Advanced Review

Addressing the risk of maladaptation to climate change

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Edited by Maria Carmen Lemos, Domain Editor, and Mike Hulme, Editor-in-Chief

This paper reviews the current theoretical scholarship on maladaptation and provides some specific case studies—in the Maldives, Ethiopia, South Africa, and Bangladesh—to advance the field by offering an improved conceptual understanding and more practice-oriented insights. It notably highlights four main dimensions to assess the risk of maladaptation, that is, process, multiple drivers, temporal scales, and spatial scales. It also describes three examples of frameworks—the *Pathways*, the *Precautionary*, and the *Assessment* frameworks—that can help capture the risk of maladaptation on the ground. Both these conceptual and practical developments support the need for putting the risk of maladaptation at the top of the planning agenda. The paper argues that starting with the intention to avoid mistakes and not lock-in detrimental effects of adaptation-labeled initiatives is a first, key step to the wider process of adapting to climate variability and change. It thus advocates for the anticipation of the risk of maladaptation to become a priority for decision makers and stakeholders at large, from the international to the local levels. Such an *ex ante* approach, however, supposes to get a clearer understanding of what maladaptation is. Ultimately, the paper affirms that a challenge for future research consists in developing context-specific guidelines that will allow funding bodies to make the best decisions to support adaptation (i.e., by better capturing the risk of maladaptation) and practitioners to design adaptation initiatives with a low risk of maladaptation.

How to cite this article:
WIREs Clim Change 2016, 7:646–665. doi: 10.1002/wcc.409

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Conflict of interest: The authors have declared no conflicts of interest for this article.

INTRODUCTION

There is a general consensus that efforts to support socio-ecological systems threatened by ongoing and partly irreversible climate change are now more urgent than ever, from the local to the global scale. The problem is, however, that not enough is currently understood about what sort of initiatives enhance the ability of socio-ecological systems to adapt on the long run, and which ones have little or no impact.[1–3] Even worse, some initiatives can actually turn out to be harmful. As a result, although these efforts can potentially foster adaptation in the short term, there is a risk that they affect territories', sectors', and people's long-term capacity and opportunities to cope with and manage the impacts of climate change. This possibility generally describes 'maladaptation.'[4–6]

Despite growing efforts worldwide to adapt to climate change, there appears to be little concern about the risk of maladaptation. There is a real possibility, however, that initiatives taken in the name of adaptation might not only waste financial resources, but could also aggravate the consequences of one-off and gradual climate-related changes. In essence, maladaptation describes an action that results in an undesirable and unintended outcome(s). This leads to increased vulnerability, which the action was meant to reduce. Interestingly, there is sometimes a very fine line between success and failure vis-à-vis adaptation, and this raises a crucial question: what does the risk of maladaptation mean in reality?

This paper critically reviews the current theoretical scholarship on maladaptation and, based on an analysis of specific case studies, advances the field by offering an improved conceptual understanding—by identifying the key features of maladaptation—and more practice-oriented insights—using frameworks to capture the risk of maladaptation. *Insights from the Scientific Literature* section takes stock of the way the maladaptation concept has been shaped from evolutionary biology to climate change science. *Insights from the Field: Illustrative Concrete Examples* section presents four concrete examples of real-world adaptation efforts that raise fundamental questions about how to conceive of and delimit maladaptation. *Moving Ahead: Future Research Perspectives* section builds on the previous sections by offering and expanding on four main dimensions to assess the risk of maladaptation, that is, process, multiple drivers, temporal scales, and spatial scales. The following section moves from theory to practice by providing examples of frameworks to address the risk of maladaptation and support more robust adaptation strategies and actions. It concludes that a challenge for future research is to develop context-specific guidelines to allow both funding bodies to support and practitioners to design adaptation initiatives with a low risk of maladaptation.

INSIGHTS FROM THE SCIENTIFIC LITERATURE

Obviously, maladaptation is not a concept exclusive to the climate change context. Like adaptation, it emerged from the world of evolutionary biology. Scholars have since applied it to cultural issues and, later, to the human/environment interface. The use and definition of maladaptation in the context of climate change is relatively recent and there are three overarching points of contention: (1) whether maladaptation only arises from intended adaptation, or is also a possible outcome of poor planning that inadvertently makes people more vulnerable to climate change (i.e., the multiple drivers concern); (2) whether the negative impact of the adaptation strategy must occur in the same location as the strategy itself (i.e., the spatial scale concern); and, (3) whether the emergence of negative impacts on the medium to long run justifies qualifying the initial adaptation initiative as maladaptive (i.e., the temporal scale concern). The following section distils peer-reviewed literature[a] to identify the origins of the concept and its significance in the current literature on climate change.

The Origins of 'Maladaptation'

Evolutionary biologists were most probably the first to use the word maladaptation in the context of evolution of species adapting to changing environments. Because some adaptation is slow and the environment is constantly changing, maladaptation refers here to the instances where species are adapted to the environments of previous generations but not to current environments.[7] It has also been applied to mean evolution 'gone wrong' or in medicine—using the 'disadaptation' term—, for example, to refer to failed physiological adjustments rendering one unfit or unable to adapt. The use of maladaptation suggests that adaptation is seen as an 'ideal' process[b] but that there is a possibility of failure.

Evolutionary maladaptation is the subject of numerous studies,[8] however, these scarcely touch on the type of maladaptation relevant to the human dimensions of climate change. Exploring the human side of the problem, Richerson and Boyd[9] indicate, for example, that it is humans' ability to learn and develop ideas, alongside related behaviors that are inefficient or detrimental, that enables both adaptation and maladaptation. In parallel, Kim[10] concurs that culture is what makes humans stand apart from other species when it comes to biological adaptation and maladaptation. A point Aunger[11] also raised, a decade before, using the example of deliberate food deprivation in the Democratic Republic of Congo.

It is difficult to identify when the concept of maladaptation emerged in the climate change discourse. The main conceptual foundations appear to lie in scholarship aimed at understanding how a change in the environment can influence a society to take action that results in making it worse off—the

cause of collapse of multiple ancient societies.[12,13] Indeed, collapse is usually seen as an extreme form of maladaptation.[14,15] It suggests complete failure. Additionally, Janssen and Scheffer[16] highlight the 'sunk-cost effect'[c] as a major driver of past societies' collapse, arguing that the difficulty that societies experienced in adequately taking into account the possibility of different future conditions in their daily decisions was, and still is, the main source of their inability to anticipate changes. Although these latter scholars use of the term 'maladaptation' is not explicit, they mention the adverse consequences of some strategies and options, as Orlove[14] does in his study of three past collapses—the Classic Maya, the Vikings in Greenland, and the United States during the Dust Bowl. He writes that 'in all three cases, societal responses [to climate stresses] created environmental problems that made it more difficult for them to cope with climate variability' (Ref 14, p. 597), and he concludes that collapse is 'the most dramatic form of maladaptation' (Ref 14, p. 598).

In the Context of Climate Change

The foundation for the study of maladaptation from a climate change perspective is the analysis of environmental neglect by human societies. Scheraga and Grambsch[4] provide some of the first significant thoughts on maladaptation to climate change. In their paper on nine fundamental principles for designing 'good adaptation,' they emphasize the importance of taking into account the 'potential adverse side effects of adaptive strategies [in order to] avoid solutions that are worse than the problem' (Ref 4, p. 85). They explicitly use the term maladaptation, as they claim in the eighth principle that 'maladaptation can result in negative effects that are as serious as the climate-induced effects being avoided' (Ref 4, p. 87). Burton,[17] Smithers and Smit,[18] Adger,[19] Niemeyer et al.,[20] Schipper,[21] as well as Heyd and Brooks[22] also mention the term, to describe an unfavourable outcome of adaptation efforts. Studying the 1970s famine in the Sahel, Heyd and Brooks[22] define maladaptation as 'the pursuit of policies and practices [that] make people more vulnerable to changes in the natural environment in which human systems are embedded' (Ref 22, p. 275).

There is, however, unease with the concept of maladaptation in the climate change context. The IPCC defined it in the Third Assessment Report as: 'any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead' (Ref 23, p. 990). The discomfort is evident in this dual definition, which appears unable to decide whether maladaptation is a case of planned adaptation that failed or one of spontaneous responses leading to unpredictable change. The definition from the Third Assessment Report does not refer to either temporal or spatial scales, although these are key features that allow for one to distinguish between adaptation and maladaptation. The word appears only once in the 'Impacts, Adaptation and Vulnerability' component of the Fourth Assessment Report,[24] and fewer than 15 times in the nearly 600-page SREX report.[25] The IPCC Working Group II contribution to the Fifth Assessment Report[26] contains numerous references to the concept, including an entire section dedicated to 'Addressing Maladaptation.'[3] This suggests both that there is growing scholarship on maladaptation, and that the concept is making its way into the mainstream. Unfortunately, this does not indicate that there is any more clarity on what it means in practice.

