## Annex F: Climate Change Analysis

Madagascar is a country with natural capital and biodiversity but with high levels of poverty, food insecurity, and population growth, faces several development challenges. Climate change poses an increasing threat to achieving development goals but is not always systematically considered in development plans and project designs. The objective of this climate risk screening review is to provide a synthesis of the best-available information regarding climate change impacts and effects on specific sectoral interests in Madagascar.

Climate risks in Madagascar include increasing temperatures, reduced and more variable precipitation, more frequent droughts, more intense cyclones, and rising sea levels. The climate risk screening review synthesize the observed and projected impacts of these climatic changes on water resources, agriculture, coastal and terrestrial ecosystems and ecosystem services, fisheries, and human health. Also, the screening exercise present recommendations for USAID, NGOs, and other organizations on how to better incorporate climate risks into development strategies and projects.

### Policy context

In 2010, Madagascar adopted a National Policy against climate change, which aims to reinforce national resilience to climate change, reduce national vulnerability and develop approaches for low carbon emissions (Cochrane et al., 2019). Within the government of Madagascar, the Cellule de Prévention et Gestion des Urgences (CPGU) is in charge of Disaster Risk management, the Directorate General of Meteorology (DGM) produces weather forecasts and long term climate research, and the National Bureau for Coordination of Climate Change (BNCCC) REDD+ is in charge of climate change adaptation and mitigation (CPGU and BNCCC, 2017). A National Adaptation Plan (NAP) is currently being prepared and the process will involve stakeholders identifying the needs and priorities for adaptation to climate change (Cochrane et al., 2019; CPGU and BNCCC, 2017). The German government aid agency, Gesellschaft für Internationale Zusammenarbeit (GIZ), is providing institutional support for many climate change activities, including preparation of the NAP, trainings on climate finance, and development of a database of current climate change adaptation and mitigation activities (https://prjctmp.de/; GIZ interview). Madagascar's climate change forum, Groupe Thématique sur le Changement Climatique (GTCC) also provides administrative support and serves as a platform for knowledge exchange and capacity building. There are two main subgroups, one on adaptation and one on mitigation, and there are currently 40 member entities working in all sectors.

Chesney and Moran et al. (2016) developed a Climate Security Vulnerability Model to map climate change vulnerability and security concerns. The model includes five indicator categories to assess governance capabilities, including government responsiveness, government response capacity, openness to external assistance, political stability, and presence of violence. The model suggests that Madagascar has moderate to low governance capabilities to address climate-related challenges, and overall is among the most vulnerable countries in southern Africa to the effects of climate change.

**Climate change in Madagascar (historical and future projections).**

Madagascar's climate varies greatly across the island (Figure 1). On the east coast, the climate is hot and humid, and rainfall varies from 1100-3700 mm per year. The most rain occurs from January to April, although rain falls throughout most of the year, and the average annual temperature is between 23 and 26°C. On the west coast, the climate is tropical with a hot, dry, summer. Annual rainfall decreases from 1500 to 400 mm per year from north to south across the west coast. The dry season lasts from April to October, and the annual average temperature varies between 24 and 27°C. The southwest part of the island is semi-arid, and annual rainfall is about 500-700 mm per year. In the central highlands, there is a lot of interannual variation in temperature and precipitation. The average annual rainfall is 900 mm per year in some areas, up to 1500 mm per year in others, and the average annual temperature ranges from 16 to 22°C (Rakotondravony et al., 2018). The North and Northwest region has a tropical climate with monsoon conditions driving rainfall in the summer (Rakotoarison et al., 2018). Madagascar ranked #4 in Climate Risk Index (a level of exposure and vulnerability to extreme events) in 2018 but did not make the top 10 list for 1999-2018 (Eckstein et al., 2020).

Not all areas of the country have adequate weather data. Direction Générale de la Météo (DGM) would like to have at least one weather station every 100 km across the country and an office in each region to collect the data. The World Wildlife Fund (WWF) has installed 14 weather stations. The United Nations Development Programme (UNDP) and GIZ are working on installing an additional 40-50 automatic weather stations across Madagascar to provide more fine scale information, but training people to operate the stations can be a challenge, especially as both groups are installing different equipment. Additionally, GIZ is working to modernize DGM's infrastructure to set up a centralized database with data from all weather stations.

***Figure 1: The five climate regions of Madagascar*** **(Rakotoarison et al., 2018)**

- The eastern coast has a warm and humid tropical climate;
- The central highland has a high altitude tropical climate;
- The western region has a warm climate and two distinct seasons, a dry winter and a hot and humid summer;
- The north and northwest region has a tropical climate, with the northwest monsoon conditions driving rainfall during the summer season;
- The southern region of the country has a semi-arid climate.

