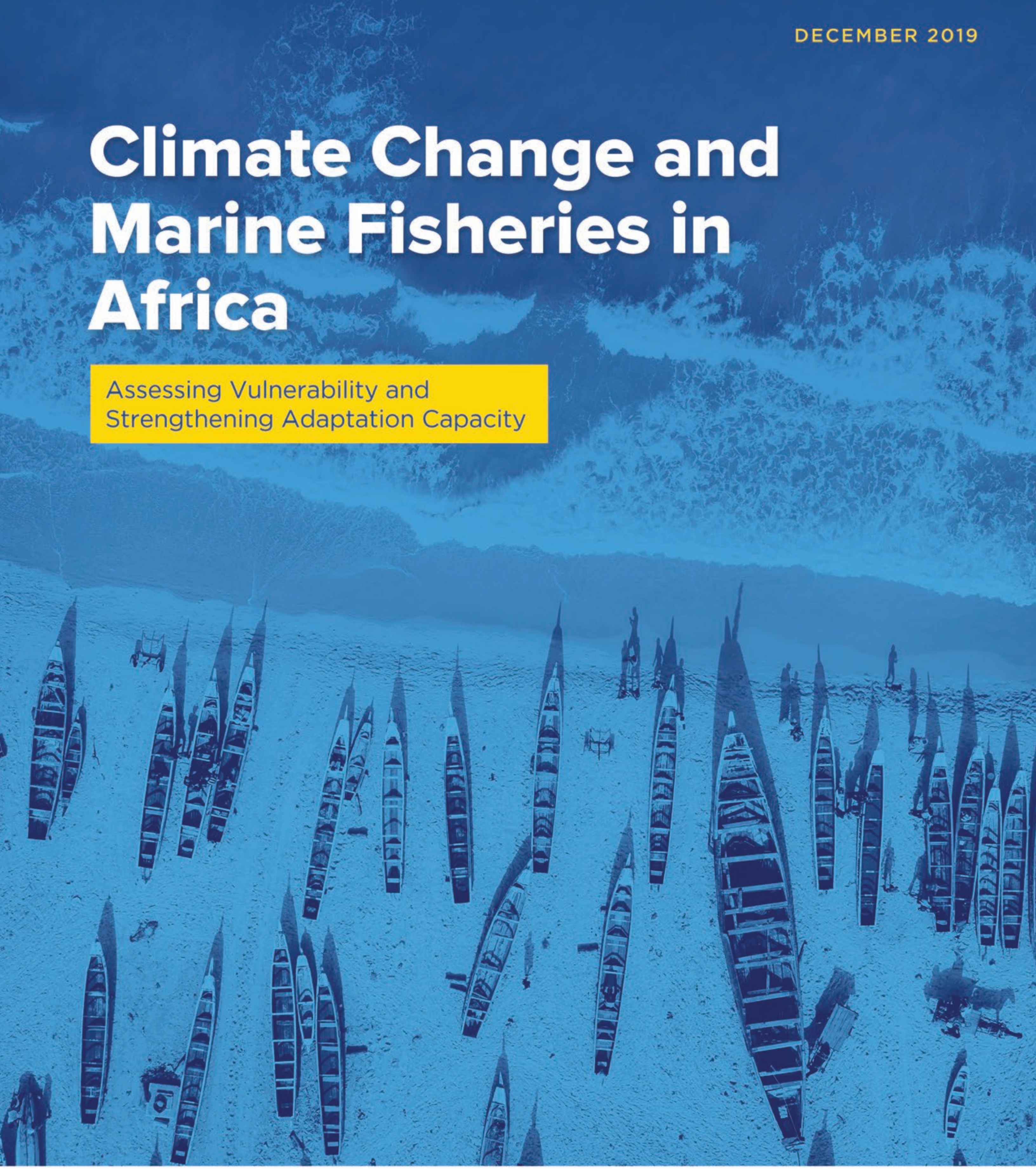
DECEMBER 2019

Climate Change and Marine Fisheries in Africa

Assessing Vulnerability and Strengthening Adaptation Capacity



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Foreword and Acknowledgements

Rigorous assessments of the impacts of climate change, both observed and modeled, are increasingly demonstrating that the effects on marine ecosystems, fisheries, and the millions of fishers and processors who depend on them are likely to be more severe than originally expected. This is an alarming finding, especially in sub-Saharan Africa, where the intensity of climate impacts, combined with the limited adaptation capacity of many in the fisheries sector, contributes to the vulnerability of the affected communities. Despite the growing body of evidence documenting the impacts of climate change, much remains unknown, or at least unquantified, including their precise direction and effect. Policy makers, donors, and other stakeholders urgently need additional analysis and evidence-based information to guide investments and initiatives in climate change mitigation and adaptation, with the ultimate goal of maximizing prospects for development and poverty reduction throughout Africa.

To that end, the World Bank called on a network of expert partners and contributors to fill this knowledge gap and deepen our understanding of the impacts of climate change on marine fisheries in Africa. This process builds directly on the Impacts of Climate Change on Fisheries and Aquaculture report that the UN Food and Agriculture Organization (FAO) published in 2018 and on the special report of the Intergovernmental Panel on Climate Change (IPCC) Global Warming of 1.5°C. This report takes stock of available knowledge on the economic importance of marine fisheries in sub-Saharan Africa and the populations that depend on them and provides a biophysical analysis of the impacts of climate change as they have already been measured and how they are modeled to evolve, a socioeconomic analysis of the same impacts of climate change, and preliminary estimates of the vulnerability of marine fisheries.

A series of consultations with a selected network of targeted partners and contributors with expertise in climate change and African fisheries was undertaken in the preparation of this report. The Nordic Development Fund financed this work. The Nippon Foundation Nereus Program at the University of British Columbia and a World Bank team lead by Bérengère Prince prepared this report. The Fisheries Economic Research Unit, the Sea Around Us, and the Changing Ocean Research Unit provided data and advice. Experts from the Nordic Development Fund provided valuable advice and guidance. Consultations were held with high-level representatives of institutions such as the African Union Inter-African Bureau of Animal Resources; the African Union Development Agency–New Partnership for Africa's Development; FAO; the South African Department of Agriculture, Forestry and Fisheries; the Fisheries Committee for the West Central Gulf of Guinea; the Sub-regional Fisheries Commission of West Africa; and the German Agency for International Cooperation, who all strongly supported the preparation of the report and provided useful guidance and inputs throughout the drafting process. Representatives from research institutes and academic institutions such as the University of Ghana, University of Senegal, University of Cape Town, Western Indian Ocean Marine Science Association, and Kenya Marine and Fisheries Research Institute were also consulted. The report was written by Vicky Lam (UBC) and Charlotte de Fontaubert (World Bank), with contributions by Daniel Lyng and Carolina Giovannelli (World Bank) and benefited from review by and suggestions from the Chair of IPCC Working Group II AR6.

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Abbreviations and Acronyms

DBEM	Dynamic Bioclimate Envelope Model
EEZ	Exclusive Economic Zone
ESM	Earth system model
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
IPCC	Intergovernmental Panel on Climate Change
MCP	Maximum catch potential
SDG	Sustainable Development Goal

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Executive Summary

This study used ecological and socioecological simulation modeling to forecast the impacts of climate change in Africa on fish stocks and the fisheries and fishing communities that depend on them, by 2050 and 2100. It also examined the subsequent impacts on African countries and communities, highlighting those most at risk.

Climate change is likely to have a significant impact on Africa's marine fisheries by as early as 2050. Countries are likely to be affected to varying degrees, but tropical West African countries stand to be the most affected, whereas higher-latitude countries are less likely to be affected and, in some limited instances, could see some benefits. The simulation models forecasting the impacts of climate change on marine fisheries show that the maximum catch potential (MCP) will decrease by 30 percent or more as early as 2050 in many tropical West African countries, including the Democratic Republic of Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Liberia, and São Tomé and Príncipe. At higher latitudes, by contrast, catch potential is projected to decrease only moderately or even increase (e.g., in the waters off Senegal, The Gambia, and Cabo Verde).

The impacts of climate change on marine fisheries will make it difficult for many countries that depend on these fisheries to achieve several of the Sustainable Development Goals (SDGs). This is particularly true with regard to SDG 1 (No poverty), SDG 2 (Zero hunger), and SDG 3 (Good health and well-being) in fishing communities that are especially vulnerable to climate change because of their economic dependence on fisheries for their livelihoods and for food and nutrition security.

Building on projections of ecological impacts of climate change on fisheries, this study also considered social and economic repercussions by assessing socioecological risk scores. These risk scores can help disentangle ecological impacts (risk to marine species and population exposure) from socioeconomic or indirect impacts (degree to which coastal populations are sensitive to climate change or have room for adaptation). The study found that the ecological risk is very high for a large proportion of Africa's coastal countries, including in the Gulf of Guinea, from Gabon to Guinea-Bissau, and along Africa's east coast from Eritrea to Mozambique. The study also highlights margins of adaptation, where countries with high ecological risk do not necessarily face equally high socioecological risk depending on their adaptation capacity (e.g., the extent to which marine resources—including fisheries—are under effective management, or whether alternatives to affected fisheries are available).

For all African coastal countries, climate change impacts will require decision makers to rethink their approach to fisheries management. Even under best-case scenarios, the models clearly show that the impact of climate change on fisheries will be serious, although not evenly felt, and that stressed fisheries resources, for example overfished stocks, are at additional risk from this additional impact. This is crucial given that fisheries are often exploited to the point at which uncontrolled levels of fishing prevail, causing certain stocks to collapse and leading to moratoria or other measures designed to give these stocks the opportunity to recover. In the face of anticipated reductions in MCP, however, these corrective measures may need to be more stringent, and moratoria will likely need to be longer—and thus economically more onerous—and in some cases could even fail to give affected stocks the chance to recover. In other words, the boom and bust overfishing cycle may no longer be one from which fish stocks can recover when combined with the additional impacts of climate change.

Each country has different pathways to adapt to the impacts of climate change on its marine fisheries. An important distinction needs to be made between ecological risks, which, to a large extent, are beyond the control of African coastal states (and even under the most optimistic Intergovernmental Panel on Climate Change scenario, these risks are still alarmingly high), and the socioeconomic factors, over which they can, and should, have direct control. Exposure, sensitivity, and adaptation capacity can all be influenced through policy interventions and are the only elements over which coastal states have any control.

Key Findings

- The impacts of climate change on African fisheries will be serious, even under the most optimistic scenarios, and countries will be affected differently.
- **Ecological risks:** African countries at low latitudes will be hardest hit. Tropical West African countries stand to be the most affected, whereas the impact on higher-latitude countries is likely to be milder.
  - By 2050: The models forecasting the impacts of climate change on marine fisheries show that MCP will decrease by 30 percent or more in many tropical West and Central African countries, including the Democratic Republic of Congo, Côte d'Ivoire, Equatorial Guinea, Gabon, Liberia, and São Tomé and Príncipe.
  - By 2100: It is likely that the largest decrease in MCP (40 percent or more) will occur in tropical West and Central African countries, including Ghana, São Tomé and Príncipe, Liberia, and Côte d'Ivoire.
  - In higher-latitude regions, it is projected that catch potential will decrease much less, for example in Senegal, The Gambia, and Cabo Verde.
- **Socio-ecological risks:** A distinction needs to be made between ecological risks, which, to a large extent, are beyond the control of African coastal states, and socio-ecological risks, which can be mitigated through a variety of management measures.
  - The Horn of Africa, parts of West Africa, and Nigeria are particularly at risk, with climate change posing great risk to the national economies of these countries through fisheries.
- The impacts of climate change on fisheries and fishing communities are not a foregone conclusion; the extent of socio-ecological risk depends on a number of important variables, including the effectiveness of fisheries management measures.

1. Introduction

Our understanding of the impacts of climate change on fisheries is constantly increasing and can be organized around several main factors—ocean acidification, sea-level rise, higher water temperatures, deoxygenation, changes in ocean currents—although these factors are unequally known and hard to model in terms of scope—where they will occur and where they will be felt the most—and severity. For instance, although the impacts of acidification are not as well understood as the effects of the other impacts, and are more difficult to measure, it is likely that they are more severe and widespread, particularly on shell-forming species, invertebrates, and coral-associated species and throughout any carbon-dependent ecological processes.

The impacts of climate change are already being felt and can be measured. The special report of the Intergovernmental Panel on Climate Change (IPCC), Global Warming of 1.5°C, showed moderate impact on small-scale low-latitude fisheries from 2006 to 2015 and forecasted—with high confidence—large impact on fisheries productivity, especially at low latitudes. These impacts will be felt at three fundamental levels: on the fish stocks themselves, on the critical marine and coastal ecosystems on which they depend, and on fishing communities exposed to more-frequent extreme weather events. Climate change has already begun to alter ocean conditions, particularly water temperature and various aspects of ocean biogeochemistry. Marine biodiversity responds to shifting temperatures and other ocean conditions through changes in organismal physiology and phenology[1] and in population dynamics and distribution. It has been projected that these responses to ocean–atmospheric changes will lead to altered patterns of species richness, changes in community structure and ecosystem functions, and consequential changes in marine goods and services. Fishing communities and African academics are already reporting and documenting some of these changes (box 1).

Climate change is becoming a game changer for fisheries management for two reasons it has strengthened the case for a comprehensive approach, including the status of fish stocks and ecosystems that are at the forefront of the impacts of climate change, and it adds a sense of urgency to necessary management reforms, because these relatively new and growing impacts interact with those of overfishing and mismanagement, further increasing the level of uncertainty and removing the safety mechanism that allowed depleted stocks to recover after overexploitation. These impacts, which are inexorably becoming more severe, are and will continue to be felt in fisheries that are globally being fully used, and in some cases overused, and are often in need of comprehensive governance reform.

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[1] Phenology is the study of the timing of recurring biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation of phases of the same or different species (Lieth 1974)

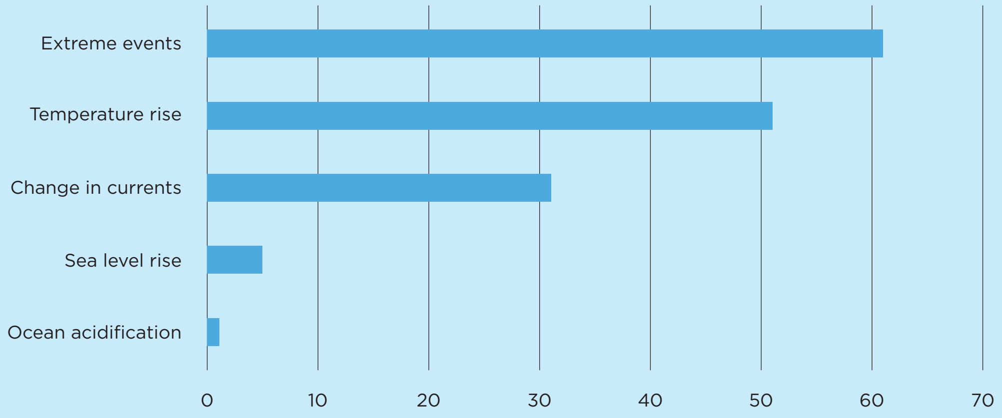
Africa is considered particularly vulnerable,[2] given the unique characteristics of its marine ecosystems and the socioeconomic reliance of communities on this sector for food, jobs, livelihoods, and revenues. Marine species are reaching their environmental limits because of a combination of extreme environmental conditions, the array of human disturbances to which African fisheries are exposed, and the sensitivity of the biota to environmental fluctuations. In addition, African fleets tend to be small, not very mobile, and vulnerable to extreme weather events.

This report aims to assess, to the extent possible, the potential impact of climate change on fisheries and the related well-being of coastal African countries. After a brief overview of the socioeconomic importance of the sector for sub-Saharan Africa, simulation modeling approaches are described that assess the impacts, vulnerability, and risk to their marine biodiversity and fisheries from climate change. It focuses on how the observed and anticipated ecological impacts of climate change are likely to affect fish stocks and the fisheries that depend on them and highlights the coastal countries and regions in Africa that are most vulnerable to climate change. Based on these projections, the report further assesses subsequent socioeconomic impacts on coastal countries and communities. The report concludes with a discussion of lessons learned from the modeling results.

BOX 1. **Climate change as witnessed and monitored**

All along the African coast, fishing communities report changes in fishing pattern and species caught. In 2013, the World Bank surveyed 463 fishermen in Morocco, who reported fewer fishing days because of weather events, changes in species caught, increased sea temperatures, and shifts in current patterns (figure B1.1) (World Bank 2013a). In Liberia, the number of fishing days has decreased because of longer rainy seasons.* In Mauritania, the National Fisheries and Oceanographic Research Institute reports an increase in sea surface temperature of 0.34°C over 20 years (22.69°C in 1989–1998 to 23.03°C in 2009–2018) and a decrease in upwelling strength trends from 1980 to 2018 (Institut Mauritanien de Recherches Océanographiques et de Pêches 2019).

Survey results of fisher climate observations
(% of fishers observing increased phenomena)



Source: Morocco Climate Change Mitigation and Adaptation Strategy, The World Bank, 2013

** See video at: West Africa Regional Fisheries Program in Liberia https://www.youtube.com/watch?v=6m06e6s8RZo.*

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[2] In its present iteration, this report focuses on sub-Saharan Africa and therefore does not include the Mediterranean area, the coast of North Africa, or the Red Sea, although many of its conclusions are likely to apply to the latter two, there are important differences in oceanography and other biophysical aspects.

2. Socioeconomic Importance of Marine Fisheries for African Coastal Countries and Contribution to the Global Agenda

Although policy makers often undervalue the importance of their fisheries sector, the contribution of fisheries to national economies is considerable. African fisheries are vital drivers of pro-poor economic growth, principally because the many small-scale fisheries are a significant source of employment and livelihoods for people in coastal communities.

LOOKING BEYOND THE MERE VALUE OF CATCHES

To better capture the accurate value of African fisheries, we must consider not only the value generated from catch landings, but also the value added through postharvest activities and multiplier effects. This in turn requires understanding the fisheries value chain on the continent. A typical value chain is shown in figure 1, although it does not consider the spectrum of consumers and the diversity of standards required under national regulations.

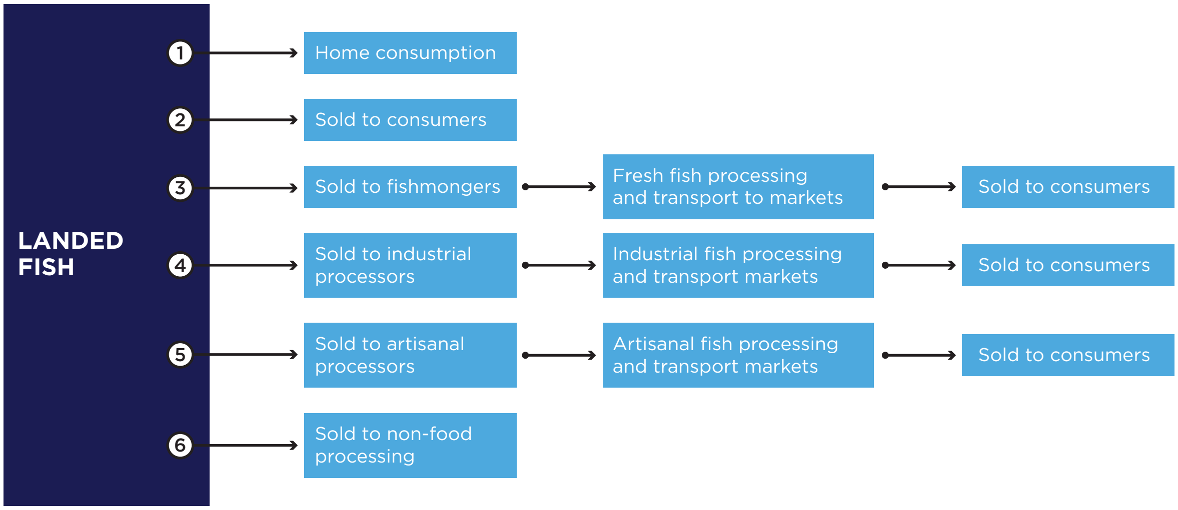
Although the valuation of a sector is typically measured according to its contribution to gross domestic product (GDP), other metrics allow for a more comprehensive and accurate assessment of the sector's importance. First, the gross value of a sector should include the value added by activities up and down the value chain, with particular focus on the contribution of postharvest processing. The employment that the sector generates and livelihoods it supports should also be considered, with special focus on the significance of the sector to vulnerable groups, including those living in poverty and extreme poverty and women. Finally, the sector's contribution to food security, including animal protein, is of crucial importance. Catch data capture only a fraction of the actual value that the sector generates along the value chain.

FISH FOR JOBS

From a socioeconomic standpoint, the Food and Agriculture Organization of the United Nations (FAO) estimates that approximately 10 percent of the global population derives its livelihood from fisheries. African catch data are often underestimated because gatherers and gleaners are usually omitted. Despite this shortcoming, official sources confirm the importance of the sector for employment.

Estimates of jobs that the marine fisheries sector generates, including the postharvest segment, vary from 6.4 million (de Graaf and Garibaldi 2014) to 25.5 million (World Bank 2012). Lack of data and inconsistent or unreliable reporting can explain this wide range. Employment figures, especially employment of women, may be undercounted in the first estimate because it is based on survey responses from government officials who are often confronted with data scarcity and who

FIGURE 1. **Typical value chain for fish products**



Source: de Graaf and Garibaldi 2014.

may have “underestimated [the number of] women working part-time as processors” (de Graaf and Garibaldi 2014).

