity through using new technologies and improving efficiencies; and 2) increasing opportunities to access affordable capital, credit, and insurance[22, 23, 24]. Some coastal residents also benefit from social investments (e.g., healthcare) that help to prevent a decline of existing assets (e.g. household assets critical to sustaining livelihoods)[22, 24]. For example, Malaria is a cause of morbidity and mortality in many tropical coastal areas, and households affected by death or illness of household members may find their attempts to secure their livelihoods thwarted by having to meet the costs of recurrent illnesses, often having to sell productive assets (land, livestock, and fishing gear) to cope. This then erodes their capacity to adapt to future shocks

97 and adverse trends[23]. Interventions to address Malaria (e.g. by improving availability of
98 insecticide-treated bed-nets, or improving availability of anti-malarial drugs and emergency
99 care), could therefore help such households escape these 'poverty traps'[22] and build the
100 household assets that could, in the long term, help them adapt to a changing climate. This
101 illustrates the complex and multi-scale interactions between planned and autonomous
102 adaptive action to multiple stressors.
103
104 Attempts to build or secure assets can focus on individuals (for example, providing micro-
105 credit loans) or community-scale public goods (such as infrastructure or information
106 dissemination). However, investments in public goods may fail to reach the most vulnerable
107 if certain social mechanisms (such as caste systems, gender inequality, etc.) prevent some
108 people from accessing the benefits[13, 25, 26]. In these situations, attempts to build adaptive
109 capacity can strongly differentiate society, and it is critical to be aware of the power
110 asymmetries and political dimensions that underpin the potential impacts of intervention.
111
112 Although it is often assumed that the wealthy are better able to adapt to change than the
113 poor[18, 27], building assets that enhance people's ability to exploit natural resources may
114 actually increase the vulnerability of coastal communities to climate change by undermining
115 the long-term sustainability of coastal ecosystems. This represents both temporal and social
116 trade-offs inherent in adaptation strategies, which must be heeded when designing
117 interventions to enhance adaptive capacity. For example, in Tanzania, fishers who were more
118 likely to intensify fishing effort in response to lower catches (thereby increasing exploitation)
119 were those who had assets, but lacked flexibility to change livelihood strategies[28]. Wealthier
120 fishers were thus more likely to catalyse a 'social-ecological trap', whereby lower yields
121 increased fishing exploitation, which in turn further decreased yields[28]. Likewise, investments
122 in basic infrastructure such as roads may increase people's assets by improving market
123 accessibility, while serving as a catalyst for other types of development (e.g., access to
124 education, healthcare, and markets)[29] that can provide greater flexibility and agency to
125 manage climate shocks[30]. However, access to markets is also a key driver of
126 overexploitation[31] and habitat destruction[32], and may increase social-ecological
127 vulnerability[20].
128

**Flexibility**

The flexibility domain of adaptive capacity reflects opportunities for switching between adaptation strategies and captures the diversity of potential adaptation options available. Organisations and individuals with more flexibility are better able to adapt to climatic impacts. In coastal communities reliant on natural resources, flexibility within people's current occupations (e.g., fishing or marine-based tourism) can enable them to minimize losses or even take advantage of climate-related changes, such as shifting species abundance, species range[1, 20], or habitat destruction. Flexibility allows people to change fishing strategies and the location of fishing grounds and tourism operations. For example, fishers in Peru were able to rapidly change from gill and seine nets aboard their fishing boats to trawl nets in response to an abundance of shrimp that appeared with the extreme marine heat wave associated with the 1997-98 El Niño[23]. Flexibility also entails the capacity to shift into different occupational sectors (e.g., agriculture and non-natural resource based enterprises), either temporarily or permanently, in response to climate change impacts (e.g., reductions in fisheries yields or eco-tourism revenue). At a larger scale, the flexibility of organizations and institutions (i.e. both formal and informal rules and norms) to adjust rules, boundaries, partners, and membership helps to manage shocks and perturbations associated with climate change[23, 33, 34]. For example, in coastal cities in Queensland, Australia, local governments have implemented policies to facilitate the re-building of housing and infrastructure at higher levels after flooding[34].