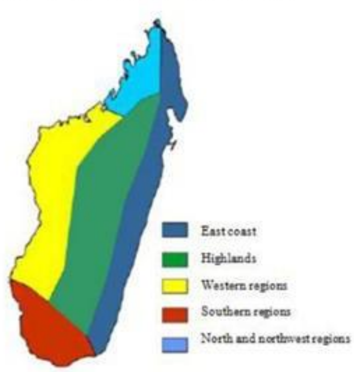



**Figure 1.** The five climate regions of Madagascar.

## Temperature Trends

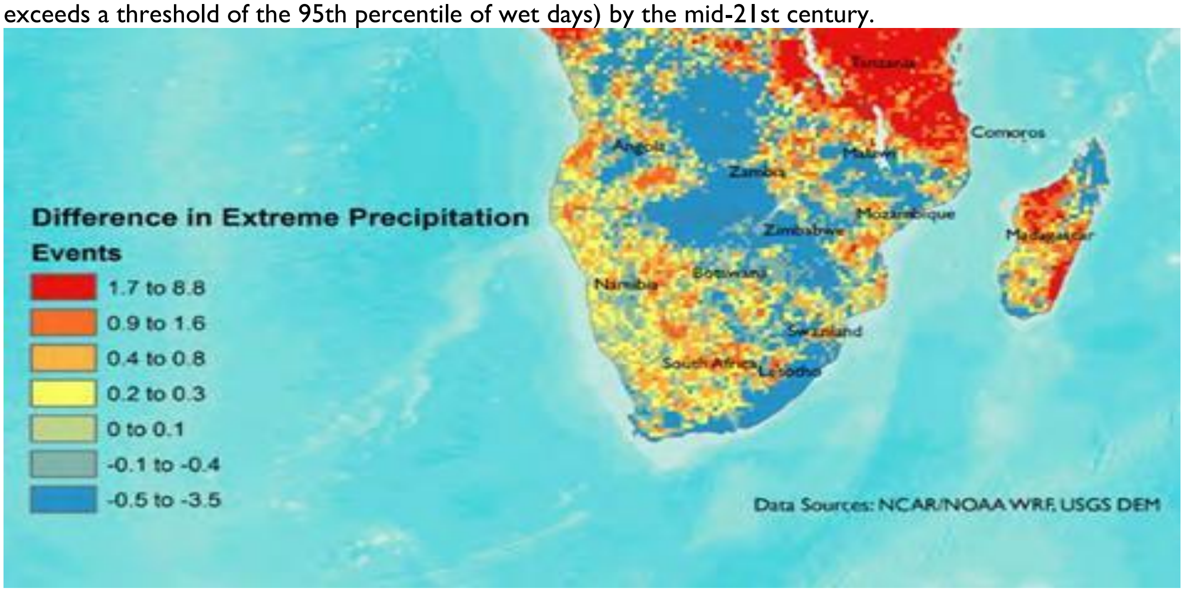
Observed temperatures have been increasing across Madagascar (Niang et al., 2015; Raholijao et al., 2019). Coastal water temperatures have also been increasing (Cochrane et al., 2019). Mean, maximum, and annual temperatures are projected to increase under all climate change emission scenarios (Rakotondravony et al., 2018). Under a high emissions scenario (RCP 8.5), mean annual temperature is projected to rise by 4.1°C by 2100. Under RCP 2.6, warming could be limited to 1.1°C (World Health Organization, 2016).

There has been a warming trend in the ocean since at least 2005 noted in the (IPCC Fifth Assessment Report (IPCC, 2019a). This trend is further confirmed by the improved ocean temperature measurements over the last decade. By 2100, the ocean is very likely to warm by two to four times as much for the low emissions scenario (RCP 2.6) and five to seven times as much for the high emissions scenario (RCP 8.5) compared with the observed changes since 1970 (IPCC, 2019b).

## Precipitation Trends

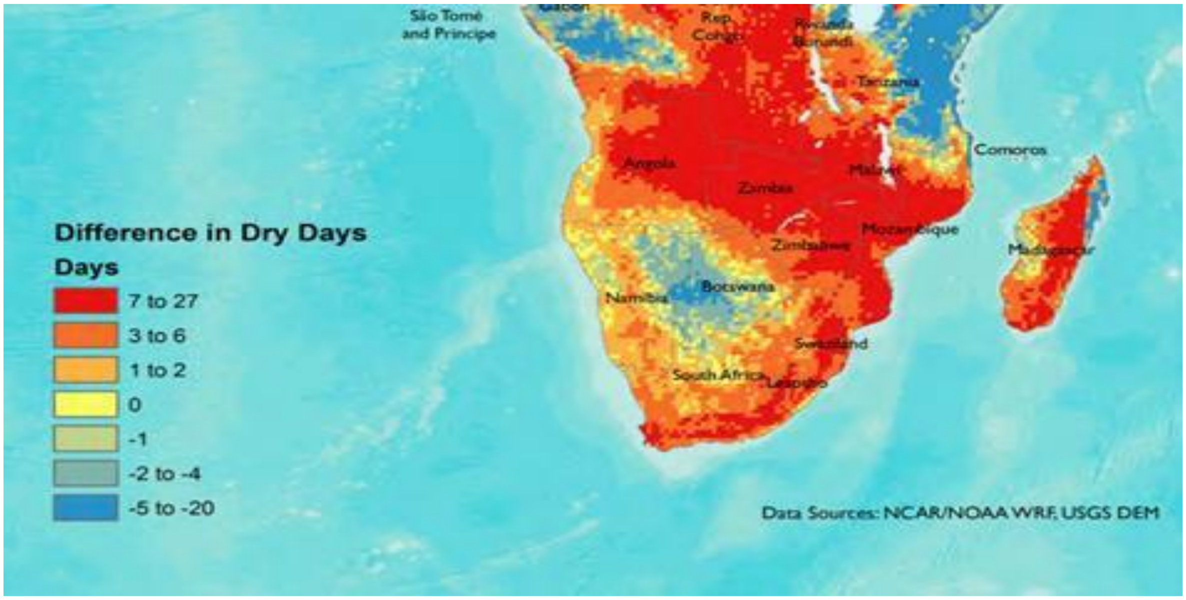
Annual rainfall has decreased across most weather stations in Madagascar, although this trend is weak compared to interannual variability (Raholijao et al., 2019). In the western part of the island, precipitation has become more intense (Rakotondravony et al., 2018), and more extreme precipitation is expected in parts of the island (Figure 2A) (Chesney and Moran, 2016). More dry days are projected as well (Figure 2B). Under a high emissions scenario, the longest dry spell is projected to increase by about 20 days on average by 2100 (World Health Organization, 2016). Local weather trends can also be impacted by deforestation and land use change (Ghulam, 2014).