Studies converge on the prominence of the postharvest segment. De Graff and Garibaldi (2014) estimate that 56.5 percent of these jobs are filled in the processing subsector, and the World Bank (2012) report concludes that the majority of employment in the fisheries sector is not in the catching of fish but in postharvest activities such as processing. This is particularly significant because assessments of the postharvest workforce reveal high levels of female employment, whereas women are typically not as involved in catching fish.

Marine fisheries are an important source of employment for women in Africa. De Graaf and Garibaldi (2014) estimate that women make up 27 percent of the workforce in the African marine fisheries sector, but this figure is low because of the aforementioned undercounting of women engaged in fish processing. Given that 54.4 percent of processors are women, the World Bank (2012) estimate of the number of processors of 17.6 million puts women’s employment at 9.6 million. (Because fewer than 1 percent of women are fishers in the marine fisheries sector, the number of women employed as processors is approximately equal to the number of women employed in the sector.)

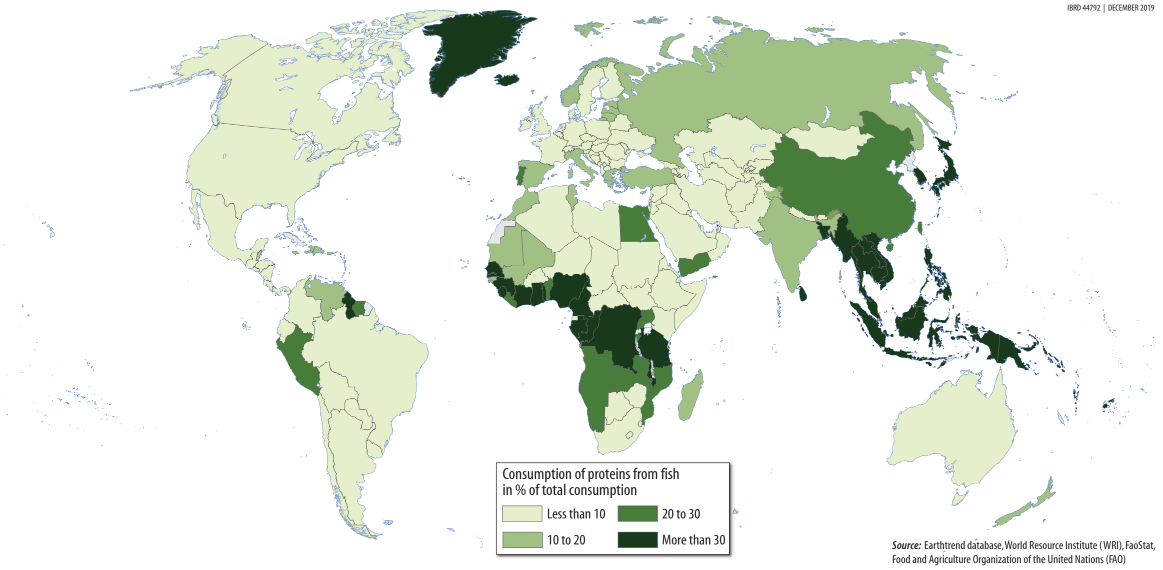
In some coastal countries, up to 20 percent of the labor force is employed in fisheries. Although total employment is a small fraction of the total labor force of coastal regions in Africa, in some least developed countries, small-scale marine fisheries provide employment for up to 20 percent of the labor force (Belhabib, Sumaila, and Pauly 2015). When the number of dependents is incorporated, 4.8 million people, or 16 percent of the coastal population, depend on small-scale marine fisheries in West Africa alone (Belhabib, Sumaila, and Pauly 2015). Although similar data are unavailable for other regions of Africa, these findings illustrate the importance of the marine fisheries sector in providing employment and livelihoods for coastal communities.

FISH FOR FOOD AND HEALTH

Fish products are also an important source of nutrition, particularly protein, for Africans and are therefore a vital contributor to food security. WorldFish (2009) estimates that 400 million Africans rely on fish as an essential component of their diets. FAO data suggest that fish provides 22 percent of animal protein intake in Africa but more than half of animal protein intake in some poor coastal countries (FAO 2018). Figure 2 illustrates the dependence of several African nations on fish for protein intake. Fish also provides up to 9 percent (180 calories) of daily calorie intake for individuals in coastal areas (FAO 2018). Although reliable data disaggregating the contribution of marine fisheries from inland fishing and aquaculture are unavailable, small-scale fisheries of all kinds together account for “the bulk of [African] fish supply” (AUC and NEPAD 2014). Given that 45.2 percent by weight of fresh and processed fish is landed from marine fisheries, it is reasonable to conclude that marine fisheries are responsible for a large amount of the African fish-provided protein and calorie supply (de Graff and Garibaldi 2014). Per capita fish consumption in sub-Saharan Africa is projected to decline at an annual rate of 1 percent to 5.6 kg from 2010 to 2030 (World Bank 2013b), which is the result of demand for fish growing faster than production. Fish imports in 2030 are projected to be 11 times as high as in 2000.

Fish can provide essential amino acids, fats, and micronutrients such as iron, iodine, vitamin D, and calcium. Experts from the FAO and World Health Organization emphasize that fish consumption reduces mortality due to coronary heart disease in adults and improves the neurodevelopment of fetuses and infants. It is thus an important part of the diets of pregnant women and nursing mothers (FAO and WHO 2011).

FIGURE 2. **Consumption of Protein from Fish as Percentage of Total Consumption of Animal Proteins**



Source: Earthtrend database, World Resources Institute (WRI), Washington; FAOSTAT, FAO. Adapted from Philippe Rekacewicz, February 2006, available at: http://www.grida.no/resources/5620

BEST ESTIMATES OF VALUE OF CATCHES

Based on reported catch levels, the total value of the marine fisheries sector in Africa is estimated to be slightly less than USD15 billion (de Graaf 2014), accounting for approximately 0.78 percent of the continent’s GDP. Although most fresh and processed fish come from inland fishing, marine fisheries contribute 45.2 percent by weight of fresh and processed fish to Africa. Postharvest activities are usually divided into three main categories: marketing of fresh fish, artisanal fish processing, and industrial fish processing. Across the total fisheries sector (including inland fisheries), the sale of fresh fish creates the majority of postharvest value (USD1,230,750 (70 percent)), followed by artisanal fish processing

(USD356,074 (20 percent)), and finally by industrial fish processing (USD171,045 (10 percent)).

If reconstructed catch data are used (Annex 1), the direct contribution of marine fisheries excluding postharvest activities is more than USD16.7 billion (if total landed value is considered to represent the value of capture).[3] Based on de Graaf's estimate that postharvest activities account for 34 percent of gross value added, the total value of the marine fisheries sector, when adjusted under data reconstruction, accounts for more than USD25 billion, or 1.3 percent of African GDP, but de Graaf considers only downstream components of the value chain and ignores the potential contribution of upstream industries, such as those selling fishing gear, building boats, and fixing engines (figure 1). Although data estimating the value of upstream activities are not available, considering upstream industries would significantly increase the sector's gross value added.

These metrics help quantify the overall value of marine fisheries in Africa and are particularly important for Africa's poorest people. Marine fisheries generate a significant amount of employment for Africans in the poorest coastal states; provide calories, protein, and other essential nutrients; and create livelihoods for women and families in areas where they might otherwise be unavailable. In turn, this sector contributes to several Sustainable Development Goals (SDGs).

CONTRIBUTION TO HIGHER OBJECTIVES: SDGS AND AFRICA 2063

The impacts of climate change on marine fisheries will make it difficult for many countries that depend on these fisheries to achieve several of the SDGs. With regard to SDG 1 (End poverty), SDG 2 (Zero hunger), and SDG 3 (Ensure healthy lives and promote well-being for all at all ages), fishing communities are especially vulnerable because of their dependence on fisheries for their livelihoods, food security, and nutrition. This report aims to support achievement of these SDGs by emphasizing the need for adaptation measures to increase resilience and consequently reduce poverty, increase food security, and improve health by improving nutrition. By fostering identification of cost-effective adaptation measures for African communities that depend on fisheries and considering the potential contribution of fisheries to job creation and economic growth, the report also supports achievement of SDG 8 (Decent work and economic growth). In addition, the report fits squarely within the framework of activities

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[3] Fisheries data are not consistently reported, and even in cases in which they are available, they are often not collated in comparable and compatible formats. Reconstructed catch data are based on official catch estimates and corrected to add estimated catches from illegal, unregulated, and unreported fishing and discards at sea, usually of bycatch. Although reconstructed catch data are available to compensate for data scarcity and shortcomings, the methodology supporting these data is debatable.

that support achievement of SDG 13 (Climate action) and SDG 14 (Life below water).

The report also contributes to achievement of the African Union Agenda 2063, the strategic framework for the socioeconomic transformation of the continent through 2063 because, in the face of climate change, actions aimed at reducing poverty and inequality as set in Agenda 2063 hinge on the ability of countries to design and apply effective measures to reduce the impacts of climate change and enhance adaptation capacity and, in parallel, the ability of vulnerable people, such as African coastal communities, to increase their resilience. The core objective of this report is to analyze the biophysical and socioeconomic impacts of climate change, current and modeled, to estimate risk to marine fisheries from climate change and ultimately guide decision makers in making prioritized, cost-effective investments in the fisheries sector to respond to uncertainty due to climate change.

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3. Methodology Overview—Ecological and Socioeconomic Approaches

PROJECTED CHANGES IN CATCH POTENTIAL UNDER THE IMPACTS OF CLIMATE CHANGE

The impact of climate change on marine biodiversity and fisheries in Africa can be projected by estimating changes in catch potential caused by a variety of ecological impacts and factors (e.g., increases in sea temperatures, oxygen concentration, ocean acidification, changes in frequency and intensity of extreme events, changes in biochemical structures). These changes in turn affect the abundance, physiology, phenology, and spatial distribution of targeted species, which contribute to changes in food webs and, particularly when combined with ongoing fishing efforts,[4] to maximum catch potential (MCP) (figure 3). MCP should not be considered as a proxy for real catches, as outlined in box 2. Variations in MCP as a result of climate change are highlighted in section IV.

FIGURE 3. Impact of climate change on marine resources

Source: Gabriel Reygondeau and Vicky Lam, University of British Columbia.

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[4] The fishing effort is a measure of the level of fishing. Frequently, some surrogate is used related to a given combination of inputs into the fishing activity, such as the number of hours or days spent fishing, number of hooks used (in longline fishing), or kilometers of nets used.

BOX 2. **Effects of climate change as measured in change in maximum catch potential (MCP)**

MCP is the maximum theoretical catch of a species in an ecosystem. The projections developed from the two models used in this report do not reflect potential changes from current catch levels but rather estimate changes from their current capacity in the future capacity of oceans to produce fish. This capacity is different from actual catches because the latter depend on two important factors: the productive capacity of the oceans (as measured in MCP) and management decisions made in response to this productive capacity.

CATCHES = CAPACITY + EFFECTS OF FISHERIES MANAGEMENT

This, in turn, means that changes in MCP may not correlate exactly with catch variations. For example, future catches in an area where the productive capacity is expected to decline may actually increase if management measures can restore stocks that are overexploited. Conversely, in areas where MCP increases, catches could fail to increase if adequate management measures are not implemented.

SOCIOECOLOGICAL RISK OF CLIMATE CHANGE

Although ecological studies exploring climate change impacts on shift in species distribution and MCP measure the hazard and exposure level, the degree of exposure of a species does not reflect its sensitivity and adaptation capacity, and a relationship therefore cannot be inferred. Thus, this study used an ecological risk assessment combining the biological and ecological characteristics of marine species to identify and assess countries with high ecological risk to climate change and species that are particularly vulnerable. The impact of these changes on marine biodiversity and MCP, which varies depending on the regions where the impacts of climate change are felt, also depends on the economies and fisheries management of the countries involved.

To identify coastal countries in Africa that are most vulnerable to the impacts of climate change, a socioecological risk assessment framework, based on the IPCC approach, was applied. An ecological risk assessment (species-specific estimates of exposure and ecological and biological traits) was conducted that was then integrated into the socioecological risk assessment (figure 14) to assess the risk on African fisheries and their dependent communities from climate change.

PHOTO CREDIT
Charlotte De Fontaubert / World Bank

4. Projected Changes in Catch Potential Under the Impacts of Climate Change

APPROACH

This study used the approach outlined in the FAO report on the impact of climate change on fisheries and aquaculture published in 2018. It assesses the ecological impacts of climate change to project future changes in MCP for the main species within the exclusive economic zones (EEZs) of African nations. These projections are drawn from two models that model ecological processes in two different ways: the Dynamic Bioclimate Envelope Model and the Multi-species Size-based Ecological Model. Both models draw on the same outputs from collections of Earth system models (Phase 5 of the Coupled Model Intercomparison Project) and are thus comparable.[5] The models are run under two greenhouse gas (GHG) emission scenarios, the lowest (Representative Concentration Pathway 2.6) and the highest (Representative Concentration Pathway 8.5), to account for the uncertainty that still prevails in climate change modeling, with two different time horizons, 2050 and 2100.

The results are presented in two sets, one for the Dynamic Bioclimate Envelope Model and the other for the Multispecies Size Spectrum Ecological Model. For each model, the results are divided between changes under two different climate change scenarios (Representative Concentration Pathways 2.6 and 8.5), and for each scenario, the results are mapped for 2050 and 2100.

RESULTS: FUTURE PROJECTIONS OF FISH CATCH POTENTIAL UNDER CLIMATE CHANGE

For each model, GHG emission scenario, and timeline, the projected changes in MCP vary greatly geographically, with substantial differences between African countries. Averaged across the two models, the projections show that, by the end of the century, the largest decrease (40 percent or more) will likely occur in tropical African countries, including Ghana, São Tomé and Príncipe, Liberia, and Côte d'Ivoire, but over the longer term, potential catches are also projected to decrease substantially (20 percent or more) in the temperate northeast and southeast Atlantic. In higher-latitude regions, by contrast, catch potential is projected to increase or at least decrease much less, as expected in temperate regions (e.g., Senegal, The Gambia, Cabo Verde).

Tables 1 and 2 lay out the percentage by which potential catches are expected to change—mostly decrease, but also, in a few cases, increase—by 2050 and 2100. The data in these tables are then shown on a series of maps, which indicate that the impacts of climate change on MCP will vary greatly, from countries that will experience the greatest changes to others that will remain relatively unscathed. Purely from an ecological standpoint, and without regard for fisheries management, the economic importance of the sector, or the vulnerability of affected populations, climate change will have different impacts on fisheries resources of different countries.

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[5] The Geophysical Fluid Dynamic Laboratory Earth system model 2G, the Institut Pierre Simon Laplace Climate Model, and the Max Planck Institute Earth system model.

TABLE 1. Percentage Changes in Maximum Catch Potential (MCP) Under Low and High Greenhouse Gas (GHG) Emission Scenarios, by 2050 and 2100 (Dynamic Bioclimate Envelope Model)

Exclusive economic zone	Low GHG emission scenario (Representative Concentration Pathway 2.6)		High GHG emission scenario (Representative Concentration Pathway 8.5)	
	2050	2100	2050	2100
Angola	−23.70	−19.97	−43.65	−63.95
Benin	−20.91	−15.34	−24.68	−65.97
Cameroon	−18.28	−19.45	−34.01	−55.42
Cabo Verde	17.52	20.93	24.03	26.92
Comoros	0.51	−0.82	−9.82	−46.51
Congo, Dem. Rep.	−29.09	−33.82	−42.65	−60.57
Congo, Rep.	−46.29	−48.51	−53.86	−63.79
Côte d’Ivoire	−31.14	−31.82	−37.73	−72.25
Equatorial Guinea	−34.11	−34.24	−47.48	−67.72
Gabon	−48.15	−47.39	−63.73	−69.85
Gambia, The	4.63	7.76	6.19	−28.31
Ghana	−25.76	−25.19	−35.02	−76.15
Guinea	−14.29	−14.62	−30.32	−65.00
Guinea-Bissau	−14.32	−10.86	−20.95	−65.03
Kenya	1.88	3.42	2.02	−48.43
Liberia	−41.32	−38.81	−44.32	−76.26
Madagascar	−1.84	−4.59	−12.20	−39.90
Mauritania	−5.26	−4.42	−6.13	−17.36
Mauritius	−3.32	−6.54	0.23	−4.34
Mayotte (France)	3.58	1.81	−10.96	−48.84
Morocco	−2.38	−7.32	−6.59	−14.46
Mozambique	−8.51	−13.70	−14.25	−34.90
Namibia	−12.47	−6.10	−16.60	−34.46
Nigeria	−17.12	−15.38	−33.82	−52.75
Réunion (France)	−6.05	−12.52	−11.17	−15.73
São Tomé and Príncipe	−32.15	−33.05	−53.14	−82.68
Senegal	1.98	5.17	4.72	−28.38
Seychelles	−8.39	−8.66	−15.58	−68.45
Sierra Leone	−17.21	−22.69	−35.13	−57.41
Somalia	−10.30	−9.52	−22.39	−60.89
South Africa	−8.25	−9.54	−15.26	−21.19
Tanzania	0.80	2.14	−1.60	−52.40
Togo	−22.60	−16.78	−30.63	−71.47

Djibouti and Eritrea are missing because MCP projections were available from only one model.

TABLE 2. **Percentage Changes in Maximum Catch Potential (MCP) Under Low and High Greenhouse Gas (GHG) Emission Scenarios, by 2050 and 2100 (Multispecies Size Spectrum Ecological Modeling)**

Exclusive economic zone	Low GHG emission scenario (Representative Concentration Pathway 2.6)		High GHG emission scenario (Representative Concentration Pathway 8.5)	
	2050	2100	2050	2100
Angola	−5.10	−3.40	−11.12	−34.43
Benin	−17.57	−15.54	−16.93	−33.02
Cameroon	−8.64	−4.76	−12.29	−22.87
Cabo Verde	−10.73	−5.93	−19.33	−36.15
Comoros	−12.38	−10.90	−14.31	−26.05
Congo, Dem. Rep.	−5.83	−4.30	−9.61	−19.73
Congo, Rep.	−7.51	−6.82	−11.41	−23.92
Côte d’Ivoire	−22.73	−18.00	−20.46	−35.31
Equatorial Guinea	−10.63	−6.65	−12.38	−28.37
Gabon	−6.28	−4.56	−7.86	−18.72
Gambia, The	−18.43	−10.39	−17.64	−35.14
Ghana	−22.66	−15.15	−20.34	−38.36
Guinea	−20.07	−15.88	−15.66	−29.72
Guinea-Bissau	−24.69	−18.29	−17.37	−32.30
Kenya	−18.78	−11.76	−19.93	−34.92
Liberia	−20.96	−20.14	−19.71	−32.04
Madagascar	−6.16	−4.88	−10.57	−18.86
Mauritania	−2.52	−4.79	−8.57	−16.87
Mauritius	−11.59	−12.37	−13.12	−23.09
Mayotte (France)	−9.49	−8.43	−11.71	−21.86
Morocco	2.64	−2.68	5.05	−8.32
Mozambique	−7.14	−4.84	−10.74	−20.37
Namibia	−2.17	−2.33	−3.64	−11.22
Nigeria	−10.81	−9.42	−11.14	−24.20
Réunion (France)	−7.62	−9.14	−12.38	−21.45
São Tomé and Príncipe	−11.24	−10.59	−13.45	−29.05
Senegal	−16.76	−9.04	−18.98	−36.15
Seychelles	−19.92	−14.86	−21.29	−33.51
Sierra Leone	−22.44	−19.40	−18.70	−31.45
Somalia	−15.46	−11.01	−19.06	−36.53
South Africa	−2.13	−1.84	−2.29	−3.83
Tanzania	−17.44	−12.40	−18.22	−32.24
Togo	−17.97	−15.57	−17.13	−34.72

Djibouti and Eritrea are missing because MCP projections were available from only one model.

CATCH POTENTIAL MAPS: UNDERSTANDING THE LEGEND

The following legend is used in Figures 4a through 7b, with differences throughout the maps easily recognized. In some instances, the upper or lower bounds of the underlaying data will be less than others, but the band ranges never change, and the colors are consistent between the maps. This same logic is used for all other maps in the report.

LEGEND Change in maximum catch potential (MCP) (%)

🟥	-83 to -45
🟥	>-45 to -30
🟥	>-30 to -15
🟥	>-15 to -0
🟥	>0 to 27

PHOTO CREDIT
Charlotte De Fontaubert / World Bank

FIGURE 4. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios by 2050 Using the Dynamic Bioclimate Envelope Model

a.

