DEVELOPING A CONCEPTUAL MODEL TO EVALUATE THE POTENTIAL CHANGES IN INLAND FOOD FISH SUPPLY UNDER VARIOUS GLOBAL CLIMATE CHANGE SCENARIOS

Climate change adaptation: Indigenous Species Development/Study/16IND04MS

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ABSTRACT

Inland fish and fisheries are critical for food security in Burma. Burma is experiencing an increase in tropical storms and tidal surges along its coastline, the impacts of which can be severe due to the typography, shallow coastal ocean, and high population density in the region. Additionally, an increase in precipitation throughout the majority of Burma will likely cause increased flooding. In an effort to provide managers, policy makers, and development programs anticipate changes in inland wild and aquaculture fisheries, a systematic literature review was used to identify the impacts of climate change and applicable management strategies to address these impacts. Using the software Publish or Perish, search strings beginning with "("Myanmar" OR "Burma") AND ("fish" OR "fisheries" OR "aquaculture") AND "climate change" AND" were follow by any of the following: temperature, precipitation, sea level rise, monsoons, cyclones, or extreme weather events. Publication returns for each search string were copied into an Excel spreadsheet and three reviews were conducted to identify publications to read in full. Four management themes were identified (barrier vegetation, agriculture-aquaculture land use, protected areas, and coastal zone management) that could be addressed within three response levels (business as usual, low intervention, and high intervention). These response levels are based on the financial investment necessary to implement the management strategies and combinations of strategies from different levels can be employed. This systematic literature review sought to summarize management approaches and present them in a way that is useful to natural resource management agencies, development agencies, and nongovernmental organizations in Burma addressing impacts to wild and aquaculture fisheries.

INTRODUCTION

In Burma, the limited availability of reliable data on the status of fish populations constrains the ability of fisheries managers and policy makers to determine the current status of local fish stocks or even intervene when fisheries are in decline, until the system has virtually collapsed. This makes management efforts to anticipate the impacts of global change drivers (e.g., climate, land use) on fisheries resources exceeding difficult. For example, Allison et al. (2009) found that the Bangladesh and Cambodia national economies were both highly vulnerable to climate change impacts on fisheries, but they were unable to estimate similar impacts for Burma due to the lack of needed information on fishers and fisheries. Given the importance of inland fisheries to food security in Burma, anticipating the potential impacts of global change agents to these critical resources will help managers, policy makers and development programs anticipate and address potential challenges to inland fisheries and local communities, by region in Burma.

OBJECTIVE

Develop a conceptual model to examine the potential changes in inland food fish supply under various global change (e.g. climate, land-water use) scenarios.

METHODS AND MATERIALS

A systematic literature review was conducted using Publish or Perish (Harzing 2007) to initiate searches in Google Scholar. Search strings were entered under the prompt "All of the words:" and, with default settings, would return up to 1000 publications. All search strings began with "("Myanmar" OR "Burma") AND ("fish" OR "fisheries" OR "aquaculture") AND "climate change" AND" and were follow by any of the following: temperature, precipitation, sea level rise, monsoons, cyclones, or extreme weather events. Search returns included the following data number of times cited, author(s), title, year, source, publisher, article URL, cites URL, GSRant, query date, type, DOI, ISSN, citation URL, volume, issue, start page, end page, and ECC. Publication returns for each search string were copied into an Excel spreadsheet and three reviews were conducted to identify publications to read in full. In the first review, citations were removed if they met any of the following criteria: (1) lacked an article URL, (2) did not have a remotely relevant title (e.g., an article about the impact of cooking temperature on nutrient availability of a fish commonly harvested in Burma), or (3) came from a source not related to the environment or region. For the second review, the abstracts of the remaining publications were reviewed for relevance to climate change impacts or management strategies in the region with a specific focus on Burma and Bangladesh. All publications whose abstract did not indicate relevance were removed. The third review consisted of a reading of the full article and in the event the paper was not relevant that publication was also discarded from the list.

Once a final set of papers was identified, the papers were reviewed again and relevant content and the appropriate citation were identified. Once relevant content was collected, patterns in climate impacts and management responses were identified and summarized in two tables (See Table 1 and Table 2). Using the climate impacts table (Table 2), the scale and certainty of the impacts were determined for each of the following climate impacts: temperature, precipitation, sea level rise, drought, cyclones, extreme events and storm surge. For certainty, a score of zero indicated no confidence, one for some confidence, and two for high confidence. For scale, a score of zero indicated no impact, one for modest impact, and two for a high impact. The outcomes of this analysis is presented in Figure 1. The second table (Table 1) focused on the cost (low or high) of management strategies. Using the information generated by these summary tables of the systematic literature review, a management matrix was developed to illustrate the low and high cost management options for four management themes addressing climate impacts (Table 1). A poster communicating these management options is in development.

RESULTS

Scale and Certainty of Climate Impacts

While literature searches were defined using particular climate drivers, additional climate change impacts were identified that could affect fisheries with varying degrees of scale and certainty of impact (Figure 1). These included temperature, stream flow, storm surge, sea level rise, precipitation, flooding, extreme events, drought and cyclones. All climate change impacts were rated at least a one for both scale and certainty. Stream flow and storm surge had the largest scale and certainty ratings with a two for each criteria. Droughts, extreme events, and cyclones all received a two for the scale of their impacts, but a one for confidence in the certainty of those impacts. Flooding and temperature were both rated the same for scale (1.67), but the certainty of the impact for temperature impacts was high (1.44) than that for flooding (1). Precipitation and sea level rise both have the same certainty rating (1.5), but the scale of sea level rise is slightly higher (1.6) than that of precipitation (1.5). The sections below highlight the specific information on these climate impacts and how they may affect fish and fisheries.

Temperature
Increasing temperatures will pose a challenge to both wild and aquaculture fisheries; as waters warm fish abundance and distribution may change altering capture fisheries and an increase in decomposition will limit available oxygen negatively impacting aquaculture fisheries.

An increase in temperature has been demonstrated in recent years to cause an increase in the decomposition rate of aquatic vegetation, decreasing the oxygen, and reducing aquaculture production in Burma (Policarpio & Sheinkman 2015). Temperatures are expected to increase 0.5 - 2.9 degrees Celsius depending on the model used, location, and distance into the future (Rao et al. 2013; Horton et al. 2016; Shrestha & Htut 2016). Temperature is incredibly important for fish physiology, abundance, and distribution (Vivekanandan et al. 2016), and the mobility of a species will limit its ability to respond to temperature increases.

Sea Level Rise
Sea level rise is expected to be uniform across coastal Burma with the greatest impacts being felt in the Irrawaddy River Delta region. It is expected that this increase will impact productivity of natural areas such as mangroves, increase habitat for brackish water fish, and pose a risk to aquaculture infrastructure and survival of culture species that have low salinity tolerance.

Coastal areas and low-lying river deltas are at risk from sea level rise with consequences such as salt water intrusion, siltation, and land loss (Huq et al 2004). Saltwater intrusion is expected to adversely impact groundwater (Hossain & Selvanatham 2013) and the effects of sea level rise have already been felt in neighboring Bangladesh, where they have seen a reduction in available drinking water due to salinization of groundwater (Toufique & Islam 2014). It is predicted that the average rise in sea level will be similar across the Burma coast (Mandle et al. 2017), but the Irrawaddy Delta region may be particularly vulnerable to the impacts of sea level rise due to the high productivity and population density in the area (Taft & Evers 2016). A predicted 0.5m increase in sea level, for example, will cause the coastline of the Irrawaddy Delta to move 10km inland (NAPA 2012 as cited in Taft & Evers 2016). Additionally, tidal gauge data has indicated a 3.4-6mm/year increase in relative sea level (Syvitski et al. 2009 as cited in Brakenridge et al. 2017). The influx of salt water can alter the productivity of an area, such as mangroves, (Huq et al. 2004) and may also increase the habitat for brackish water fish (Najnin 2014). However, rising sea levels pose a risk to aquaculture infrastructure (Najnin 2014) and the species being cultured, which not be tolerant of increasing levels of salinity (Cochrane at al. 2009).

Precipitation and Stream Flow
An overall increase in precipitation and, therefore, stream flow is anticipated with slight variations based on geographic location and timeframe. An increase in the amount of time lowland areas are inundated with flood waters may impact inland fisheries given that many fisheries in Burma are located in floodplains.

While an overall increase in precipitation is expected, there are variations based on season, geographic location, and distance into the future (Shrestha & Htut 2016). The Bago River Basin, for example, has variable projections for precipitation and based on the anticipated changes in precipitation, the overall inflow into the Moeyingyi wetland is expected to decrease (Shrestha, Shrestha, & Datta 2017). Additionally, the central dry forest is expected to see a decrease in rainfall (Rao et al. 2013). The overall increase in precipitation will also increase the risk of flash flooding and increase the amount of time low-lying areas are inundated (NAPA 2012, as cited in Taft & Evers 2016).

The anticipated changes in precipitation are likely to cause an increase in stream flow. For example, the headwaters of the Irrawaddy River are fed by glacial melt in the Himalayas (Taft & Evers 2016). The precipitation increase that is expected during the wet season will likely cause increased flooding (Rao et al. 2013) with the Bago River Basin seeing an increase in flow during the wet season (Shrestha & Htut 2016).

Storm Surge and Cyclones

It is unclear how the frequency of cyclones will change in the future, the high storm surge and winds associated with these storms pose great risk to infrastructure for both wild and aquaculture fisheries.

The topography, shallow coastal ocean, and high population density in coastal Burma increase the scale and certainty of storm surge impacts caused by cyclones (Vivekanandan et al. 2016). In neighboring Bangladesh, fishers are particularly vulnerable to the impacts from storm surge because of the often fragile nature of fishing structure and equipment (Chowdhury et al. 2012). While the certainty about a change in frequency of cyclones is unclear, when they do happen they cause incredible damage when they do happen (Hossain & Saha 2017; Najnin 2014).

Drought and Extreme Events

It is unclear if the observed increase in extreme events is related to climate change, however, events such as drought threaten fisheries with their contribution to siltation of water bodies in neighboring Bangladesh.

While there has been a documented increase in the number of extreme events, it is not clear if this increase is directly related to climate change (Taft & Evers 2016). And while the frequency, intensity, and duration of these events is also unclear, the impact of an event will be related to the vulnerability of the area (Rao et al. 2013). For example, in Bangladesh, drought has contributed to the siltation of river beds and other water bodies, negatively impacting fisheries (Toufique & Islam 2014).

Management Options

Sea Level Rise

Aquaculture and rice are the food production sectors in Burma that will be impacted by sea level rise. Salinity intrusion, for example, may result in annual welfare losses up to US$10.59 billion on the global rice markets and Burma will likely go from exporting to importing rice, potentially causing increased food insecurity (Chen et al. 2012). Tidal inundation onto farm lands and fish ponds decrease involvement in farming, fish culture, and fish trade, reducing employment opportunities (Dasgupta et al. 2012). For freshwater aquaculture in areas vulnerable to saltwater intrusion, management response options include changing the cultured species or relocating operations (Cochrane et al 2009; Dasgupta et al. 2012). For rice, alternatives include freer trade for imports and switching to salinity tolerant rice varieties (Dasgupta et al. 2012; Chen et al. 2012).