Barnett and O'Neill[5] formulated another definition of maladaptation to climate change: 'an action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups' (Ref 5, p. 211). These authors establish a difference between unsuccessful adaptation and maladaptation: the former describes a failed adaptation initiative not producing any significant detrimental effect; the latter specifically refers to an increase in the vulnerability of a system, sector, or group. This distinction emphasizes the key link between maladaptation and vulnerability, in line with the IPCC's earlier suggestion in the Third Assessment Report. Barnett and O'Neill's definition, however, refers specifically to how an initiative taken can increase the vulnerability of 'other' systems, sectors, or social groups. As such, it excludes initiatives that can also have detrimental impacts on the territory, sector, or group of people conducting the initiative. This leaves the definition somewhat incomplete and problematic. There is always a risk of adversely affecting people or ecosystems 'downstream,' and indeed it is arguable that this may be inevitable to some degree. There are also many examples around the world of attempts to reduce vulnerability to climate change in one location or for one group of people—women, for example—that may in fact have the exact opposite effect on the same location or group.[27–29] It is the challenge of not just failing to adapt but exacerbating the situation that warrants deep reflection, especially at the project planning stage.

Barnett and O'Neill[30,31] also hypothesize that there is a decreasing gradient of risk of maladaptation from initiatives only dealing with exposure to natural hazards, to initiatives designed for enhance adaptive capacity at large—which is supposed to be beneficial even without climate change. Other authors refer to maladaptation as a risk of increasing current and/or future vulnerability. In a study on the Solomon Islands, Fazey et al.[32] argue that 'understanding "trajectories of change" is an important initial step for designing appropriate adaptation strategies' (Ref 32, p. 1276). They conclude their study by affirming that 'given that the overall trajectories of change are not reducing underlying drivers [of vulnerability] and that capacities for collective adaptive response are being eroded, the trajectory of change in Kahua [the island studied] can be described as maladaptive' (Ref 32, p. 1288). Here, as in the study of past societies' collapse, the authors emphasize the temporal dimension of maladaptation. More recent publications also place maladaptation into the broader context of adaptation pathways.[d] [33,34] Although many scholars refer to the multiple dimensions of maladaptation—environmental, economic, social, cultural, institutional, and political—they usually do not clearly explain the relationships between these different dimensions. Most notable, all studies agree on the importance of understanding maladaptation as an adverse effect, conscious or not, of an adaptation initiative that can result in increased vulnerability. Working Group II's contribution to the Fifth Assessment Report [Ref 26, see glossary] reflects this: 'Actions that may lead to increased risk of adverse climate related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.' Going a step further, Juhola et al.[6] provide the most comprehensive definition to our view, when asserting that 'maladaptation could be defined as a result of an intentional adaptation policy or measure directly increasing vulnerability for the targeted and/or external actor(s), and/or eroding preconditions for sustainable development by indirectly increasing society's vulnerability' (Ref 6, p. 139). This definition better help emphasizing the multiple drivers, the spatial and the temporal dimensions of maladaptation, some points we will come back on in the *Moving Ahead: Future Research Perspectives* section. Juhola et al.[6] approach, however, proposes an *ex post* analysis of maladaptation (i.e., downstream the implementation of the adaptation-labeled initiative), while what we argue in this paper is that there is also a need for *ex ante* approaches, precisely in order to help limit the risk of maladaptation.

The scholarship on 'sustainable adaptation,' defined as 'adaptation that contributes to socially and environmentally sustainable development pathways, including both social justice and environmental integrity' (Ref 35, p. 8), parallels the literature on maladaptation. Addressing the underlying drivers of vulnerability—that is, socio-environmental processes such as conflict, marginalization, economic restructuring, among other things—the authors refer to the challenge of reducing long-term vulnerability and, therefore, avoiding maladaptation. Accordingly, one can consider sustainable adaptation and maladaptation as two sides of the same coin. Eriksen et al.[35] consider adaptation a process and further stress the temporal dimension as a crucial element to assess whether or not an initiative is, or could be, detrimental.

Resilience scholars also contribute to the discussion on maladaptation by touching on the issue of whether resilience should be built with one specific hazard in mind (i.e., 'specific resilience') or as a general characteristic (i.e., 'general resilience'). The critical argument is that a focus on building resilience to a specific hazard may come at the cost of building resilience to other hazards.[36] This could apply to maladaptation in that addressing one specific dimension of risk could lead to a new driver of vulnerability. For example, in order to get irrigation water for their crops, farmers in Nepal responded to the 2010 drought by excavating ponds in the dry riverbed and pumping groundwater into their fields. When the rains and water returned, however, the deformed riverbeds made the river run differently, flooding large areas that had not been flooded before, causing new damage. Resilience scholars confront the 'undesirable' dimension of resilience, namely the aspect that generates an 'undesirable source of traps, rigidity, inertia, and path dependency' (Ref 37, p. 1), and the mechanisms that drive it. As with maladaptation, Robards et al.[36] suggest that this discussion, which among the resilience community focuses on 'robustness' versus 'rigidity', is not sufficiently developed.

Remaining Questions

Ultimately, maladaptation theory generally recognizes that maladaptation is an increase in vulnerability, but there is little consensus as to whether maladaptation refers only to the people, ecosystem, or location where the adaptation strategy was planned. Barnett and O'Neill,[5] for example, propose that the adverse effect takes place elsewhere. This matters when identifying these adverse effects and tracing causal linkages.

It also matters for another reason: does maladaptation has to result from adaptation or can also arise from poorly planned development unrelated to climate change? This is significant because suggesting that adverse effects of bad development make people worse off is not new and, at the same time, requires a much larger discussion beyond one on maladaptation. The discourse on maladaptation thus appears to encompass more than a failure to describe how projects, plans, policies, and decisions can actually exacerbate the initial pressure and increase current and/or future vulnerability. The discourse, however, currently lacks a rigorous framing that goes beyond intuition to encompass the interactions of the temporal and spatial scales, and that would facilitate identification of when or where maladaptation has or might take place.[6]

Indeed, an initiative labeled 'adaptation' can reduce vulnerability in the short term but can also be detrimental in the long run. For example, a seawall built following a cyclone or a flooding event, if it first secures the area, might have the negative effect of attracting more people to the area, precisely because it is now perceived as safe. The 'safe development paradox' describes the phenomenon,[38] which the 2005 Hurricane Katrina catastrophe in New Orleans notably demonstrated.[38–40] An 'adaptation' initiative can also be detrimental if it reduces the vulnerability of one location by placing pressure on another. Here, one classic example is a small-scale irrigation system that diverts the river upstream, resulting in farmers or other downstream users no longer having access to the same quantity of water as before. Furthermore, if the climate is becoming drier, the downstream users are likely to need even more than they previously had, making the loss of water flows a compounding pressure. Are these both maladaptation or is only the former maladaptation because the latter is instead a classic outcome of poor development?

Answering such a sensitive question requires a proper conceptual framework that must be, we argue, rooted into the real world. To this aim, looking at concrete examples can be inspiring.

INSIGHTS FROM THE FIELD: ILLUSTRATIVE CONCRETE EXAMPLES

This section highlights key features of maladaptation that emerge from case studies taken from various geographical areas and describing various projects. By offering a broad perspective, it lays foundations for a more generally applicable approach to define and diagnose maladaptation, emphasizing four critical issues to identify: process, multiple drivers, temporal scales, and spatial scales.