Figure 2: A) Projected difference in extreme precipitation events (days per year when the daily rainfall rate exceeds a threshold of the 95th percentile of wet days) by the mid-21st century.




Source: Chesney and Moran, 2016

Figure 2B) Difference in the number of dry days (days where rainfall levels fell below 1mm for at least 21 consecutive days) projected by the mid-21st century.

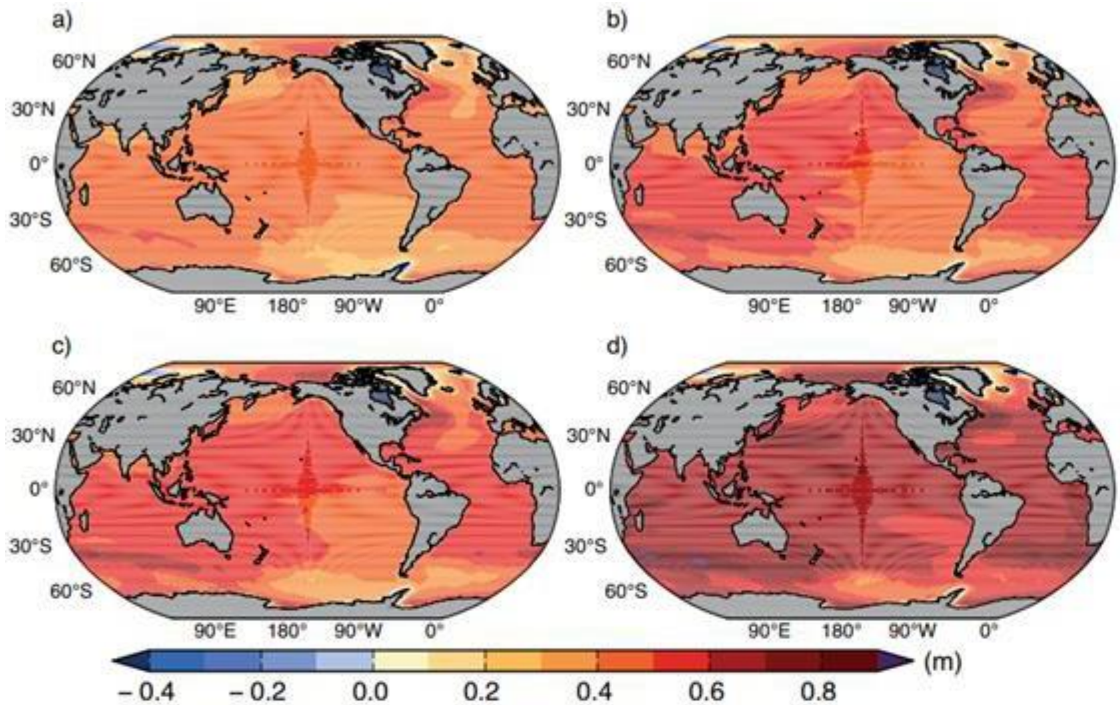



Source: Chesney and Moran, 2016

## Sea level rise

Sea level rise (SLR) in Madagascar has been 1.57 mm / year between 1993 and 2017, which is lower than the global rate of 2.87mm / year (Raholijao et al., 2019). Global SLR is projected to be faster by the end of this century under all scenarios, including those compatible with achieving the long-term temperature goal set out in the Paris Agreement IPCC (2019). There is medium confidence that the Global Mean Sea Level (GMSL) will rise between 0.43 m (0.29–0.59 m; RCP 2.6) and 0.84 m (0.61–1.10 m; RCP 8.5) by 2100 relative to 1986–2005. Relative SLR depends on a variety of factors. Differences from the global mean can be greater than ±30% in areas ofrapid vertical land movements, including those caused by local anthropogenic factors such as groundwater extraction (Figure 3). GMSL, in combination with tides, storm surge, and extreme waves, causes impacts to coastal communities. These extreme events are likely to become more frequent in the future (Oppenheimer et al., 2019). SLR and the resulting coastal erosion threatens vital infrastructure and unique ecosystems. Also, SLR can result in salinization of groundwater and soils, which then have an impact on food security (CPGU and BNCCC, 2017).