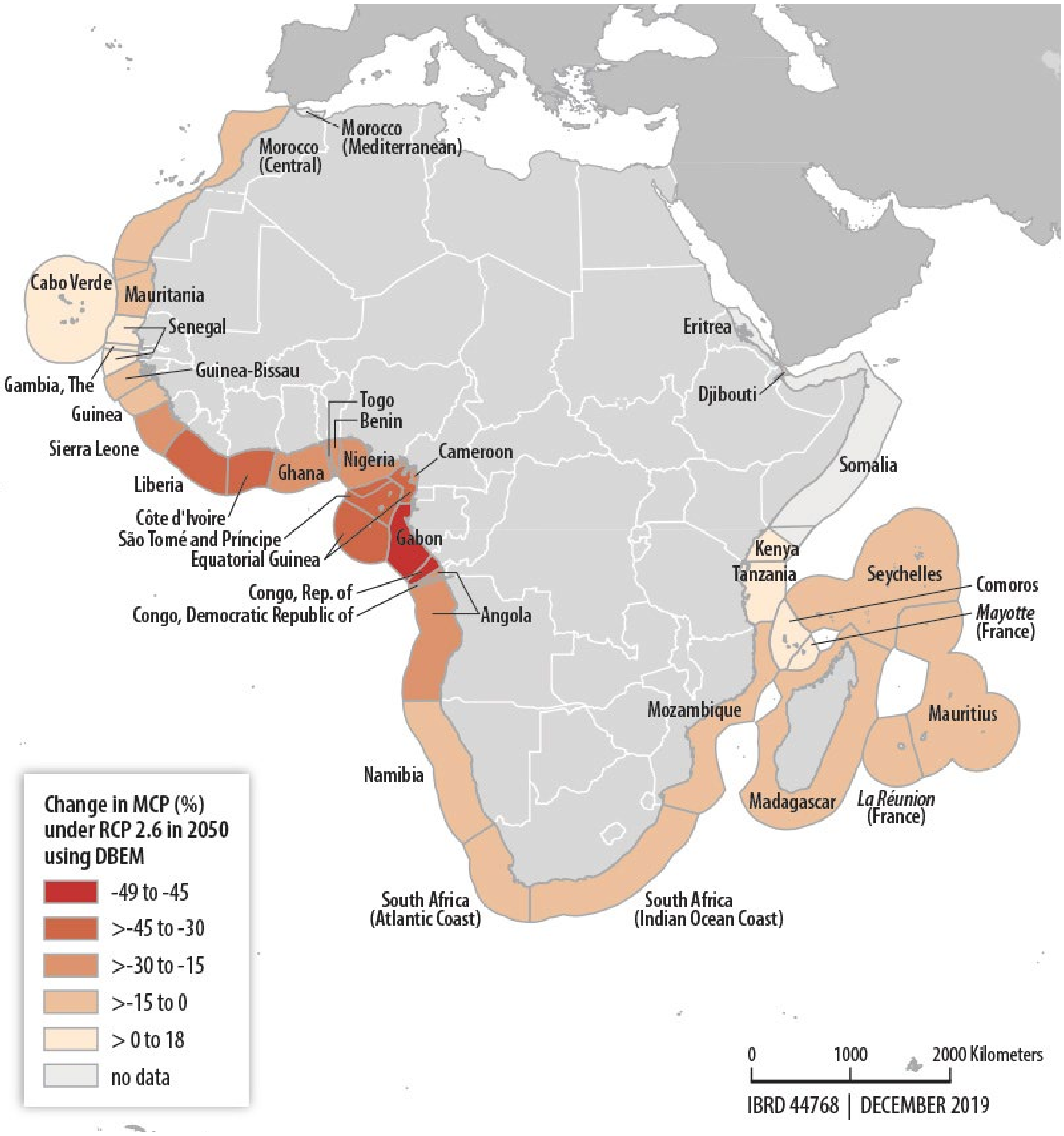

FIGURE 4. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios by 2050 Using the Dynamic Bioclimate Envelope Model

b.

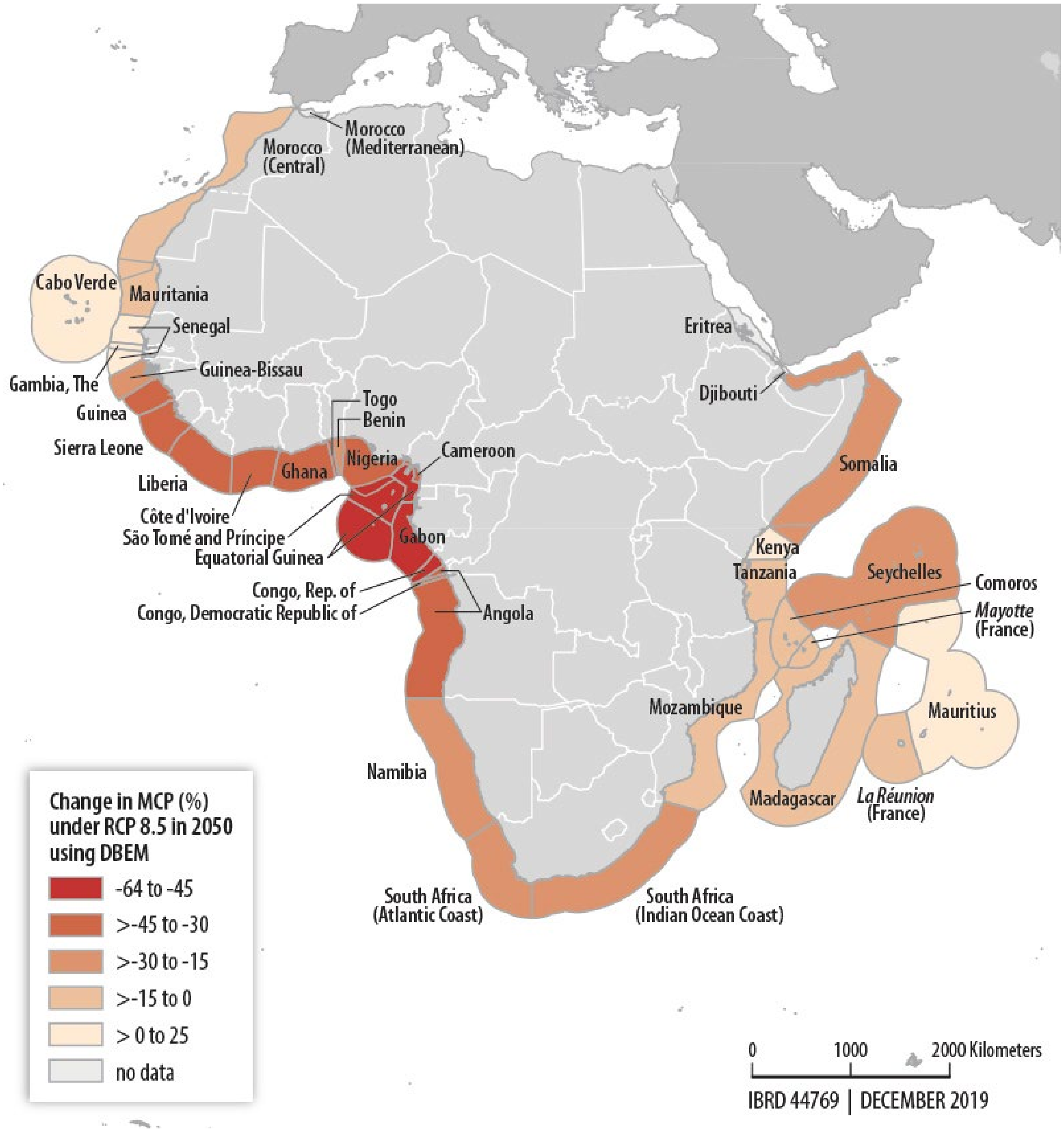

FIGURE 5. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios by 2100 Using the Dynamic Bioclimate Envelope Model

a.

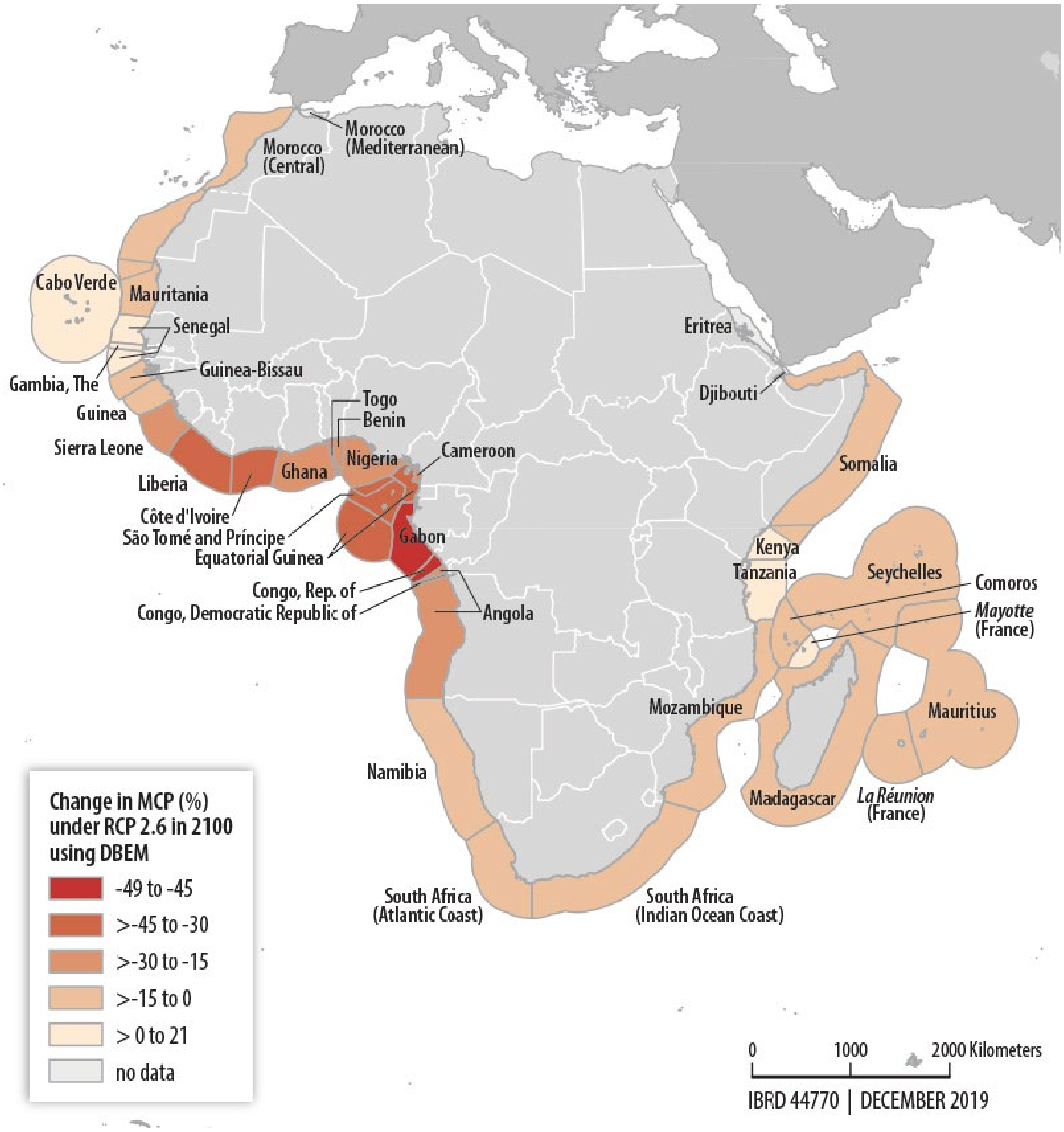

FIGURE 5. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios by 2100 Using the Dynamic Bioclimate Envelope Model

b.

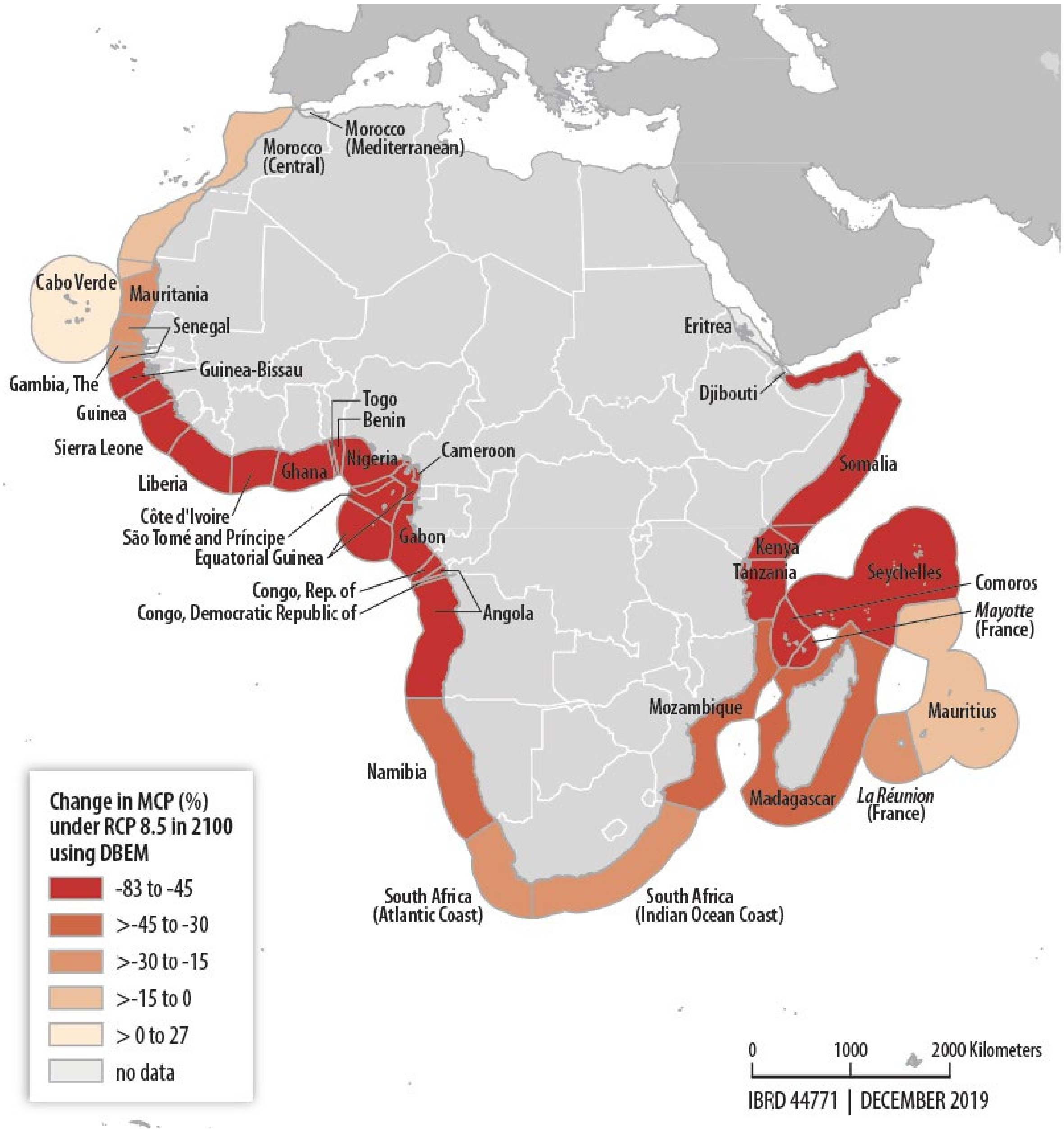

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FIGURE 6. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios in 2050 Using Multispecies Size Spectrum Ecological Modeling

a.

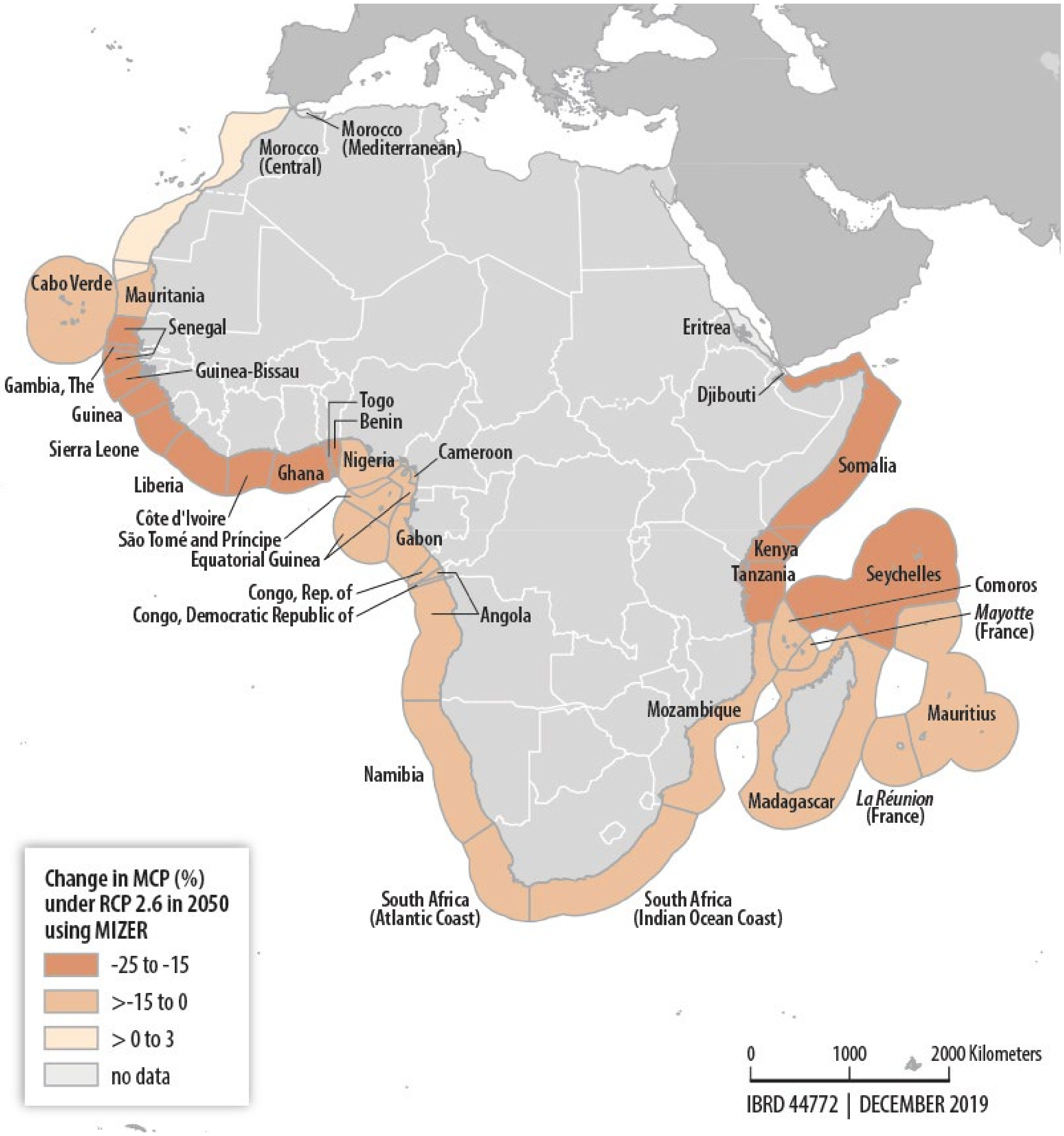


FIGURE 6. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios in 2050 Using Multispecies Size Spectrum Ecological Modeling

b.

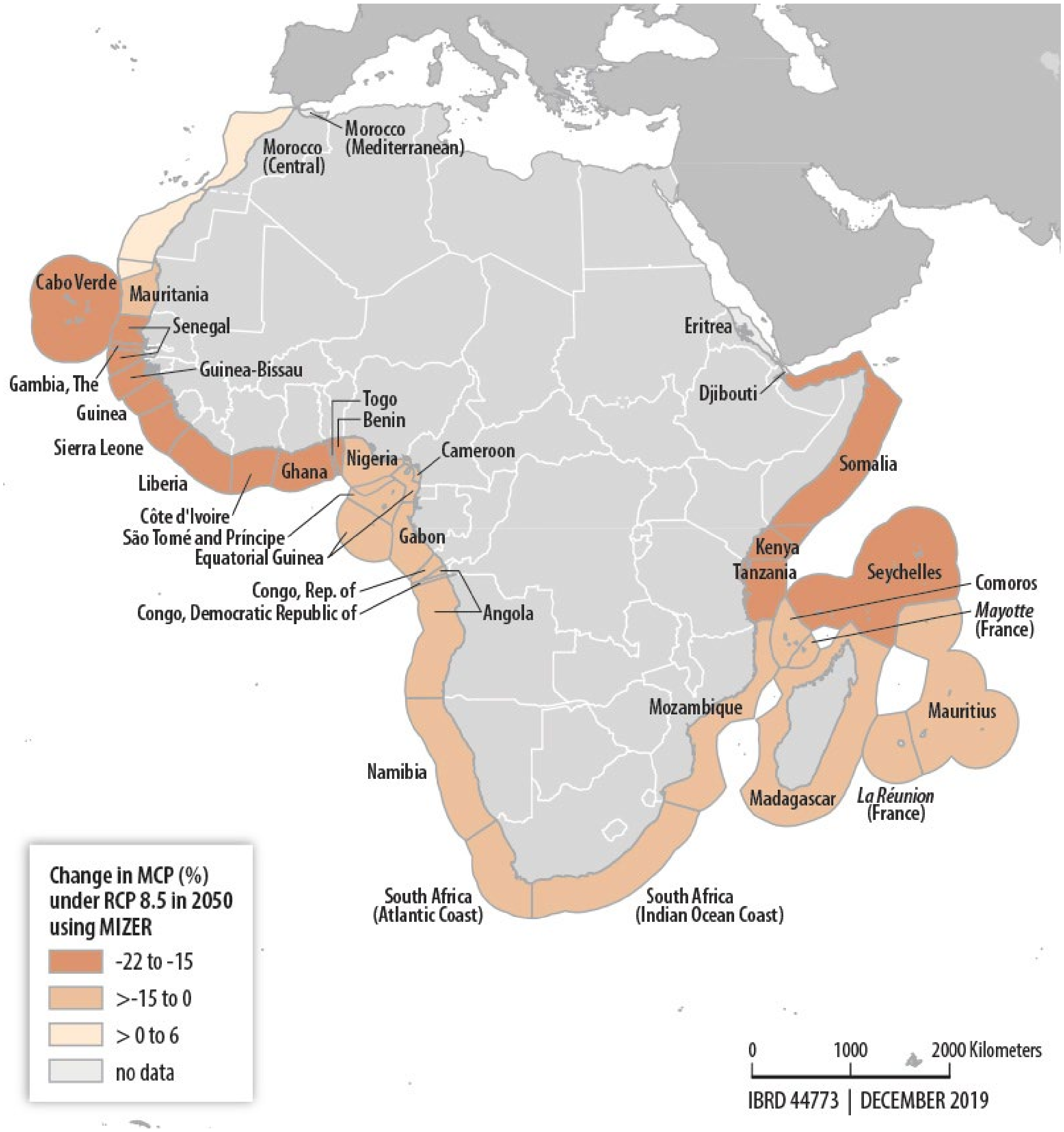


FIGURE 7. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios in 2100 Using Multispecies Size Spectrum Ecological Modeling

a.