Precipitation

As precipitation is projected to increase in Burma with most global climate models, management measures principally focus on managing and mitigating for increased flood waters. There are three major levels of management options for flood events: forecasting, adaption, and control. Flood forecasting does not require infrastructure to implement, but it does require hierarchical cooperation, integrated coastal zone management (Ahmad 2011). Flood adaptation measures include increasing natural vegetation to reduce inland flood risks (Mandle et al. 2017); converting farmland to fish ponds in flood prone areas and selectively cultivating quick-growing agricultural crops for production immediately after floods (Huq and Ahmed 1996); implementing integrated cropping systems (e.g., rice-fish farming; SeinnSeinn et al. 2015); and flood proofing and retrofitting buildings, roads, and flooding shelters (Kulatunga 2012). Direct flood control development projects include installing tube

wells, active irrigation, and resowing crops (Dewan et al. 2003; Kulatunga et al 2012); constructing coastal embankments (Hossain and Saha 2017); and implementing large-scale dams to control major flood pulses (Brakenridge et al. 2017). These more active measures, while providing protection in one location may cause significant impacts to fish habitat, migration routes, spawning grounds, and fishery-dependent livelihoods in other locations (Hossain and Saha 2017; Dewan et al. 2003). An additional concern of note is that, beyond local impacts, increasing conflicts may arise due to potential foreign investments in water resources (Taft and Evers 2016).

Extreme Events

Burma is hit by 0.51% of the world's total tropical storms, and due to climate change effects, the incidences of tropical storms and tidal surges have increased along the coastal belt of Burma (Rahman and Rahman 2015). Coastal zone management measures range from restoring natural vegetation to reinforcing infrastructure and implementing warning systems and community shelters (Hasan 2015). Traditional and indigenous practices, such as reinforcing building structures with fishing nets can be a simple measure to protect roofs from storm damage (Sarker and Azam 2012). Improving the accuracy of storm-surge predictions and cyclone warning systems can help protect the safety of fishermen and income potential in preparation for impacted fishing trips (Kausher et al. 1996; Chowdhury et al. 2012). One of the most effective policies for mitigating risks associated with extreme events is the maintenance of a buffer zone of mangrove forest as protected areas along the coast (Zöckler et al. 2013). Deep-rooted shrub type vegetation can serve as a defense of storm surge and prevent coastal erosion (Murty and Flather 1994); in particular, mangroves are highly effective of reducing coastal vulnerability to storms (Mandle et al. 2017; Aung et al. 2011). Mangrove systems, additionally, provide ecosystem services in their own right, providing timber and productive habitat for fisheries (Zöckler et al. 2013). It is important to note that sustainable forestry practices, especially in such critical regions, are essential to protect vulnerable populations living in delta regions; deforestation provides little resistance to surge flooding (Brakenridge et al. 2017). Fishers often prefer intervention to reduce immediate, short-term and long-term vulnerability to climate change, with some of these adaptation priorities community specific (Hasan 2015). However, more extensive management measures may be required for adaptation of some fishing-dependent communities, including climate-induced migration if their location is highly vulnerable to extreme events and no longer suitable for habitation (Islam 2013).

DISCUSSION

Based on the management information, four management areas emerged: barrier vegetation, agriculture to aquaculture, protected areas, and coastal zone management that could be addressed across three levels (business as usual, low intervention, and high intervention; Table 1). This information facilitated the development of a conceptual model illustrating these different management techniques (in development). The **business as usual** approach consists of maintaining the status quo. The **low intervention** approach, characterized by low financial investment required but rendering a substantial benefit. A more financially intensive management approach, or **high intervention**, takes some of these approaches a set further or implements a different management strategy.

Barrier Vegetation

If the status quo is maintained (**business as usual**), a continued loss of coastline and natural vegetation along coasts, rivers, and other water bodies. The **low intervention** approach encourages minor efforts to establish deep-rooted, shrub-type vegetation along embankments and restore coastal mangroves provide a low-cost, nature-based solution to address the loss of coastline and natural vegetation. The **high intervention** approach to address barrier vegetation would include intensive mangrove restoration and planting of deep-rooted, shrub-type vegetation in coastal and riparian zones.

Agriculture-Aquaculture
It is expected that there will be a loss of agriculture and aquaculture, which would cause an increase in importation of staple crops to meet demand if the **business as usual** approach is maintained. The **low intervention** approach suggests that to prevent loss of agriculture and aquaculture, the construction of embankments can help protect against flooding, but it is also important to be aware that while they may prevent flooding in one location they can also cause flooding in other areas. Given the potential for saltwater intrusion, switching to salinity tolerant varieties of rice and fish will agriculture and aquaculture operations adjust to changing climate conditions. It may also be necessary to resow crops after an event such as a flood. To increase availability of freshwater, rainwater can be harvested and stored for future use. Active irrigation and controlled flooding are low cost options to decrease the impact of flooding and maintain appropriate sediment loads, while planting vegetation can also help guard against soil erosion that can adversely impact agriculture. To address concerns with agriculture and aquaculture, the **high intervention** approach incorporates the repair of drainage systems and flood embankments and in flood-prone areas the focus would shift to integrated cropping systems (e.g., rice-fish farming) since complete conversion of agriculture to aquaculture is unlikely to be well received within Burma.

Protected Areas
The **business as usual** strategy results in a decrease in high quality habitat provided by protected areas throughout Burma. To allow high quality habitat to continue to be available, it would be necessary to maintain and enforce existing protected areas under the **low intervention** approach. To increase the availability of high quality habitat, protected area coverage could be increased within the **high intervention** approach.

Coastal Zone Management
There will also be a continued loss of life and infrastructure from storm and flood damage as well as continued poverty and poor quality of life if the current coastal zone management practices are maintained with **business as usual** strategy. Improving coastal zone management encompasses a multitude of approaches under the **low intervention** strategy, but the first step is the improvement of prediction and warning systems for flooding, storm surge, and cyclones. Additionally, providing more cyclone shelters in the event of an emergency is another low cost option that can accompany flood proofing structures by building on higher ground, reinforcing structures to withstand cyclones (e.g. using fishing nets to protect roofs from high winds), and developing flood control projects such as low lift pumps and tube wells. Finally, a **high intervention** approach to coastal zone management would include improving the construction of coastal embankments, relocation of residents out of vulnerable areas, and improving education systems, reducing poverty, enforcing regulations, and providing alternative livelihoods.

CONCLUSIONS AND LESSONS LEARNED

This work summarizes management approaches and seeks to present them in a way that is applicable to colleagues in Burma addressing the impacts of climate change on wild and aquaculture fisheries. While we have grouped management approaches into categories of high and low, we recognize a combination of the approaches discussed may be more practical based on available resources and the needs of a given region or town. For example, one location may find that they wish to invest heavily in restoring mangroves and establishing deep-rooted, shrub-type vegetation while taking a lower investment approach with their agriculture and aquaculture practices based on the resources that are most common in the area. Alternatively, another area may choose to focus on coastal zone management and continue with business as usual in other areas.

It was also important to recognize that current regulations may make implementation of management strategies more or less desirable. In some places, it is not possible to completely convert an

agricultural area to aquaculture ponds in an effort to take advantage of flooding. Additionally, community perception of management approaches must be taken into consideration because if the community believes revenue may be lost, it is unlikely to be well received.

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TABLES AND FIGURES

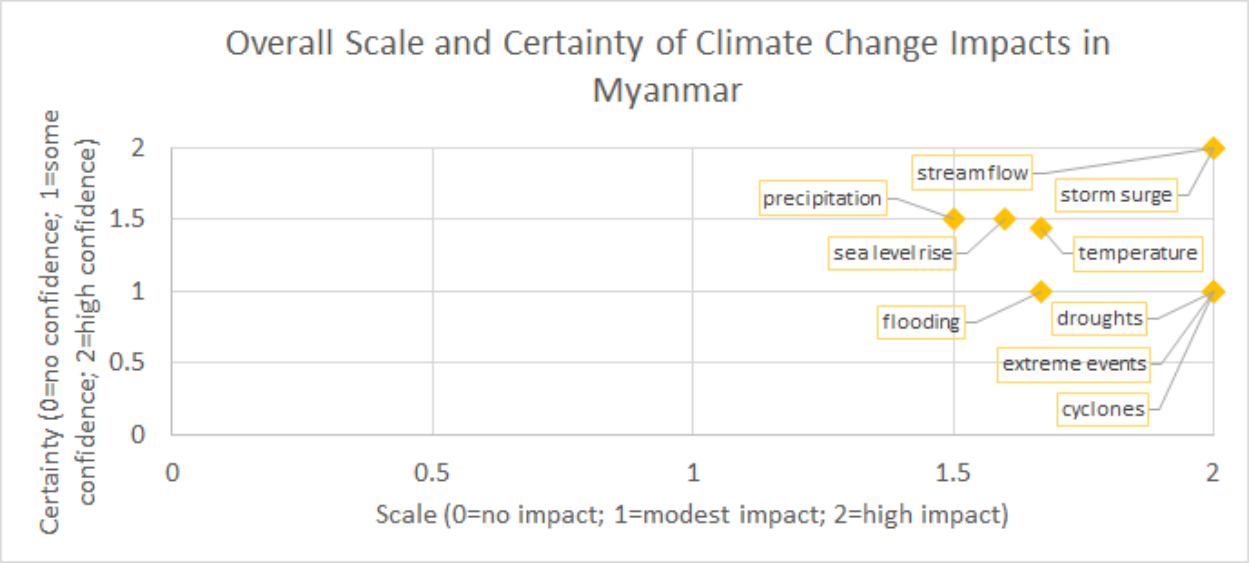

Figure 1. Numerical values for scale and certainty of climate change impacts were calculated for each source addressing a particular impact and an average of these values was used to obtain both a scale and certainty value for each impact.

Table 1. Management approaches to address climate change impacts on wild and aquaculture fisheries in Burma based on financial investment.