Methodological Background

The authors of the present paper coorganized or contributed to a 3-day workshop[e] to discuss assumptions about maladaptation reflected in the literature and assess the relevance of existing definitions (see *Insights from the Scientific Literature* section above) to help capture maladaptation in the field. To focus the discussion, most of the meeting participants also presented a concrete case study that they felt was representative of maladaptation. They had been asked to follow a prescribed structure: presenting the nature and context of the initiative—that is, the challenges/problems it addresses; the surrounding social, economic, and environmental conditions; the expected impacts of climate change; and, its objectives, time horizon, and spatial scale—and its expected outcomes—that is, direct and indirect, short term to long term, and beneficial or detrimental to environmental, social, and economic dimensions. In total, 12 examples had been discussed, including projects undertaken by international organizations on infrastructures in rural Bangladesh, artificial islands in the Maldives, coastal protection from storm surges in South Africa, tourism development in an agricultural area in Norway, agricultural transformations in Bangladesh, the (mis)use of climate finance in development practices, the role of insurance in exacerbating risks in coastal regions of the United States and wildfire prone areas in the Rocky Mountain west, water systems (aquifer recharging and irrigation) and crop diversification in rural India, population resettlement in Vietnam and in Mexico, houses and infrastructure reconstruction after floods in Pakistan, development of a planned centralized cropping policy in Indonesia (to the detriment of traditional cropping and ritual calendar), and the disjuncture between disaster risk reduction programs and livelihood programs in Bangladesh.

This section provides a brief description of four case studies that some of the authors of this paper developed during the 3-day workshop, and that allow browsing a wide although not exhaustive range of geographical scopes (coastal/inland contexts, local-/country-scale lenses), types of initiatives (tourism/residential dynamics, infrastructures/social processes/financial investments), and stakeholders (local communities/national authorities/international agencies). These examples are not used here to decide whether we face adaptation or maladaptation, but

rather to illustrate situations where maladaptation emerges, and then help identify critical features to describe the risk of maladaptation.

Case Studies

Case Study 1: Hulhumalé, Maldives

Hulhumalé is 'an artificial island reclaimed to establish a new land mass required to meet the existing and future housing, industrial, and commercial development demands of the Malé region' (Ref 41, p. 761), the capital island, Malé, gathering 27% of the country's 345,000 inhabitants (in 2013). Malé Island's population density is currently around 39,600 inhab.km^2, and Hulhumalé (currently around 2 km^2, expected to reach around 7 km^2 by 2040) is supposed to host between one third and one half of the Maldivian population by 2050 (expected to be around 503,000 inhab.). Hulhumalé is located 2 m above the current mean sea level and coastal defenses surround the majority of the island. Accordingly, Hulhumalé has been a key part of the government strategy to develop 'Safer islands' to better protect people from current and future sea-related hazards[42,43]—including sea-level rise, which is expected to be on the order of half a meter by 2100.[44] The project has had major immediate detrimental effects on the surrounding reefs, especially large-scale dredging. But, as it gathered initially scattered communities in better-protected areas and, consequently, also reduced environmental pressures in many local places in the outer atolls, it is a potentially relevant response to multiple challenges, such as sea-level rise, economic development, and increased demography and environmental degradation in the outer atolls.

Such uncertain and mixed outcomes prompt some fundamental questions, in particular: When can maladaptation be diagnosed, implicating *spatial and temporal scales* to be considered? What are the relevant benchmarks to assess whether Hulhumalé is/has been/will be a success or a failure, implicating the *process* and *multiple drivers* dimensions of maladaptation? These points relate to the issue of assessing an adaptation initiative's effectiveness and the risk of maladaptation, which relates not only to scientific estimates, but also political ones, including economic and social dimensions.

Case Study 2: Afar, Ethiopia

The Afar is a dryland and largely pastoral area (100,860 km^2) in Northeastern Ethiopia. Severe recurrent droughts and warming that may intensify with climate change have hit Afar in the last decade. Efforts to adapt demonstrate how adaptation-labeled programs that contribute to rather than challenge current unsustainable development trajectories in Ethiopia also run the risk of producing poor and/or unintended consequences.[45] Current conceptions of adaptation implies that climate change, rather than multiple socio-environmental stressors, is understood to drive vulnerability, and accordingly, that appropriate policy interventions addressing these climate threats, such as adjustments in technology, practice, and governance systems, will lead to adaptation. Multiple social processes, however, make Afar pastoralists—representing more than 80% of the 1.4 million population of the Afar region—vulnerable during droughts, including conflicts, loss of drought grazing areas, loss of livestock, the inability to migrate in search of water once settled, and the building of a dam for irrigation that has contributed to flooding of grazing lands and settlements. Sedentarization and loss of grazing land to agriculture—mainly sugar cane plantations—have been ongoing for decades and have intensified over the past few years. The massive losses of livestock are undermining the integrity of the whole pastoral livelihood system, leading to impoverishment and increased vulnerability in the face of recurrent droughts. Since 2010, regional adaptation policies for Afar promote investment in irrigation agriculture and nonpastoral livelihoods. Such measures result in some people migrating further for grazing, which sometimes reinforces conflict with other groups, and many shifting out of pastoralism into very marginal livelihoods, including trade and charcoal production. Although some influential individuals are shifting to irrigation agriculture, this livelihood is highly unreliable both in terms of economic viability and exposure to climate variability and change. It also further undermines the adaptive capacity of the community by converting important drought grazing lands to private agricultural land. Hence, social differentiation and vulnerability are reinforced.

The case exemplifies the critical issues of the *multiple drivers* and the *process* of maladaptation. It indeed shows how adaptation policies do not question which development goals are furthered by adaptation measures. Instead, official adaptation efforts dovetail neatly with modernization—that is, sedentarization of pastoralists and expansion of irrigation farming—as an uncontested development pathway. A climate-change centered understanding of adaptation, although it first leads to reducing the threat of climate change, also carries the risk of neglecting—even sometimes reinforcing—the

multiple drivers of vulnerability, thus increasing the risk of maladaptation.

Case Study 3: Cape Town, South Africa

This case addresses the cost to coastline processes and local economy of protecting private properties located too close to the shoreline. Houses at Leisure Bay on the west coast of Cape Town were subjected to erosion of their coastal banks. Storm surges in winter were undercutting the bank and reducing the extent of garden space, with each storm event resulting in progressively worse damage. In the early 2000s, the owners' association, the Leisure Bay Body Corporate, funded and installed sandbags along the bank to reduce erosion. Unfortunately this has led to numerous unintended consequences including loss of beach area, reduced recreational value, and loss of tourism and tourism-derived revenue at the bay scale. The impact on the biophysical system has also been significant as the sandbags were not ultraviolet light resistant and thus broke apart releasing strands of plastic. Even if erosion is held at bay, the presence of the sandbags has also reduced the value of the property and locked it into an undesirable state.

This case illustrates how a much localized response to erosion has threatened the entire public coastal zone, demonstrating the *spatial scale* dimension of maladaptation, both from a biophysical and socio-economic perspective. It also stresses the *temporal scale* dimension of maladaptation, prompting questions about city planning, which makes the decision to allow this kind of development, and what it means for future development.

Case Study 4: Coastal Region of South-West Bangladesh

Decision-makers can sometimes justify investments in adaptation on the basis of short- to medium-term benefits, with a high benefit to cost ratio. Over time, as the effects of climate change increase, the benefits can decline and the investment may have serious adverse consequences. In this way beneficial adaptation can yield poor outcomes. One illustrative example is the USD 160 million Coastal Climate-Resilient Infrastructure Project in southwest Bangladesh jointly funded by the Asian Development Bank (ADB), the International Fund for Agriculture and Development (IFAD), the KfW Development Bank, and the Government of Bangladesh. The project aims to increase climate resilience and reduce vulnerability by upgrading to around 540 km of roads, bridges and culverts, as well as improvements to local markets, including more reliable access. It also expects to build and improve cyclone shelters and animal shelters, and according to IFAD, 'the total project beneficiaries will reach about 600,000 households or 3.5 million people in 12 selected districts of Bangladesh.'[f] This project has a good short-term rationale and should serve to improve the local economy and reduce current risks from tropical cyclones, storm surges, floods, and sea-level rise. To the extent that it is successful it may insidiously encourage the resident population to remain in these hazardous areas—described as 'very poor, least developed, and vulnerable to natural disasters such as tidal surges, cyclones, and floods' by IFAD—, slow down out-migration, and may also spark in-migration if the economy strengthens. Future extreme events trends and long-term sea-level rise, however, induce a potential for the dislocation of some 35 million people by 2050 in the coastal districts, according to the ADB.[g] Furthermore, whatever the design standards of the infrastructure, climate change's current rate makes it almost certain that sea-level rise will permanently impact large parts of the project area.

This example illustrates some quite dangerous long-term effects of a too short-sighted adaptation strategy. Accordingly, it has been described as 'palliative adaptation,' or making things better until they get worse.[46] This case stresses the *temporal scale* of maladaptation, as well as the role of *multiple drivers* (poverty, geographical setting, etc.) in explaining the limits to adaptation.