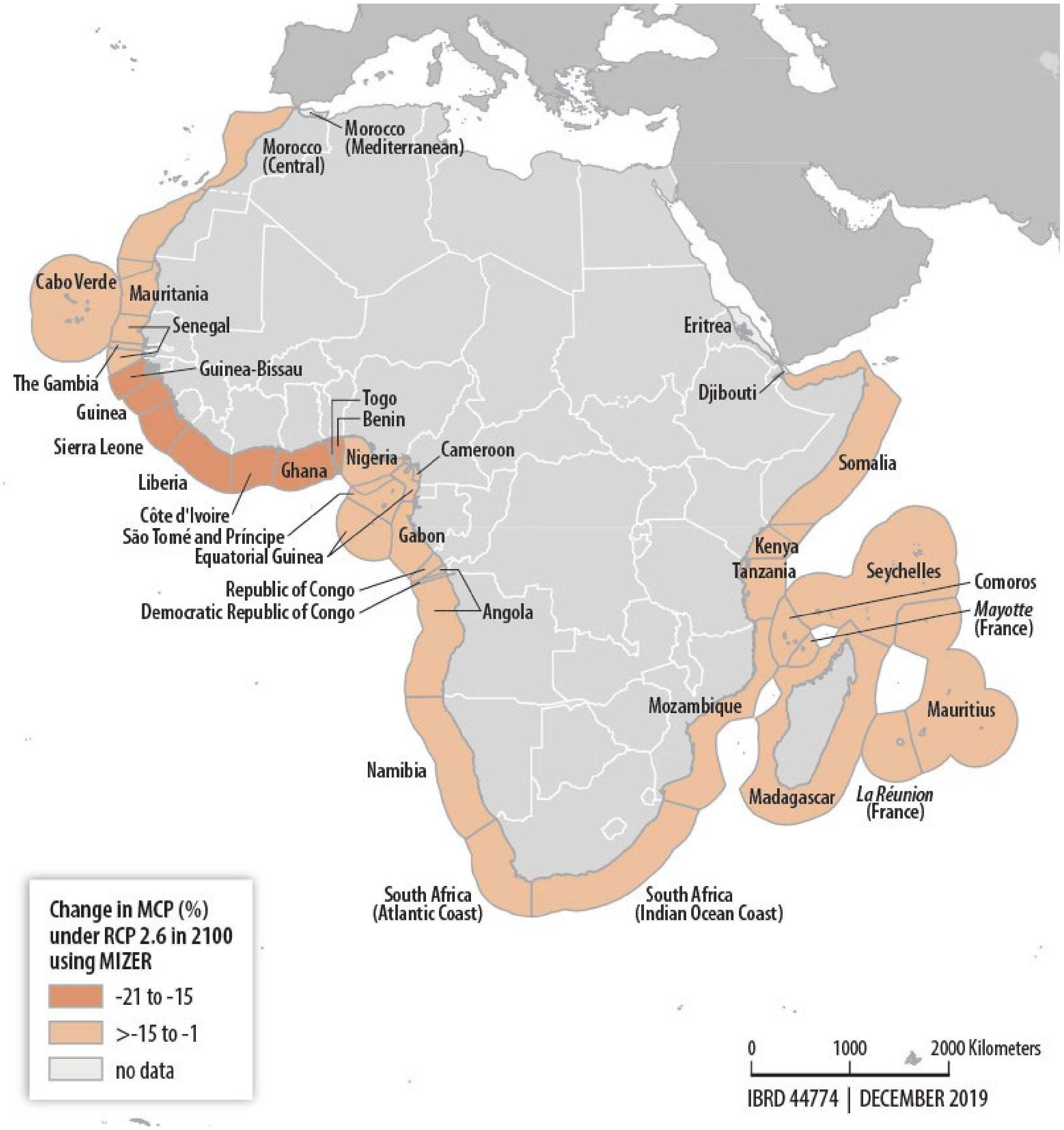
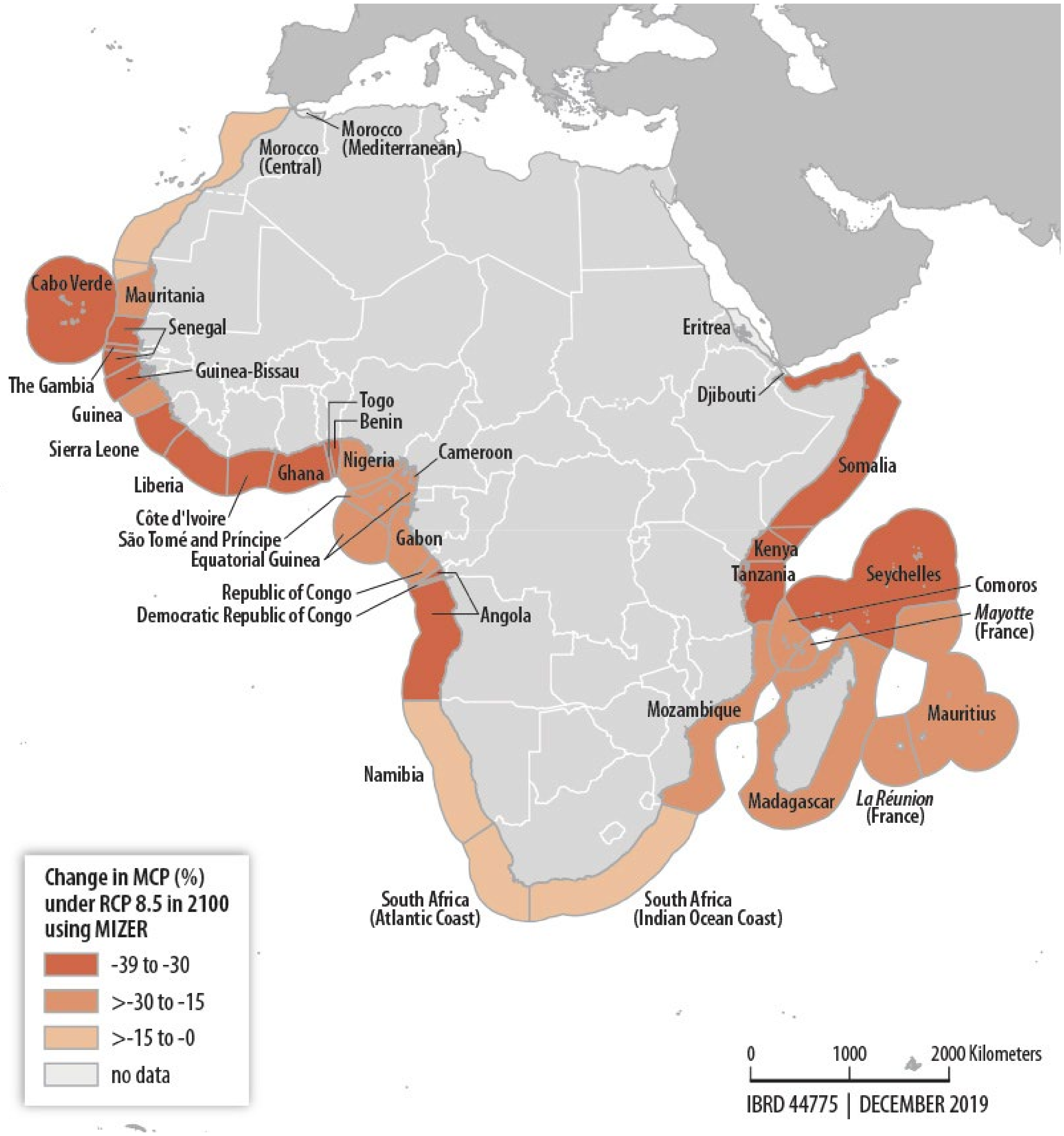


FIGURE 7. Change in MCP (%) Under (a) Low and (b) High Greenhouse Gas Emission Scenarios in 2100 Using Multispecies Size Spectrum Ecological Modeling

b.



5. Mapping Adaptation Through Uncertainty

As highlighted above, the ecological modeling that allows the ecological impact of climate change on fisheries to be assessed is based on two models run under two different climate change scenarios at two different times. This combination of variables leads to a situation of high uncertainty, under which the difference between the models used could lead to markedly different results.

To assess the differences that might arise, the six sets of maps below illustrate the differences in projected change in MCP for each possible variation between the two models used (Dynamic Bioclimate Envelope Model, Multispecies Size Spectrum Ecological Model), between the two scenarios, and between the two periods (2050, 2100). The EEZs with the diagonal lines represent the change in direction when these two models predict change in different directions.

These maps show that the models indicated different levels of variation in MCP, although for the vast majority of coastal African countries, the models converged around a decrease in MCP by the middle and end of the century. This finding is consistent with the IPCC's special report, Global Warming of 1.5°C, which shows moderate impact on small-scale low-latitude fisheries from 2006 to 2015 and forecasts—with high confidence—a large impact on fisheries productivity, especially at low latitudes.

FIGURE 8. Change in MCP (%) Between Dynamic Bioclimate Envelope Model and Multispecies Size Spectrum Ecological Model Under Representative Concentration Pathway 2.6 by (a) 2050 and (b) 2100

a.

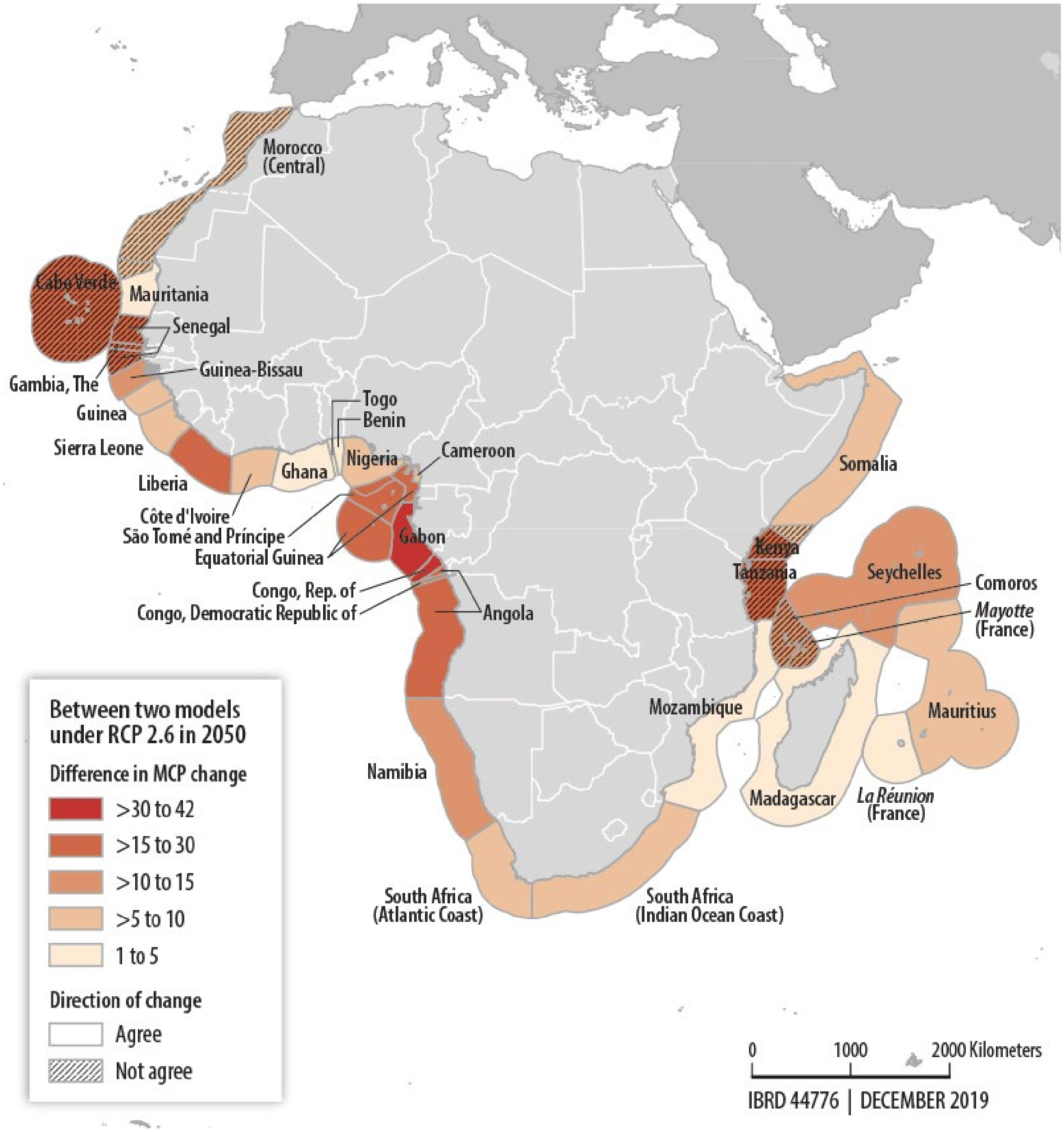


FIGURE 8. Change in MCP (%) Between Dynamic Bioclimate Envelope Model and Multispecies Size Spectrum Ecological Model Under Representative Concentration Pathway 2.6 by (a) 2050 and (b) 2100

b.

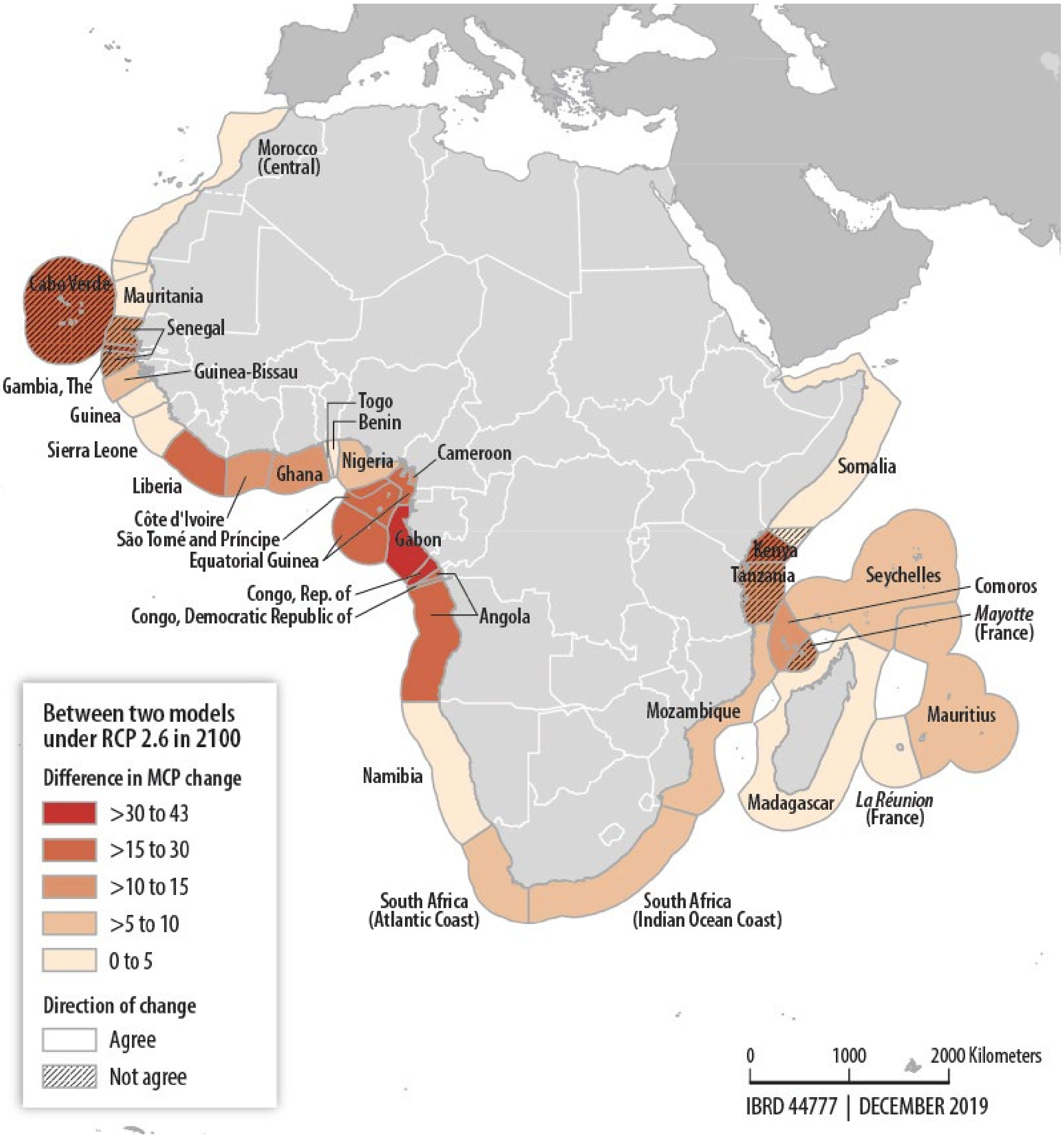


FIGURE 9. Change in MCP (%) Between Dynamic Bioclimate Envelope Model and Multispecies Size Spectrum Ecological Model Under Representative Concentration Pathway 8.5 in (a) 2050 and (b) 2100

a.

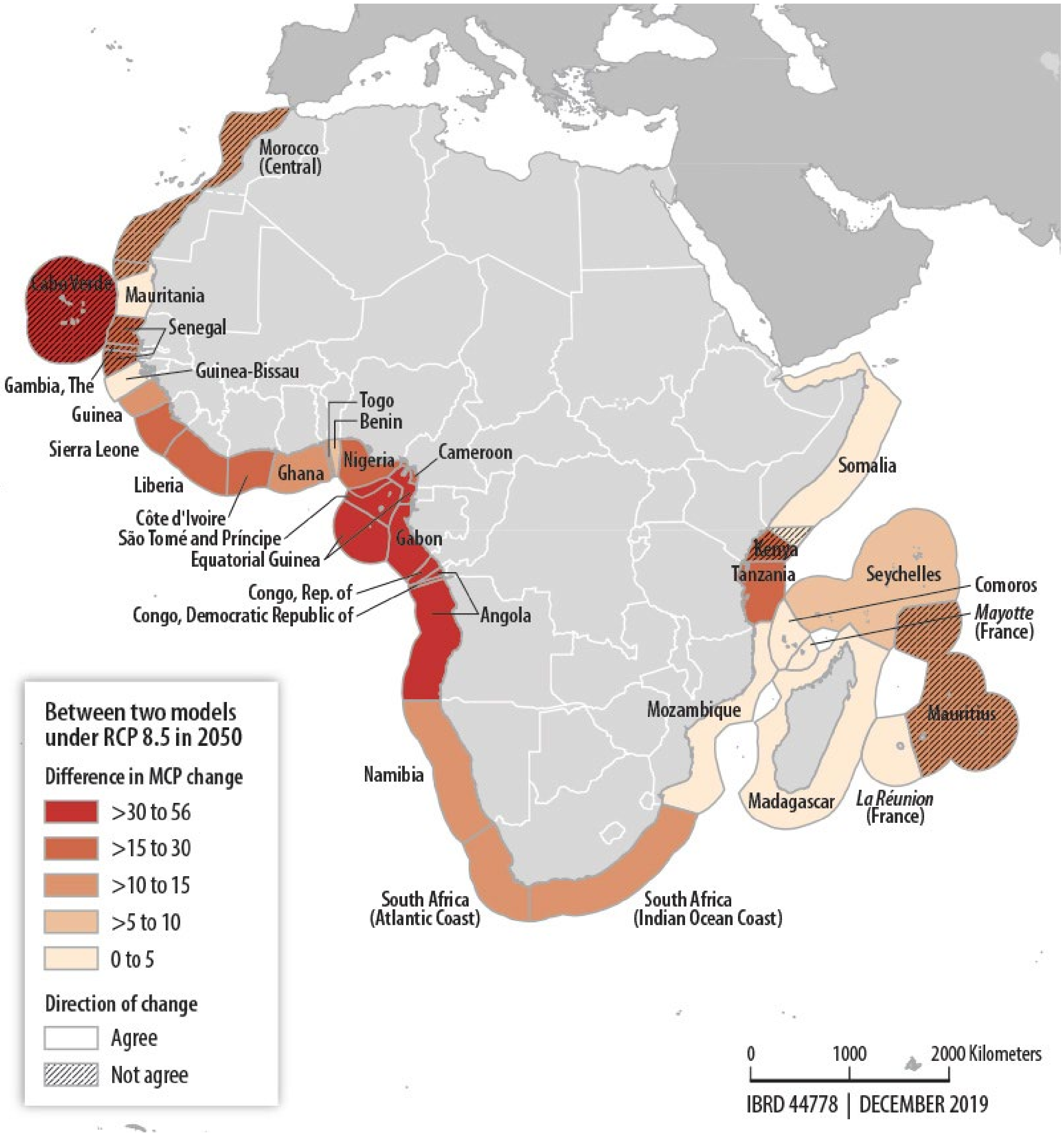


FIGURE 9. Change in MCP (%) Between Dynamic Bioclimate Envelope Model and Multispecies Size Spectrum Ecological Model Under Representative Concentration Pathway 8.5 in (a) 2050 and (b) 2100

b.