Figure 3: Ensemble means regional relative sea level change (meters) evaluated from 21 CMIP5 models for the RCP scenarios (a) 2.6, (b) 4.5, (c) 6.0 and (d) 8.5 between 1986–2005 and 2081–2100. Each map includes effects of atmospheric loading, plus land ice, glacial isostatic adjustment and terrestrial water sources




Source: *Church et al., 2013*

## Drought and extreme events

Madagascar has the highest risk of cyclones in Africa and currently experiences 3 to 4 cyclones per year between November and April (Rakotoarison et al., 2018). The eastern, northwestern, and western regions are most affected by cyclones (Rakotoarison et al., 2018). While cyclone intensity is expected to increase in the future (CPGU and BNCCC, 2017; Delille, 2011; Rakotoarison et al., 2018), the frequency of tropical cyclones making landfall over Madagascar is projected to decrease in 1, 2, and 3 °C warmer scenarios (Malherbe et al., 2013; Muthige et al., 2018).

Droughts are most common in southern Madagascar but can also occur in the central highlands and eastern region (CPGU and BNCCC, 2017; Rakotoarison et al., 2018). Evapotranspiration increased significantly at some weather stations between 1980 and 2010 (Djaman et al., 2018). Droughts have become more common in the southern part of the island (World Health Organization, 2016), and have increased slightly in northern Madagascar from 1951-2010 (Spinoni et al., 2014). Deforestation and poor land use practices have exacerbated damage caused by floods (Rakotondravony et al., 2018). In addition to floods, water scarcity, and cyclones, Madagascar is exposed to a number of other climate hazards, including wildfires (Chesney and Moran, 2016).

## Sectoral impacts

### <u>Water resources</u>

### General Context

Currently, Madagascar is experiencing one of the worst water crisis in the world, with numerous challenges associated with water management infrastructure (Rakotondravony et al., 2018; Serele et al., 2019):

- In 2018, an estimated 66% of rural populations and 49% in urban areas were deprived of drinking water.
- More than 20% of the rural population use surface water (lakes, rivers, streams) for drinking.
- Only 27% of households have drinking water on site, and 40% (urban) to 53% (rural) of households report that it takes at least 30 minutes to fetch water and return.
- About 750,000 people do not have access to clean water; nearly 100,000 people practice open defecation.

In general, the water and sanitation sectors are characterized by poor water management. Numerous inadequacies exist regarding flood risk reduction, pollution exposure, behavior of the general population, budget allocations, and regulatory enforcement. The sanitation facilities are restricted to the perimeters of city centers; many have exceeded their project life and need repair. Many households do not have the infrastructure needed to dispose of waste/excrement; tens of thousands of cubic meters of excreta are poured into the urban network without treatment. This, along with poor water quality, results in water-based diseases that are the main causes of sickness and death. Various natural and anthropogenic pressures such as deforestation, erosion, saltwater intrusion, etc. exacerbate these problems (García-Ruiz et al., 2017; Rakotondravony et al., 2018). Erosion and the resulting excessive sedimentation can lead to enormous infrastructure maintenance costs because of damages to bridges, irrigation ditches, and reservoirs. Few studies have assessed the exact economic cost, but their global value has been estimated to be billions of dollars per year (García-Ruiz et al., 2017).

Southern Madagascar generally has erratic rainfall and an arid climate, with very poor access to water for domestic and agricultural consumption, making it among the most water-stressed areas of the country (Serele et al., 2019). During the dry season, groundwater (the predominant source of water in southwestern Madagascar) becomes even more limited, resulting in extremely poor hygiene practices and very high pressure on functioning water points. Fifty percent of the population of southern Madagascar (850,000 people) required humanitarian assistance in 2016. Groundwater recharge is strongly influenced by rainfall patterns. Using five years of observational data, Carriére et al. (2019) noted a correlation between monthly rainfall patterns, groundwater recharge, food production, and human health. They found that groundwater recharge is highly dependent on rainfall from extreme events (i.e., cyclones and tropical storms), which in turn affects plant production. Furthermore, their preliminary analysis suggests a significant increase in health center admissions about one year after a severe drought. While they could not confirm that drought causes increased illness, this study shows the complexity of the water-food production-human health relationship (Carrière et al., 2019).

### Climate change effects

Because most of the population relies mainly on surface water, the water supply depends heavily on the rainfall regime and will therefore be very sensitive to any disturbance of the climate, including the projected decreases in annual rainfall and increased evapotranspiration. In addition, Madagascar is expected to experience relative sea level rise from 20 to 50 cm, which might increase saltwater intrusion of the groundwater along parts of the coast. These changes are likely to worsen the availability of water resources (Rakotondravony et al., 2018).

In the region of Antananarivo, which has a projected population of 5,040,500 in 2025, the surface water in the basin might no longer be able to supply the water demands by 2025, let alone 2050 or 2100 (Rakotondravony et al., 2018).

## Agriculture

### General context

About 62% of the population in Madagascar is rural and mainly dependent on subsistence farming for food security and household income (Central Intelligence Agency, 2020). Agriculture employs 80% of the workforce and generates 25% of GDP; an estimated 71% of farmers are smallholder farmers (i.e. have less than 2 ha of land) (CPGU and BNCCC, 2017; Rakotobe et al., 2016). Low land availability and limited investment capacity have led much of this population to maintain traditional agricultural practices with low use of agricultural inputs, limited soil conservation practices, and poor use of hydro-agricultural infrastructure (Delille, 2011; Harvey et al., 2014; Rakotondravony et al., 2018). Traditional practices such as tavy and hatsake (slash-and-burn agriculture) are the dominant production methods for rice in the east and central part of the island and maize production in drier areas (Abbink, 2018; Desbureaux and Damania, 2018). Many farmers have low productivity plots of essential food crops such as rice, cassava, corn, and sweet potato (Rakotondravony et al., 2018), and many (75% in a recent study of three regions in Madagascar) do not produce enough rice to feed their household for the year (Harvey et al., 2014). Anthropogenic pressures from farming such as deforestation and silting have been degrading natural resources, including soil, water, and biodiversity (Rakotondravony et al., 2018). Most farmers in Madagascar have rainfed agriculture, and thus rely on crops grown during the rainy season (Delille, 2011; Harvey et al., 2014). Smallholder farmers are particularly vulnerable to climate shocks due to dependence on rainfed agriculture, limited land area for growing crops, high poverty, food insecurity, and lack of information and resources to prepare for and cope with extreme events (Rakotobe et al., 2016). Moreover, many farm villages are remote, with limited access to roads or means of transportation, and no formal safety nets (Harvey et al., 2014).

