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Climate change impacts on fisheries in West Africa: implications for economic, food and nutritional security

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West Africa was identified as one of the most vulnerable regions to climate change in previous global analyses. Adverse changes in marine resources under climate change may pose significant threats to the livelihoods and well-being of the communities and countries that depend on fisheries for food and income. However, quantitative studies on the potential impact of climate change on fisheries and its subsequent impact on human well-being in West Africa are still scarce. This paper aims to assess the potential impacts of climate change on fisheries and their effects on the economics, food and nutritional security in West Africa. We use a dynamic bioclimatic envelope model to project future distribution and maximum fisheries catch potential of fish and invertebrates in West African waters. Our projections show that climate change may lead to substantial reduction in marine fish production and decline in fish protein supply in this region by the 2050s under the Special Report on Emission Scenarios (SRES) A1B. Combining with economic parameters, we project a 21% drop in annual landed value, 50% decline in fisheries-related jobs and a total annual loss of US$311 million in the whole economy of West Africa. These changes are expected to increase the vulnerability of the region through economics and food security of West Africa to climate change.

Keywords: consumption, economic impact, employment, food security

Introduction

Climate change is affecting marine ecosystems and is expected to affect fisheries and other ecosystem services (e.g. Hughes et al. 2003, Cheung et al. 2010, 2011, Sumaila et al. 2011). Marine species may show various responses to climate change including changes to physiology, phenology, distribution ranges and ecology (e.g. Perry et al. 2005, Cheung et al. 2009). These biological responses affect the distribution and productivity of marine fisheries. Using simulation models that account for the major biological responses to climate and ocean changes, Cheung et al. (2010) projected that many tropical regions are expected to have a large reduction in their maximum catch potential by the 2050s under the Special Report on Emissions Scenario (SRES) A1B, whereas high latitude regions may gain. As the economics of the fishing sector is tightly linked to the status of fisheries resources, the projected changes in catch potential due to climate change will result in changes in economic rent that can be derived from fisheries. The national and regional economic impact of climate change may be either positive or negative depending on fishery and country. For example, Arnason (2007) predicted that global warming may have positive effects on the fisheries in Iceland and Greenland and thus contribute positively to their gross domestic product (GDP), whereas earnings to the European sardine fishery are estimated to decrease by up to 1.4% on average per year with rising temperatures (Garza-Gil et al. 2010). Fisheries in low latitudinal regions such as West Africa may be affected the most (Cheung et al. 2010) and this sector is particularly crucial as a source of protein and income to impoverished societies in these regions.

Climate change may further exacerbate the existing stresses on the food security and economy in West Africa. According to Boko et al. 2007 and Allison et al. 2009, Africa is one of the continents with the highest vulnerability to climate change. Even without taking into account the impact of climate change, it is predicted that about 6% of the population in sub-Saharan Africa will suffer from chronic hunger or undernourishment by 2050 (FAO 2006a). With climate change, agricultural productivity would be negatively affected in many West African countries (World Bank 2007, Shah et al. 2008). Simultaneously, Cheung et al. (2010) showed that climate change would largely reduce the potential fisheries catch in the Exclusive Economic Zones (EEZs) of West African nations.

The predicted decrease in the productivity of marine resources under climate change may have large impacts on the livelihoods of West African communities. In general, fishers have different strategies and responses to adapt to resource fluctuations and uncertainties (Allison and Ellis 2001), including temporarily switching to alternative occupations, permanently leaving the fishery, increasing fishing effort, changing fishing grounds and shifting to alternative fishing gears that are usually more efficient (often more destructive) (Pauly 1990, Cinner et al. 2008). However, the adaptive ability of fishers depends on several factors including mobility of fishing vessels and availability of alternative livelihoods. Off West Africa, the dominance of domestic fleets may limit their ability to adapt to changes in resource and environmental conditions. Also, opportunities for coastal communities in this region are usually limited by the lack of alternative occupations, low education levels and high levels of poverty.

Climate change may also affect demographics such as population growth and migration patterns, and various other factors that influence food security in West Africa. Rapid population growth in West Africa from 2000 to 2050 is expected to exert tremendous stress on the food security in this region (United Nations 2009). Because 40% of the population there live in coastal cities, the combination of rising sea levels and extreme weather events may cause a large group of people to move inland (Boko et al. 2007). Meanwhile, prolonged drought in the inland regions of West Africa may cause more human migration to the coastal regions (Perry and Sumaila 2007). The inland-to-coastal migration is expected to impact on employment opportunities and the exploitation of natural resources in coastal regions.