	BUSINESS AS USUAL	LOW INTERVENTION	HIGH INTERVENTION
BARRIER VEGETATION	Loss of coastline, natural vegetiation, etc.	Mangrove restoration (minor)	Mangrove restoration (intensive)
		Establish deep-rooted shrub type vegetation as coastal embankments in defense of storm surge can also prevent coastal erosion (minor)	Establish deep-rooted shrub type vegetation as coastal embankments in defense of storm surge can also prevent coastal erosion (intensive)
AGRICULTURE - AQUACULTURE	Loss of agriculture / aquaculture, importation of staple crops	Switch to salinity tolerant varieties of rice and fish species in coastal inundated areas	Repair and maintain flood embankment and drainage systems for agricultural and aquacultural sites
		Harvest rainwater to enhance freshwater availability	Convert farms to fish ponds in flood prone areas and focus on integrated cropping systems (e.g. rice-fish farming)
		Active irrigation	
		Controlled flooding	
		Resow crops	
PROTECTED AREAS	Loss of protected areas and high quality habitat	Enforce and maintain existing protected areas	Increase protected area coverage
COASTAL ZONE MANAGEMENT	Continued loss of life, infrastructure, etc. from storm and flooding damage; continued poverty and poor quality of life	Improved flood forcasting, storm surge predictions, and cyclone warning systems	Improve construction of coastal embankments
		Offer more cyclone shelters	Climate-induced migration (relocation of residents in vulnerable areas)
		Flood proofing (e.g., building on higher ground, retrofitting flood prone buildings, providing flooding shelters, designing roads above flood level)	Improve quality of life (education, reduce poverty, enforce regulations, providing alternative livelihoods)
		Flood control development projects (e.g., low lift pump, shallow tubewell, and improved cropping practices)	
		Reinforcing building structures with fishing nets is an indigenous practice to protect roofs from storm damage	

Table 2. Patterns in climate impacts and management responses.

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
sea level rise	adaptation and freer trade because rice is a major food staple	$$	with sea level rise, Burma goes from exporting rice to importing; as rice is a major staple, this will have a $$ effect on the economy.	Chen, C.C., McCarl, B., Chang, C.C., 2012. Climate change, sea level rise and rice: Global market implications. Clim. Change 110, 543–560. doi:10.1007/s10584-011-0074-0	Rice production is sensitive to sea level rise resulting in annual welfare losses ranging up to US$10.59 billion. The more significantly negative impacts fall in Bangladesh, Japan, Taiwan, Burma, Egypt, and Vietnam. Under the 6 m case imports rise by 292% for Bangladesh, 41% for Japan, and 3%for Taiwan. Burma, Vietnam, and Egypt go from being exporters to importers. Rice prices could be increased by 10% to 40% and depends on the effects of sea level rise and crop yield effects on rice production in each region with Bangladesh, Japan, Taiwan, Burma, and Egypt suffer from both effects. Such price increases may cause food insecurity.	Precipitation
extreme events	adaptation of fishing-dependent people	$-$$	simple adaptation measures include improvement of radio signals, weather forecasts, and warning systems; more complex adaptation measures include improving education, reducing poverty, enforcing regulations, providing alternative livelihoods	Islam, M.M., 2013. Vulnerability and Adaptation of Fishing Communities to the Impacts of Climate Variability and Change : Insights from Coastal Bangladesh Md Monirul Islam Submitted in accordance with the requirements for the degree of Doctor of Philosophy The University of. University of Leeds.	Adaptation of fishing-dependent people is impeded by both natural and anthropogenic factors: physical characteristics of climate and sea, technologically poor boats, inaccurate weather forecasts, poor radio signals, lack of access to credit, low incomes, lack of education, skills and livelihood alternatives, underestimation of cyclone occurrence, coercion of fishermen by boat owners and captains, unfavorable credit schemes, lack of enforcement of fishing regulations and maritime laws, and lack of access to fish markets.	Precipitation, Extreme Weather Events

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
extreme events	climate-induced migration	$$	migration requires considerable $$ and available livelihood strategies for positive outcomes for migrants	Islam, M.M., 2013. Vulnerability and Adaptation of Fishing Communities to the Impacts of Climate Variability and Change : Insights from Coastal Bangladesh Md Monirul Islam Submitted in accordance with the requirements for the degree of Doctor of Philosophy The University of. University of Leeds.	One direct impact of climatic shocks, such as cyclones and floods, is loss of life. Climatic shocks have killed several hundred thousand people in coastal Bangladesh, many of them fishermen or their household members, friends, or relatives (IPCC, 2007a). Other impacts include physical injuries (Badjeck et al., 2010) and health effects (Kovats et al., 2003). Cyclones and floods also damage boats, nets, fishing gear, and fish landing centres, as well as educational, health, housing and other community infrastructure (Jallow et al., 1999; Adger et al., 2005b;Westlund et al., 2007). Exposure, sensitivity, and adaptive capacity influence the vulnerability of fishery-based livelihoods in varied ways. Those who are most exposed are not necessarily the most sensitive or least able to adapt. That means the climatic stresses and shocks have unequal impacts in different fishery-dependent communities. The most important climate-related elements of exposure are floods and cyclones, while the key factor determining sensitivity of an individual household is the dependence on marine fisheries for livelihoods. Adaptive capacity is underpinned by the combination of physical, natural, and financial capital and is influenced by the diversity of livelihood strategies. The findings corroborate with the literature suggesting that climate induced migration may bring considerable positive outcomes for migrants (Black et al., 2011b) - positive livelihood outcomes were not immediate and required reduction on dependency on marine fisheries.	Precipitation, Extreme Weather Events
cyclones	Coastal zone management needs more interaction and integration with traditional ways of adaptation.	$	integrate traditional (low cost) adaptation methods into coastal zone management	Rahman, M.A., Rahman, S., 2015. Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. Weather Clim. Extrem. 7, 84–95. doi:10.1016/j.wace.2014.12.004	Due to climate change effects, the incidences of tropical storms and tidal surges have increased in the coastal belts of Bangladesh, India, Burma and Sri Lanka; Burma is hit by 0.51% of the world's total tropical storms.	Sea Level Rise
storm surge	Coastal zone management needs more interaction and integration with traditional ways of adaptation.	$	integrate traditional (low cost) adaptation methods into coastal zone management	Rahman, M.A., Rahman, S., 2015. Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh. Weather Clim. Extrem. 7, 84–95. doi:10.1016/j.wace.2014.12.004	Due to climate change effects, the incidences of tropical storms and tidal surges have increased in the coastal belts of Bangladesh, India, Burma and Sri Lanka; Burma is hit by 0.51% of the world's total tropical storms.	Sea Level Rise
flooding	construction and improvement of coastal embankments	$	coastal embankments can protect from flooding in one location but may cause negative impacts downstream	Hossain, M.S.S., Saha, D., 2017. Major infrastructural adaptations in coastal areas of Bangladesh considering cyclone and tidal flood. Dhaka, Bangladesh.	Coastal embankments may provide protection from flooding in one location but may cause deterioration in downstream locations , creating an imbalance in sediment budget, disturbing fish habitat, and impacting livelihoods.	Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
precipitation	Controlled flooding to prevent catastrophic impacts in the future	$	utilizing the current infrastructure (dams) to implement controlled flooding to reduce sediment starvation	Brakenridge, G. R., Syvitski, J. P. M., Niebuhr, E., Overeem, I., Higgins, S. A., Kettner, A. J., & Prades, L. (2017). Design with nature: Causation and avoidance of catastrophic flooding, Myanmar. Earth-Science Reviews, 165, 81–109. https://doi.org/10.1016/j.earscirev.2016.12.009	. If large dams are now constructed upstream, it will become even more critical that some delta land areas be subject to controlled flooding in order to lesson such differential subsidence. Dam-related sediment starvation is a long term and progressive factor; like deforestation and population growth in vulnerable areas, it sets the stage for severe losses of people and economies along the coast. Addressing these more-distal causes, however, can improve the efficacy of better warnings, evacuation routes, local shelters, and increased risk awareness.	Cyclones, Monsoons, Precipitation, Sea Level Rise
all	cost of adaptation will likely be high and make fishing less profitable. Also, there is a need to promote “safety at sea” more intensively, and to incorporate disaster risk management into fisheries management plans, and fisheries management into disaster risk reduction planning	$-$$	$ measures may include introduction of a new gear type for changing conditions but most adaptation measures will be $$ because the adaptive capacity of the traditional fishing communities is quite low	Vivekanandan, E., Hermes, R., O’Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.012	The traditional fisheries will be the most vulnerable to climate change. In the east coast of India and northern Bay of Bengal, there are thousands of boats without any form of mechanization or motorization, and depend entirely on wind power for propulsion. Along the east coast of India alone there are 36,657 traditional boats (CMFRI, 2012). With no alternate income and with poor literacy, the fishermen who depend on the traditional type of fishing are faced by poverty. With restricted mobility, the competitive capacity of this fleet with other fleets is limited. The availability of fish to this fleet is also likely to decline. The traditional fisheries have demonstrated considerable resilience to climate variability in the past. For example, with the increasing abundance of small pelagics, the traditional fishers have introduced a new gear, the ring seine, for efficiently catching the oil sardine. However, any objective assessment of traditional fisheries in the region would conclude that ex- posure and sensitivity to climate change threat are high, while adaptive capacity is low (for example FAO, 2005). Among the reasons for this conclusion are:the negative impacts on the sector, e.g. through habitat and ecosystem damage such as bleaching of corals, additional stress on mangroves and sea grasses; high dependence on fishing and related activities for livelihoods; many fisher folk reside in vulnerable, low-lying coastal areas which exposes their physical assets (e.g. boats, gear, homes) and put their lives at great risk due to climate-related events such as cyclones, sea level rise and sea erosion; inadequate sea safety mechanisms to protect from extreme events, which are projected to become more frequent and/or intense in the future; and factors such as lack of consistent access to capital on reasonable terms, weak fisher folk organizations and consequently low bargaining power with governments and other sectors.	Monsoons