### Climate change effects

Crops may respond positively to elevated $CO_2$ concentrations, but increasing variability of rainfall, more intense cyclones, and increasing temperatures can reduce agricultural production (Lal et al., 2015). Some areas of Madagascar are projected to experience declines in crop production, while other parts are projected to experience increases (Lal et al., 2015). For example, increasing temperatures and droughts have been associated with reduced maize production (Ngwakwe, 2019; Shi and Tao, 2014), and maize production is projected to decrease over large parts of Madagascar due to reduced precipitation, even if conservation agriculture techniques are implemented (Folberth et al., 2014). Rice and sugar cane yields are projected to drop due to water stress and an increase in parasites (Rakotondravony et al., 2018). However, it is also possible that rice will be able to grow at higher altitudes; this could benefit farmers but is likely to increase deforestation. Increased climate variability could lead to increases in locust plagues, thereby increasing the risk of food insecurity (CPGU and BNCCC, 2017).

Too much rainfall can lead to crop diseases, while too little rainfall can be a disaster for rainfed crops (Amusan and Odimegwu, 2015). Reduced precipitation and a longer dry season are projected to decrease the number of growing season days by up to 50 days by 2100, especially in southern and western Madagascar (Chesney and Moran, 2016; Rakotondravony et al., 2018). Farmers in some areas have already reported a shortening of the rainy season (Delille, 2011). Droughts can lead to increased deforestation as farmers expand areas of cultivation to compensate for reduced crop yields, although protected areas have been at least partially effective in limiting deforestation (Desbureaux and Damania, 2018). Droughts can also lead to outbreaks of migratory locusts that can extend over large areas and destroy entire fields, although this is also impacted by locust control measures (Gay-des-Combes et al., 2017). Madagascar is also projected to become more suitable for cassava pests (Niang et al., 2015).

Increasing frequency of droughts in Southern Madagascar is challenging development programs. In the past, organizations have known when food aid would be needed for the season, but recent changes in drought frequency have made this difficult. Increased foreign disaster assistance may be needed in the future. Continuing to provide humanitarian assistance without reducing underlying causes of vulnerability will not be an effective strategy moving forward. In the southeast/eastern part of the country, shifting rainfall patterns and intensity have been a bigger issue than droughts. Heavy rainfall, including rainfall associated with cyclones, intensifies depletion of soil nutrients (including nitrogen, phosphorus, and potassium) associated with slash-and-burn agriculture, especially if farmers are not using cover crops.

Cyclones can destroy crops, and associated flooding (especially in areas with high deforestation) can leave behind a layer of sand that ruins plots for cultivation (Abbink, 2018). For example, Cyclone Giovanna in 2012 caused a significant amount of crop loss and loss of stored grains, which increased food insecurity for farmers (Rakotobe et al., 2016). Strong winds associated with cyclones are projected to decrease vanilla production (Rakotondravony et al., 2018).

After agriculture, livestock production is the second most frequent livelihood activity in Madagascar (Rakotondravony et al., 2018). Livestock are used for food and as a source of savings. While there is only limited evidence to date for climate change impacts on livestock production, projected changes in temperature and rainfall amount and distribution, could have direct and indirect impacts on livestock (Thornton et al., 2015). Above 30 °C, many livestock species reduce their food intake. Changes in rainfall could reduce forage quality and quantity and lower the carrying capacity of rangelands. Changing climatic conditions could also alter the distribution and phenology of plants, forcing farmers to change their practices and supplement fodder (Delille, 2011; Rakotondravony et al., 2018; Thornton et al., 2015). Additionally, climate change could alter the spread of diseases and pests (Rakotondravony et al., 2018). Interactions with other stressors such as rangeland degradation, variability in water access, and fragmentation of grazing areas could compound climate driven impacts (Niang et al., 2015).

***Coastal ecosystems***

***General context***

Madagascar is the country with the highest level of coral biodiversity in the Indian Ocean. Coral reefs are highly vulnerable to climate change due to ocean acidification and ocean warming; a combination of these impacts is causing bleaching around Madagascar and around the world (IPCC, 2019a). There are several Marine Protected Areas (MPAs) in Madagascar that contain high levels of biodiversity and provide important contributions to national economic development. The coastal areas of Madagascar are home to 40% of inhabitants. Along with its high ecological significance, the archipelago's natural resources ensure the livelihoods of local communities who depend on subsistence fishing and farming (Rakotondrazafy et al., 2014). One MPA, Ambodivahibe Bay in the Diana region, is managed by CI, and is ecologically important because it contains several flagship species (sea turtles, giant groupers, napoleon fish, humpback parrots) and very important ecosystems (reefs, mangroves, underwater pits) (Rakotondravony et al., 2018). Another MPA located in the Diana region, Nosy Hara, covers 1,500 ha; the coral reefs are among the most intact in Madagascar and the wider Northern Mozambique Channel area.