Despite the considerable implications of climate change for the communities and economies in West Africa, there has not been a comprehensive study of the potential impacts on fisheries catch under climate change on the food and nutritional security and the economy in this region. This study aims to analyse the socio-economic implications of the potential catch projections under climate change (Cheung et al. 2010) by the 2050s, with an emphasis on food and nutritional security, and local economies of the region. Food security is defined as the physical, social and economic access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life (World Food Summit 1996, FAO 1999a). Although this definition is made up of four key dimensions: availability, access, stability and utilisation (FAO 2006b), only the first two are addressed here.

This paper begins with assessing the direct impact of climate change on the food security and nutritional quality for West Africans through the change in fish supply and the total amount of protein from marine captured fish (i.e. food availability). The indirect impact of climate change on food security was then assessed through change in food access, which can be evaluated by projecting changing in the landed value and fisheries-related employment. Both of these factors affect people's purchasing power on buying cheap sources of calorie-rich staples such as rice, millet, yam, maize, cassava, etc. and other nutritious food. The change in landed values under climate change also has indirect and induced effects on other sectors of the economy in West Africa. The direct, indirect and induced economic impact from the fisheries sector was estimated using the economic output multipliers (Dyck and Sumaila 2010). The countries that will face higher vulnerability to food security and local economy due to climate change effects on marine resources are identified.

Background

We included 14 West African countries in this study, ranging from Western Sahara in the north, which is a non-self-governing territory according to the United Nations, to Nigeria in the south. These countries include Benin, Cape Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mauritania, Nigeria, Senegal, Sierra Leone, Togo and Western Sahara (Figure 1).

Importance of fish and fisheries to West Africa

West Africa is highly dependent on fish and fisheries as source of food and income. The average annual per capita food fish consumption in this region is 14.6 kg per capita, with Senegal having the highest consumption (27.8 kg per capita) in the region in the early 2000s (averages from 1999 to 2003) (FAO 2011). Although the annual per capita consumption of fish in West Africa is not as high as that in other regions and also lower than the global average annual per capita consumption (15.9 kg per capita for the period 1999–2003, FAO 2011), West Africans generally eating less animal protein other people in more developed countries, but they consume more fish. Thus, comparing fish dependence in West Africa with other regions is more instructive than comparing the absolute figures of fish consumption per capita. Fish also acts as an important source of essential micronutrients such as iron, iodine, zinc, calcium and vitamins A and B, which are not found in other staples such as rice, maize and cassava (Roos et al. 2007, Kawarazuka 2010). Due to the decline in the performance of agriculture and other natural resource sectors, the main source of cheap animal protein for many West African states is from coastal and offshore fisheries, and fish harvested from capture fisheries and aquaculture contributes as much as 50% of animal protein consumed in these countries (FAO 2009, Smith et al. 2010). Countries in West Africa also rely on fish and fisheries as a source of income, providing jobs for 7 million West and Central Africans (FAO 2006b). The value-added from fisheries allows people to purchase high calorie staples such as rice and wheat, and other nutritious food such as vegetables and meat.

Although marine fish and invertebrates exported from West Africa amounts to only US$600 million annually (FAO 2007) and contribute only about 2% to the total export value from West Africa countries, the fisheries sector in the region plays an important role in the local economy of certain countries, e.g. Mauritania and Senegal are net exporters of fish. However, Smith et al. (2010) revealed that the low level of exports from West Africa relative to other regions reflects access agreements between West African countries and countries in Europe and Asia. The landings under these access agreements are not considered as African exports but the value of license agreement fees comes in some other category. Furthermore, the fisheries sector, particularly the artisanal, is a major source of employment and income for unskilled young men and women of coastal communities through direct and ancillary activities (FAO 2006b).