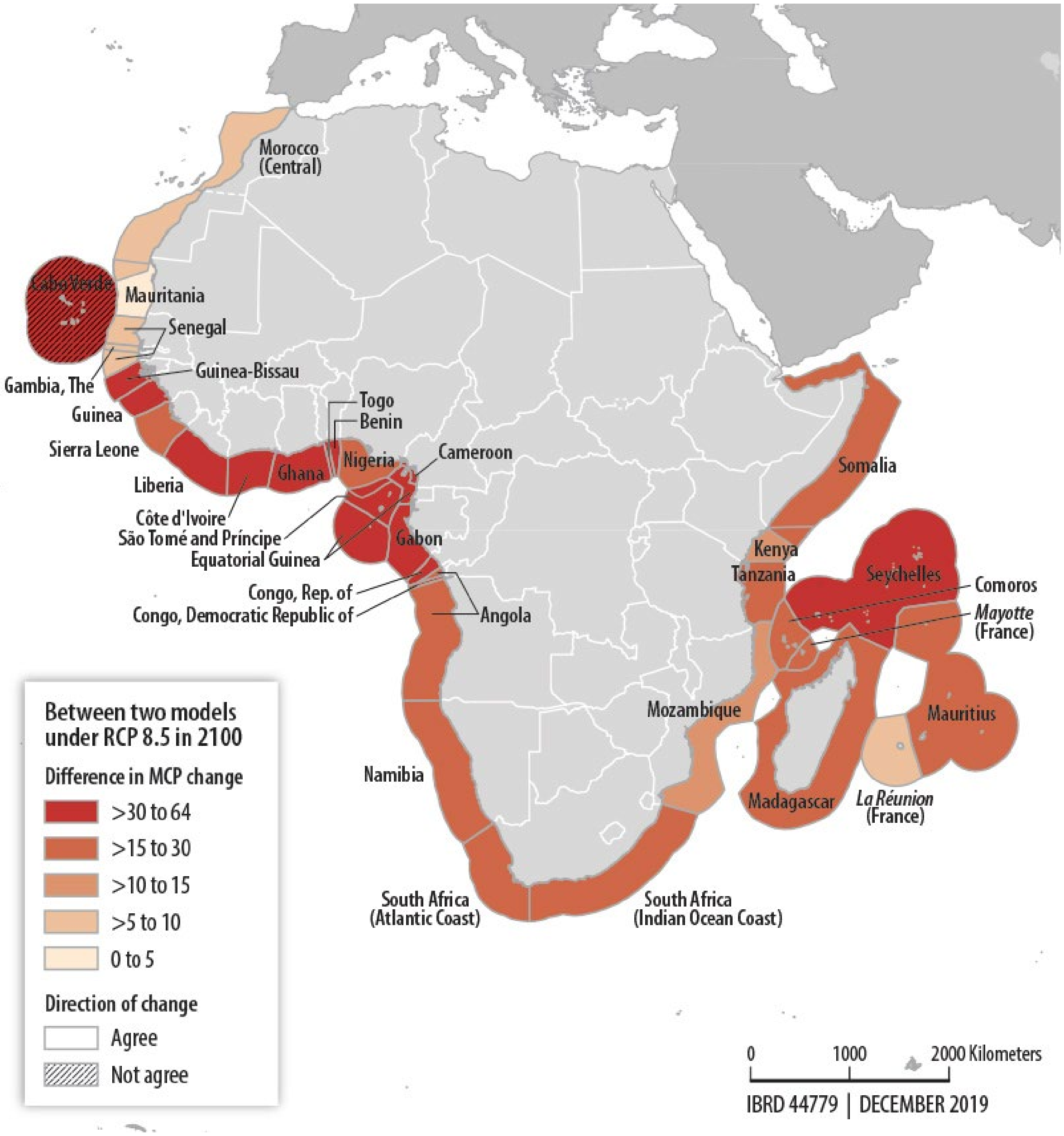


FIGURE 10. Change in MCP (%) Between Representative Concentration Pathways 2.6 and 8.5 Using the Dynamic Bioclimate Envelope Model in (a) 2050 and (b) 2100

a.

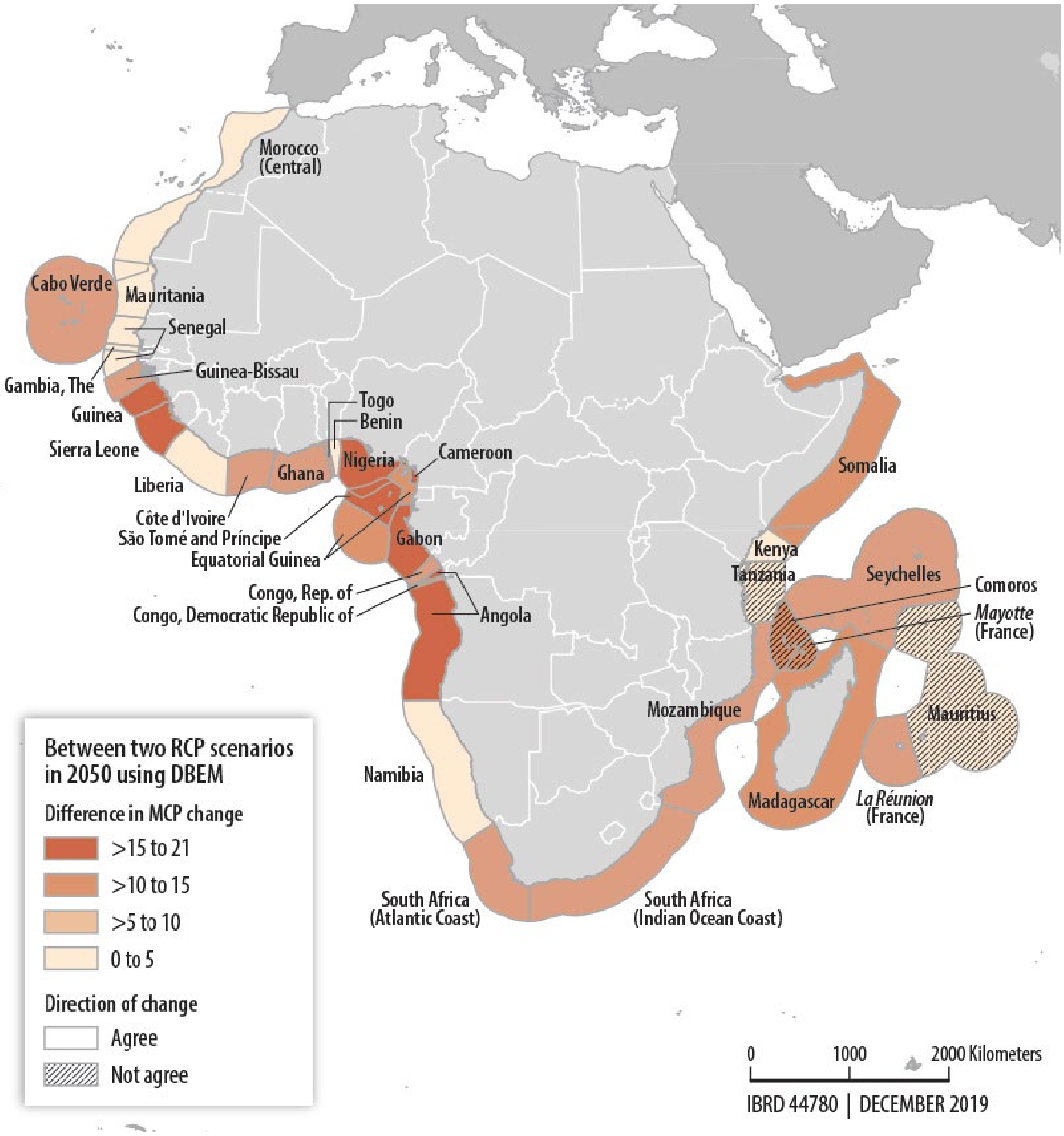


FIGURE 10. Change in MCP (%) Between Representative Concentration Pathways 2.6 and 8.5 Using the Dynamic Bioclimate Envelope Model in (a) 2050 and (b) 2100

b.

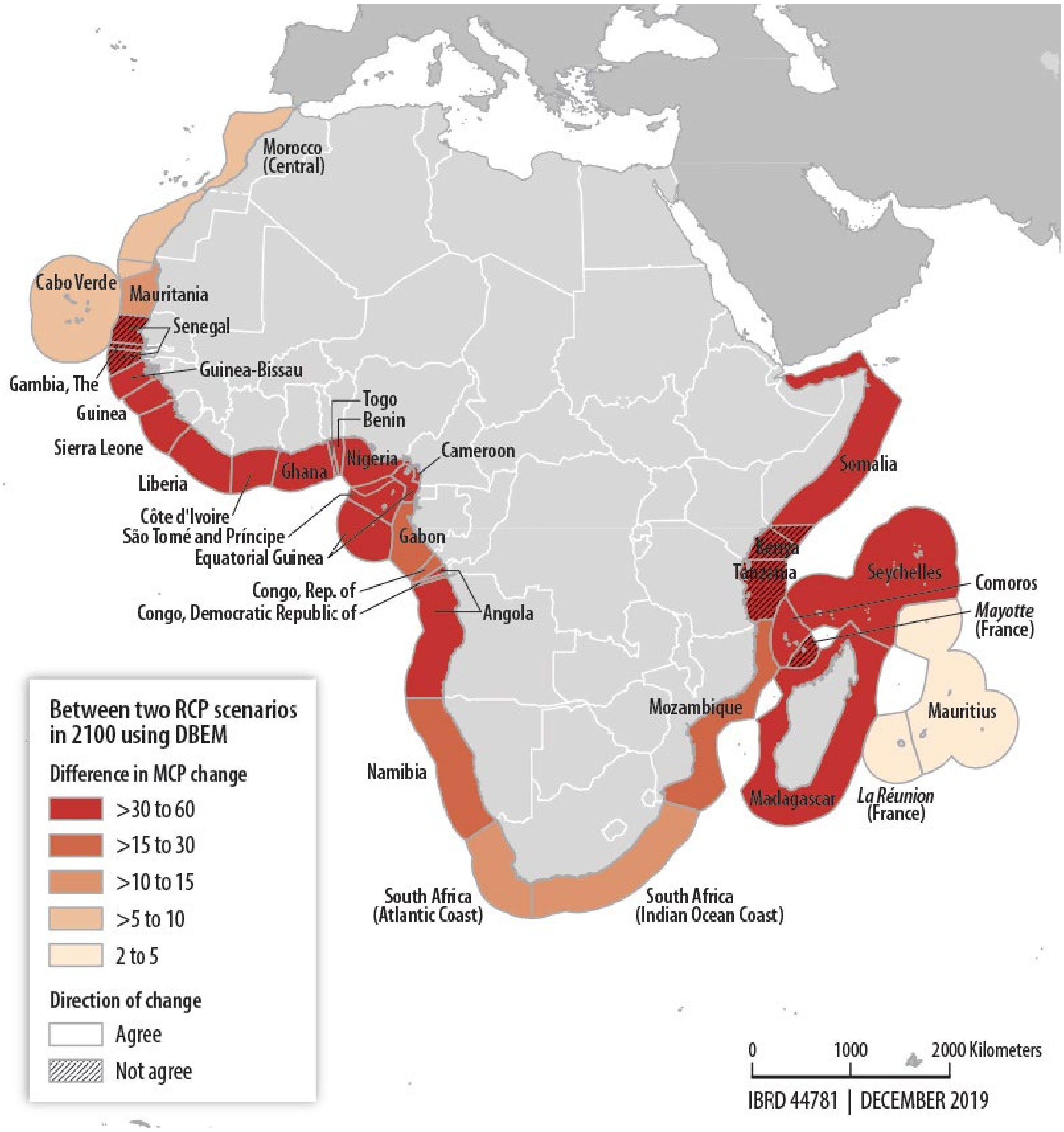


FIGURE 11. Change in MCP (%) Between Representative Concentration Pathways 2.6 and 8.5 Using Multispecies Size Spectrum Ecological Modeling in (a) 2050 and (b) 2100

a.

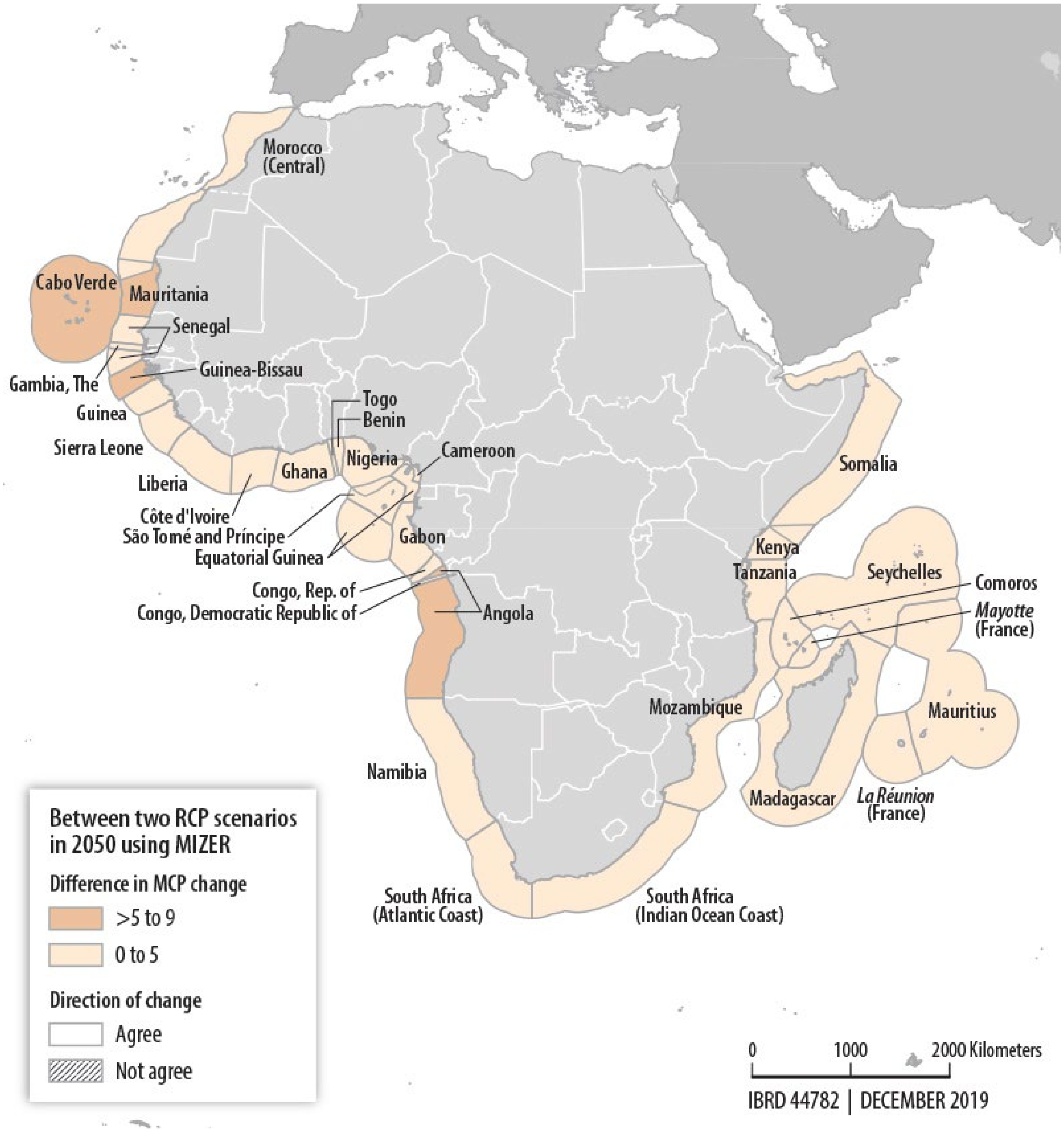


FIGURE 11. Change in MCP (%) Between Representative Concentration Pathways 2.6 and 8.5 Using Multispecies Size Spectrum Ecological Modeling in (a) 2050 and (b) 2100

b.

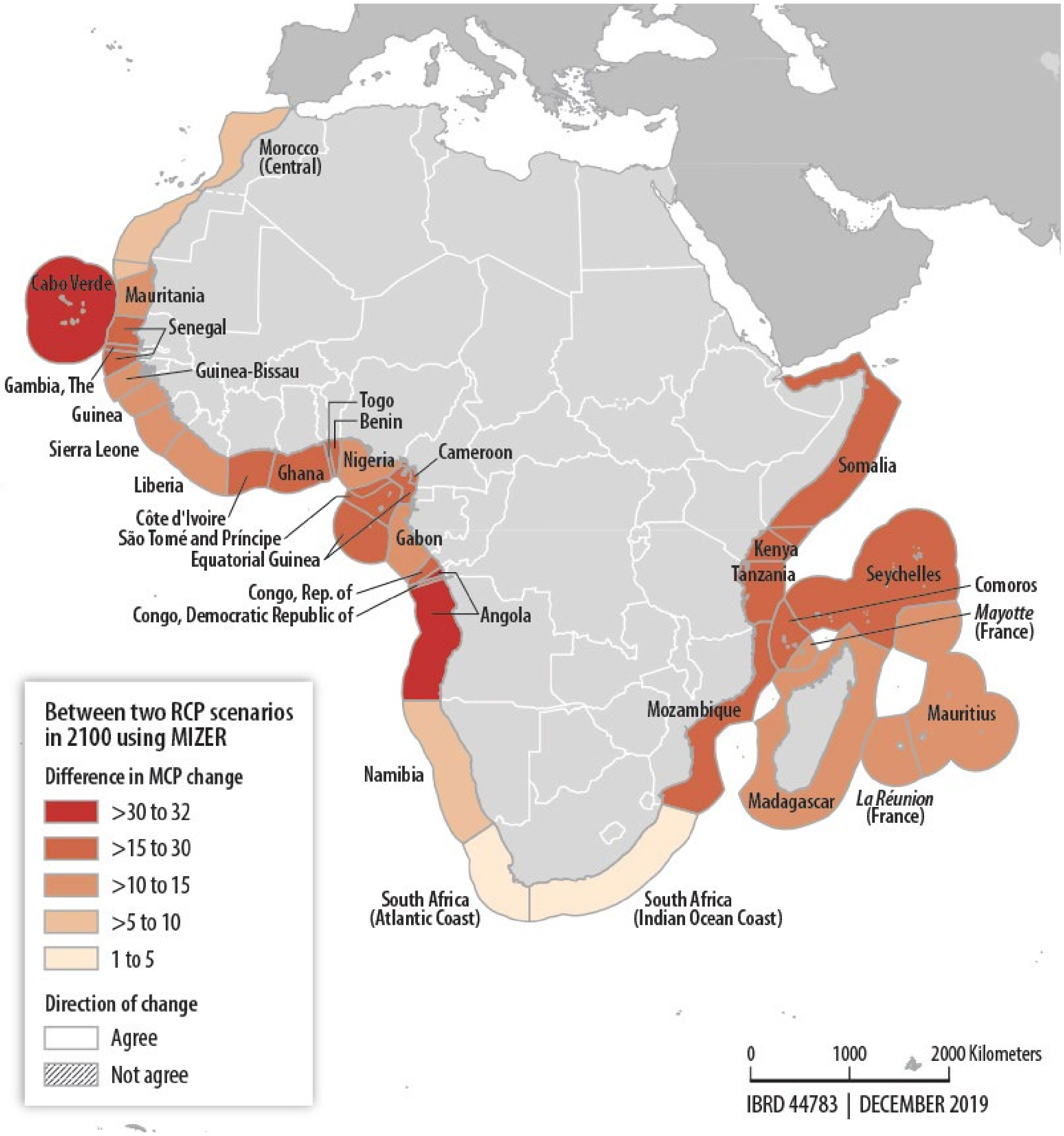


FIGURE 12. Change in MCP (%) Between 2050 and 2100 Using Dynamic Bioclimate Envelope Model Under Representative Concentration Pathways (a) 2.6 and (b) 8.5

a.