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
cyclones	cyclone warning system	$	Institutionalizing a better cyclone warning system will be a low cost method to save lives	Chowdhury, S.R., Hossain, M.S., Shamsuddoha, M., Khan, S.M.M.H., 2012. Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh. Center for Participatory Research and Development, Dhaka, Bangladesh.	While the fishermen choose not to risk lives and refrained from fishing trips, they had to accept loss of income potential. Following the issuance of a warning fishers had to come back early by abandoning the fishing trip. The unfinished trips caused a significant loss of their livelihoods, especially in the peak fishing period. The fishers claimed that they have been faced couple of warnings throughout the monsoon. By the time they could come back to safety, their investments for the purchase of food, fuel and other commodities have all been consumed, while the catch volume was much reduced than expected. Many lost their boats and nets when the weather had become stormy. Since it all started with the increase in sea surface temperature, one cannot ignore the fact that it had been essentially triggered by global warming. Perhaps, such an extreme event provides the first ever evidence that climate change and its consequences are actually affecting people's lives and livelihoods in Bangladesh, especially in the coastal areas.	Monsoons
storm surge	deep-rooted shrub type vegetation as coastal embankments in defense of storm surge can also prevent coastal erosion; dams; warning systems and community shelters;	$	low cost measures include planting shrubs against storm surge and erosion, instituting early warning systems, and creating community shelters	Murty, T.S., Flather, R.A., 1994. Impact of Storm Surges in the Bay of Bengal. J. Coast. Res. 149–161.	Though the frequency of cyclones is not highest in the Bay of Bengal, there is a disproportionately large impact of storm surges on the coast of Bangladesh because: (1) The phenomenon of recurvature of tropical cyclones in the Bay of Bengal; (2) Shallow continental shelf, especially in the eastern part of Bangladesh; (3) High tidal range; (4) Triangular shape at the head of Bay of Bengal; (5) Almost sea level orography of the Bangladesh coast, coupled with many inlets and some rivers and estuaries; (6) High density of population, especially on low lying islands.	Monsoons
all	development projects aimed at addressing food insecurity and food production shortfalls - such as fish production for domestic consumption and exports with a special emphasis on rural poverty alleviation and employment generation	$$	addressing food insecurity and food production is a major undertaking	Alam, R., Bahauddin, K.M., 2014. Mainstreaming Climate Change Adaptation into Regional Planning of Least Developed Countries: Strategy Implications for Regions in Bangladesh. Manag. Sustain. Dev. 6, 5–17. doi:10.2478/msd-2014-0001	rural poor in less developed countries are vulnerable as they depend on the productivity of climate-sensitive ecosystems for livelihoods (including fisheries)	Sea Level Rise
Sea Level Rise	Farming to aquaculture transition	$	opportunistic transition of food production systems from farming to aquaculture	Cochrane, K., De Young, C., Soto, D., Bahri, T., & Eds. (2009). Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. FAO Technical Paper, 530, 221. https://doi.org/ISSN 2070-7010	Interactions between food production systems could compound the effects of climate change on fisheries production systems but also offer opportunities. Aquaculture based livelihoods could for example be promoted in the case of salination of deltaic areas leading to loss of agricultural land.	Extreme Weather Events
flooding	Flood Control Development projects (e.g., low lift pump, shallow tubewell, and improved cropping practices)	$	flood control measures can reduce flooding at low cost (but with impact to habitat)	Dewan, A.M., Nishigaki, M., Komatsu, M., 2003. Floods in Bangladesh: a comparative hydrological investigation on two catastrophic events. J Fac Env. Sci Technol 8, 53–62.	Control measures have switched from large-scale embankments to small-scale Flood Control Development projects but these can lead to a decline and fishery and wildlife habitat	Monsoons

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
flooding	flood forecasting	$	improved flood forecasting and integrated coastal zone management	Ahmad, Q.K., 2011. Climate change and freshwater resources of Bangladesh, in: Hossian, M., Selvanatham, A. (Eds.), Climate Change and Growth in Asia. Edward Elgar Publishing, Cheltenham and Northampton, UK, pp. 62–77.	hierarchical cooperation (local, national, regional) needed for flood forecasting and integrated coastal zone management.	Precipitation
flooding	flood mitigation through rice-fish culture; convert farms to fish ponds in ares vulnerable to flooding	$	low cost measures to mitigate floods include rice-fish culture and transitioning to fish pond aquaculture	Huq, S., Ahmed, A.U., 1996. Vulnerability of Bangladesh to Climate Change and Sea Level Rise, in: Downing, T.E. (Ed.), Climate Change and World Food Security. Series I: Global Environmental Change, Vol. 37. NATO Scientific Affairs Devision, Berlin, Germany, pp. 347–379.	About 78 per cent of the agricultural value addition is created through crop production. Livestock and poultry account for 7.6 per cent of agricultural incomes; fisheries and forestry account for 7.5 per cent and 6.6 per cent respectively. Currently, the agricultural sector (crop, livestock, forestry and fisheries) employs about 65 per cent of the labour force [in BANGLADESH]; Other means of mitigating flood effects are the cultivation of quick-growing homestead vegetables, pulses, modem short-duration mustard, maize field peas inter crop, potato under zero tillage, and rice-fish culture. These cultivation practices would intensify crop production immediately after the flood and should generate cash incomes and provide food for the affected population.	Precipitation, Sea Level Rise
flooding	Flood proofing (e.g., building on higher ground, retrofitting flood prone buildings, providing flooding shelters, designing roads above flood level) and flood forecasting	$	low cost measures to flood proof and flood forecast	Kulatunga, U., Wedawatta, G., Amaratunga, D., Parvez, A., Biswas, R., 2012. Disaster risk reduction measures in Bangladesh, in: Global Challenges in Construction Industry: World Construction Symposium, 28 – 30 June 2012. Colombo, Sri Lanka, pp. 209–220.	These are evident of ineffectiveness of embankments as flood controlling measures. On top of that, adverse impact of construction of embankments is broadened to obstruction of fish migration routes and spawning grounds, and deterioration of floodplain ecosystem	Monsoons
sea level rise	Gher is an unsustainable adaptation model - current rice breeds are not salt tolerant enough and embankment repair requires structural maintenance. The absence of a robust mechanism to prevent salinity seepage into croplands requires more research	$-$$	rice-fish culture is not always an effective transition model; more research is needed	Boiragi, K.S., 2016. Why Gher Cannot Serve as a Climate Change Adaptation Model: A Case Study on Shrimp-Rice Intercropping in Joymoni, Mongla, Bangladesh. York University.	Gher = intercropping method of cultivating paddy, shrimp and fin fish; The coastal belts are threatened primarily with Sea Level Rise (SLR), floods, cyclones, surges, erosion, and salinity intrusion; Salinity reduces soil quality, and can force farmers to use fertilizers and pesticides at extra expense. This does not bring sufficient production, but harms the natural quality of the soil further. As people do not get a good harvest from their rice paddy, they try to do gher with the idea that they could revive their losses by selling shrimp and fish. Continuous gher, instead of promising sustainable income, deteriorates the soil quality further. Ultimately farmers do not get crops, nor do they get shrimp and fin fish. Cyclones, surges, erosion, and floods exacerbate the issues	Precipitation
precipitation	harvesting rainwater	$	inexpensive means to enhance the availability of freshwater	Ahmad, Q.K., 2011. Climate change and freshwater resources of Bangladesh, in: Hossian, M., Selvanatham, A. (Eds.), Climate Change and Growth in Asia. Edward Elgar Publishing, Cheltenham and Northampton, UK, pp. 62–77.	ponds in rural areas and rooftop facilities in urban areas can enhance the availability of freshwater.	Precipitation

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
extreme events	improve coastal home construction, offer more cyclone shelters, improve warning systems	$	simple home improvements and community activities can have large impacts on warning systems	Hasan, Z., 2015. Artisan fishers' perceptions of, and adaptation to, climate change in the southeast coast of Bangladesh. University of Adelaide.	Some of the most popular long-term adaptation techniques in response to cyclones, floods and storm surges are: ? Migration, ? Borrowing money from the local moneylenders or from friends and family members, Strengthen fishing boats and nets. ? Home improvements (for example, to raise the height of plinth), ? Strengthen nets and fishing boats, Sell off assets to get some funds to rebuild their lives,	Precipitation
flooding	improve flood forecasting and early warning; repair / maintain flood embankment and drainage systems	$-$$	from simple to long-term adaptation interventions	Hasan, Z., 2015. Artisan fishers' perceptions of, and adaptation to, climate change in the southeast coast of Bangladesh. University of Adelaide.	See Table 6.2 for adaptation preferences; Fishers' adaptation priorities indicated that fishers prefer intervention to reduce immediate, short-term and long-term vulnerability to climate change, with some of these adaptation priorities community specific	Precipitation