Building flexibility in tropical coastal communities will require a number of strategies. At a larger scale, organizations and institutions can build flexibility through processes of ongoing monitoring and review, with regular formal revision. At the individual scale, flexibility could be fostered by removing social and legal barriers that can constrain key adaptation actions, such as switching to new fishing gears[35]. Building the flexibility to change the location of fishing grounds or tourism operations will not only require the removal of barriers to fishing in different locations, but also require developing ecological knowledge about new places[36], the capacity to reach them (i.e. potentially larger boats). Efforts to build the flexibility to shift occupations primarily focuses on developing alternative income or subsistence livelihoods that are often implemented in conjunction with interventions to reduce poverty[37]. For

example, in North Sulawesi, Indonesia, the introduction of seaweed farming as an alternative to fishing improved villagers' material assets[38].

There are often interactions between flexibility and other domains of adaptive capacity that potentially create other adaptation trade-offs. For example, as coastal communities become wealthier (i.e., have more assets), they often exhibit lower livelihood flexibility[39]. As with the building of assets, the building of flexibility also has potential ecological consequences. For instance, since different fishing gears selectively target different sizes and species of fish, there can be ecological consequences of adopting fishing gears that preferentially target specific species, e.g., those that play a critical role in the maintenance and recovery of coral reef ecosystems[40]. In addition, increasing people's spatial flexibility to adapt to climate change may have negative ecological consequences (such as boom and bust episodes for high demand fish species)[41]. Increased mobility may also be at odds with property rights-based fisheries management or marine spatial planning initiatives that aim to promote sustainability and reduce conflict by defining and limiting where certain activities can occur[42]. Specifically, fisheries management strategies such as Territorial Use Rights for Fishers (TURFs) that define and limit entry into fishing grounds may limit other aspects of flexibility, such as the ability of fishers to move their fishing activities along the coast[42]. Diversification of livelihood activities can also create unintended ecological consequences. For example, investments in alternative livelihoods in aquaculture lead directly to pollution loading and contribute to salinity intrusion, thereby disrupting ecosystem services and the well-being of others[43, 44].

There are a number of challenges to building flexibility. Alternative livelihood projects often fail for social and cultural reasons[45]. For example, the extent that fishers create a sense of themselves around their occupation ("occupational identity") or their place of residence ("place attachment") can limit whether they are able to re-imagine themselves in other roles or places if the need to change arises[46, 47]. Additionally, diversification is not always an option for households that are trapped in deep poverty because there can be insurmountable costs and risks associated with trying something new[24, 48]. In these cases, building the flexibility component of adaptive capacity requires that costs and risks are buffered with the provision of skills and access to capital[49, 50].

**Social organization**

Social organization is the domain of adaptive capacity that captures the ways in which society is organized to enable (or inhibit) cooperation, collective action, and knowledge sharing[16, 51]. Formal and informal relationships between individuals, communities, and organizations can help people deal with change by providing social support and access to knowledge and resources[16]. Critically, social organization is by nature multi-scale, containing individual, collective, and organizational dimensions[16]. For example, preparing for or recovering from high-intensity storms often requires individual people to help one another and state agencies to coordinate short-term recovery and long-term resilience strategies[52]. Likewise, networks that promote information exchange and cooperation can help communities adapt to changes such as increasingly variable fish catch or weather patterns[53].

Trust and social cohesion within communities (referred to as bonding social capital) can play a key role in whether or not people will support each other in times of crisis, or agree on coordinated action to confront climate-induced threats[54]. Governments, development agencies, and civil society organizations can build bonding social capital by creating opportunities for sustained interaction among groups through community events, recreational activities, and spiritual gatherings[55]. Building connections across communities (bridging social capital), and to people or organizations operating at larger scales, (e.g., international NGOs and financial organizations; linking social capital) can help to secure access to resources, scientific information, and technological innovations that facilitate adaptation[56]. For example, when climate change impacts are so severe that people must change livelihoods, bridging connections can provide crucial information about new job opportunities[57]. Likewise, linking social capital can provide access to novel sources of information and resources, and give people a voice in adaptation planning and policy occurring at higher levels[54]. Bridging and linking social capital can be fostered by creating shared values and interpretation of experience through dialogue and engagement, through reducing disparities in income and wealth, and by enabling a sense of involvement in working towards collective goals[58]. Such efforts can include developing or strengthening institutions for collective action, such as co-management[59, 60]. Indeed, collaborative management processes have been shown to improve adaptive capacity by strengthening links among

people responsible for disaster planning in Trinidad and Tobago[61], and among fishers in Chile[62].