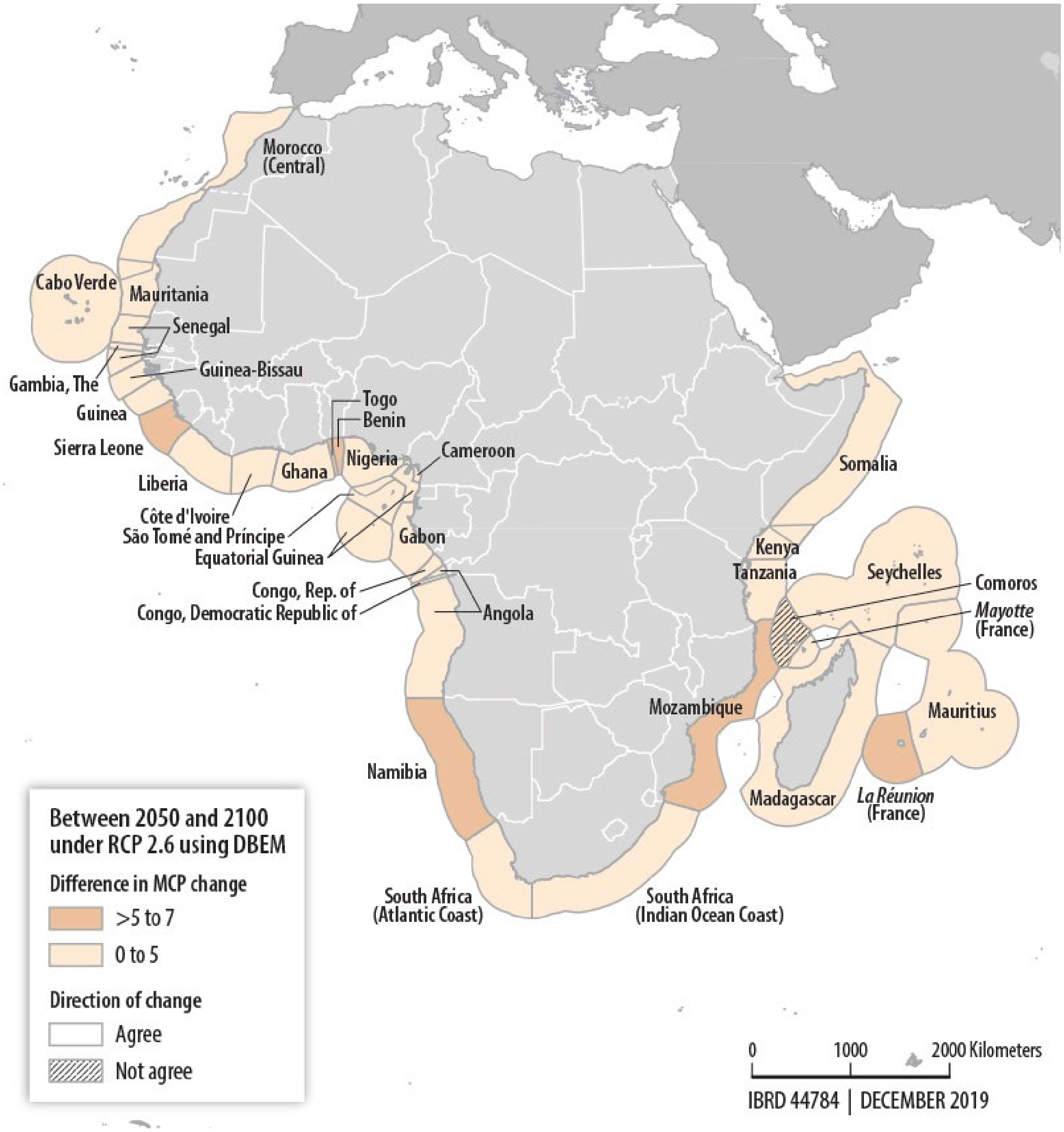


FIGURE 12. Change in MCP (%) Between 2050 and 2100 Using Dynamic Bioclimate Envelope Model Under Representative Concentration Pathways (a) 2.6 and (b) 8.5

b.

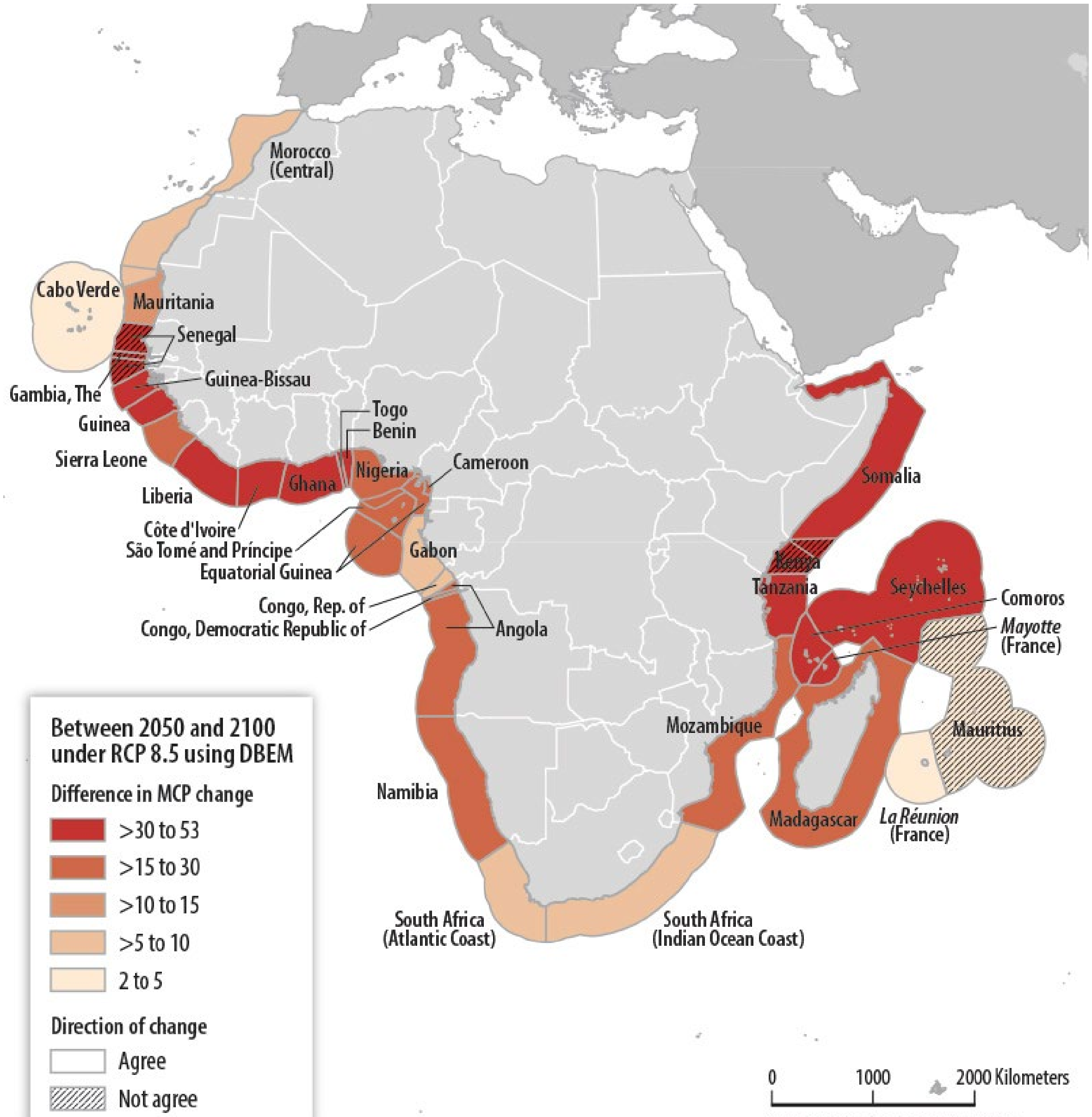


FIGURE 13. Change in MCP (%) Between 2050 and 2100 Using Multispecies Size Spectrum Ecological Modeling Under Representative Concentration Pathways (a) 2.6 and (b) 8.5

a.

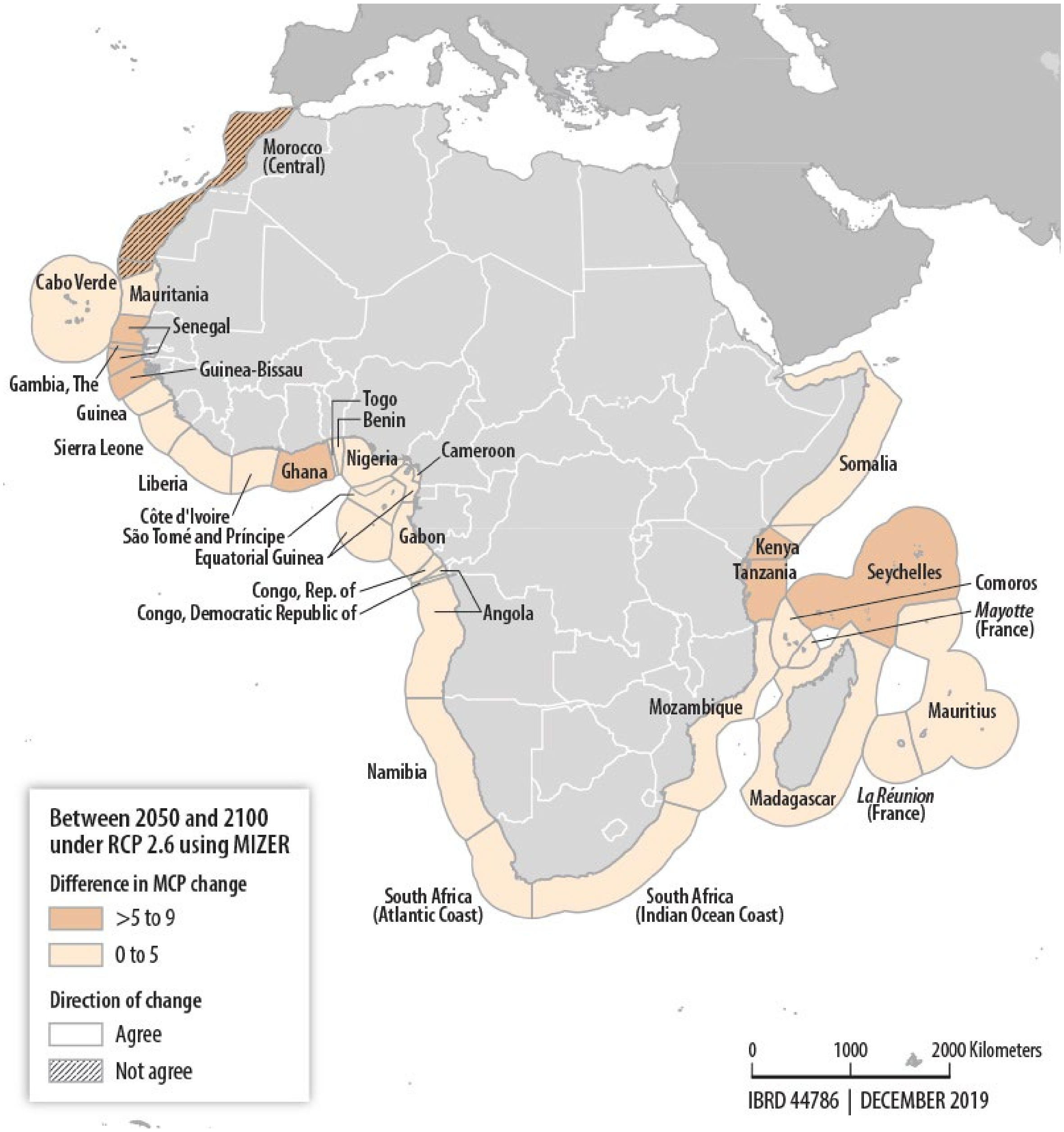


FIGURE 13. Change in MCP (%) Between 2050 and 2100 Using Multispecies Size Spectrum Ecological Modeling Under Representative Concentration Pathways (a) 2.6 and (b) 8.5

b.

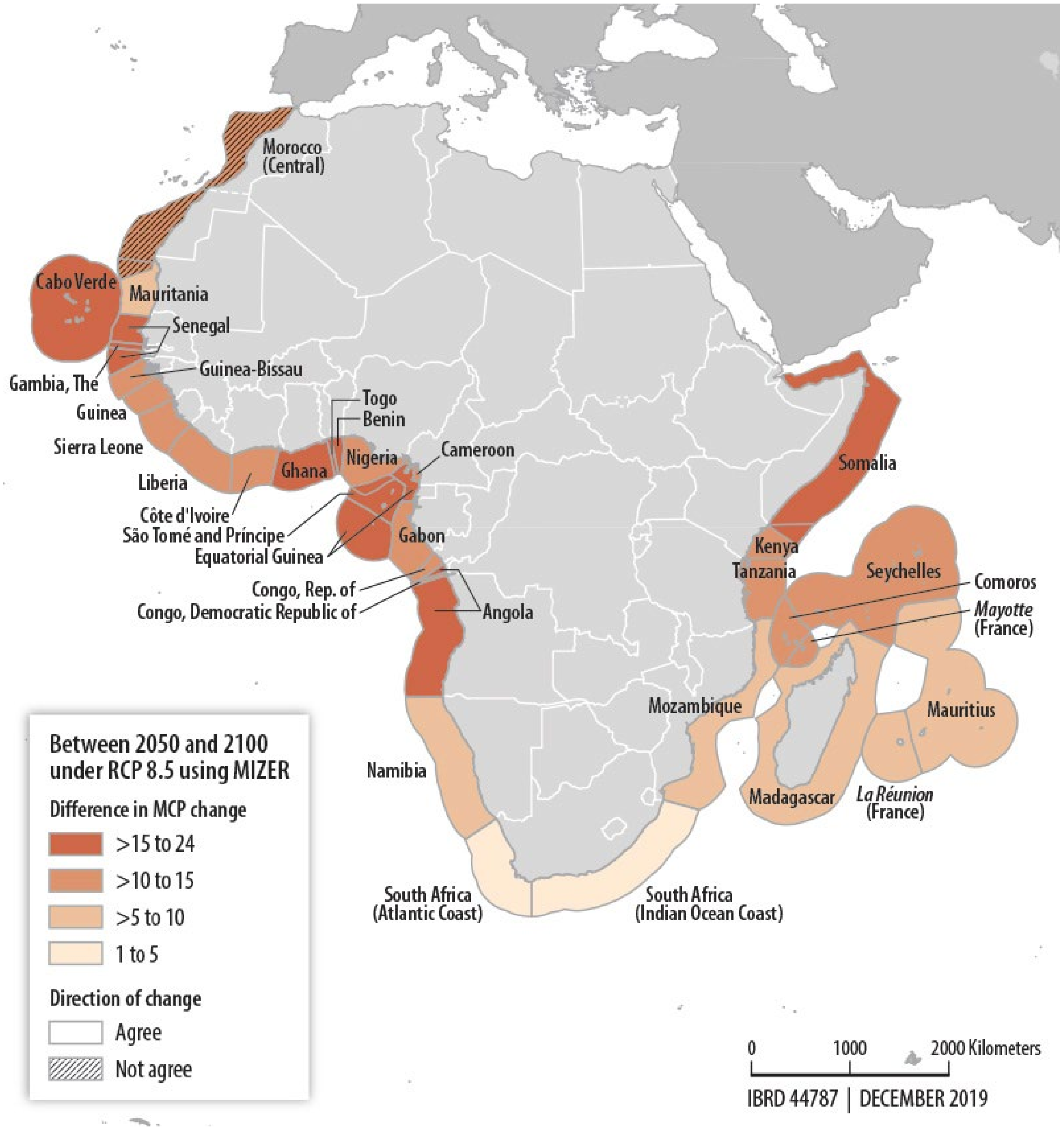


PHOTO CREDIT
Nicole Macheroux-Denault / Shutterstock.com

6. Socioecological Risk of Climate Change

APPROACH

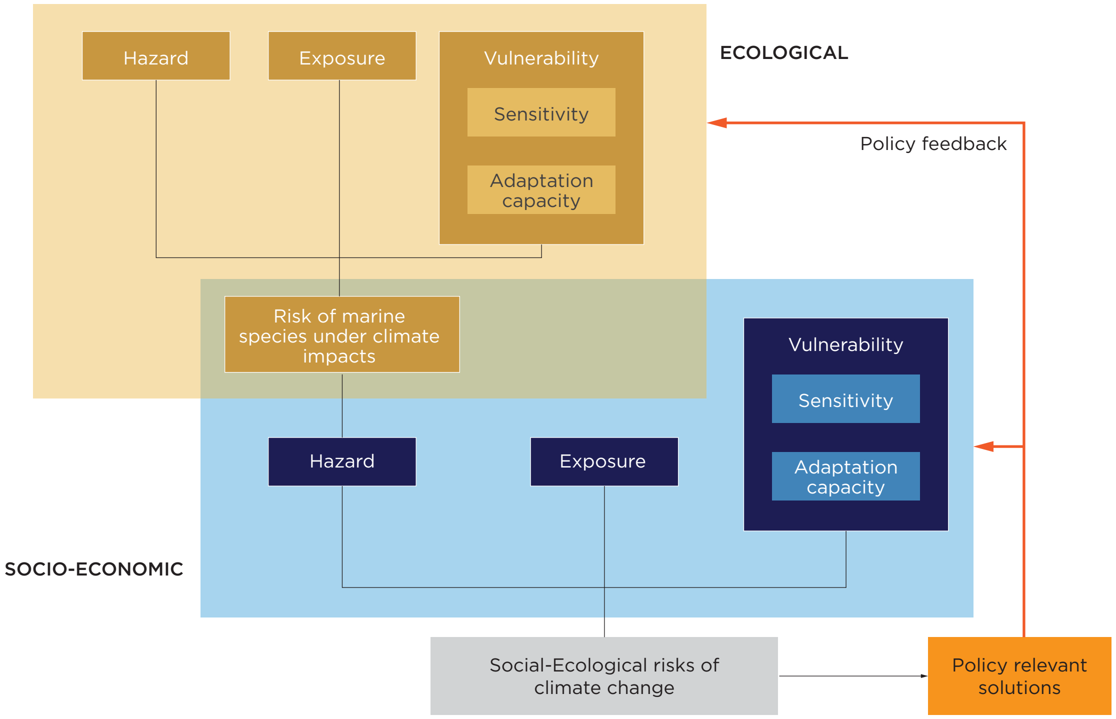
Building on the latest IPCC approach to risk analysis, socioecological risk scores were estimated based on ecological and socioeconomic risk assessments.

The socioecological risk indicator is composed of ecological hazard, exposure, sensitivity, and adaptation capacity components of the national and social aspects of the economy of each African country.

Ecological risk assessment

The approach used in this report synthesizes data on species-specific exposure and hazard from climate change and assesses the risk level for each species based on ecological and biological traits. As with the IPCC approach, ecological risk is measured as a function of hazard, exposure, and vulnerability (which itself is a function of sensitivity minus adaptation capacity). This approach was then used to project the future impact of climate change on marine living resources and fisheries and the resulting ecological hazard to the coastal communities under climate change. The values of these indicators were estimated based on changes in environmental variables, as measured in section IV. In each African country, the exploited marine species were identified, the average ecological risk values to climate

FIGURE 14. Linked socioecological risk framework



change for all marine species in each EEZ were then calculated, and the resulting values were used as the hazard values in this analysis.

Socioecological risk assessment

Socioecological risk assessments have been used in various disciplines to assess the susceptibility of natural or human systems to human activities or natural pressures. According to the IPCC Working Group II Fifth Assessment Report, the socioecological risk of climate change is a function of hazard, exposure, and adaptation capacity (sensitivity minus adaptation capacity). Under this framework, the definitions of the indicators are modified for the context of fisheries and climate change.

- Hazard is the climate-related impact on the marine ecosystem. The risk from climate change for each marine species estimated in the ecological risk assessment is used as a proxy for estimating the hazard to the socioeconomic system.
- Exposure is the presence of people and exploited marine resources that could be adversely affected.
- Sensitivity indicates the intrinsic degree to which the national economies and food security depend on fisheries.
- Adaptation capacity is the ability of a social system in the current context to anticipate, respond to, and adjust to the impacts of climate change and to minimize, cope with, and recover from the consequences of climate change.
- Vulnerability is a function of sensitivity as modified by adaptation capacity.
- Risk measures the potential impacts of climate change on the national and social aspects and economies as a function of hazard, exposure, and vulnerability.

For each of the four components of risk—hazard, exposure, sensitivity, adaptation capacity—a number of indicators were selected in consultation with experts on living marine resources in Africa (table 3). The relative risk score, and the scores of each component, range from 0 to 100. In countries with higher risk scores, climate change poses a greater threat to the national economies of these countries through fisheries, but it is important to remember that these scores are relative and merely compare countries with one another. In other words, if one country has a score of 20 and another a score of 40, it does not mean that the risk is twice as high in the second as in the first but merely that one is more at risk than the other.

TABLE 3. Examples of Indicators for Each of the Risk Components and Risk Assessment

INDICATOR	VARIABLE
Hazard	
Climate-related impacts on marine ecosystem	Ecological risks of climate change for all marine species and their related ecosystem in each exclusive economic zone in small-scale and industrial fisheries sectors
Exposure	
Relative human presence in coastal areas	Percentage of coastal to total population for each African country
People involved in fisheries sector	Number of male and female fishers in small-scale and industrial fisheries sectors
People involved in fisheries-related sector	Number of employees in upstream and downstream activities, including marketing, processing, exports, boat building
Sensitivity	
Employment	Proportion of economically active population in fisheries sector
	Proportion of economically active population employed in upstream and downstream activities such as marketing, processing, exports, boat building
Nutritional dependence	Fish protein as proportion of all animal protein
	Child malnutrition
Economic dependence	Country's dependence on fisheries sector for revenue; fisheries' contribution to gross domestic product
	Fisheries export value as proportion of total exports
	Total fisheries landings
	Poverty rate (number of people and percentage of population below national poverty line)
Coastal protection dependence	Population density in low-elevation zone
	Land area below 5 m elevation
Adaptation capacity	
Health	Life expectancy at birth
Education	Literacy rates (number and percentage of people over age 15 who can read and write, both sexes)
	School enrollment ratios (number and percentage of tertiary-age people enrolled in tertiary education, both sexes)
Governance (sector specific)	Political stability and absence of violence
	Government effectiveness
	Regulatory quality
	Rule of law
	Voice and accountability
	Corruption
Fisheries management	Proportion of territorial sea protected
	Area coverage of effectively managed marine protected areas established in support of fisheries
Size of economy	Gross domestic product
Access to scientific knowledge	Proportion of "good"* fisheries subsidies to total fisheries subsidies
Employment alternatives	Economic diversity
Political action	Climate adaptation planning

* "Good" subsidies is used as a proxy for quantifying access to scientific knowledge, because part of "good" subsidies is often used for scientific research and management purposes.

Integrating the two approaches

The risks to ecological and socioeconomic systems are considered by integrating the two risk assessments (figure 14). In this overall framework that IPCC has provided, the risks to marine species in each country under climate change affect the subsequent ecosystem goods and services that the ocean provides (e.g., fisheries). The results can be used to inform policy-relevant solutions for mitigating and adapting to their impacts. Meanwhile, a policy feedback path loops back to the ecological and socioeconomic assessments.