Madagascar contains Africa's fourth largest extent of mangroves, which in 2010 comprised approximately 213,000 ha; over 20% of that extent is estimated to have been deforested through charcoal production, timber extraction and agricultural development (Benson et al., 2017). Mangroves have a critical role in the ecology of the coastal environment, including providing habitats for breeding and nursery grounds for commercially important fish stocks. In addition, mangroves can provide coastlines with protection against natural disasters such as tsunamis and cyclones, and local communities with products such as fuelwood and building materials (Benson et al., 2017). The level of vulnerability depends on the health of the mangroves. Where mangroves are mostly intact, their resilience and adaptive capacity are high and vulnerability is low; the opposite is true for mangroves that are highly degraded (Rakotondrazafy et al., 2014).

Thirteen of the world's seagrass species are found in the Western Indian Ocean, with eight of these reported on the southwest coast of Madagascar. The main non-climate stressor on seagrasses is human trampling, which has caused a decline in coverage proportional to the intensity and duration of foot traffic (Côté-Laurin et al., 2017).

Numerous non-climate stressors reduce the resiliency of these systems to climate change. For example, coral reefs in Toliara Bay and Ranobe Bay have increased vulnerability due to fishing pressure and population growth in Toliara, which increases the number of fishers, as well as increasing pollution and excessive sedimentation. In Nosy Hara MPA, the local community relies heavily on mangroves for wood harvesting. In Lavenombato, in the southwest of Madagascar, mangroves are affected by direct human disturbances, over-salinization, erosion, and silting (García-Ruiz et al., 2017; Rakotondravony et al., 2018; Rakotondrazafy et al., 2014). The heavy reliance on mangrove ecosystems is leading to increasing and wide-spread degradation and deforestation throughout Madagascar, with an estimated net loss of 21% between 1990 and 2010 (Benson et al., 2017).

### Climate change effects

According to the IPCC (2019), for coastal systems and lowland zones, expected climate-related changes include: a sea level rise from 0.25 to 1.0 m or more by 2100, a gradual sea surface temperature increase of 1 to 3°C, tropical and extra-tropical cyclones of increasing intensity, more frequent extreme waves and storms events, a modification in the rainfall (distribution and quantity), and ocean acidification. Cochrane et al. (2019) summarize the climate impacts in Table 1. Part of the coastal areas of Morondava and Mahajanga might be submerged by 2100 because the average sea level rise is projected to be 7.4 mm per year. Climate change will also have indirect effects on this ecosystem; for example, populations of migratory marine mammals from the Indian Ocean are likely to be affected by climate change during their feeding season in the polar regions (Rakotondravony et al., 2018). Nematchoua et al. (2018) report observations of decreased marine species (mollusks, crustaceans, and coral reefs of cold water) in seasonal activities and migration. These effects, along with other drivers - insufficient surveillance and maritime and coastal protection; siltation, coastal accretion; urbanization; population growth; poverty; poor governance structures; political instability; and lack of ecologically-friendly economic incentives – result in high vulnerability for the coastal and near-shore marine ecosystem (Cochrane et al., 2019; Rakotondravony et al., 2018).

## Terrestrial ecosystem and ecosystem services

### General context

Madagascar is considered a biodiversity hotspot (Ganzhorn et al., 2001) and contains 5% of the world's biodiversity. About 90% of species are endemic, and a large number are threatened with extinction (Fisher and Girman, 2000; Ganzhorn et al., 2001; Greene et al., 2008; IUCN, 2018; Vieites et al., 2009). Like many tropical forests in the Anthropocene, Madagascar's ecosystems face significant anthropogenic pressure, including habitat loss and fragmentation, agricultural expansion, biodiversity loss, invasive species, overharvesting, and climate change (Malhi et al., 2014; Morelli et al., 2020). For over a century, deforestation has been a main threat to biodiversity; forest loss is estimated at almost 100,000 ha per year, and 44% of natural forest cover was lost between 1953 and 2014 (Rakotondravony et al., 2018; Vieilledent et al., 2018). Figure 5 shows a map of forest loss and degradation between 1994 and 2014 (Yesuf et al., 2019). Slash-and-burn agriculture for subsistence farming has been a primary driver (Waeber et al., 2015), but unsustainable logging for valuable timber such as rosewood also contributes to deforestation (Neudert et al., 2017). The Menabe region has lost over 60% of its forest cover over the last 10 years; droughts in the south have caused people to migrate to the Menabe area, where they have cut down forest for agricultural land and have moved into the Core Area of the Menabe Antimena Protected Area.

A recent survey of smallholder farmers living near tropical dry forests in Madagascar identified a number of ecosystem services associated with forests, including provision of raw materials and protection from flooding and sedimentation (Dave et al., 2017). Rural populations also use forests to collect wood for domestic energy, to produce charcoal (used by almost 90% of households for daily cooking), to serve as pasture areas for livestock, and a source of non-timber forest products such as fruit, bushmeat, and medicinal plants (GIZ, 2017a; Neudert et al., 2017; Waeber et al., 2015). Current practices for wood extraction and charcoal production are accelerating forest degradation (GIZ, 2017b, 2017a). Reducing forest biodiversity would lead to a reduction in forest productivity, which would negatively impact these activities (Liang et al., 2016). As the population grows, these pressures continue to increase (GIZ, 2017c). Additionally, the political crisis that lasted through 2014 led to an upsurge in illegal exploitation (GIZ, 2017c).