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
precipitation	Increase in natural vegetation/restoration/creation of protected area	$	nature-based solutions and engineering solutions to monsoon impacts	Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., … Su Mon, M. (2017). Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLoS ONE, 12(9), 1–23. https://doi.org/10.1371/journal.pone.0184951	Precipitation is projected to increase in most, but not all GCMs. In general, precipitation increases are projected to be largest in the monsoon season. See Supporting information (S2–S4 Data) and Horton et al. [51]for more detail on the range of projected changes in temperature and precipitation....Natural vegetation plays the greatest role in reducing inland flood risk in places with dense forest and high precipitation, where peak flow is higher....To maintain baseline levels of water quality, water availability and flood risk likely requires more than preserving existing stocks of natural capital. Nature-based solutions, such as habitat resto-ration, can be considered alongside traditional, engineering-based approaches [54], and further assessments could help identify the most effective places for these activities. At the same time, it is important to recognize that necessary interventions to enhance ecosystems and their resilience can be challenging to effectively complete, and do not replace the need to protect existing natural capital [55]...Our assessment therefore suggests that conservation of natural vegetation in these areas is likely to secure valuable benefits for the people of Burma today and in coming decades. We note that our analyses assume no major shifts in vegetation type or function occur over this time scale. Accounting for the effects of climate change on ES through changes in vegetation and ecological processes would be a valuable next step...By highlighting areas where loss of natural ecosystems would have outsized negative consequences for Burma's people and existing infrastructure, the national assessment can guide land use planning for agricultural expansion and resettlement plans, as well as inform the location and design of infrastructure projects...	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
storm surge	increase accuracy of storm-surge predictions	$	improve storm surge predictions	Kausher, A., Kay, R.C., Asaduzzaman, M., Paul, S., 1996. Climate Change and Sea-Level Rise: the Case of the Coast, in: Warrick, R.A., Ahmad, Q.K. (Eds.), The Implications of Climate and Sea-Level Change for Bangladesh. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 335–407.		Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
precipitation	installing tube wells, active irrigation, resowing crops	$	install tube wells, active irrigation,	Kulatunga, U., Wedawatta, G., Amaratunga, D., Parvez, A., Biswas, R., 2012. Disaster risk reduction measures in Bangladesh, in: Global Challenges in Construction Industry: World Construction Symposium, 28 – 30 June 2012. Colombo, Sri Lanka, pp. 209–220.		Monsoons
precipitation	integrated cropping systems (e.g., rice-fish farming) which can be environmentally secure and sustainable for household income	$	simple integrated cropping systems	SeinnSeinn, M., Ahmad, M., Thapa, G., Shrestha, R., 2015. Farmers' Adaptation to Rainfall Variability and Salinity through Agronomic Practices in Lower Ayeyarwady Delta, Myanmar. J. Earth Sci. Clim. Change 6, 258. doi:10.4172/2157-7617.1000258	Although double cropping of rice in monsoon and summer has provided higher cropping intensity and farm income, it has promoted the soil salinity and environmental unsustainability. Policy instruments are therefore suggested for an effective implementation of soil conservation and integrated farming system in lowland rainfed rice-based cropping system.	Sea Level Rise
all	International Conventions related to wetlands, biodiversity, and climate change	$$	complex international governance coordination	Gopal, B., 2013. Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. Aquat. Sci. 75, 39–61. doi:10.1007/s00027-011-0247-y	The main problem with the governance and management of wetlands arises from the multiplicity of stakeholders and institutions dealing with different resources and their users. Irrigation, fisheries, agriculture, land use, water pollution, recreation are all dealt with by different institutions/organi- stations. Inadequate interagency coordination was recognized as a major barrier to a coherent management strategy for wetlands throughout the lower Mekong basin. The developed countries have started realizing the social and cultural differences and the need for community partici- pation in managing the natural resources. It is quite possible that appropriate shifts in policy will occur in response to the demands from within as well as outside the countries, and there will be greater international cooperation. The loss of ecosystem services of wetlands is likely to compel the governments and local communities to start restoration activities and change the paths of development. Successful long-term restoration and management of wetlands hinges upon our ability and capacity to manage efficiently the limited freshwater resources for meeting both human and environmental needs, coupled with our effective adaptive responses to the incremental, often synergistic, threats from climate change.	Precipitation
precipitation	Manage foreign investment in water resources	$	increase research to understand climate change dynamics for water systems	Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Due to the lack of scientific research in the country, of-ten uncertain or incomplete databases and rapid political and economic changes, future perspectives for human–water dynamics in Burma's river basins can only be assessed with high uncertainties. However, it should be possible to indicate the major drivers of future changes. Undoubtedly, the avail- ability and quality of freshwater is and will be the core of the country's future development, but increasing conflicts on water may arise due to growing foreign investments and various international and national interests...See Figure 3	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
storm surge	Mangrove Plantings	$	low-cost nature-based solution	Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., … Su Mon, M. (2017). Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLoS ONE, 12(9), 1–23. https://doi.org/10.1371/journal.pone.0184951	Mangroves are very effective at reducing coastal vulnerability to storms, especially compared to seagrass beds [50], and so the presence of man- groves (Fig 1) generally corresponded with the highest role of coastal habitat in reducing exposure	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
storm surge	Mangrove Plantings	$	low-cost nature-based solution	Aung, T. T., Than, M. M., Katsuhiro, O., & Yukira, M. (2011). Assessing the status of three mangrove species restored by the local community in the cyclone-affected area of the Ayeyarwady Delta, Myanmar. Wetlands Ecology and Management, 19(2), 195–208. https://doi.org/10.1007/s11273-011-9211-9	This study focuses on three species, Avicennia officinalis L., Heritiera fomes (Lour.) Poir. and A. marina (Forssk.) Vierh. The first two species have wide ecological amplitudes in this area (Aung et al. 2004a, b; Than et al. 2006) and seem to have a high potential for successful plantation as well as quick return to people in the form of poles, post and fuel wood, and high quality timber from H. fomes. A. marina, on the other hand, has a narrower ecological amplitude, but local people prefer it for use as poles for their construction materials...[In results section] This is consistent with the belief held bylocal people, based on their common knowledge of the region and without any special scientific investigation, that A. marina was very resistant to defoliation by Cyclone Nargis...So it is highly probable that the taller the trees in a plantation, the greater the impact by cyclones. The very low mortality of 2% for A. marina seemed to be due not only to the cyclone, but also due to effects of unfavorable site factors for this species such as drought in summer...According to our field observation, local people prefer restoring A. officinalis, rather than other species, because of its quick return benefit. If the main objective behind restoration of the plantations is utilization of the trees by local people, for example, as wood for fuel or poles other than timber, exploitable limits should be reconsidered carefully...[In conclusion section] In summary, the cyclone did not affect the survival rates of the mangrove species on these study plots to a great extent; only a slight decline was observed in A. officinalis on low ground and in A. marina on high ground. The plantations in this study are far from the seaside, and the wave effect might be negligible...During the intense cyclone of April 1991 in Bangladesh, many of the mangrove plantations were damaged, but by July 1991 most plantations showed clear signs of recovery (Siddiqi, unpublished data), except in areas of significant silt deposition. Damage to non-mangrove species raised on coastal embankments (such as Acacia nilotica) was significantly higher than that to mangrove species; the less developed root systems in non- mangrove species may have contributed to their susceptibility to ‘wind-throw’ (Saenger and Siddiqi 1993)...Since growth and productivity differ significantly on low versus high ground, more successful benefits for local communities can be achieved by establishing A. officinalis and A. marina on low ground and H. fomes on high ground.	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
extreme events	Mangrove restoration	$	low-cost nature-based solution	Zöckler, C., Delany, S., & Barber, J. (2013). Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambirdge, UK.	Burma is very susceptible to extreme weather events and sea-level rise related to current and predicted future climate change. Coastal erosion and flooding are further risks which are predicted to grow...Mangroves along the Burma coast are of immediate value to local people, particularly as firewood and charcoal for cooking, timber for construction and as productive habitat for fisheries. A positive correlation between fish and shrimp catches in nearshore waters and the extent of mangrove area has been widely proven (Matosobroto & Naamin 1977; Saeskumar et al. 1992; Comach & Bagariano 1987). Artisanal fisheries along the Burma coast are largely mangrove dependent. Mangrove forest ecosystems contribute a wide range of goods and services from which local people have benefited since time immemorial. There is a wide range of direct and indirect products from mangrove, which forms the basis for mangrove dependent economic activities vital to many coastal peoples in Burma. Unsustainable exploitation has led to the depletion of many mangrove areas...Mangroves can reduce storm surge water levels by slowing the flow of water and reducing surface waves...Mangroves can therefore potentially play a role in coastal defense and disaster risk reduction, either alone or alongside other risk reduction measures such as early warning systems and engineered coastal defense structures (e.g. sea walls)(UNEP 2006). Measured rates of storm surge reduction through mangroves range from 5 to 50 centimeters water level reduction per kilometer of mangrove width. In addition, surface wind waves are expected to be reduced by more than 75% over one kilometer of mangroves...As global temperatures continue to increase, weather patterns will grow increasingly unstable and sea levels will continue to rise, causing more coastal erosion and flooding. One of the most effective policies for mitigating all these risks is the maintenance of a buffer zone of mangrove forest along the coast.	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
Sea Level Rise	Mangrove restoration	$	low-cost nature-based solution	Zöckler, C., Delany, S., & Barber, J. (2013). Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambirdge, UK.	Burma is very susceptible to extreme weather events and sea-level rise related to current and predicted future climate change. Coastal erosion and flooding are further risks which are predicted to grow...Mangroves along the Burmacoast are of immediate value to local people, particularly as firewood and charcoal for cooking, timber for construction and as productive habitat for fisheries. A positive correlation between fish and shrimp catches in nearshore waters and the extent of mangrove area has been widely proven (Matosobroto & Naamin 1977; Saeskumar et al. 1992; Comach & Bagariano 1987). Artisanal fisheries along the Myanmar coast are largely mangrove dependent. Mangrove forest ecosystems contribute a wide range of goods and services from which local people have benefited since time immemorial. There is a wide range of direct and indirect products from mangrove, which forms the basis for mangrove dependent economic activities vital to many coastal peoples in Burma. Unsustainable exploitation has led to the depletion of many mangrove areas...Mangroves can reduce storm surge water levels by slowing the flow of water and reducing surface waves...Mangroves can therefore potentially play a role in coastal defense and disaster risk reduction, either alone or alongside other risk reduction measures such as early warning systems and engineered coastal defense structures (e.g. sea walls)(UNEP 2006). Measured rates of storm surge reduction through mangroves range from 5 to 50 centimeters water level reduction per kilometer of mangrove width. In addition, surface wind waves are expected to be reduced by more than 75% over one kilometer of mangroves...As global temperatures continue to increase, weather patterns will grow increasingly unstable and sea levels will continue to rise, causing more coastal erosion and flooding. One of the most effective policies for mitigating all these risks is the maintenance of a buffer zone of mangrove forest along the coast.	Cyclones
all	migration	$$	migration requires considerable $$ and available livelihood strategies for positive outcomes for migrants	Chowdhury, S.R., Hossain, M.S., Shamsuddoha, M., Khan, S.M.M.H., 2012. Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh. Center for Participatory Research and Development, Dhaka, Bangladesh.	Migration is driven by both push and pull factors in the coastal Bangladesh. Main push factors are landscape changes caused by erosion where accretion of new land and economic solvency act as pull factors of migration. Migration is considered as a coping strategy and most migrant fishers are seasonal fishers to other coast or island places.	Monsoons
all	Modification of land use rights	$$	significant governance oversight to implement new land-use planning measures	Zöckler, C., Delany, S., & Barber, J. (2013). Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambirdge, UK.	Loss of land and land rights can force local communities to turn to less sustainable harvest types and methods and can cause environmental degradation. The introduction of comprehensive land-use policies and land-use planning, consistent with sustainable livelihoods of the local communities and biodiversity conservation, will be a crucial instrument for the sustainable development of the coastal zone in Burma.	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
extreme events	Need to prevent deforestation or plant mangroves	$	low-cost nature-based solution	Brakenridge, G. R., Syvitski, J. P. M., Niebuhr, E., Overeem, I., Higgins, S. A., Kettner, A. J., & Prades, L. (2017). Design with nature: Causation and avoidance of catastrophic flooding, Myanmar. Earth-Science Reviews, 165, 81–109. https://doi.org/10.1016/j.earscirev.2016.12.009	Deforestation. The expansion of population in the eastern delta, where Yangon is situated, occurred together with deforestation to the west. This may have substantially increased Nargis storm damage and fatalities, via the removal of mangrove and other delta forests, and as compared to previous storms. The delta had lost much mangrove forest along the coast to shrimp farms and rice paddies in the decade prior to Nargis, and continuing a trend established for many years prior. Deforestation had long been underway: “by the late 19th century most of the dense low- land evergreen forests, swamp and mangrove forests were cleared following human settlement” (Giri et al., 2010). As the 20th century ended, the remaining forests were concentrated to the west, in the less accessible estuaries of the delta. Just before Nargis, deforestation in the Ayeyarwady delta region had accelerated: “more than 20% of the mangrove forests…lost in only 10 years; the major cause being fuel wood collection” (Leimgruber et al., 2005)(Giri et al., 2010) (Frenken, 2012).Yan- gon and its environs grew very fast in population, while the re- maining populations in the southernmost delta areas lived in a recently deforested landscape with increasingly little resistance to surge flooding. Under a “business-as-usual” scenario, some re- searchers project that unprotected Ayeyarwady delta mangrove forests could be completely deforested by 2026 (Webb, 2013). Post-Nargis, however, sustainable forestry practices could in- stead help protect the millions of inhabitants now living in the delta	Cyclones, Monsoons, Precipitation, Sea Level Rise
all	no regrets' actions	$	simple measures to reduce habitat loss, degradation, or restore or protect existing areas are "low-hanging" fruit	Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	The first set of actions involves ‘no regret’ actions in the absence of good biodiversity base- line and forecast data. A strategy for conserving regional biodiversity in a dynamic climate is to conserve the full spectrum of geophysical settings. If geophysical diversity helps to maintain species diversity, then conserving representative examples of geophysical settings could potentially protect biodiversity under both current and future climates (Beier and Brost 2010). Importantly, reducing or removing the effects of non-climate-related threats such as habitat loss and degradation and overexploitation will increase the ability of species and eco- systems to respond to climate change. Improving management and restoration of existing protected areas and ensuring adequate representation and replication within the protected area network will facilitate resilience.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
all	Protected areas	$-$$	can be implemented directly but will require strong safeguards to be effective	Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	Based on the above, a series of best practice principles have been actively promoted for adaptation planning that are relevant in Burma: (1) Substantially expand the current protected area system to maintain viable populations of priority species and maximize adaptive capacity; (2) Expand the current protected area system so as to capture refugia; (3) Assign priority to protecting large, intact landscapes; (4) Ensure functional connectivity is maintained beyond protected areas; (5) Develop and implement strong environmental safeguards to protect biodiversity within a context of rapidly evolving economic development in the form of large-scale infrastructure projects	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
extreme events	Protected areas	$-$$	can be implemented directly but will require strong safeguards to be effective	Zöckler, C., Delany, S., & Barber, J. (2013). Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambirdge, UK.	We propose, however, that the protected area network should be expanded much more widely to include most of the Tanintharyi coast and much of the Rakhine coast. This is necessary to ensure the protection of vital ecosystem services, the last remaining marine turtle and dugong breeding sites and other important sites for wintering water birds. All these will provide essential economic incentives for the development of sustainable tourism	Cyclones
Sea Level Rise	Protected areas	$-$$	can be implemented directly but will require strong safeguards to be effective	Zöckler, C., Delany, S., & Barber, J. (2013). Sustainable Coastal Zone Management in Myanmar. ArcCona Ecological Consultants, Cambirdge, UK.	We propose, however, that the protected area network should be expanded much more widely to include most of the Tanintharyi coast and much of the Rakhine coast. This is necessary to ensure the protection of vital ecosystem services, the last remaining marine turtle and dugong breeding sites and other important sites for wintering water birds. All these will provide essential economic incentives for the development of sustainable tourism	Cyclones
cyclones	reinforcing building structures with fishing nets is an indigenous practice to protect roofs from storm damage	$	simple, low-cost measures to protect from storm damage	Sarker, T., Azam, M., 2012. Super Cyclone SIDR 2007: Climate change adaptation mechanisms for coastal communities in Bangladesh. Asian J. Environ. Disaster Manag. 4, 85–105. doi:10.3850/S1793924012001149	Devestating super cyclone on Nov. 15th, 2007 in Bangladesh - Official sources reported approximately 3500 deaths, total or partial destruction of more than 80 percent of thatched houses, damage to 70 percent of the near-harvest rice paddies, 60 to 70 percent of fisheries and huge numbers of livestock. Economic loss was estimated to be worth around Tk. 6,000 Crore which may eventually reach Tk. 16100 Crore. Damage to income generating assets included loss of fishing boats and gear.	Sea Level Rise
Sea Level Rise	Relocation of aquaculture	$	aquaculture siting based on climate projections	Cochrane, K., De Young, C., Soto, D., Bahri, T., & Eds. (2009). Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. FAO Technical Paper, 530, 221. https://doi.org/ISSN 2070-7010	...culture areas must be shifted further upstream to mitigate climatic change effects. On the other hand, climate impacts could make extra pond space available for shrimp farming, providing adequate links in the supply chains	Extreme Weather Events
sea level rise	Salinity tolerant rice varieties and fish species should be innovated and replicated in the coastal area	$	use salinity tolerant agriculture varieties to adapt to changing conditions	Dasgupta, S.K., Usami, K., Rahman, M.A., Sharifullah, A.K., 2012. Climate change and preparedness at the villege level in coastal areas of Bangladesh. Nagoya, Japan.	survey respondents indicated that tidal inundation and stagnation of saline water on farmlands and homesteads during the next 25 years will drastically decrease involvement in farming, fish culture, fishing, and fish trade and coastal communities would need to change their professions due to decreases in employment opportunities.	Precipitation