Bonding, bridging, and linking social capital facilitate different types of adaptation. For example, strong bonding ties can be crucial for survival in the face of extreme natural disasters and conflict[63], while bridging and linking ties can help national and regional adaptation policies to reflect the goals and objectives of local communities. Robust adaptive capacity depends on having a balance of different types of social capital, where having too much of one type can actually inhibit adaptation. For example, strong cohesive groups can become locked into a particular way of thinking that prevents learning about change or adaptation options[64]. Likewise, when only local elites have bridging and linking connections, the wider community may lack access to the assets needed to effectively respond to change[17]. Consequently, efforts to build social capital need to consider whether and how different types of social capital are available to people, and how social organization interacts with the other components of adaptive capacity.

Empirical examples of building the social organization dimension of adaptive capacity are limited, but emerging evidence suggests that practical efforts can include: 1) establishment and strengthening of networks across scales (e.g. community, provincial, and national)[65]; 2) community currency, or time banking systems, where individuals are incentivised to volunteer[66]. This not only creates novel connections in the community, but also material and mental health benefits among participants[67]; and 3) creation of interaction arenas where people can work together towards shared goals, build trust, and develop social cohesion[67]. Such arenas occur through community meetings and the facilitation of other social events, as well as through town/community planning that creates physical interaction spaces.

**Learning**

Learning reflects people's capacity to generate, absorb, and process new information about climate change, adaptation options, and ways to live with, and manage, uncertainty[23, 33, 68]. Learning can be experimental or experiential, and occurs within and across multiple organisational, spatial, and temporal scales[69]. For example, in response to climate change,

255 fishers will have to learn about new fishing grounds, gears, weather patterns, technologies,
256 species, and in some cases, new ways of making a living.
257
258 Building the learning domain of adaptive capacity to climate change will require supporting
259 processes that enable people to frame or reframe problems by recognizing change,
260 attributing this change to its causes, and assessing potential responses[18, 70]. This may involve
261 supporting formal education[71], as well as informal forums for learning.
262
263 Provision of access to critical information, such as market prices and weather forecasts, is
264 central to building the learning domain of adaptive capacity in coastal communities. For
265 example, early warning systems can help fishers assess potential risks, reduce lost or
266 unproductive fishing days, and ultimately reduce deaths[23]. Likewise, seasonal forecasts can
267 help coastal farmers to choose crops with the best yields under new climatic conditions[7], and
268 future rainfall projections can help local governments manage areas vulnerable to flooding[34].
269 Learning to adapt to climate change also requires investment in peer-to-peer networks (also
270 referred to as communities of practice)[72] that allow people to share experiences of ecological
271 surprise from other locations and other knowledge systems (e.g., expert, local, indigenous).
272 Such peer-to-peer networks have not only facilitated learning, but also empowered people
273 to develop novel adaptation strategies[73]. For example, the Locally Managed Marine Areas
274 network connects and shares experiences among coastal communities across the Indo-
275 Pacific, blending scientific and local ecological knowledge systems to implement a range of
276 community-based fisheries management strategies[74].
277
278 Learning may emerge in a locally generated or self-organized form triggered by crisis, or
279 because of an active adaptive co-management strategy. Learning provides depth in
280 understanding and occurs across time scales, where instrumental single-loop learning occurs
281 within short-to medium periods, and deeper double-loop learning occurs over longer time
282 scales. Instrumental single-loop learning only informs and changes the most immediate
283 technical operations (e.g. turning on the air conditioner in a heatwave), while deeper double-
284 loop learning may change governance procedures at the organizational level (e.g. local green
285 infrastructure planning), and even overarching values and norms at the policy and
286 paradigmatic levels (e.g. reduction of carbon emissions at a societal level)[75] . Both single and

double-loop learning are challenging to orchestrate as they tightly couple with other domains of adaptive capacity, and building this domain can have knock-on effects. For example, supporting formal education opportunities can indirectly reduce poverty and improve health[71]. Yet, learning may only enable adaptation when other domains of adaptive capacity, such as agency, flexibility, and social organization, are sufficient.