**Climate change effects.**

Climate change is expected to impact biodiversity, ecosystems, and ecosystem services (CPGU and BNCCC, 2017). Species may respond to climate change by altering behavior, shifting their range, or altering the timing of biological events (phenology). A recent review found that Madagascar may have a high number of species vulnerable to climate change (Pacifici et al., 2015). At the ecosystem level, climate change may alter the primary production, species interactions, and the spread of invasive species. Changes to ecosystems can impact local populations that depend on them for services.

Species may shift their ranges to follow changing climate conditions (e.g. by moving towards the poles or higher in elevation to maintain preferred temperatures) or experience range reductions (Busch et al., 2012). Eastern humid forests are expected to contract their range by 2080, while western dry forests may shift to the east (Rakotondravony et al., 2018). On Tsaratanana Massif, the highest mountain in Madagascar, reptiles and amphibians are moving upslope (Niang et al., 2015). A recent study modeled the future distributions of 57 species in Madagascar, and projected that 27 species will have future distributions of <50% of their current range; 14 species will have distributions <20% of their range; and 6 species are projected to have distributions <1% of their current range, including 3 species projected to go extinct (Brown and Yoder, 2015). Importantly, many of these species lack suitable habitat to connect their current habitat with future suitable habitat (Brown and Yoder, 2015).

Changing climatic conditions can also alter the timing of biological events (phenology). For example, some plant species are very sensitive to precipitation changes, and leaves come out when precipitation increases. These species may be particularly vulnerable to increasing variability in precipitation (Rakotondravony et al., 2018). Examples of vulnerable species include Grewia sp. and Rhigozum madagascariense for gallery forest and Uncarina grandidieri and Terminalia fatraea for xerophytic forest (Rakotondravony et al., 2018). When changes in phenology are not uniform, phenological mismatches between species can impact ecological communities and function, although few examples have been observed to date (Morellato et al., 2016). For instance, if plant flowering becomes mismatched with pollinators, plants may experience decreases in recruitment (Morellato et al., 2016). Because plants are at the bottom of the food chain, changes in plant phenology can impact vertebrates that depend on these species for food. The maki (Lemur catta) and Verreaux's sifaka (Propithecus verreauxi), for example, have diets that depend on plants that are vulnerable to water deficits (Rakotondravony et al., 2018).

An increase in the number, intensity, or duration of extreme events can negatively impact biodiversity. For example, drought can reduce survival of plant species and thus reduce productivity (Rakotondravony et al., 2018). Alternatively, it is possible that plant productivity will increase due to $CO_2$ fertilization (Lawal et al., 2019). Extreme events can also indirectly impact ecosystems. For instance, people may be able to use new openings in the forest to reach forest areas that were previously inaccessible (Waeber et al., 2015). Habitat destruction after extreme events can also accelerate the spread of invasive species (Rakotondravony et al., 2018).

Climate change is likely to exacerbate the other anthropogenic threats to Madagascar's terrestrial ecosystems. For example, a recent study projected that suitable habitat for two Critically Endangered ruffed lemurs (Varecia variegata and V. rubra) will decline by 62% in a scenario of no new deforestation in protected areas, and 81% in a scenario where deforestation in protected areas continue (Morelli et al., 2020). Climate change may also indirectly affect lemur populations by changing human behavior; if climate change leads to greater food insecurity, individuals may increase hunting of wildlife such as lemurs (Morelli et al., 2020). WCS is currently assessing species vulnerability to climate change, and WWF has conducted assessments of current vulnerability for species and habitats such as lemurs, radiated tortoise, coral reefs, and mangroves. Loss of Madagascar's ecosystems and biodiversity can reduce tourism and associated economic benefits, although in some cases, the benefits of ecotourism do not compensate for the costs of forest protection at local and regional levels (Busch et al., 2012; Neudert et al., 2017).

## Fisheries

### General Context

Marine and freshwater fisheries provide valuable services to communities in Madagascar (Benstead et al., 2003; Cochrane et al., 2019). Marine fisheries, including shrimp, octopus, and coral reef fish, enhance coastal communities by supporting livelihoods through nutrition and income generation (Cochrane et al., 2019). For example, marine fisheries in the Atsinanana Region provide a main source of protein and income for the coastal population and traditional fishermen and generates approximately € 125.7 million per year (Rakotondravony et al., 2018). Freshwater fisheries are also important in certain regions in Madagascar. Lake Alaotra contains the largest inland fishery in Madagascar with inland fisheries activities making up one of two main sources of income (Lammers et al., 2015). Additionally, many of the native freshwater fish populations are highly endemic to Madagascar and contribute to a global hotspot of freshwater diversity (Benstead et al., 2003). Freshwater fish in Madagascar include many basal taxa (i.e. a lineage that evolved early and is closely related to the common ancestor of the group), which are of conservation importance, as basal taxa can serve as some of the only evidence of evolution in related groups (Benstead et al., 2003).