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
all	sustainable fishing practices	$-$$	win-win regardless of climate change but can be difficult to implement	Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.013	Moderately-fished stocks are likely to be more resilient to climate change impacts than heavily-fished ones. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change (Brander, 2007). Reduction of fishing effort (i) maximizes sustainable yields, (ii) helps adaptation of fish stocks and marine ecosystems to climate impacts, and (iii) reduces greenhouse gas emission by fishing boats (Brander, 2008). Hence, some of the most effective actions to tackle climate impacts are to deal with the familiar problems such as overfishing (Brander, 2008), and adopting implementable measures (which may differ from country to country) from the Code of Conduct for Responsible Fisheries, and an Ecosystem Approach to Fisheries Management (FAO, 2007).	Monsoons
all	Transition to more self-sustaining aquaculture strategies	$	consider more effective aquaculture practices with changing conditions	Cochrane, K., De Young, C., Soto, D., Bahri, T., & Eds. (2009). Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. FAO Technical Paper, 530, 221. https://doi.org/ISSN 2070-7010	Aquaculture systems, which are less or non-reliant on fishmeal and fish oil inputs (e.g. bivalves and macroalgae), have better scope for expansion than production systems dependent on capture fisheries commodities.	Extreme Weather Events
all	Vulnerability assessment	$-$$	conducting vulnerability assessments is one thing; implementing their recommendations is another	Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	The second category of actions involves undertaking vulnerability analyses for threatened species and ecosystem services, modeling future ecological states (accepting uncertainties) and integrating into a holistic planning framework that includes human responses to climate change impacts (Seimon et al. 2011; Cross et al. 2012). A first step is to build critically important knowledge and capacity to make climate change adaptation of conservation management effective in the absence of data. More advanced climate modeling studies are critical to under- standing climate change at relevant spatial and temporal scales in Burma. Subsequently, **scenario building exercises with scientists and stakeholders may be used to consider how outcomes may vary and what actions would be appropriate for different combinations of factors driving environmental responses to climate change**.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
storm surge				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.005	The Burma coast (Gulf of Martaban, Irrawaddy estuary) is also exposed to very damaging cyclones (e.g. cy- clone Nargis in 2008). The problem can be fathomed from the fact that during the past two and a half centuries, 20 out of 23 major cyclone disasters (with human loss of life 10,000 or more and not considering the damages) in the world have occurred over India and Bangladesh. One of the major reasons for this is the serious storm tide problem in these coasts. A tropical cyclone of specific intensity when it strikes the northern Bay of Bengal, usually produces a higher storm surge compared to that when such a cyclone strikes elsewhere in the world. This is because of the special nature of the coastline, the shallow coastal ocean topography and the characteristics of tide. Furthermore, the high density of population adds to the severity of the problem.	Monsoons
temperature				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.006	Sea surface temperatures (SST) have increased by 0.2–0.3 °C along the Indian coast of the Bay for the 45 year period from 1960 to 2005 (Vivekanandan et al., 2009a; Fig. 2). They have predicted increase of 2–3.5 °C by the end of the century	Monsoons
sea level rise				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.007	Sea level rise is mostly caused by thermal expansion and researchers have noted an accelerating rate of increase at 12–13 mm/decade for the northern Indian Ocean (Unnikrishnan and Shankar, 2007). The most far reaching consequences of sea level rise are threats to the coasts and coastal people through coastal erosion, inundation, and saltwater intrusion into freshwater sources and habitats, not only in Bangladesh and the Maldives, but also in Sri Lanka, Sumatra and other coastal areas of the Bay of Bengal, which may experience significantly more sea-level rise than the global mean, and this will increase the environmental stress on these coasts and islands (Han et al., 2010).	Monsoons
temperature				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.008	Most fish species have a fairly narrow range of optimum temperatures needed for their basic metabolism and the survival of their food supply. Being poikilotherms, even a difference of 1 °C or 0.1 unit pH in seawater may affect their physiology, abundance, and distribution. The more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the habitat area it occupies may expand, shrink or be relocated. As a result, the distribution of marine fish will increase in some areas, decline in others, or shift altogether.	Monsoons

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
temperature				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.009	The northern Indian Ocean is landlocked, and there is a natural barrier to further latitudinal shift due to the Asian continent landmass. Marine species are also inhibited by the freshwater plume of the Ganges–Brahmaputra–Megna river delta and the heavy sediment load. Warming ocean waters cause fish species to shift to deeper depths in the water column.	Monsoons
all				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.010	There is also increasing evidence of phenological changes as a result of climate change.	Monsoons
all				Vivekanandan, E., Hermes, R., O'Brien, C., 2016. Climate change effects in the Bay of Bengal Large Marine Ecosystem. Environ. Dev. 17, 46–56. doi:10.1016/j.envdev.2015.09.011	Currently, it is difficult to establish how much of catch fluctuation is due to changes in fish distribution and phenology. However, these changes may have impact on nature and value of fisheries (Perry et al., 2005). If small-sized, low-value fish species with rapid turnover of generations are able to cope with a changing climate, they may replace large-sized high-value species, which are already showing declining trends due to fishing and other non-climatic factors (Vivekanandan et al., 2005).	Monsoons
precipitation				Shrestha, M., Shrestha, S., Datta, A., 2017. Assessment of climate change impact on water diversion from the Bago River to the Moeyingyi wetland, Myanmar. Curr. Sci. 112, 377–384. doi:10.18520/cs/v112/i02/377-384 CURRENT	In this study, the impact of climate change on water availability of the upper BRB and Moeyingyi wetland has been investigated. Two emission scenarios and three GCM outputs were used to predict the future climate data, which were used in the SWAT model to predict future discharge in the Bago River. Three future periods of up to 2050 as 2020s, 2030s and 2040s were considered for the study. The bias-corrected data of temperature show that the basin average temperature increases continuously throughout the study period, reaching up to 1.2–2.7?C, indicating an increase in evapotranspiration. It is also observed that the overall precipitation will decrease during the near future and will rise in the middle of the 21st century. The monthly analysis of precipitation also shows a decrease during the monsoon period, except in July when precipitation will increase. With increasing temperature and decreasing precipitation, a decrease in mean annual discharge will be evident at both Zangtu and Bago stations, indicating a decrease in water availability in the BRB. The projected monthly changes in discharge reveal that will decrease during May and October. These can have a serious consequences on water diversion to the Moeyingyi wetland. On the other hand, an increase in discharge during the monsoon season can worsen the regular floods in Bago city. Similarly, a large increase in discharge is predicted during April due to an increase in precipitation. Overall, the inflow at Moeyingyi wetland is expected to decrease in the future.	Precipitation