**Agency**

Effective adaptation to environmental change not only requires that people have assets, flexibility, learning, and social organization, but also that they have the power and freedom to mobilize these components of adaptive capacity to actively shape their future. Agency, our fifth domain of adaptive capacity, generally refers to the ability of people – individually or collectively – to have free choice in responding to environmental change[11, 12]. It is dependent upon people's belief in their own ability to perform and manage prospective situations and control events that affect them, encompassing aspects of empowerment, motivation, and cognition[14, 76].

Agency plays a pivotal role in activating the other domains of adaptive capacity. For example, the availability, access to, and interpretation of information about the impacts of climate change on fisheries (which are key aspects of learning) are insufficient to enact adaption unless fishers are willing or able to use this information to support the adaptation process[77]. People have little incentive to adapt unless they believe that their actions can produce desired outcomes or forestall undesired ones[78]. As such, agency is the basis for creating visions of alternative futures when large-scale changes are necessary. For example, fishers in Chile have created a new alternative vision for biodiversity conservation in which they have conservation rights within TURFs[79]. However, agency can also be the source of resistance and opposition to adaptation efforts, particularly when they encroach upon key cultural values such as place attachment and occupational identity[80].

Building agency for adaptive capacity to climate change involves three key types of actions: 1) incorporating local or customary knowledge, skills, and management into both science and policy[36, 81]. For example, climatologists and communities have used indigenous knowledge to develop climate history and baseline data, to formulate research questions and develop

locally acceptable climate adaptations[81]; 2) empowering people through participatory processes such as adaptive co-management[33, 82]. For example, in the Philippines, people became actively involved in climate adaptation because decentralization devolved management authority to the municipality level[83]; and 3) removing barriers that may inhibit people´s ability to exercise agency[14, 15]. For example, reduction of regulatory and economic barriers that restrict small-scale water storage has been associated with increased household agency over water security in Small Island Developing States[84].

**Frontiers in building adaptive capacity to climate change**

Scientific frontiers for the building of adaptive capacity relate to trade-offs between the different domains of capacity, issues of justice and distribution, and management of the complexity of feedbacks. First, where are the important trade-offs in adaptive capacity, and where are investments likely to have greatest benefits? Current models and concepts of adaptive capacity do not resolve critical issues of optimal investment across the different domains of adaptive capacity to influence adaptation. They also fail to determine how investments in adaptive capacity may differ by type, for example, investment in adaptation to long-term environmental stresses from climatic changes will differ considerably to investment in adaptation to short-term weather-related shocks. Future research should address these issues through resolving two dimensions: the substitutability of elements of adaptive capacity and the existence of trade-offs, for example through inadvertently reducing one domain of adaptive capacity through investing in others.

The analysis and examples reviewed here suggest that there is limited substitutability between domains of adaptive capacity with respect to shocks and long-term change: investment in assets does not provide the same capacity to adapt as increasing social and individual learning or managing risk. The concept of limited substitution means that adaptive capacity may be restricted by the weakest of its underlying determinants—the so-called weakest link hypothesis[85, 86]. However, the weakest link idea has not been tested, and would require longitudinal and control studies to assess such trade-off effects[87].

A further question for trade-off analysis is whether building specific domains of adaptive capacity may actually crowd out or undermine other domains. For example, collective action

and civic volunteerism can be crowded out by the provision of certain types of government services (i.e. building assets)[58]. Measuring and monitoring the effectiveness of different types of adaptive capacity building programs will be critical to informing these debates[88], where a portfolio approach that builds capacity across domains would minimise the risks of significant trade-offs.