Synthesis of the Case Studies

Four dimensions to describe what maladaptation is emerge from the examples above (Table 1), as well as from the existing scientific and gray literature (*Insights from the Scientific Literature* section). These critical dimensions relate to the fundamental nature of maladaptation as a *process* that is influenced by *multiple drivers* and involves various *temporal* and *spatial scales*. They are detailed in the following section.

FOUR CRITICAL DIMENSIONS TO CAPTURE THE RISK OF MALADAPTATION

Maladaptation as a Process

The previous sections underscore that maladaptation is a process that exacerbates the negative impacts of climate change on the territory, sector, and/or group of people through the exacerbation of existing causes of vulnerability or the creation of new ones. It is evident from previous work that maladaptation relates

TABLE 1 | Four Critical Dimensions of Maladaptation: Insights from Four Examples

	Hulhumalé, Maldives (Example 1)	Afar, Ethiopia (Example 2)	Cape Town, South Africa (Example 3)	South-west Bangladesh (Example 4)
Process	●	●	●	◓
Multiple drivers	●	●	○	●
Temporal scales	●	◓	◓	●
Spatial scales	◓	○	●	○

● Strong evidence in the example.
◓ Only suggested by the example.
○ Not suggested by the example.

directly to vulnerability, and happens when vulnerability increases or emerges (see *Insights from the Scientific Literature* section). Exposure and sensitivity to a threat, however, may define vulnerability,[47] both of which continuously change, making vulnerability extremely dynamic. Exposure is an evolving characteristic because natural hazards and environmental resources themselves are changing, partly because of climate change.[48–50] Ecosystem sensitivity is not a fixed state, first, because climate change forces broader environmental changes. Society also affects local environmental dynamics. On coral islands, for example, population growth combined with aggressive development activities has caused rapid changes in environmental conditions and an increase in the number of people exposed to sea-related hazards.[51–53] Elsewhere, other human-driven factors are related to inequities in access to resources, conflicts, and overexploitation of natural stocks, among other things. Last, society's sensitivity to climate-related stresses evolves, as a result of both the negative feedbacks on the economy—for example, from the pressures exerted by humans on natural resources—and changes in various determinants, such as societal cohesion, risk management systems, and level of development (see, e.g., the Afar example above). Worldwide, these processes have resulted in an increase in populations' vulnerability to environmental threats.[54]

Ultimately, vulnerability is not an immutable state, but rather a succession of different states. Even if a territory, a sector or a group of people succeeds in reducing its vulnerability to climate-related stressors, perpetual adjustments to maintain low vulnerability are still necessary.[55] As a result, maladaptation is also a process that, evidenced by the emergence of the adverse effects of adaptation initiatives, occurs when there is increased short and/or long-term vulnerability (Figure 1). Note, however, that some immediate detrimental effect is justifiable in a longer-term strategy, as suggested in the Hulhumalé example above as well as in emerging work on 'Adaptation Pathways.'[33,34,58] This again emphasizes that the dividing line between adaptation and maladaptation is often subtle, and whether we are on one side or the other depends on the stage of the response process, as well as the time and spatial scales considered (see subsections below). This point is consistent with the IPCC's definition of adaptation as an 'adjustment process'[23] and with Barnett and O'Neill's view regarding the need to minimize the risks of maladaptation.[31,34]

Multiple Drivers

Maladaptation to climate change relates to the increase of vulnerability to climate variability and change in a location, sector, or group of people. In other words, only an initiative that would negatively affect exposure and/or the sensitivity of ecosystems and/or society to climate-related stressors should be considered maladaptive to climate change. In addition, as expressed previously, neglect of the future impacts of climate change and related uncertainty and neglect of the main drivers of the system's vulnerability—social characteristics and cultural values, economic diversification, governance system, among other things—are factors that drive maladaptation. Although these two factors differ in nature—one refers to natural hazards while the other refers to anthropogenic issues—one should consider the combination of the two when approaching maladaptation. Accordingly, to capture maladaptation, one should systematically consider both direct and indirect drivers of vulnerability to climate-related pressures.

Discussion on direct versus indirect drivers of maladaptation raises a fundamental question[6]: What threshold(s), in terms of the connection to climate-related stresses, should one consider describing an 'indirect' or 'background' influence on vulnerability to climate-related pressures? This question deserves careful thought, as it refers to the wider debate on the links between adaptation and development (see

the Ethiopian and Bangladeshi cases, for example). This is however beyond the scope of this paper. Here, we only consider the fact that such threshold(s) is (are) necessarily context specific. Accordingly, we argue that in a time of decreasing margins of error and as climate change advances, focusing on its consequences—rather than opening the reflection to environmental changes at large, development, or global change—militates in favor of using the available 'adaptation funds' as efficiently as possible. We, of course, recognize that climate change takes place in the wider context of global transformations[54,59] and, consequently, that both adaptation and maladaptation to climate variability and change are influenced by other dynamics, such as the globalization of the economy, the depletion of environmental resources or the occurrence of non climate-related natural hazards. In theory, therefore, climate change is too narrow a context to encompass the multiple potential drivers of maladaptation. Such a stance is, however, incompatible with the need for pragmatism in practice[6]: if maladaptation is about all possible drivers, scientists, decision-makers, and stakeholders can do nothing to avoid it and any anticipative measure is useless. This position is of course untenable as both the cumulative evidence on climate change and the limited availability of funding for adaptation require pragmatic and affirmative action.

Temporal Scales

Maladaptation significantly undermines capacities or opportunities for present and future adaptation, as suggested by Niemeyer et al.,[20] Heltberg et al.,[60] and Hallegatte,[61] and also as highlighted in the previous Maldivian and Bangladeshi case studies notably. Adaptation refers to both being resilient to current climate-related hazards and being able to anticipate future ones.[54,62,63] As a result, maladaptation stresses the importance of keeping enough space to maintain a wide range of possible choices when dealing with future climate-related changes. Accordingly, any initiative labeled 'adaptation' that creates detrimental irreversibility—for example, urban planning that neglects hazard-prone areas, or coastal tourism development that destroys natural buffers such as coral reefs and sand dunes—should be considered maladaptive. This view addresses concerns regarding uncertainty and timescale, as it avoids the following critical (and likely indeterminate) question: At what point can maladaptation be diagnosed? Although there is general consensus in the international scientific community that adaptation is about reducing long-term vulnerability to climate change, many uncertainties surround local impacts, ecosystems' responses, and society's ability to develop and implement the right options. These uncertainties make it difficult to assess today the future effectiveness of adaptation initiatives, as some benefits and adverse effects might appear over the long-term only.[6] Conversely, some initiatives that are undertaken today might appear maladaptive in the short term, but yield possible positive impacts in a more distant future (see the Maldivian case, for example). This inevitably intertwined temporal dimension of maladaptation is also in line with the emerging 'Adaptation pathways' approach.

Spatial Scales

Maladaptation also has a strong spatial component—that is, scales' interactions. An 'ideal' adaptation initiative would have an attenuating effect on the vulnerability of the system in which it is developed or, at the very least, no collateral effect, for example, on the overexploitation of resources, on habitat degradation or on pollution of ecosystems. The ideal is, however, not always possible in practice, as it is often necessary to trade-off between development challenges and environmental challenges, as shown in the Hulhumalé example. This results not only from financial costs to projects but very often from other types of costs (loss of social networks, loss of habitats, loss of livelihood activities, etc.), as demonstrated in the South African case. Henceforth, one may only consider the initiative adaptive if it takes its own *in situ* negative effects into account and if, in parallel, it puts in place compensation mechanisms in the event of deleterious outcomes. In a way, one can argue Hulhumalé partly relieves pressure on the outer atolls, which plays an indirect compensation role. If the initiative does not do so, then it can be considered maladaptive, as it simply reduces *in situ* pressures by displacing them onto another connected system—that is, neighboring or ecologically/socio-economically connected ones. How far to extend the effort to avoid displacing pressures however remains an outstanding concern.[6,55]

Stocktake

The previous examples (*Insights from the Field: Illustrative Concrete Examples* section) and developments section above help better capture the full risk of maladaptation. They suggest, in line with Juhola et al.'s definition,[6] that maladaptation is a *process* that results in increased vulnerability, and/or significantly undermines capacities or opportunities for present and future adaptation to climate variability and