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
all				Hasan, Z., 2015. Artisan fishers' perceptions of, and adaptation to, climate change in the southeast coast of Bangladesh. University of Adelaide.	See Table 7.1 for fish catch impacts	Precipitation
sea level rise				Toufique, K.A., Islam, A., 2014. Assessing risks from climate variability and change for disaster-prone zones in Bangladesh. Int. J. Disaster Risk Reduct. 10, 236–249. doi:10.1016/j.ijdrr.2014.08.008	most fisher households (87%) in the coastal district of Bagerhat [of BANGLADESH] suffered from chronic drinking water shortages because of groundwater salinity and inadequate tube-well facilities	Monsoons, Precipitation, Sea Level Rise
flooding				Toufique, K.A., Islam, A., 2014. Assessing risks from climate variability and change for disaster-prone zones in Bangladesh. Int. J. Disaster Risk Reduct. 10, 236–249. doi:10.1016/j.ijdrr.2014.08.008	flash flood zones [in BANGLADESH] remain under water for several months, there is opportunity for fishing. Almost half of the households catch fish from the wild in this zone.	Monsoons, Precipitation, Sea Level Rise
drought				Toufique, K.A., Islam, A., 2014. Assessing risks from climate variability and change for disaster-prone zones in Bangladesh. Int. J. Disaster Risk Reduct. 10, 236–249. doi:10.1016/j.ijdrr.2014.08.008	Sandification of arable land [in BANGLADESH] results in soil degradation while fishing grounds are increasingly lost due to siltation of the river beds and other water bodies;	Monsoons, Precipitation, Sea Level Rise
cyclones				Hossain, M.S.S., Saha, D., 2017. Major infrastructural adaptations in coastal areas of Bangladesh considering cyclone and tidal flood. Dhaka, Bangladesh.	cyclone Nargis in Burma caused death of more than 138000 people (Saito and McInnes, 2014)	Sea Level Rise
flooding				Kausher, A., Kay, R.C., Asaduzzaman, M., Paul, S., 1996. Climate Change and Sea-Level Rise: the Case of the Coast, in: Warrick, R.A., Ahmad, Q.K. (Eds.), The Implications of Climate and Sea-Level Change for Bangladesh. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 335–407.	could extend the period of seasonal flooding of floodplain land which, combined with higher temperatures and increased food supplies, could extend fish breeding and growing seasons; however - human population pressure and interventions into the floodplain make these projections uncertain.	Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
sea level rise				Salmivaara, A., 2012. Myanmar: Assessing Freshwater Vulnerability in the Irrawaddy and Salween River Basins, in: Lamadrid, A., Kelman, I. (Eds.), Climate Change Modeling For Local Adaptation In The Hindu Kush-Himalayan Region (Community, Environment and Disaster Risk Management, Volume 11). Emerald Group Publishing Limited, pp. 177–206. doi:10.1108/S2040-7262(2012)0000011016	Irrawaddy delta is vulnerable in terms of low natural variability of temperature and intensive land use on wetlands that occupy most of the area; high intensive cropping and high population density - future pressures include population growth, urbanization, land-use change, and climate change influencing hydrology and sea level	Precipitation, Sea Level Rise
all				Ketelsen, T., Taylor, L., Vinh, M.K., Ma, K., Gyi, M., Charles, M., 2017. State of Knowledge: River Health in the Ayeyarwady. Vientiane, Lao PDR.	Burma government statistics indicate that inland fisheries produced 1.3 million tons of fish in 2013. Over the last decade, fisheries exports have grown steadily, at an average annual growth rate of 4.5%, and were valued at USD 653 million in 2012 (WorldFish, 2014). With climate change, fish stocks may be affected by degraded water quality, changes in fish migration, intensified competition in fishing areas and more migration of fishers.	Precipitation, Extreme Weather Events, Sea Level Rise
sea level rise				Huq, S., Reid, H., Konate, M., Rahman, A., Sokona, Y., Crick, F., 2004. Mainstreaming adaptation to climate change in Least Developed Countries (LDCs). Clim. Policy 4, 25–43. doi:10.1080/14693062.2004.9685508	Coastal zones and low lying delta areas in Asia, such as those in Bangladesh, Burma and Cambodia, are at risk from sea level rise and more frequent and severe storms due to climate change (IPCC, 1998; 2001). Deltas and estuaries will also increasingly suffer from saltwater intrusion, siltation and land loss. Sea level rise will threaten the rich biodiversity of wetlands, as it will decelerate wetland renewal. Mangroves will be affected by the rise in sea level as it will change the salinity distribution and productivity of those areas. Severe coral bleaching can be expected as a result of warmer seawater and higher incident solar radiation. The impact of global warming on fisheries will depend on how sea-level rise and changes in ocean currents affect the food chain. Increased frequency of El Niños could lead to a decline in plankton biomass and fish larvae abundance in the coastal waters of Asia, which would have a negative impact on fisheries (IPCC, 2001).	Precipitation
sea level rise				Najnin, A., 2014. Integrated Approach to Assess Vulnerability of the Coastal Region of Bangladesh due to Climate Change. Westfälische Wilhelms-Universität.	Sea-water intrusion due to sea- level rise and declining river runoff is likely to increase the habitat of brackish water fisheries but coastal inundation is likely to seriously affect the aquaculture industry and infrastructure particularly in heavily-populated mega deltas (IPCC 2007). Coastal regions are constantly subject to the action of ocean waves and storms and naturally experience erosion and inundation over various temporal and spatial scales (Westmacott 2001).	Precipitation

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
cyclones				Najnin, A., 2014. Integrated Approach to Assess Vulnerability of the Coastal Region of Bangladesh due to Climate Change. Westfälische Wilhelms-Universität.	Tropical cyclones are a major threat to the coastal areas, causing loss of human lives and livestock and severe damage to crops and fisheries. In the last 125 years, more than 42 cyclones have hit the coastal areas of Bangladesh.	Precipitation
sea level rise				Hossain, M., Selvanatham, A., 2013. Global warming induced extreme weather conditions and the threats to livelihoods in the Bay of Bengal. Int. J. Environ. 3, 1–9.	Bangladesh has doubled its fish production between 1984 and 2006; however, the achievements in the fisheries sector illustrated above are now under major threat from sea-level sea-level rise. Finan [7] painted a very alarming picture for the development of shrimp aquaculture in the coastal belt of the Bay of Bengal due to sea-level rise. In recent decades, commercial shrimp production alone has been earning more than US$350 million each year from exports. According to Finan, sea-level rise will likely result in a much larger volume of saline water moving into the canals that feed the beels (shallow water lakes), contaminating water resources and eroding gher (commercial shrimp cultivation in earthen mini-polders) embankments, which are the major sources of commercial shrimp cultivation. Another likely result of sea-level rise is saltwater intrusion through groundwater flows. This would have major adverse consequences for the groundwater irrigation system of the delta	Precipitation
cyclones				Chowdhury, S.R., Hossain, M.S., Shamsuddoha, M., Khan, S.M.M.H., 2012. Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh. Center for Participatory Research and Development, Dhaka, Bangladesh.	Fishers from all the 10 locations identified windstorm, wave height and current velocity as the major climatic anomalies in the Bay of Bengal in recent years. Fishers are highly vulnerable to climate extremes because fishing implements prove to be fragile. Tropical cyclones and tidal surges may damage house, boat, fish- landing jetty, road and other physical assets that make the fishers workless. Inexperience and unavailability of other occupations can easily insecure the livelihoods of poor fishers. Sometimes they become bound for fishing even in rough weather. No alternative income generating options are reported by 99% and 97% fishers at Hatiya and Kutubdia respectively.	Monsoons
storm surge				Chowdhury, S.R., Hossain, M.S., Shamsuddoha, M., Khan, S.M.M.H., 2012. Coastal Fishers' Livelihood in Peril: Sea Surface Temperature and Tropical Cyclones in Bangladesh. Center for Participatory Research and Development, Dhaka, Bangladesh.	Fishers from all the 10 locations identified windstorm, wave height and current velocity as the major climatic anomalies in the Bay of Bengal in recent years. Fishers are highly vulnerable to climate extremes because fishing implements prove to be fragile. Tropical cyclones and tidal surges may damage house, boat, fish-landing jetty, road and other physical assets that make the fishers workless. Inexperience and unavailability of other occupations can easily insecure the livelihoods of poor fishers. Sometimes they become bound for fishing even in rough weather. No alternative income generating options are reported by 99% and 97% fishers at Hatiya and Kutubdia respectively.	Monsoons

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
all				**Horton, R., De Mel, M., Peters, D., Lesk, C., Bartlett, R., Helsingen, H., Bader, D., Capizzi, P., Martin, S. and Rosenzweig, C. 2016. Assessing Climate Risk in Myanmar. New York, NY, USA: Center for Climate Systems Research at Columbia University, WWF-US and WWF-Myanmar.; Htut AY, Shrestha S, Nitivattananon V, Kawasaki A (2014) Forecasting Climate Change Scenarios in the Bago River Basin, Myanmar. J Earth Sci Clim Change 5: 228. doi:10.4172/2157-7617.1000228**	**This report provides a great summary of the impacts of climate change in Burma with a focus on temperature, precipitation, sea level rise, and extreme weather events!**	
temperature				Shrestha, S., & Htut, A. Y. (2016). Land Use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar. Environmental Modeling & Assessment, 21(6), 819–833. https://doi.org/10.1007/s10666-016-9511-9	The seasonal results are based on three clearly distinguishable seasons in Burma: summer (JFMA), rainy (MJJA), and winter (SOND). All GCMs under both RCP scenarios indicate an increase in Tmax and Tmin for seasonal as well as annual projections. Average annual Tmax is projected to increase by 0.7 to 1.7 °C and 1.1 to 2.9 °C under RCP4.5 and 8.5 respectively. Similarly, all seasons show an increasing temperature under both scenarios in all three periods except the summer of 2020s for RCP4.5. Under the RCP8.5 scenario, all seasonal and annual changes in Tmax are projected to increase by 2.7 °C or higher in the 2080s. Similar future changes in Tmax are projected under RCP4.5 but of much smaller magnitude. Average annual Tmin is projected to rise by 1.3 and 2.5 °C under RCP4.5.and 8.5, respectively. In the case of seasonal changes, the winter of the 2050s is affected the most under RCP4.5 while it is the summer for the 2080s for RCP8.5. Future changes in Tmin are projected to be larger in magnitude under RCP8.5 than RCP4.5.	Cyclones, Precipitation, Extreme Weather Events

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
precipitation				Shrestha, S., & Htut, A. Y. (2016). Land Use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar. Environmental Modeling & Assessment, 21(6), 819–833. https://doi.org/10.1007/s10666-016-9511-9	Average annual precipitation is estimatedtoincreaseby30–120 mm under RCP4.5 and by 110–125 mm under RCP8.5. As for seasonal changes, all sea- sons are likely to receive more precipitation in the future with respect to the baseline values. The winters of the 2020s and 2050s show a definite increase in precipitation by about 225 mm under RCP8.5 and 250 mm under RCP4.5. However, the increase in precipitation for the summer in the 2020s under both scenarios is relatively smaller. RCP4.5 pro- jects a greater increase in winter precipitation compared to RCP8.5. Both scenarios show similar changes in annual precipitation for the first two periods. On reaching 2080s, RCP8.5 still projects a continuous increase of precipitation, while in RCP4.5, the change is subsiding. Therefore, as per the projection, the future climate in the Bago River Basin is expected to be wetter than baseline period. The winter season is highly affected under both RCPs...[In Conclusion section] In general, an increase in precipitation was observed in the future, subject to monthly variations.	Cyclones, Precipitation, Extreme Weather Events
stream flow				Shrestha, S., & Htut, A. Y. (2016). Land Use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar. Environmental Modeling & Assessment, 21(6), 819–833. https://doi.org/10.1007/s10666-016-9511-9	It is observed that the stream flow within June to October is projected to increase at both stations. The peak of the stream flow is observed in September (the beginning of the winter sea- son) under both scenarios in all periods at the two stations although the baseflow peaks in August. The summer sea- son flow (January to April) is projected to remain with the same variation as the baseline period at the Bago station for all periods. However, at the Zaungtu station, the base- line stream flow is higher than the projected flow under both scenarios in the summer season. In the winter sea- son, the projected seasonal flow is higher than the base- line at the Bago station, but the Zaungtu station has a different variation (lower than the baseline) in the month of December. In 2080s, three months (October, November, and December) will witness lower stream flow at the Zaungtu station. During August, the projected stream flow is higher than the baseline period under both RCP4.5 and 8.5; however, variability is observed in September. The projected peak streamflow under RCP4.5 is higher than that of RCP8.5 in September of early and mid future at both stations...10b.In all periods, the projected stream flow is greater under the RCP8.5 scenario. Results indicate that the stream flow can increase to 350m3/s in the 2020s period under the RCP4.5 scenario and the same level in the 2080s under RCP8.5.	Cyclones, Precipitation, Extreme Weather Events