A detailed description of this methodology is available in Annex 2. Source data are also provided in Annex 3.

RESULTS

Ecological risk indicator

TABLE 4. Ecological Risk Score for Each African Country

Country	Ecological Risk Indicator
Angola	66.307
Benin	80.216
Cameroon	78.947
Cape Verde	80.220
Comoros	69.996
Congo, Dem. Rep.	67.747
Congo, Rep.	66.703
Côte d'Ivoire	78.224
Djibouti	84.273
Equatorial Guinea	79.959
Eritrea	87.304
Gabon	77.648
Gambia, The	80.427
Ghana	76.872
Guinea	79.226
Guinea-Bissau	83.411
Kenya	75.339
Liberia	75.849
Madagascar	75.843
Mauritania	64.471
Mauritius	78.376
Mayotte (France)	77.853
Morocco	53.896
Mozambique	76.737
Namibia	58.916
Nigeria	75.270
Réunion (France)	79.255
São Tomé and Príncipe	76.409
Senegal	70.766
Seychelles	77.320
Sierra Leone	83.969
Somalia	81.796
South Africa	65.469
Tanzania	83.232
Togo	76.582

Socioecological risk indicator

The results reflect the differences in catch value based on how these catches are measured (tables 5 and 6): the FAO data that are collected based on information that the government of each country provides and the reconstructed catches that the Sea Around Us produces, which aim to incorporate unreported catches, including catches from subsistence and recreational fishing sectors; discards; and illegal, unregulated, and unreported fishing, which, by definition, are not part of official national data reported to the FAO.

FIGURE 15. Ecological Risk Score for Each Coastal African Coastal Country

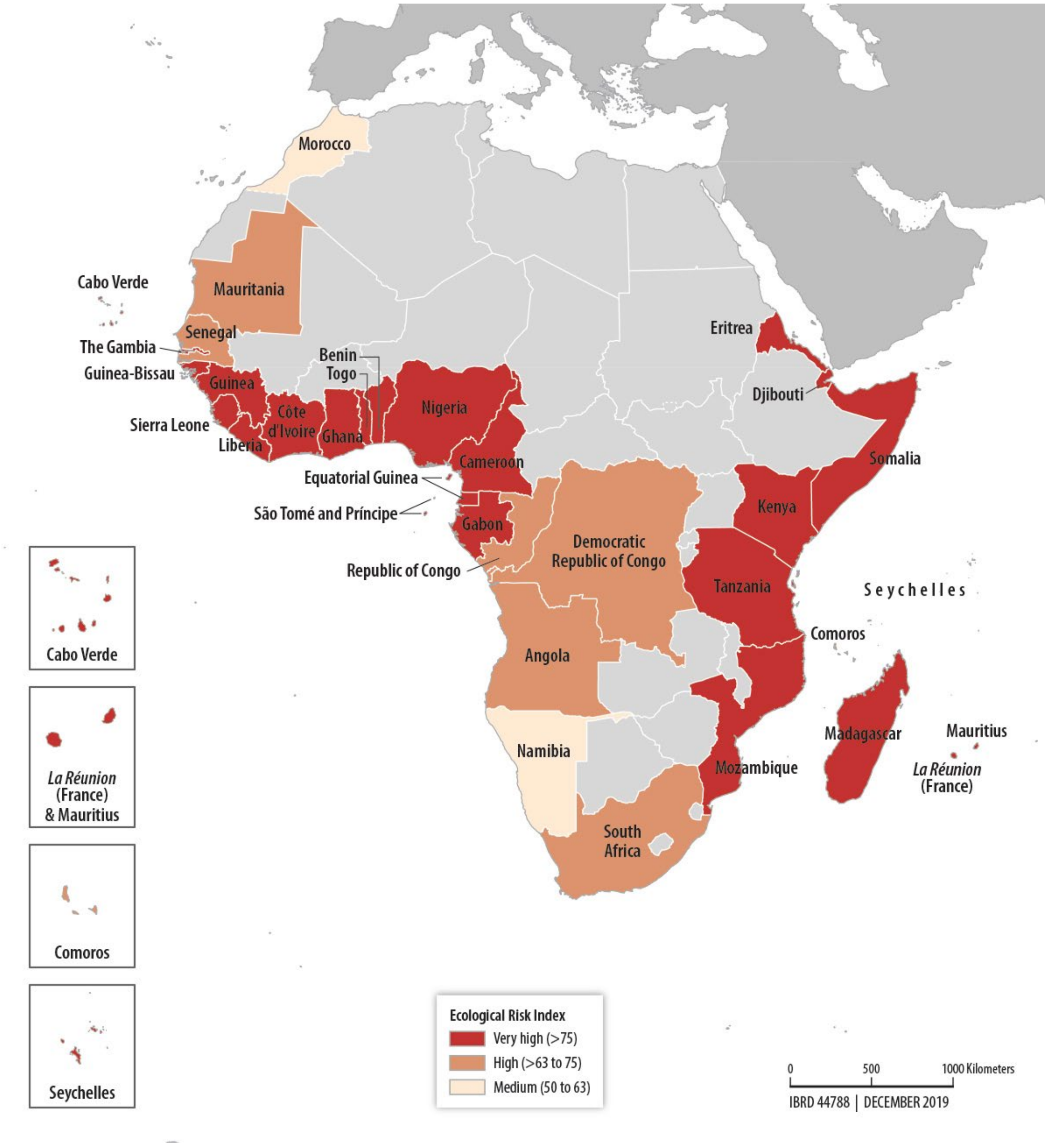


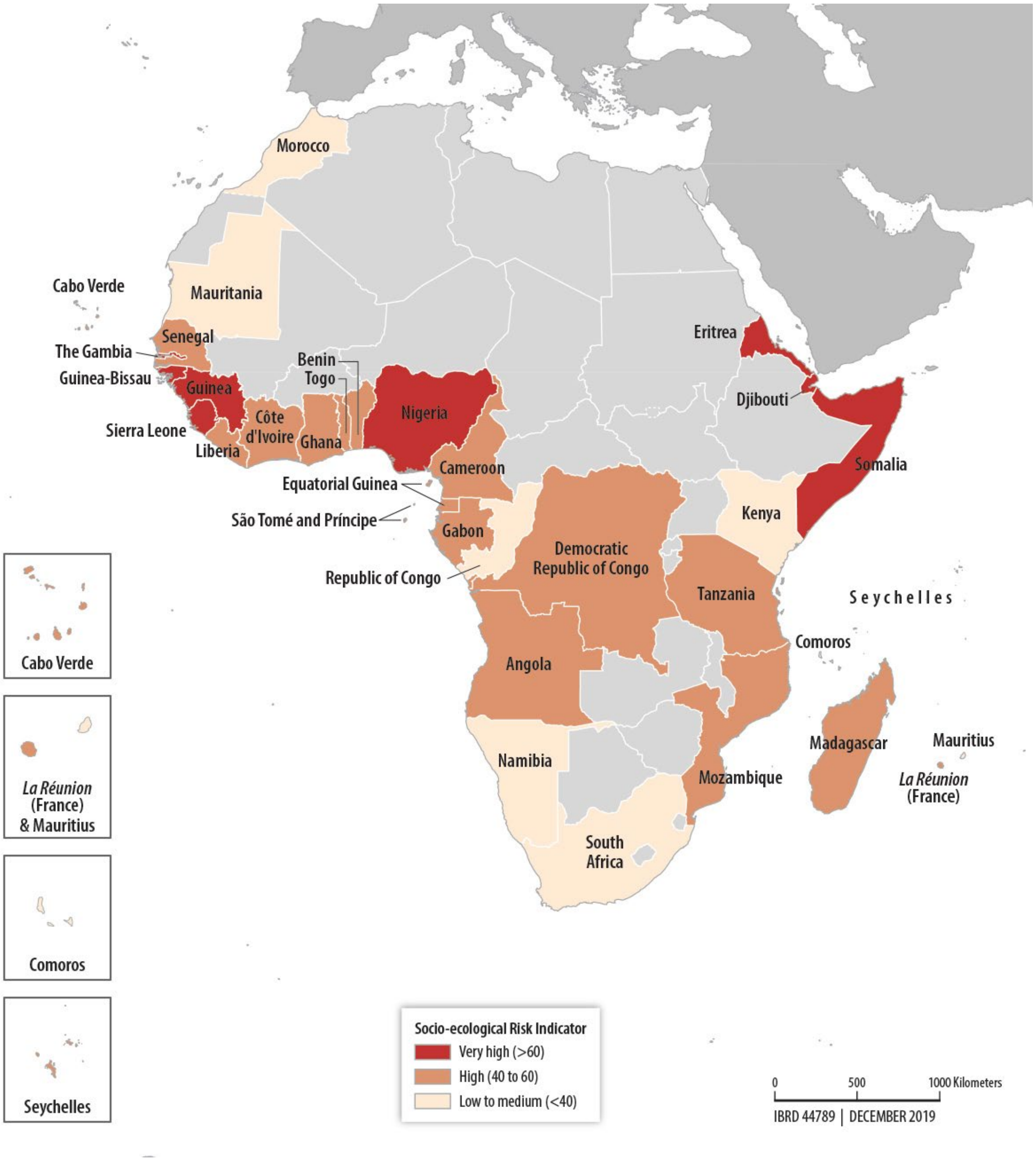
TABLE 5. Individual Component Risk Scores, According to Country (Food and Agriculture Organization–Reported Catches)

Country	Hazard	Adaptation capacity	Exposure	Sensitivity	Vulnerability	Risk
	Score					
Angola	37	20	11	28	41	41
Benin	79	28	6	29	56	55
Cameroon	75	21	6	19	52	52
Cape Verde	79	44	1	32	47	46
Comoros	48	18	2	18	38	38
Congo, Dem. Rep.	41	18	35	30	57	57
Congo, Rep.	38	38	1	18	22	21
Côte d'Ivoire	73	13	6	25	58	58
Djibouti	91	21	0	29	63	62
Equatorial Guinea	78	15	1	13	51	51
Eritrea	100	18	2	34	72	72
Gabon	71	31	1	19	43	42
Gambia, The	79	19	2	52	70	70
Ghana	69	37	14	23	47	47
Guinea	76	17	11	30	63	63
Guinea-Bissau	88	24	10	46	73	73
Kenya	64	32	9	9	38	37
Liberia	66	20	3	26	50	50
Madagascar	66	38	13	31	49	48
Mauritania	32	36	3	38	31	31
Mauritius	73	58	0	20	30	30
Mayotte (France)	72	12	0	1	43	43
Morocco	0	54	15	23	4	3
Mozambique	68	25	18	27	57	57
Namibia	15	63	1	25	1	0
Nigeria	64	29	100	38	100	100
Réunion (France)	76	n.a.	0	0	0	51
São Tomé and Príncipe	67	32	1	35	48	48
Senegal	50	35	12	36	44	44
Seychelles	70	41	0	33	44	44
Sierra Leone	90	10	5	32	71	71
Somalia	84	5	9	21	68	68
South Africa	35	56	12	16	15	15
Tanzania	88	32	12	14	54	54
Togo	68	20	2	25	50	50

TABLE 6. **Individual Component Risk Scores, According to Country (Sea Around Us, Reconstructed Catch Data)**

Country	Hazard	Adaptation capacity	Exposure	Sensitivity	Vulnerability	Risk
	Score					
Angola	37	20	11	28	41	41
Benin	79	28	6	29	56	56
Cameroon	75	21	6	19	52	52
Cape Verde	79	44	1	32	47	47
Comoros	48	18	2	18	38	38
Congo, Dem. Rep.	41	18	35	30	57	57
Congo, Rep.	38	38	1	18	22	22
Côte d’Ivoire	73	13	6	25	58	58
Djibouti	91	21	0	29	63	63
Equatorial Guinea	78	15	1	13	51	51
Eritrea	100	18	2	34	72	72
Gabon	71	31	1	19	43	43
Gambia, The	79	19	2	52	71	71
Ghana	69	37	14	23	48	47
Guinea	76	17	11	31	64	64
Guinea-Bissau	88	24	10	48	74	74
Kenya	64	32	9	9	38	38
Liberia	66	20	3	26	50	50
Madagascar	66	38	13	31	49	49
Mauritania	32	36	3	40	32	32
Mauritius	73	58	0	20	30	30
Mayotte (France)	72	12	0	0	43	42
Morocco	0	54	15	23	4	3
Mozambique	68	25	18	26	57	57
Namibia	15	63	1	24	0	0
Nigeria	64	29	100	37	100	100
Réunion (France)	76	n.a.	0	0	0	51
São Tomé and Príncipe	67	32	1	35	48	48
Senegal	50	35	12	35	44	44
Seychelles	70	41	0	33	44	44
Sierra Leone	90	10	5	32	72	71
Somalia	84	5	9	21	68	68
South Africa	35	56	12	14	15	15
Tanzania	88	32	12	14	54	54
Togo	68	20	2	25	50	50

FIGURE 16. Socioecological Risk Indicator (Normalized Score) for Each Coastal African Country



HOW TO INTERPRET THESE RESULTS

Although the map of socioecological risk identifies pockets of high risk, it represents risks as they are currently assessed assuming ecological impacts occur as modeled in section IV and the level of management remains the same. In that sense, the map is rather static, in that it does not show what could be if, for example, fisheries management were to improve, coastal habitat protection was increased, or destructive activities were curtailed. Perhaps the most striking observation that can be made from the comparison of the maps in figures 15 and 16 is that some of the countries that are the most at risk ecologically are not the most vulnerable from a socioeconomic standpoint, illustrating that, even if the impacts of climate change are as dire as might be expected, governments can increase their adaptation capacity and reduce the overall vulnerability of their fisheries sectors. In addition, lessons from the results of this assessment can be learned at different levels.

First, and although this study focused on 178 of the exploited marine species in the region, the findings regarding the general pattern of climate change impacts on marine biodiversity are likely to be applicable to many fishes and invertebrates in Africa. Because many species are highly adapted or already at the edge of their environmental ranges, their sensitivity to any environmental or habitat perturbation is likely to be high. The likelihood that some local species could be driven to extinction is thus also high, particularly if other contributing factors such as rampant habitat destruction or other anthropogenic impacts are allowed to continue unabated.

Second, when studying individual countries, a country's high ecological risk from the impacts of climate change does not necessarily translate into high socioecological risk, either because the national economy is not particularly dependent on fisheries or because adaptation capacity is high (e.g., if there are alternatives available) or even because better fisheries management measures are in place. This last point is well illustrated in the case of Namibia, where the ecological risk is relatively low, and the sector benefits from particularly sustainable fisheries practices, which together contribute to the lowest socioecological risk for the continent. There are many points of entry where governments and stakeholders can take action and change what would otherwise have resulted from intense ecological change. It is the ultimate purpose of this report to identify the pathways through which governments can identify action and investment projects through which they can mitigate these ecological impacts and ultimately increase the resilience of their fisheries sectors.

Third, an important distinction needs to be made between ecological risks, which to a large extent are beyond the control of African coastal states (and even under the most optimistic IPCC scenario, these risks are still alarmingly high), and the socioeconomic factors over which they can, and should, have direct control. Socioeconomic exposure, sensitivity, and adaptation capacity can all be influenced through policy interventions and are the only elements over which coastal states have much control.

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7. Conclusion: A Game Changer for Marine Fisheries Management in Africa

Despite the differences between scenarios, between models, and over the different timelines, the findings of this modeling exercise are sufficiently dire to raise the alarm for decision makers, who now know enough to take preventive and adaptive measures to address the risks, both ecological and socioecological, facing their fisheries in the face of climate change. The major lessons from these findings can be summed up as follows.

a. Even under the best-case scenarios, the models clearly show that the impact of climate change on fisheries will be serious, although not evenly felt, and that stressed fisheries resources such as overfished stocks are at added risk from this additional impact. This is crucial because fisheries are often mismanaged to the point where uncontrolled levels of fishing prevail and certain stocks collapse, which then calls for moratoria or other measures designed to allow stocks to recover. In the face of anticipated reductions in MCP, these corrective measures may need to be more severe, and moratoria will likely need to be longer—and thus economically more onerous—and in some cases might not be adequate to allow affected stocks to recover. In other words, the boom and bust overfishing cycle may no longer be one from which fish stocks can recover when combined with the additional impacts of climate change.

b. There are thus clear parallels between measures designed to strengthen the adaptation capacity of fishing communities to climate change and broader measures targeted at fostering fisheries governance reform. The same measures may be justified by the need to reduce overcapacity or address problems that stem from open access and to the need to adapt to climate change. The importance lies not so much in knowing in which category these conservation and management measures fall as in knowing that they will be undertaken.

c. Likewise, when examining the different components of risk — hazard, exposure, sensitivity, and adaptation capacity — it is apparent that some of their constituent parts may fall beyond the narrow scope of fisheries management. For instance, strengthening the adaptation capacity of a community may require improvements in areas such as education, health, and alternative livelihood development, which would not usually fall within the purview of a ministry in charge of fisheries. Preparing fisheries to withstand the impacts of climate change will thus likely require a multisectoral and coordinated approach. Besides, this multisectoral approach to fisheries management is a no-regret investment because it has positive outcomes with or without climate change.

d. The African countries on which this report focuses are likely to suffer disproportionately more from the impacts of climate change than other countries that may have contributed to a much higher degree to the causes of climate change (e.g., in the case of species that will migrate away from the equator toward the poles in response to increases in sea temperatures), although this does not mean that African countries can focus solely on climate change adaptation. Development of national fishing fleets in Africa is expected to add to climate change, making the situation even more dire. The response to climate change should thus incorporate mitigation as well as adaptation.

e. As illustrated in the brief overview of the ecological patterns of climate change on marine fisheries, impacts will be felt directly on the species that fisheries traditionally target and on the marine and coastal ecosystems on which these species depend. This in turn calls for adaptation measures targeted not only at the stocks, including through reductions in the level of fishing and capacity, but also at the protection of these ecosystems, which too often are already subject to excessive anthropogenic impacts (e.g., coastal development, sand mining, destruction of coral reefs, deforestation of mangroves). Again, it is likely that these adaptation measures will fall outside the traditional scope of fisheries management and require a broader multisectoral approach.

Beyond these general observations about what the next steps should be, each country will need to determine its path to adaptation, its blueprint for preparing national fisheries for the impacts of climate change, at the national level. This will require a detailed review of the individual components of each contributing factor.

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Annex 1. Volume and Value Of Catches – Food and Agriculture Organization Data and Reconstructed Catches

Reconstructed catch data are based on official catch estimates and corrected to add estimated catches from illegal, unregulated, and unreported fishing and discards at sea, usually of bycatch.

Country	Landings (tons) according to Food and Agriculture Organization	Landings (tons) according to Sea Around Us	Landed value in 2010 real USD value according to Sea Around Us
Angola	401,057	679,098	1,373,871,366
Benin	18,599	75,837	97,486,370
Cameroon	167,365	156,150	154,722,458
Cape Verde	28,887	23,377	56,965,480
Comoros	26,091	23,185	35,388,362
Congo, Dem. Rep.	4,528	25,472	48,959,732
Congo, Rep.	39,031	101,370	150,675,689
Côte d'Ivoire	61,747	172,319	213,400,383
Djibouti	2,011	3,618	7,601,240
Equatorial Guinea	7,316	37,975	97,381,769
Eritrea	4,098	9,437	14,664,823
Gabon	23,902	184,107	259,373,132
Gambia, The	43,716	210,696	250,113,495
Ghana	238,993	420,725	496,843,307
Guinea	109,282	867,539	1,123,880,584
Guinea-Bissau	6,548	710,894	1,117,672,872
Kenya	10,179	18,310	48,357,359
Liberia	12,000	93,980	115,998,627
Madagascar	89,740	163,117	338,985,723
Mauritania	416,570	1,754,744	1,826,249,782
Mauritius	11,674	20,712	62,469,965
Mayotte (France)	15,254	5,739	17,913,435
Morocco	1,244,835	2,989,906	4,020,365,748
Mozambique	160,809	160,413	218,804,921
Namibia	468,405	649,241	654,710,602

Country	Landings (tons) according to Food and Agriculture Organization	Landings (tons) according to Sea Around Us	Landed value in 2010 real USD value according to Sea Around Us
Nigeria	367,954	476,755	1,176,551,504
Réunion (France)	2,785	3,572	17,093,491
São Tomé and Príncipe	9,233	14,098	27,151,556
Senegal	420,300	677,822	1,044,893,930
Seychelles	87,594	65,189	116,703,162
Sierra Leone	200,476	325,388	260,003,279
Somalia	29,800	149,624	258,776,435
South Africa	570,550	636,853	692,175,636
Tanzania	93,704	130,967	237,429,721
Togo	17,609	61,901	70,289,137
Total	**5,412,642**	**12,100,128**	**16,703,925,076**

Annex 2. Description of Models And Methodologies

DESCRIPTION OF MODELS USED FOR PROJECTED ECOLOGICAL IMPACTS OF CLIMATE CHANGE

Dynamic Bioclimate Envelope Model (DBEM) description

The DBEM is a dynamic process-based species distribution model that simulates changes in distribution, abundance, and catches of 178 exploited marine fishes and invertebrates in African exclusive economic zones (EEZs) under climate-change scenarios. These species account for 25 percent of total fisheries catches from the EEZs in Africa in the 2000s. Ocean variables projected from the Earth system models (ESMs) that drive the simulations in the DBEM include seawater temperature (surface and bottom), oxygen concentration (surface and bottom), hydrogen ion concentration (surface and bottom), net primary production (depth integrated), salinity (surface and bottom), and surface advection.