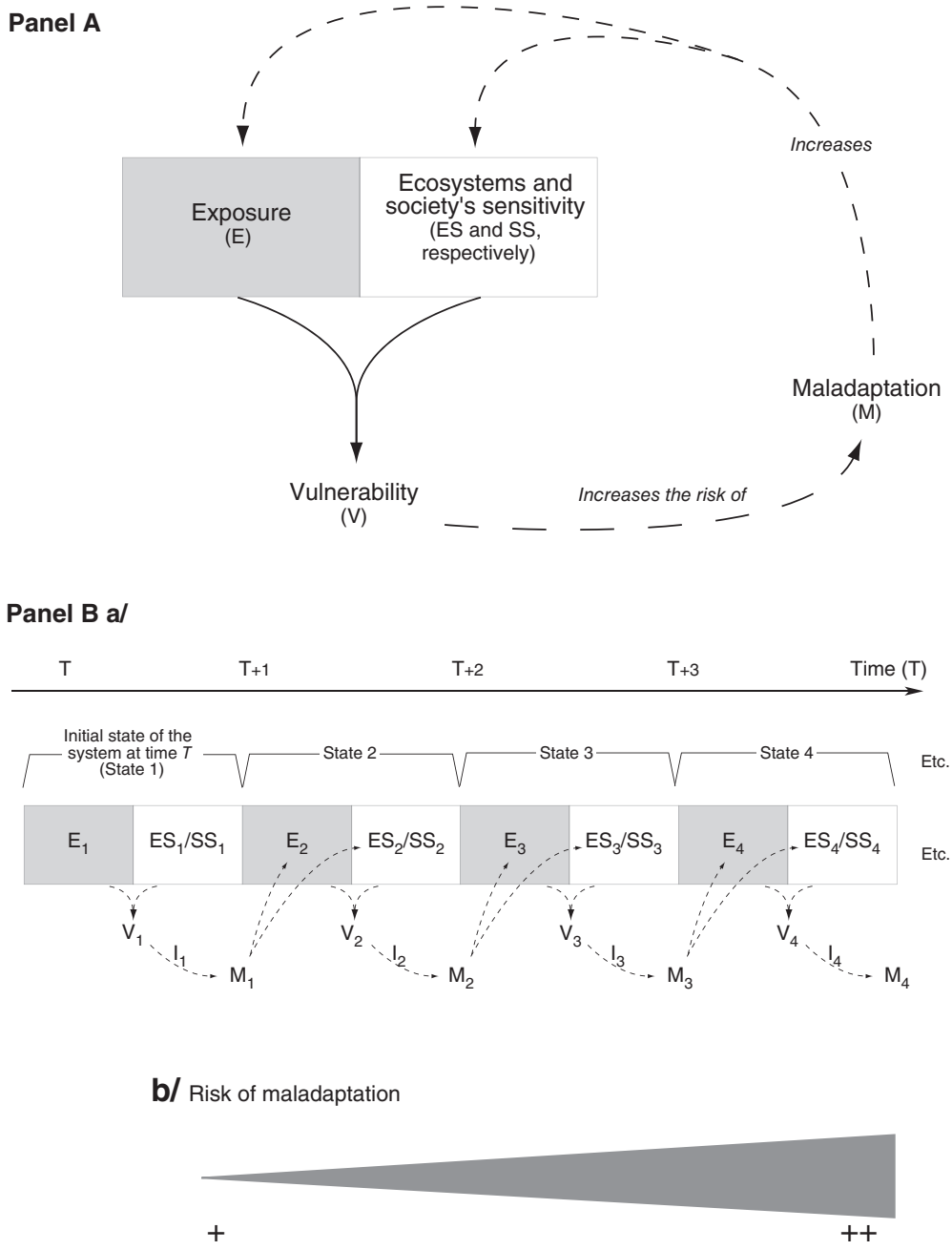

FIGURE 1 | Legend on next page.

change. It is influenced by *multiple drivers* and involves various *temporal* and *spatial scales*. In practice, maladaptation refers to initiatives—for example, policy, plan, project, decisions, etc.—that are designed initially for adaptation but are actually at high risk of inducing adverse effects either on the system in which it is developed, or on another connected system, or both.

Maladaptation is thus an adverse effect of an adaptation action that does not adequately account for *multiple drivers*. It can result from failure to consider future climate impacts and related uncertainty in the design phase of the initiative, rendering the action short sighted and producing potentially greater problems in the long term. Second, maladaptation can be the consequence of neglecting direct and/or indirect drivers of vulnerability: for example, social characteristics and cultural values, the level of diversification of economic and/or subsistence activities, the governance system, etc.[54,64] Accordingly,

Figure 1 | The role of maladaptation in increasing vulnerability and, in turn, the influence of increased vulnerability on the risk of maladaptation. Panel A. Maladaptation (M) affects vulnerability (V) through increasing either the system's exposure (E) or its ecosystems' and /or society's sensitivity (ES and SS, respectively) to climate-related changes, both extreme events and gradual changes. Panel B shows that in turn, the increase in vulnerability (V) exacerbates the risk of maladaptation (M), depending on the initiatives (I) undertaken to cope with vulnerability. Part a/State 1 describes the initial situation, that is, the current state of vulnerability (V_1) as a result of the current combination of the system's exposure (E_1) and its ecosystems' and society's sensitivity (ES_1 and SS_1). State 1 applies before any adaptation initiative. To cope with current risks and vulnerability, however, authorities, for example, decide for an initiative (I_1) in the name of adaptation, but that in fact reveals being maladaptive (M_1). An example is a network of dykes set up after a storm surge in a low-lying coastal area (I_1)—for example, what happened since the 18th century in New Orleans, LA[39]; or since the 1950s in Charente-Maritime, France.[56] Although a network of dykes can make the area more secure immediately, it perversely tends to induce more and more urbanization behind the dyke,[37] thus inducing partly irreversible impacts on coastal ecosystems and a growing sensitivity of the population to extreme events (due to a decrease in hazard awareness and preparation, as well as to an overconfidence in the effectiveness of hard defenses that in fact usually suffer from a lack of maintenance[57]). This leads to a State 2 where ecosystems' sensitivity has changed (from ES_1 to ES_2), as well as society's one (from SS_1 to SS_2). Obviously, climate change being ongoing, exposure also increases (from E_1 to E_2). As a result, the system's vulnerability is also exacerbated (from V_1 to V_2). Conditions have changed and thus the nature of risk too, so that new answers are needed. Owing to new challenges (e.g., increased coastal population density and economic activities), it is decided to add new dykes (I_2)—as it happened in New Orleans after cyclone Betsy in 1965—and/or to increase the height of the existing protections—for example, what happened in Charente-Maritime after the Xynthia Storm in 2010. Of course, such a decision puts more pressure on coastal ecosystems (e.g., loss of the wetlands in the Eastern boundary of New Orleans), so that their sensitivity to climate-related changes moves from ES_2 to ES_3. If this hard-defense option is not accompanied with drastic urbanization constrains, alert systems, and population's awareness programs—which partly describes the post-Xynthia situation in France—, it is at risk of not reducing society's sensitivity, which will on the contrary increase (from SS_2 to SS_3). In parallel, climate change naturally increases exposure to sea-related hazards (from E_2 to E_3), as sea level is rising and even in the case of no change in current storms patterns. At the end, vulnerability increases again (from V_2 to V_3). Part b/And so on until the risk of maladaptation is not enough considered and become fully part of the design of adaptation choices. This schematically illustrates the role of maladaptation in increasing long-term vulnerability (Panel B a/), that is, the less maladaptation is addressed upstream, and the more vulnerability is at risk of increasing. It, however, also highlights a feedback effect: the more vulnerability increases, the more the system is maladapted, and the more it is at risk of maladaptation in the future. Such a vicious cycle emphasizes a maladaptation process made of both natural (especially climate change) and anthropogenic (environmental degradations, increase in coastal population densities, non diversified economies, etc.) drivers.

adverse effects can be diverse in nature: environmental, sociocultural, institutional and/or economic.