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
stream flow				Shrestha, S., & Htut, A. Y. (2016). Land Use and Climate Change Impacts on the Hydrology of the Bago River Basin, Myanmar. Environmental Modeling & Assessment, 21(6), 819–833. https://doi.org/10.1007/s10666-016-9511-10	The results show that the hydrology of the basin is more impacted by climate change compared to land use change in the near future (2020s) (Table 11). The average annual flow is projected to increase by 31–37 % and 56–58 % in Zaungtu and Bago stations, respectively, under climate change scenarios. Whereas the average annual flow is projected to increase by 10–11%and 12–13%Zaungtu and Bago stations, respectively, under land use change scenarios...This result indicates that climate change and land development alter the seasonal distributions of the stream flows rather than the change in the average annual stream flow.	Cyclones, Precipitation, Extreme Weather Events
temperature				Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., … Su Mon, M. (2017). Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLoS ONE, 12(9), 1–23. https://doi.org/10.1371/journal.pone.0184951	In general, slightly more warming is projected in interior regions than in southerly and coastal areas.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
Sea Level Rise				Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., … Su Mon, M. (2017). Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLoS ONE, 12(9), 1–23. https://doi.org/10.1371/journal.pone.0184951	Changes in average ocean height are expected to be essentially homogenous across the entire Burma coast and by season.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
precipitation				Mandle, L., Wolny, S., Bhagabati, N., Helsingen, H., Hamel, P., Bartlett, R., … Su Mon, M. (2017). Assessing ecosystem service provision under climate change to support conservation and development planning in Myanmar. PLoS ONE, 12(9), 1–23. https://doi.org/10.1371/journal.pone.0184951	Precipitation changes are likely to also alter both the amount of sediment reaching reservoirs and being retained by upstream vegetation. For the 15 reservoirs assessed in this study, sediment export to reservoirs in the absence of any land use change was estimated to decrease by an average of 3.4% (standard deviation (SD) = 1.2%) at the low end, but increase by 23.3% (SD = 3.3%) at the high end of the range of likely climate change. In addition, the amount of sediment retained upstream decreased an average of 3.4% (SD = 1.2%) under the low estimate and increased 23.3% (SD = 3.4%) under the high estimate.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
precipitation				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	The head- waters of the Ayeyarwady River are fed by glacier melt in the Himalayan Mountains and the river discharge is likely to change due to climate change impacts.	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
flooding				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Burma's climate is directly influenced by the Indian summer monsoon (ISM; Sen Roy and Kaur, 2000; Sein et al., 2015), which is the second basic source of Burma's rivers. It is currently still not predictable whether the complex Asian monsoon circulation will strengthen, weaken or become more variable as a re- sult of global warming (Turner and Annamalai, 2012; IPCC, 2014). Already now there seems to be a trend to a delay and an earlier ending of the monsoon rains of 2 weeks in Burma respectively (Irrawaddy, 2015).	Cyclones
extreme events				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	The occurrence of extreme weather events like floods, cyclones and severe droughts has shown an increasing trend over the last 6 decades in Burma, most likely as a result of climate change (GCCA, 2012).	Cyclones
extreme events				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Extreme weather events have become more frequent and intense during the last decades, related to their direct impacts on socio-economy, which could also be detected for Burma (GCCA, 2012). Most likely, the intensity and frequency of droughts in the dry zone, particularly during ENSO events, will increase (IPCC, 2014).	Cyclones
Sea Level Rise				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Sea-level rise, decreasing river runoff and increasing intensity and frequency of droughts will lead to even more in- creased saltwater intrusion into river deltas...the Ayeyarwady have not been conducted yet. The low-lying Ayeyarwady delta is particularly exposed to sea-level rise and vulnerable due to its high food productivity and population density. It is assumed that a 0.5m sea-level rise would advance the shoreline along the Ayeyarwady delta by 10km in- land (NAPA, 2012).	Cyclones
temperature				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	In the medium term, enhanced glacier melt and snowmelt in the source areas of rivers will cause generally higher discharges and potential floods. However,	Cyclones

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
precipitation				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Changes in river flow will likely increase the risk of flash floods and lowland regions will be regularly inundated (NAPA, 2012).	Cyclones
temperature				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	The central dry zone experienced higher maximum temperatures and less rainfall in the 1990s compared to other regions in Burma (Ministry of Forestry of the Union of Burma, 2005). This	Cyclones
precipitation				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	The central dry zone experienced higher maximum temperatures and less rainfall in the 1990s compared to other regions in Burma (Ministry of Forestry of the Union of Myanmar, 2005). This	Cyclones
precipitation				Taft, L., & Evers, M. (2016). A review of current and possible future human-water dynamics in Myanmar's river basins. Hydrology and Earth System Sciences, 20(12), 4913–4928. https://doi.org/10.5194/hess-20-4913-2016	Rao et al. (2013) concluded, based on findings from Iwamura et al. (2010), that the Ayeyarwady dry forest located in the central river basin is particularly prone to future changing rainfall and temperature conditions. The authors expect that the seasonal amount of rainfall will decrease, which will exacerbate the already water-stressed region (Rao et al., 2013).	Cyclones
extreme events				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	There is low confidence1 in any observed long-term (i.e., 40 years or more) increases in the intensity, frequency, and duration of tropical cyclone activity (IPCC 2012). However, the report indicates (with high confidence) that the severity of the impacts of climate extremes depends strongly on the level of the exposure and vulnerability to these extremes. Extreme impacts on human and ecological systems can result from individual extreme weather or climate events as well as from non-extreme events where exposure and vulnerability are high.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
extreme events				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	Burma has been ranked among the top three countries most affected by extreme weather events between 1992 and 2011 by the Global Climate Risk Index (2013) which measures the extent to which countries are affected by the impacts of weather-related events (Harmeling and Eckstein 2013).	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
extreme events				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	**Table 1** summarizes the vulnerability ratings (as high, medium, low) for the occurrence of extreme weather events (e.g., cyclones) and expectations for drought and sea-level rise in Burma based on findings reported in the Myanmar INC project (Initial National Communication Project) Report (2012). Extensive low-lying coastal areas in the south and south west appear to be highly vulnerable to impacts from floods, cyclones and associated winds and storm surges, intense rainfall and sea level rise.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
precipitation				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	Predictions for 2001–2020 based on scenarios generated for Burma show temperature increases of 0.5–0.7 ?C during the year in lower parts of Burma, record high maximum temperatures and a 4% increase in precipitation during March–November across the entire country. In particular, precipitation increases are expected in the wet season in central and north Burma. High temperatures and droughts are expected to be the norm, and are likely to be associated with more frequent forest fires in the dry zone of central Burma and the northern regions. Conversely, the increase in rainfall events in the wet season is predicted to cause flooding events which could affect livelihoods, transport, and homes.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
temperature				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	Predictions for 2001–2020 based on scenarios generated for Burma show temperature increases of 0.5–0.7 ?C during the year in lower parts of Burma, record high maximum temperatures and a 4% increase in precipitation during March–November across the entire country. In particular, precipitation increases are expected in the wet season in central and north Burma. High temperatures and droughts are expected to be the norm, and are likely to be associated with more frequent forest fires in the dry zone of central Burma and the northern regions. Conversely, the increase in rainfall events in the wet season is predicted to cause flooding events which could affect livelihoods, transport, and homes.	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise

Driver	Management strategy	Cost ($, $$)	Cost rationale	Citation	Relevant content	Search
all				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	Using the findings of Iwamura et al. (2010), we can predict the relative stability of ecoregions in Burma based on these emission scenarios **(Fig. 2**).	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
all				Rao, M., Htun, S., Platt, S. G., Tizard, R., Poole, C., Myint, T., & Watson, J. E. M. (2013). Biodiversity conservation in a changing climate: A review of threats and implications for conservation planning in myanmar. Ambio, 42(7), 789–804. https://doi.org/10.1007/s13280-013-0423-5	**Table 2**	Cyclones, Precipitation, Extreme Weather Events, Sea Level Rise
Sea Level Rise				Cochrane, K., De Young, C., Soto, D., Bahri, T., & Eds. (2009). Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. FAO Technical Paper, 530, 221. https://doi.org/ISSN 2070-7010	Catfish and rohu culture of the Mekong Delta and Irrawaddy region in Viet Nam and Burma respectively are aquaculture practices that have witnessed the highest growth ever. The regions in which these activities occur can be impacted by saline water intrusion from predicted sea level rise. The species intensively cultured at very high stocking densities and with high levels of feeding, are fresh water species with relatively low salinity tolerance. As such culture areas must be shifted further upstream to mitigate climatic change effects. On the other hand, climate impacts could make extra pond space available for shrimp farming, providing adequate links in the supply chains.	Extreme Weather Events
Sea Level Rise				Brakenridge, G. R., Syvitski, J. P. M., Niebuhr, E., Overeem, I., Higgins, S. A., Kettner, A. J., & Prades, L. (2017). Design with nature: Causation and avoidance of catastrophic flooding, Myanmar. Earth-Science Reviews, 165, 81–109. https://doi.org/10.1016/j.earscirev.2016.12.009	Tidal gauge data indicate a 3.4–6 mm/y relative sea level rise (Syvitski et al., 2009)	Cyclones, Monsoons, Precipitation, Sea Level Rise
temperature				Policarpio, R. R., & Sheinkman, M. (2015). State of climate information products and services for agriculture and food security in Myanmar. CCAFS Working Paper no. 140. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).	Freshwater and marine fisheries, and livestock are key sources of protein for Burmese households. Fisheries and livestock raising have also been affected by climate factors, such as heat stroke suffered by livestock and poultry due prolonged high temperatures; higher decomposition rate of aquatic plants resulting in reduced oxygen content in the water and reduced aquaculture production.	Cyclones, Extreme Weather Events, Sea Level Rise