### Climate change effects

Climate risks for marine and inland fisheries include ocean acidification, changes in cyclone events, sea level rise, increasing temperatures, wind intensification, increased occurrence of extreme weather events, and the facilitated spread of exotic species (Cochrane et al., 2019; Rakotondravony et al., 2018). Fisheries may also face other indirect climate change threats; for example, changes in rainfall could lead to a crop failure, which could lead to an increase in fishing activities and overfishing (WWF interview). These threats impact fisheries production, marine and freshwater biodiversity, fish growth, reproduction and survival, and endemic species conservation (Bamford et al., 2017; IPCC, 2019a). Coupled with other anthropogenic stressors (such as exotic species introductions, wetland destruction, marsh clearing, deforestation, overfishing, siltation from soil erosion), marine and freshwater fisheries and habitat are vulnerable and in need of conservation and management attention (Bamford et al., 2017; Benstead et al., 2003).

## <u>Human health</u>

### General context

Lack of adequate healthcare and disease prevention, malnutrition, and poverty predisposes many people in Madagascar to the impacts of climate change. Most of the population lacks access to adequate health services; for example, 40% of the rural population is more than 5 km from a health facility and lacks a means of transportation, and bad weather can make it even more difficult to deliver health care in isolated areas. If roads become impassable after weather events, it can limit the supply of medicines in the health centers (Morondava site visit). Many health facilities also lack sufficient human resources and equipment (Rakotondravony et al., 2018). For example, the CSB2 health center in Marofandilia had no electricity or running water, only one midwife and one volunteer, and a lack of basic supplies such as tweezers and chairs (Marofandilia site visit). Natural disasters can cause significant damage to the health sector each year, and impacts continue long after the event. In general, the country lacks resources to adequately prepare for, respond to, and recover from damage caused by extreme events (Rakotoarison et al., 2018).
Infectious and non-communicable diseases are the leading cause of morbidity and mortality in Madagascar, and many of these diseases are sensitive to climatic conditions (Rakotoarison et al., 2018). Exacerbating this problem, coverage of sanitation and water supply is low, as is awareness among rural populations of the risks of communicable, diarrheal, and acute respiratory diseases. Outbreaks of communicable diseases often occur after extreme climatic events, and water-borne diseases are becoming more frequent as waterways are contaminated after floods (CPGU and BNCCC, 2017; Rakotondravony et al., 2018).

### Climate change effects

Climate changes can directly impact health in Madagascar. Increases in the number of extreme events can reduce quality of life, especially for those without adequate housing (Davis-Reddy and Vincent, 2017). Increasing temperatures and heat waves could increase heat related mortality, especially for the elderly, young children, the chronically ill, and the poor. Under a high emissions scenario, heat related deaths among those 65 years and older is projected to increase to 50 deaths/100,000 by 2080 compared to the average 1 death/100,000 between 1961 and 1990 (World Health Organization, 2016). Additionally, high temperatures can decrease the effectiveness of certain medications and vaccines such as vitamin A and tests for malaria if they are not stored in a cold place. For example, if the Marofandilia health center is unable to obtain gasoline, they will not be able to run their gasoline powered refrigerator used to store medicines at an appropriate temperature. In addition, high temperatures and drought can lead to water shortages.

Sea level rise and flooding are also a concern. Currently, 27% of people live below 100 m in elevation (Davis-Reddy and Vincent, 2017). Without large investments in adaptation, 573,200 people are projected to be impacted by sea level rise between 2070 and 2100 under a high emissions scenario (World Health Organization, 2016). Inland river flooding risk is also projected to increase as the climate changes (World Health Organization, 2016).

## Mitigation/REDD+

The BNCCC REDD+ office coordinates climate change adaptation and mitigation in Madagascar. However, they expressed concern that not all organizations working on climate change activities are coordinating with their office, and thus it is difficult to track what is going on and avoid duplication (BNCCC REDD+ interview).

As discussed in the terrestrial ecosystems and ecosystem services section, preventing forest loss and degradation is cheaper, more effective, and more cost effective than restoring forests after they have been destroyed, and should be a key climate change mitigation strategy. BNCCC REDD+ is working to sell $65 million USD worth of carbon credits for the next 5 years, but several criteria still need to be met before the deal can be finalized. The rapid deforestation rate across Madagascar threatens the success of this project. CI and WCS are working with BNCCC to develop pilot sites for REDD+, with two pilot projects in CAZ and COFAV. The USFS and Blue Ventures is also helping the Ministry of Environment conduct a carbon inventory of mangrove forests.

The Ministry of Environment, WCS, and Tany Meva were working together on a climate fund project in Makira meant to provide economic incentives for conservation. Fifty percent of the carbon credit funds went to the community to support projects that they proposed focused on improving agriculture, establishing infrastructure, and building schools, and communities also monitored conditions in the park. WCS provided assistance developing the grants, while Tany Meva helped the communities manage the funds. The project has been suspended, however, as it was decided that the Government of Madagascar should manage the fund rather than private organizations.

In addition to carbon fund projects, some organizations are also working on renewable energy projects such as improving stoves and installing solar energy. WWF has supported a renewable energy project in which they trained women from rural areas to install and maintain solar systems in their villages. Madagascar also has the potential to develop hydropower, although the current grid infrastructure is not developed to handle high or variable energy. Investing in renewable energy, for example solar panels for health centers or partnering with other organizations and the private sector, is a promising opportunity to promote both climate change mitigation and sustainable development in Madagascar.