Ultimately, this paper understands maladaptation to climate variability and change as a pathway, limits it to the detrimental effects of an adaptation initiative on a system's vulnerability, links it to the need for maintaining flexibility in the face of current and future climate-related environmental changes, and emphasizes its multiscalar nature—both temporal and spatial. The paper also argues that limiting the risk of maladaptation assumes adopting an anticipatory approach toward future climate-related risks, despite the problem of uncertainty on local-scale impacts. This means that the risk of maladaptation should be considered in the design phase of adaptation initiatives or prior to implementation, thus highlighting the following key message: an initial crucial step in any adaptation process is to limit the risk of maladaptation.[65]

MOVING AHEAD: FUTURE RESEARCH PERSPECTIVES

Acknowledging that side effects of adaptation initiatives exist in the field and that we already have a significant number of examples of such 'bad practices,' it is now clear that there is a crucial need for in-depth understanding of the roots and forms of maladaptation. Although valuable, the definitions from Barnett and O'Neill,[5] IPCC WG2 AR5,[26] and Juhola et al.[6] focus on the outcomes of an adaptation initiative that in fact ends up being maladaptive. Although an *ex post* assessment is necessary, it is insufficient. As noted in the introduction, climate change is ongoing and human societies cannot allow themselves to waste time and resources. Accordingly, there is a crucial need to develop a framework and guidance on maladaptation that allows for assessing the potential side effects of an initiative before it is implemented. In other words, when dealing with maladaptation, one must now move from an exclusively outcome-oriented perspective—*ex post* assessment of observed side effects—to an input-oriented one—*ex ante* approach of the expected side effects. That means moving from 'this adaptation initiative has in fact been maladaptive' to 'could this initiative have unintended consequences?' and 'what is the risk that this will be maladaptive?'

This last part builds on the previous sections to provide practice-oriented insights on how to address the risk of maladaptation. To that end, it develops the rationale for addressing this risk, gives some

examples of existing frameworks, and emphasizes possible next steps.

Put the Risk of Maladaptation on the Agenda

A major scientific challenge consists now in moving from theoretical understandings of maladaptation to practical guidelines. The rationale behind this is to provide guidance to help put the issue of the risk of maladaptation on the agenda. This would encourage stakeholders to acknowledge that such a risk exists and that there is a need to anticipate it, although adverse effects can neither be anticipated nor avoided in full. From that perspective, the discussion above is a first step in a wider process of reducing the gap between what is claimed in scientific and international arenas about adaptation and maladaptation one one hand, and what is crucially needed on the ground to support robust adaptation and avoid maladaptation on the other hand. Henceforth, a central question for examination is: How to concretely avoid or minimize the risk of maladaptation?

Accordingly, the development of an analytical framework comprised of guidelines (see examples in the subsection below) and designed to address the risk of maladaptation posed by initiatives labeled adaptation should direct further research on maladaptation. Although these kinds of evaluation and monitoring tools must be carefully considered as they can raise false expectations among users,[66,67] one can expect at least three major benefits. First, such a framework for limiting the risk of maladaptation could serve as an incentive to think about maladaptation, and thus put

TABLE 2 | The Five Guidelines of the *Pathways Framework* (Reprinted with permission from Ref 5. Copyright 2012 Elsevier)

Characteristic of Maladaptation (As Expressed by Barnett and O'Neill)	Guidelines to Limit the Risk of Maladaptation	justification
Increasing emissions of greenhouse gases	1. Ensure that the initiative does not increase emissions of greenhouse gases	'The problem with energy-intensive adaptation actions is that while they may address current needs, they create a positive feedback by increasing emissions of greenhouse gases, thereby increasing the likelihood that further adaptation to climate change will be required in the future' (Ref 5, p. 212). Adaptation must not contribute to increasing greenhouse gases emissions, as mitigation and adaptation are complementary means and goals of the fight against climate change.
Disproportionately burdening the most vulnerable	2. Ensure economically and socially equitable initiatives	'Adaptation actions are maladaptive if, in meeting the needs of one sector or group, they increase the vulnerability of those most at risk, such as minority groups or low-income households' (Ref 5, p. 212). Strengthening part of the society by weakening the most vulnerable cannot be a sustainable option, as it will very likely result in an increase in pressures on other natural and human systems (vulnerability increase).
High opportunity cost	3. Avoid high-cost initiatives	'Approaches may be maladaptive if their economic, social, or environmental costs are high relative to alternatives' (Ref 5, p. 212). Cost-benefit analyses (on economic, social, environmental… dimensions) should be conducted before choosing the right option to implement. Neglecting such an approach can lead to adopting options that are too costly in the long run.
Reduce incentive to adapt	4. Increase incentive to adapt	Actions are maladaptive if 'they reduce incentive to adapt, for example by encouraging unnecessary dependence on others, stimulating rent-seeking behavior, or penalizing early actors' (Ref 5, p. 212). The involvement of community, economic, and policy bodies into an adaptation process is of major importance to allow its achievement. This multilateral involvement, however, relies on various elements such as equity, risk perception, power relations, etc. that must not be eroded.
Path dependency	5. Build flexibility into the initiative	'A major issue with large infrastructural development [the one considered in the authors' case study] is the way they commit capital and institutions to trajectories that are difficult to change in the future' (Ref 5, p. 212). This deals with the extent to which present choices (here, infrastructural) can restrict the range of future options, and thus reduce the room for maneuvre of the system in the future. This criterion refers to the generation of irreversibility and the induced decrease in the system's flexibility.

this issue on the agenda. Second, understanding how to avoid maladaptation could help funding agencies and decision-makers identify the best initiatives to support, as well as practitioners to better design their initiatives on the ground.[64] Ideally, funding agencies, decision-makers, and practitioners would use common references allowing a shared understanding of what adaptation should be, or at least should not be, and enhance the robustness of adaptation initiatives addressing diverse geographic locations and scopes—that is, sectors and populations targeted.[68] Third, developing guidelines to limit the risk of maladaptation would support the challenge around monitoring and evaluation of adaptation. Indeed, one key issue that is now emerging globally at the interface of science, decision-making, and practice involves our ability to track progress in terms of adaptation.[69–71] Are we on the right road to implement adaptation on the ground, from the local to the international scales, and are our efforts sufficient to address the expected level of threat induced by climate change?

What we argue here is that by attempting to assess the risk of maladaptation posed by various initiatives labeled adaptation, such guidelines could provide scientists, decision-makers, and practitioners with empirical evidence of efforts to avoid exacerbating future threats—this is part of the adaptation process, as expressed above.

TABLE 3 | The Six Principles of the *Precautionary Framework* (Reprinted with permission from Ref 61. Copyright 2009 Elsevier)

Characteristic of Maladaptation (As Expressed by Hallegatte)	Justification
1. No-regret strategies	'These strategies yield benefits even in the absence of climate change' (Ref 61, p. 244). Hallegatte gives the example of limiting leakage in a water distribution network. He adopts an economic view, and in doing so does not address the potential costs and benefits of an action from social and environmental perspectives.
2. Reversible strategies	'It is wise to favor strategies that are reversible and flexible over irreversible choices. The aim is to keep as low as possible the cost of being wrong about future climate change' (Ref 61, p. 244). For example, urban planning on low-lying coastal areas. Here again, the author refers to economic costs, however, the notion of 'cost' could also be of another nature.
3. Safety margin strategies	'Strategies that reduce vulnerability at null or low costs (…). It is wise to be overpessimistic in the design phase [of an option because] modifying the system after it has been built is difficult and expensive' (Ref 61, p. 244). Hallegatte argues that the marginal higher cost to building bigger infrastructures (drainage infrastructures, dams, dikes…) is usually small compared to the initial total cost. Using safety margins could allow avoiding maladaptation; naturally on the condition that they represent an acceptable extra cost (economic, environmental, social…) at the time the option is designed and implemented.
4. Soft strategies	'Technical solutions are not the only way of adapting to changing climates. Sometimes, institutional or financial tools can also be efficient' (Ref 61, p. 245). For example, 'institutionalization' of long-term planning, insurance schemes, early warning systems, etc. Hallegatte refers here to nontechnical and nonengineering options, which actually represent an extremely wide range of potential maladaptations. Cultural, social, and political dimensions are thus also concerned.
5. Strategies that reduce decision-making time horizons	'The uncertainty regarding future climate conditions increases rapidly with time. Reducing the lifetime of investments, therefore, is an option to reduce uncertainty and corresponding costs' (Ref 61, p. 245). For example, species with a shorter rotation time in forestry. This criterion is quite disputable as on the other hand, one can consider the reduction in decision-making timescales as a major source of maladaptation. It could indeed encourage actors to not take into account long-term potential adverse effects of the action, inducing a potential increase in their own vulnerability or in neighboring systems' vulnerability.
6. Taking into account conflicts and synergies between strategies	'Adaptation strategies often have side effects that can be either negative or positive. (…) There are also conflicts between adaptation options, [and] adaptation also interact with mitigation policies' (Ref 61, pp. 245–246). Assessing maladaptation involves focusing on negative effects of an adaptation initiative. One should be aware, however, that this should be done by putting these negative effects into a double context: the overall effects of the initiative itself (the balance of the positive and negative) and of the implementation of other initiatives (dealing both with adaptation and mitigation). Thus, maladaptation is always relative.