All model data have been re-gridded onto a 0.5° latitude x 0.5° longitude grid using a bilinear interpolation method. The current distributions of the species, representing the average pattern of relative abundance in recent decades (1970–2000), were produced using an algorithm that predicts the relative abundance of a species on a 0.5° latitude x 0.5° longitude grid. The distributions were further refined by assigning habitat preferences to each species, such as affinity to shelf (inner and outer), estuaries, and coral reef habitats. An index of habitat suitability for each species in each spatial cell is derived from temperature (bottom and surface temperature for demersal and pelagic species, respectively), bathymetry, specific habitats, salinity, and sea ice, with 30-year averages of outputs from 1971 to 2000 from ESMs.

The DBEM estimated the temperature-preference profile of each species by overlaying the estimated species distribution with annual seawater temperature and calculated the area-corrected distribution of relative abundance across temperature for each year from 1971 to 2000, subsequently averaging annual temperature-preference profiles. The estimated temperature-preference profile was used to predict the thermal physiological performance of a species (aerobic scope) in each area. Population carrying capacity in each spatial cell is a function of the unfished biomass of the population, habitat suitability, and net primary production. It was assumed that the average of the top-10 annual catches was roughly equal to the maximum sustainable yield of the species.

The model simulated changes in relative abundance and biomass of a species based on changes in population carrying capacity, intrinsic population growth, and the advection-diffusion of the adults and larvae of the population driven by ocean conditions projected from the ESMs. The DBEM calculates a characteristic weight representing the average mass of the population in a cell. The model simulated how changes in temperature and oxygen content would affect growth and body size of the individuals using a sub-model derived from a generalized von Bertalanffy growth function. Movement and dispersal of adults and larvae were modeled through advection-diffusion-reaction equation for larvae and adult stages. Its predicted pelagic larval duration partly determines Larval movement. Population growth was represented using a logistic function.

Maximum catch potential (MCP) from each population was predicted by applying a fishing mortality rate at the level required to achieve maximum sustainable yield. For each simulation, changes in total annual MCP by 2050 (2046–2055) and 2095 (2091–2000) from 2000 (1996–2005) under Representative Concentration Pathways 2.6 and 8.5 in each EEZ of the world's oceans were calculated. The ensemble average across MCP projections from the three ESMs is presented.

Size-based model description

The size-based model uses the same parametrization unless stated otherwise below. It distinguishes fish according to their size but does not consider individual species. The ESM outputs that drive the size spectrum model are monthly sea surface temperatures and surface concentrations of different plankton functional types. In addition, the annual mean vertical distribution of total plankton biomass is used to infer the depth distribution of fish. All inputs were spatially averaged over each EEZ, and the fish model was subsequently run per EEZ. For the historical simulation (1850–2005), the model was spun up for 50 years from low fish biomass using climatological temperatures and plankton concentrations. For the projections (2006–2100), the model was initialized with the final state of the historical simulation.

Trophic interactions are represented explicitly; fish feed according to size-based rules, preferring prey a hundredth of their weight. Accordingly, the smallest fish feed on large plankton (e.g., diatoms and mesozooplankton), and larger fish feed on small fish. In the latter case, predation moves biomass from smaller weight classes (prey) to larger weight classes (predator). A search rate that depends on predator size mediates prey discovery. Ingestion and assimilation of food leads to growth of individual fish, which is represented by moving part of the fish in a size class to the next class. Mortality is due to predation and intrinsic size-dependent mortality, as well as fishing, represented by mortality of 0.2 per year for all fish larger than 1.25 g. Recruitment is not modeled explicitly. Instead, the abundance of the first size class of fish (1 mg) is derived by extending the plankton size spectrum; this assumes a continuous size spectrum from plankton to fish. Physiological rates increase with temperature according to an Arrhenius relationship with activation energy of 0.63 eV. This also affects trophic interactions.

The plankton community is represented with 10 size classes per tenfold increase in weight, which requires a total of 70 (Institut Pierre Simon Laplace) to 120 (Geophysical Fluid Dynamic Laboratory) size classes. For each plankton functional type in the ESM, we distribute the biomass of the plankton type over its specific weight range such that each interval of the same width (in log space) contains equal biomass. The authors of the ESMs (Institut Pierre Simon Laplace) provided weight ranges for each plankton type, or the weight ranges were based on the nominal size ranges used in other models for the same plankton functional type (Geophysical Fluid Dynamic Laboratory). The final plankton size spectrum is constructed by combining the size spectrum contributions of all plankton functional types. The fish model is driven with monthly mean surface concentrations of each plankton functional type, which are converted to concentrations of each plankton size class. The fish model subsequently simulates size spectra of the fish community in the surface ocean. The predicted fish concentrations at the surface are converted to depth-integrated biomass by taking the vertical distribution of fish proportional to the annual mean vertical distribution of plankton.

ECOLOGICAL AND SOCIOECONOMIC RISK ASSESSMENTS

Description of ecological risk assessment framework

A fuzzy logic expert system was used to assess the level of exposure to hazard, sensitivity, adaptation capacity, and the resulting overall risk of marine fish and invertebrates to climate change and ocean acidification in African waters (Jones and Cheung 2018). Such a system allows a subject to belong to more than one set simultaneously, with a fuzzy membership function defining the extent of membership in each instead of a subject being allocated to only one category. Therefore, fuzzy logic allows the uncertainty surrounding our knowledge of fish biological and ecological characteristics, as well as their contribution to vulnerability, to be taken into consideration. Because the spatial distribution of each species is taken into account, the vulnerability of the related ecosystem is also assessed. In the ecological context, exposure is defined as the extent to which given species will be subject to climate hazards, as measured in projected change in physical environment. Exposure is estimated based on current species distribution ranges obtained from the Sea Around Us (www.seaaroundus.org).

Projected changes in environmental parameters were used to represent climate hazard. Annual average values of surface and bottom sea water temperature (°C), oxygen concentration (mL/L), salinity, net primary production (mgC/km^2 per year), surface advection (zonal and meridional vectors, m/s), and percentage of sea ice coverage were determined from the outputs of the Geophysical Fluid Dynamics Laboratory Earth System Model (Dunne et al. 2013), the Institut Pierre Simon Laplace Model (Dufresne et al. 2013), and the Max Planck Institute for Meteorology Model (Giorgetta et al. 2013). Each environmental output was re-gridded onto a regular grid of 0.5° using the nearest neighbor method, and values in some coastal cells were extrapolated using bilinear extrapolation.

The sensitivity of marine species to climate change is based on a series of ecological and biological traits, which are identified based on published literature (table 2.1). The sensitivity and adaptation capacity indexes are estimated using an expert system based on heuristic rules. The sensitivity and adaptation capacity combine to indicate the vulnerability of each species. Finally, the risk index of the impacts of climate on each marine fish and invertebrate species is calculated for each 0.5° x 0.5° spatial grid cell based on the combination of hazard exposure in each cell where each species may occur and the vulnerability index of that species in each cell.

TABLE 2.1. Variables and Data Used in Ecological Assessment

Indicator	Variable or data	Unit
Hazard	Mean change in environmental variable between baseline and 2050 divided by standard deviation over baseline period	—
Exposure	Current species distribution range	—
Sensitivity	Temperature tolerance	°C
	Maximum body length	cm
	Maximum body length and high coral reef association	—
	Taxonomic group (ocean acidification)	—
Adaptation capacity	Latitudinal breadth	°
	Depth range	m
	Fecundity	Eggs or pups per year
	Habitat specificity	—

Description of socioecological risk assessment framework

In this study, the risk from climate change to each marine species estimated in the ecological risk assessment was used as a proxy to estimate hazard to the socioeconomic system. In each country, exploited marine species are identified based on the Sea Around Us catch database, distinguishing industrial from small-scale fisheries (or shares of a given species that industrial and small-scale fishers harvest). Then, average ecological risk values to climate change for all marine species in each EEZ are calculated, and the resulting values are used as the hazard values in the socioecological analysis. A number of indicators of living marine resources in Africa were selected in consultation with experts for each of the four dimensions: hazard, exposure, sensitivity, and adaptation capacity (table 3). National data on most of these indicators are available from various global databases and the national statistical departments of individual governments. Regional and local data were obtained from communications with local research institutions and experts.

Exposure was measured as the presence of people and exploited marine resources that the ecological hazard could adversely affect. Sensitivity usually refers to the intrinsic degree to which national economies depend on fisheries and are therefore sensitive to changes in the sector. Adaptation capacity is the ability of the social system to anticipate, respond to, and adjust to changes from climate stresses and to minimize, cope with, and recover from the consequences of climate change. Adaptation capacity thus includes elements of social capital, human capital, and the appropriateness and effectiveness of governance structures.

Using the same framework, a number of recent studies have highlighted the vulnerability of national economies to changes in their fisheries from climate change. Knowing their risk scores will enable societies and their national economies to manage immediate changes and trade-offs imposed by climate change. They will also be able to develop and institute appropriate climate change adaptation measures and seize opportunities that may arise from climate change.

Calculation of risk scores

The risk of each country to impacts on its fisheries due to climate change is calculated by taking the average of the standardized indexes for each dimension of risk. Although there are many ways of combining the components, we made no a priori assumptions about the importance of each dimension (or indicator within each dimension) in the overall function R = f (H, E, S, AC) and took the average because of the lack of a clear understanding of the interaction among these constituent components. In this way, each of the indicators is viewed as making an equal contribution (balanced weight) to a country's overall vulnerability. A previous study showed that vulnerability is resistant to change in the weightings of its components and different methods of calculations (averaging or multiplying) (Allison et al. 2009; Cinner et al. 2012)).

A country with a high risk score is assumed to have high hazard to climate change, significant exposure to climate change, a significant level of fisheries' contributions to its national economy and food security (sensitivity), or limited ability to respond and adapt to the risks that climate change poses.

Notes on data used to derive socioeconomic risk

Number of people involved in fisheries and fisheries-related sectors is missing for Réunion (France), Djibouti, and Mayotte (France).

Number of people living in areas of elevation less than 5 m and land area of elevation less than 5 m is missing for Cabo Verde.

Number of fishers, proportion of economically active population in fishery sector, fish protein as proportion of all animal protein consumed, proportion of children under five years who are malnourished (underweight), number of people living in areas of elevation less than 5 m, and land area of elevation less than 5 m are missing for Mayotte (France) and Réunion (France).

Proportion of territorial sea protected, cost of climate change adaptation, and governance indicator are missing for Cabo Verde.

Life expectancy, adult literacy rates, school enrollment rate, governance indicator, proportion of 'good' subsidies, proportion of territorial sea protected, and cost of climate change adaptation are missing for Mayotte (France).

Employment opportunity in other sectors, life expectancy, adult literacy rates, school enrollment rate, governance indicator, proportion of 'good' subsidies, proportion of territorial sea protected, and cost of climate change adaptation are missing for Réunion (France).

Annex 3. Definitions and Sources for Socioecological Indicators

DEFINITION OF SOCIOECOLOGICAL INDICATORS

Indicator	Definition	Composite index	Variable
Relative human presence in coastal areas	Coastal population; total population of each country		Percentage of coastal to total population for each sub-Saharan African country
People involved in fisheries sector		Number of male and female fishers in small-scale and industrial fisheries sectors	Number of people
People involved in fisheries-related sector		Number of employees in upstream and downstream activities, including marketing, processing, exports, boat building	Number of people
Employment	Importance of marine fisheries sector to local livelihoods	Number of fishers in marine fisheries sector	Number of fishers
		Number of fishers relative to other sectors	Proportion of economically active population in fisheries sector
Nutritional dependence	Importance of fish as source of nutrition and whether nutrition that fisheries provide is sufficient to support the health of the population	Country's dependence on fish as source of protein	Fish protein as proportion of all animal protein consumed
		Child malnutrition	Proportion of children under five years who are malnourished (underweight)
Economic dependence	Dependence of country's economy on its fisheries sector	Country's dependence on its fisheries sector for revenue	Landed values as proportion of total gross domestic product
		Fisheries export value	Value of fisheries exports as proportion of total exports
		Total fisheries landings	Catch (tons)
		Poverty rate	Number and percentage of people below national poverty line
Coastal protection	Importance of marine ecosystem services to minimize risks of climate change	Country's current and future dependence on marine systems for coastal protection	Number and percentage of people living in areas of elevation <5 m
Health	Average number of years that a person can expect to live	Life expectancy	Life expectancy at birth

Indicator	Definition	Composite index	Variable
Education	Education level	Adult literacy rates	Number and percentage of people over age 15 that can read and write, both sexes
		School enrollment ratios	Number and percentage of tertiary-age people enrolled in tertiary education, both sexes
Governance	Public institutions' ability to conduct public affairs, manage public resources, implement decisions, ensure rule of law, be accountable, and address corruption, which are generally seen as essential elements of a framework within which economies can prosper	Political stability and absence of violence	Perceptions of likelihood of political instability and politically motivated violence (−2.5 to +2.5)
		Government effectiveness	Perceptions of quality of public services, civil service and its independence from political pressures, and policy formulation and implementation and credibility of government's commitment to such policies (−2.5 to +2.5)
		Regulatory quality	Perceptions of ability of government to formulate and implement sound policies that permit private sector development (−2.5 to +2.5)
		Rule of law	Perceptions of extent to which agents have confidence in and abide by rules of society, quality of contract enforcement, property rights, police, and courts (−2.5 to +2.5)
		Voice and accountability	Extent to which country's citizens can participate in selecting their government, freedom of expression, freedom of association, and free media (−2.5 to +2.5)
		Control of corruption	Perception of extent to which public power is exercised for private gain, including petty and grand corruption and 'capture' of the state by elites and private interests (−2.5 to +2.5)
Fisheries management	Resources allocated by government to manage its fisheries sustainably	Marine protected areas	Proportion of territorial sea protected
Access to scientific knowledge		Proportion of 'good' subsidies	Value paid in USD
Political action	Climate adaptation planning		Cost of adaptation
Employment alternatives		Employment opportunities in other sectors	

SOURCES OF VARIABLES

1. EMPLOYMENT IN INDUSTRY, MALE

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank (2018)
https://data.worldbank.org/indicator/SL.IND.EMPL.MA.ZS?view=chart

2. EMPLOYMENT IN INDUSTRY, FEMALE

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank (2018)
https://data.worldbank.org/indicator/SL.IND.EMPL.FE.ZS?view=chart

3. EMPLOYMENT IN SERVICES, MALE

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank (2018)
https://data.worldbank.org/indicator/SL.SRV.EMPL.MA.ZS?view=chart

4. EMPLOYMENT IN SERVICES, FEMALE

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank (2018)
https://data.worldbank.org/indicator/SL.SRV.EMPL.FE.ZS?view=chart

5. TOTAL AVERAGE RISK INDEX

DATE: Average of last five years

NUMBER OF ENTITIES: 35

UNIT: Percentage

SOURCE:

6. FISH PROTEIN CONSUMPTION PER CAPITA

DATE: Average of last five years

NUMBER OF ENTITIES: 26

UNIT: grams of fish protein per day per capita

SOURCE: FAOSTAT (Demersal Fish, Pelagic Fish, Marine Fish, Other, Crustaceans, Cephalopods, Molluscs, Other) -
http://www.fao.org/faostat/en/

7. ANIMAL PROTEIN CONSUMPTION PER CAPITA

DATE: Average of last five years

NUMBER OF ENTITIES: 26

UNIT: grams of fish protein per day per capita

SOURCE: FAOSTAT (eggs, freshwater fish, demersal fish, pelagic fish, marine fish, other, crustaceans, cephalopods, molluscs, other, meat, aquatic mammals, aquatic animals, others)
http://www.fao.org/faostat/en/

8. NUMBER OF PEOPLE IN ECONOMICALLY ACTIVE POPULATION

DATE: Average of last five years

NUMBER OF ENTITIES: 25

UNIT: Thousands of individuals

SOURCE: International Labour Organization data provided by countries -
https://bit.ly/2KMqim6

9. TOTAL POPULATION OF SUB-SAHARAN AFRICAN COUNTRIES

DATE: Average of last five years

NUMBER OF ENTITIES: 36

UNIT: Thousands of individuals

SOURCE: UNDP (2018)
https://esa.un.org/unpd/wpp/DataQuery

10. NUMBER OF PEOPLE IN INDIRECT EMPLOYMENT OF FISHERIES

DATE: 2013

NUMBER OF ENTITIES: 33

UNIT: Thousands of individuals

SOURCE: Teh and Sumaila (2013)

11. NUMBER OF FISHERS

DATE: 2013

NUMBER OF ENTITIES: 33

UNIT: Thousands of individuals

SOURCE: Teh and Sumaila (2013)

12. QUANTITIES OF FISHERIES EXPORT

DATE: Average of last five years

NUMBER OF ENTITIES: 33

UNIT: Tons

SOURCE: FAO FishStatJ (2017)
http://www.fao.org/fishery/statistics/global-commodities-production/en

13. VALUE OF FISHERIES AND AQUACULTURE EXPORTS

DATE: Average of last five years

NUMBER OF ENTITIES: 33

UNIT: USD

SOURCE: FAO FishStatJ (2017) -
http://www.fao.org/fishery/statistics/global-commodities-production/en
UN Trade Statistics (2015)

14. VALUE OF FISHERIES LANDED

DATE: Average of last five years

NUMBER OF ENTITIES: 35

UNIT: 2010 USD, millions

SOURCE: Sea Around Us
http://www.seaaroundus.org/

15. TOTAL FISHERIES LANDINGS

DATE: Average of last five years

NUMBER OF ENTITIES: 35

UNIT: Tons

SOURCE: FAO
http://www.fao.org/fishery/statistics/global-production/en

16. TOTAL FISHERIES LANDINGS

DATE: Average of last five years

NUMBER OF ENTITIES: 35

UNIT: Tons

SOURCE: Sea Around Us
http://www.seaaroundus.org/

17. FISH PROTEIN AS PROPORTION OF ANIMAL PROTEIN CONSUMED

DATE: Average of last five years

NUMBER OF ENTITIES: 26

UNIT: Percentage

SOURCE: FAOSTAT (2017)
http://www.fao.org/fishery/statistics/global-consumption/en

18. PROPORTION OF ECONOMICALLY ACTIVE POPULATION IN FISHERY SECTOR

DATE: Average of last five years

NUMBER OF ENTITIES: 24

UNIT: Percentage

SOURCE: Teh and Sumaila (2013);

19. PROPORTION OF CHILDREN UNDER FIVE YEARS OLD WHO ARE MALNOURISHED (UNDERWEIGHT)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: WHO 2018
https://data.worldbank.org/indicator/SH.STA.MALN.ZS

20. LAND AREA OF ELEVATION <5 M (% OF POPULATION)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank Group (2018)
https://data.worldbank.org/indicator/EN.POP.DNST

21. PERCENTAGE OF POPULATION BELOW NATIONAL POVERTY LINES

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank Group (2016)

22. NUMBER OF PEOPLE AND PERCENTAGE OF POPULATION LIVING IN AREAS OF ELEVATION <5 M

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank Group (2018)
https://data.worldbank.org/indicator/EN.POP.DNST

23. POLITICAL STABILITY AND ABSENCE OF VIOLENCE

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

24. GOVERNMENT EFFECTIVENESS

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

25. REGULATORY QUALITY (-2.5 TO +2.5)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

26. RULE OF LAW (-2.5 TO +2.5)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

27. VOICE AND ACCOUNTABILITY (-2.5 TO +2.5)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

28. CONTROL OF CORRUPTION (-2.5 TO +2.5)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: −2.5 to +2.5 (worst to best)

SOURCE: World Bank Group (2018), World Governance Indicators
http://info.worldbank.org/governance/wgi/#home

29. CLIMATE ADAPTATION PLANNING (COST OF ADAPTATION)

DATE: Average of last five years

NUMBER OF ENTITIES: 21

UNIT: USD, billions

SOURCE: Pauw, W. P, D. Cassanmagnano, K. Mbeva, J. Hein, A. Guarin, C. Brandi, A. Dzebo, N. Canales, K. M. Adams, A. Atteridge, T. Bock, J. Helms, A. Zalewski, E. Frommé, A. Lindener, and D. Muhammad. 2016. "NDC Explorer." German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), African Centre for Technology Studies (ACTS), Stockholm Environment Institute (SEI). DOI: 10.23661/ndc_explorer_2017_2.0

30. GOOD SUBSIDY

DATE:

NUMBER OF ENTITIES:

UNIT: 2009 USD, thousands

SOURCE:

31. LIFE EXPECTANCY AT BIRTH

DATE: 2016

NUMBER OF ENTITIES: 32

UNIT: Year

SOURCE: World Bank Group (2018)
https://data.worldbank.org/indicator/SP.DYN.LE00.IN

32. GROSS DOMESTIC PRODUCT

DATE: Average of last five years

NUMBER OF ENTITIES: 33

UNIT: USD

SOURCE: World Bank Group (2018)
https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

33. PROPORTION OF TERRITORIAL SEA PROTECTED

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: IUCN and UNEP-WCMC (2014), World Bank (2018)

https://data.worldbank.org/indicator/ER.MRN.PTMR.ZS

34. NUMBER OF TERTIARY-AGE PEOPLE ENROLLED IN TERTIARY EDUCATION, BOTH SEXES (% OF POPULATION)

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank Group (2018), https://data.worldbank.org/indicator/SE.ADT.LITR.ZS

35. PERCENTAGE OF POPULATION OVER AGE 15 THAT CAN READ AND WRITE, BOTH SEXES

DATE: Average of last five years

NUMBER OF ENTITIES: 32

UNIT: Percentage

SOURCE: World Bank Group (2018), https://data.worldbank.org/indicator/SE.ADT.LITR.ZS

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