A second critical frontier is the intersection between social justice and the building of adaptive capacity. Better understanding of how social justice affects and is affected by efforts to build adaptive capacity will be crucial to avoiding unintended and even perverse outcomes. For example, rebuilding community-scale infrastructure after a disaster most often exacerbates existing inequalities - making already vulnerable people even more vulnerable and undermining their capacity to adapt in the future. Yet rebuilding infrastructure offers opportunities for progressive planning that redresses past injustices[68, 89, 90]. Likewise, building aspects of adaptive capacity through removing social and cultural institutions that form barriers to adaptation (e.g., customary taboos that restrict where and when people can fish) often has the perverse effect of undermining culturally important beliefs and practices that help to form a basis for agency[91]. The issue of social justice and adaptation is particularly relevant because of the politics that drive how adaptation and recovery efforts and investments are targeted towards specific populations, places, and capacities. The differential response of US hurricane relief in Texas and Puerto Rico in 2017 highlights how recovery investments can be driven at least as much by politics as need.

Place attachment and occupational identity are two further examples where building adaptive capacity towards new occupations or living in new regions can isolate or influence resource-users and impact on their capacity to adapt over the longer term[92]. Future research directions include developing insights into where identity and place attachment are important to maintain in order to ensure that system resilience occurs across scales. Communities may need strategies to maintain identity (individual or system identity) or remain in place. Policymakers should guide such interventions according to the principle of leaving no one behind, now embedded in the Sustainable Development Goals. Correspondingly, strategies that are “pro-poor” and focused on sustainable adaptation[93] highlight the difficulties associated with reaching the poorest and most vulnerable

populations. Often the factors that keep people poor keep them vulnerable, so addressing root causes of poverty in some cases will support adaptive capacity. Efforts to build adaptive capacity will also frequently need to move beyond the local, but at the same time recognise that enhancing capacities of one community may have unintended consequences or undermine capacities at another scale.

The third frontier involves better understanding key linkages and feedbacks to inform improved adaptation outcomes[33, 54]. These linkages and feedbacks occur between scales, between domains of adaptive capacity, and between social and ecological dynamics. Larger-scale social dynamics such as demographics and governance may set a social or political context that enables or inhibits adaptation at smaller scales[94]. Additionally, adaptation actions or capacity building in one location or scale may undermine the adaptive capacity of other geographies, people, and scales. These issues may be particularly relevant in tropical coastal areas where high rates of migration, ecological change, and shifting governance of natural resources exacerbate issues of resource control and conflict[94, 95]. Consequently, investigating the multiscale nature of adaptation and the larger-scale conditions that enable or inhibit local-scale adaptive capacity should be a high priority research area. Additionally, certain adaptation responses (such as changing fishing strategies), interact with ecological dynamics in ways that affect the flows of ecosystem goods and services, with knock-on impacts to human wellbeing. Scenarios, modelling, and empirical research into threshold relationships[96] and feedbacks both between domains of adaptive capacity and between social and ecological systems[97, 98] will be critical to identifying how to minimize the negative and unintended consequences of building adaptive capacity, and will also help identify where critical trade-offs exist.

In the wake of major climate-induced threats to coastal systems such as the global coral reef bleaching event associated with the 2015-16 El Niño[5], many coastal communities around the world are now adapting to the aftermath of multiple interacting stresses on their coastal environments. The need to build adaptive capacity to help these communities anticipate and deal with these changes will only continue to escalate. To date, ad hoc and localised documentation and monitoring of efforts to build adaptive capacity has rendered it difficult to assess success. Yet parties to the 2015 Paris Agreement underscored the realisation that

adaptation is no longer just a local issue but "a global challenge faced by all"[99]. Assessment of past and ongoing efforts to build adaptive capacity across the five domains we identify here will be critical to effective adaptation to this global challenge across multiple scales and places.

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**Author Contributions**

JC conceived of the concept and led the writing. WA, EA, MB, KB, PC, SG, CH, TH, JL, NM, and TM substantively contributed ideas and writing.

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**Fig. 1| Five domains of adaptive capacity to climate change: Assets, Flexibility, Social Organization, Learning, and Agency. The five domains are interlinked; feedbacks and**

**interactions can occur among any of the domains, not just the neighbouring ones graphically represented by connecting arrows.**