TABLE 4 | The Eleven Principles of the *Assessment Framework* Source Ref 64: Guidelines 1–5 refer to avoiding environmental maladaptation. Guidelines 6–8 refer to avoiding sociocultural maladaptation. Guidelines 9–11 refer to avoiding economic maladaptation.

Guidelines to Limit the Risk of Maladaptation	Justification
1. Avoid degradation that causes negative effects *in situ*	It is referred here to the socio-ecological system in which the initiative is implemented (that is, its direct environment). For example, the destruction of sand dunes that results from building a resort close to the water, which subsequently increases the new building's exposure to storm surges. 'The initiative may only be considered as "adaptation" if it takes its own *in situ* negative effects into account and if, in parallel, it puts in place compensation mechanisms (e.g., protection of marine ecosystems from pollution, to allow them to maintain their natural resilience and adaptive capacities, and then ensuring their buffer function against waves, for example)' (Ref 64, p. 7).
2. Avoid displacing pressures onto other environments (neighboring areas or areas that are connected ecologically or socioeconomically)	'The aim of any adaptation process is to reduce pressures on the environment and not to displace them, that is, not to lead to increased pressures on the environment elsewhere' (Ref 64, p. 7). For example, the development of a coastal groyne that helps limit erosion *in situ* by capturing sand, but disturbs natural movements of sand along the coast and thus generates erosion downstream. It is crucial to take such collateral effects into account and if not avoidable, to engage in parallel compensation mechanisms
3. Support the protective role of ecosystems against current and future climate-related hazards	The aim here is to maintain natural buffer zones.
4. Integrate uncertainties concerning climate change impacts and the reaction of ecosystems	This refers to maintaining enough flexibility 'to adjust activities in the event of unpredicted environmental changes and new scientific knowledge' (Ref 64, p. 7).
5. Set the primary purpose as being to promote adaptation to climate-related changes rather than to reduce greenhouse gas emissions	'If the initiative can help to reduce greenhouse gas emissions, it must above all focus on resilience and the alleviation of vulnerability to natural hazards and gradual environmental changes' (Ref 64, p. 7). This principle aims to avoid the confusion between adaptation and mitigation (for example, local stakeholders and population identifying solar panels as adaptation options).
6. Start from local social characteristics and cultural values that could have an influence on risks and environmental dynamics	'Initiatives must take into account the expectations of the community in terms of material and immaterial living conditions, both in the present and the future, as these expectations are key drivers of changes in risk exposure over time, and more generally of vulnerability to climate variability and change' (Ref 64, p. 7).
7. Consider and develop local skills and knowledge related to climate-related hazards and the environment	The aim is here to support the involvement of members of the community in and/or around the adaptation to climate change initiative. For example, raising awareness of hazards and risk areas among new inhabitants coming from other and sometimes distant areas. 'Newcomers generally know nothing about risk in the destination area, which leads them to develop bad practices such as the building of no-storey houses in low-elevated areas. Improving the awareness of risk is key to making people accept new building norms, for example' (Ref 64, p. 7).
8. Call on new skills that the community is capable of acquiring	Guidelines 6 and 7 do not necessarily imply that the community's current skills and knowledge should limit it. Acquiring new knowledge and expertise is part of adaptation. This guideline thus also raises 'the importance of enhancing people's self-confidence in their ability to drive the change' (Ref 64, p. 8).
9. Promote the reduction of socio-economic inequalities	'Inequalities indirectly affect the exploitation of natural resources and stimulate settlements in marginalized and hazard-prone areas, consequently exacerbating vulnerability and, as expressed in the *Pathways framework*, 'disproportionally burdening the most vulnerable' (principle 2). In an ideal scenario, an initiative must ensure that the present income that various groups derive from economic and/or subsistence activities does not decrease, and should provide a new source of income' (Ref 64, p. 8). The redeployment or development of activities, however, is more often not equally beneficial to all of the groups concerned, generating both 'winners and losers'. Recognizing this is a prerequisite for an initiative's to avoid maladaptation.

TABLE 4 | Continued

Guidelines to Limit the Risk of Maladaptation	Justification
10. Support the relative diversification of economic and/or subsistence activities	'By avoiding a situation where all activities are threatened by the same climate-related hazards (…), diversification enables the community to acquire or maintain a certain leeway in the event of both sudden and gradual environmental disturbances that, together with climate change, will affect various natural resources and means of production' (Ref 64, p. 8).
11. Integrate any potential changes in economic and subsistence activities resulting from climate change	Notably to 'avoid developing activities that require heavy investment in money, time, and energy, but which will quickly become obsolete due to climate change' (Ref 64, p. 8). In line with Hallegatte saying that a good way to by-pass the problem of climate uncertainty is to target 'options that [are] the most insensitive to future climate conditions' (Ref 61, p. 242).

Tentative Frameworks to Capture Maladaptation on the Ground

This section briefly presents three frameworks to capture maladaptation that we have called the *Pathways*, the *Precautionary*, and the *Assessment* frameworks.[64] Although other frameworks exist that can help track maladaptation *ex ante* (see Ref 72 on barriers to adaptation), the three ones we selected have the advantage of directly referring to maladaptation. They serve to demonstrate that the move from theory to practice has already begun and that defining guidelines to address maladaptation *ex ante*—that is, during the design phase of adaptation options—is possible, even if imperfect. Although these three examples deal with various types of initiatives and/or contexts, they also show that any framework is relevant only if it takes into account context specificities. This, however, does not preclude science that elaborates more generic frames that will precisely guide the definition of more context-specific ones, that is, design specific indicators.

The *Pathways* framework is based on the work from Barnett and O'Neill[5] on two engineering responses to water stress in Melbourne, Australia. We named this framework consistent with Barnett and O'Neill's 'five different pathways through which maladaptation arises' (Ref 5, p. 210) and 'pathways of maladaptation' (Ref 5, p. 212). They indeed identify five main characteristics of maladaptation that we rephrase in Table 2 to make them principles for tracking maladaptation.

The *Precautionary* framework refers to a paper from Hallegatte[61] that, although not using the word, addresses 'maladaptation.'[b] Claiming that 'since climate models and observation cannot provide what current decision-making frameworks need, the only solution is to amend these frameworks to make them able to take this uncertainty into account' (Ref 61, p. 242), Hallegatte insists on the importance of reducing the risk of increasing systems' vulnerability by taking into account a wide range of climate change impacts. He thus suggests that instead of looking for the best choice under one specific scenario, it is better to try to identify the most robust option, that is 'the one that is the most insensitive to future climate conditions' (Ref 61, p. 242). This is why we named his approach the *Precautionary* framework. Adopting a focus on infrastructures and engineering options, the paper advances six guidelines to avoid maladaptation (Table 3).

The *Assessment* framework focuses on coastal areas exposed to climate-related hazards and explicitly on the *ex ante* approach to the assessment of maladaptation.[64] It relies on the assumption that adaptation requires that climate change, both sudden and slow-onset events, is central to a broader approach to sustainable development—for example, preserving the environment, reducing people's exposure to natural hazards, among other things. It artificially distinguishes between environmental, sociocultural, and economic maladaptation to come up with 11 interacting guidelines (Table 4). It argues that the more guidelines the initiative addresses, the lower the risk of maladaptation.

Although indirectly and through different ways, these three frameworks offer examples of how to concretely address the four dimensions discussed previously (that is process, multiple drivers, temporal, and spatial scale). Based on a reanalysis of what is explicitly described in the original papers, Figure 2 highlights to what extent each framework matches the four dimensions. It shows for example that the *process* feature is the best addressed (by 19 out of the 22 guidelines), while the *spatial scale* one appears more difficult to capture (12 out of 22).

Next Steps

In our view, a challenge for future research consists in moving from guidelines such as the one presented here to more contextually appropriate assessments.

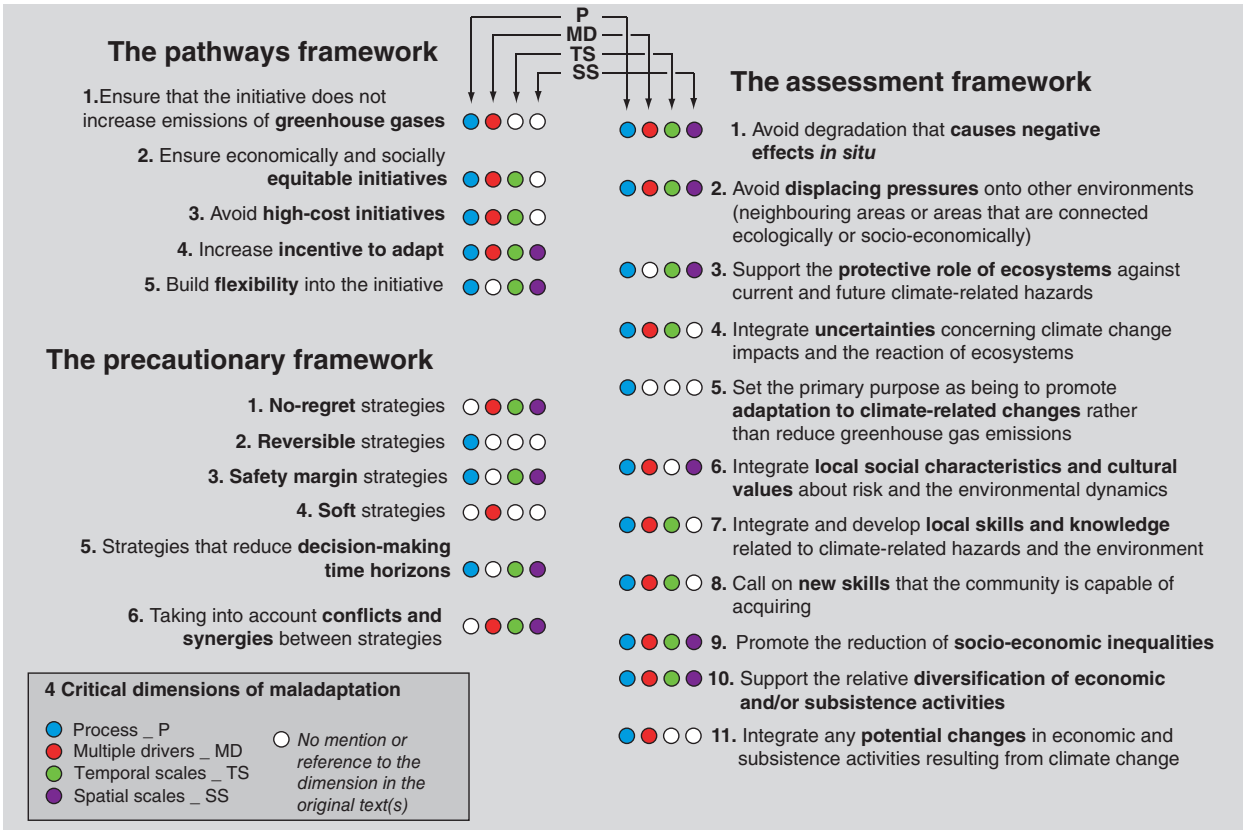

FIGURE 2 | The four critical dimension of maladaptation in the *Pathways*, *Precautionary*, and *Assessment* frameworks. This figure shows to what extent the various guidelines of the three frameworks exposed in this paper address each of the four critical dimensions of maladaptation raised in Insights from the Field: Illustrative Concrete Examples section and discussed in the Case Studies section, that is, process (P), multiple drivers (MD), temporal scales (TS), and spatial scales (SS). The circles are colored depending on whether the papers being at the root of each framework do or do not explicitly make a link with the four critical dimensions of maladaptation. The white colored circle means no explicit mention in the text(s) of origin.

Although we recognize such a perspective is a controversial issue raising intractable debates on the type and weighting of metrics, the availability of data, the assessment of qualitative parameters, relevant institutions' capacities to undertake such a work, among other things, we feel concerned with the following statement made by IPCC's Fifth Assessment Report: 'Five dimensions of maladaptation were identified by Barnett and O'Neill [in 2010 that] are useful pointers to the potential for maladaptation but their application depends on subjective assessments' (Ref 3, p. 858). The challenge of enhancing objectivity is crucial for at least two reasons. First, it is important to assess to what extent maladaptation is really happening on the ground.[68] Second, such an assessment grid could represent a powerful tool to allow funding bodies to make the best decisions to support adaptation initiatives—that is, by better capturing the risk of maladaptation—and for practitioners to design robust adaptation initiatives—that is, building initiatives with a low risk of maladaptation.

CONCLUSION

This paper argues that avoiding maladaptation is a first, key step to the wider process of adapting to climate variability and change, essentially because it mainly relies on doing well what we currently do poorly. It thus advocates for starting with the intention to avoid mistakes and not lock-in detrimental effects. It pleads for the anticipation of the risk of maladaptation to become a priority for decision-makers and stakeholders at large, from the international to the local levels.

Such an *ex ante* approach to the effectiveness of adaptation, however, supposes to get a clearer understanding of what maladaptation is. This paper thus reviews the current theoretical scholarship on maladaptation and provides an analysis of specific case

studies—in the Maldives, Ethiopia, South Africa, and Bangladesh—to advance the field by offering an improved conceptual understanding and more practice-oriented insights. It notably shows that maladaptation is fundamentally a *process* that is influenced by *multiple drivers* and involves various *temporal and spatial scales*. It also describes three examples of frameworks—the *Pathways*, the *Precautionary*, and the *Assessment* frameworks—that can help capture the risk of maladaptation. Both these conceptual and practical developments support the need for putting the risk of maladaptation at the top of the planning agenda.

Ultimately, and in line with other works (e.g.,[72]), the paper affirms that a challenge for future research consists in developing context-specific guidelines that will allow funding bodies to make the best decisions to support adaptation—that is, by better capturing the risk of maladaptation—and practitioners to design robust adaptation initiatives by building initiatives with a low risk of maladaptation.

NOTES

[a] Literature searches were conducted using Google Scholar with a combination of search terms, essentially: 'maladapt*,' 'maladapt*', AND 'climate change.'

[b] This is a debatable point that we do not explore in this paper, but that needs to be mentioned at this stage. 'Ideal' processes or outcomes indeed not exist in reality, as any adaptation effort inevitably has some negative effects, at least unexpected ones. As a result, there is no 'objective' or 'neutral' way of deciding what is ideal adaptation, as such a normative judgment is the result of the views and perspectives of those making that assessment, and who has been given the authority to make that assessment (usually 'scientists/experts' or 'policymakers'). This strongly supports the need to address (even if imperfectly) the risk of maladaptation, as suggested in this paper.

[c] 'Decisions are often based on past investments rather than on expected future returns. This leads to an unwillingness to abandon something (e.g., a settlement) if a great deal has been invested in it, even if future prospects are dim' (Ref 16, p. 1).

[d] 'A recent and relatively new approach to future-oriented analyses is conceptualizing adaptation as pathways or route maps to assist planning, implementation, and adaptation to climate change' and allowing to 'explore how different sets of possible actions can be sequenced through time to achieve overall, more desirable outcomes where achieving change is complex and uncertain' (Ref 33, pp. 1,2).

[e] '*First, do no harm.' Avoiding maladaptation to climate change* and it took place at the Bellagio Centre of the Rockefeller Foundation, Italy, on November 6–9, 2012.

[f] http://www.ifad.org/operations/pipeline/pi/bangladesh_ccrip.htm.

[g] http://adb.org/projects/details?page=details&proj_id=45084-002.

[h] Hallegatte develops the same ideas in a more recent paper.[73] We, however, kept the 2009 paper as the reference in this text, as the 2012 paper mainly consists in going in-depth on the parameters/guidelines raised in the 2009 publication.

ACKNOWLEDGMENTS

The authors thank the Rockefeller Foundation (Conference Program of the Bellagio Center), the French National Research Agency (CapAdapt and Storisk projects, ANR-2011-JSH1-004 01 and ANR-15-CE03-0003) and the Labex programme (ANR-10-LABX-01) for their support in the organization of the Bellagio workshop in November 2012. They also thank S. Anderson (IIED, UK), F. Briones (CIESAS, Mexico), S. Raihan (ActionAid, Bangladesh), A. Tauqeer-Sheikh (CDKN, Pakistan), M. Mortimore (UK), R. Peou (CGIAR, Cambodia), and H. Singh (ActionAid International, India) for their contribution to the discussions during the Bellagio workshop. They also thank R. Billé (SPC New Caledonia, France) for his comments on an earlier version of this text. Eventually, they thank the three anonymous reviewers who really help strongly to improve the manuscript. The authors also want to dedicate this paper to the five children *in utero* during the conference, who are now running around, not yet aware of the importance of adapting to climate change for their futures.

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