Current status and problems of fisheries in West Africa

Fisheries resources are highly productive along the continental shelf of West Africa. The high productivity is supported by the upwelling resulting from the Canary Current and Guinea Current along the coast. Currently, fish stocks in West African waters are already overexploited, driven to a large extent by the dominance of foreign distant water

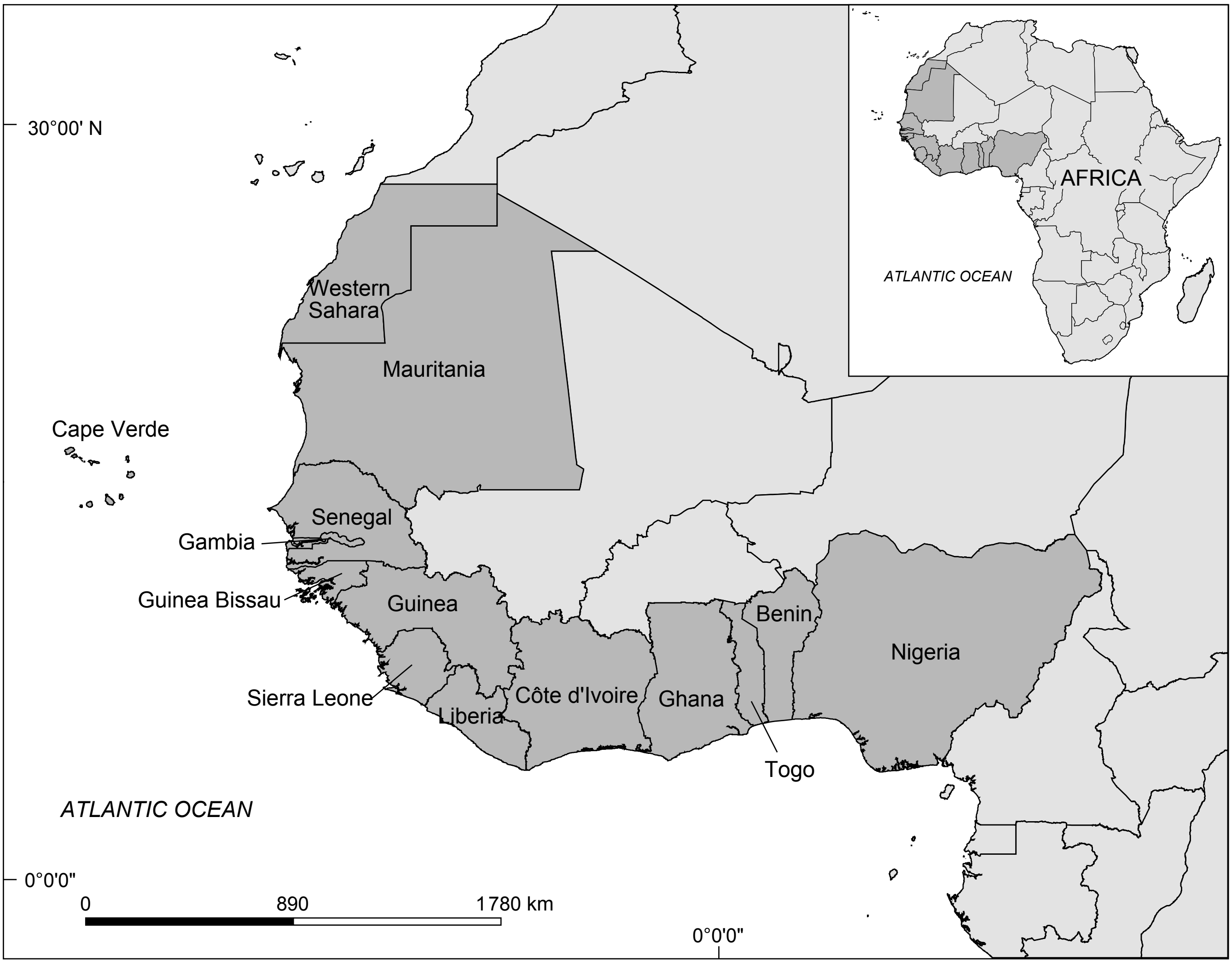

Figure 1: Map of West Africa showing the 14 countries under study

fleets in the EEZs of the West African countries (Alder and Sumaila 2004, Atta-Mills et al. 2004). Before the enactment of the United Nations Convention on the Law of the Seas (UNCLOS) in the 1980s, fishing vessels from the European Union (EU) fished freely in African waters. Later with UNCLOS, the EU officially negotiated and signed bilateral fishing agreements with Western African countries (Alder and Sumaila 2004). The main EU countries that fished in West Africa were France, Spain and Portugal, but the former Soviet Union and China were also active. Moreover, some EU countries found an indirect way through joint ventures with local businesses to fish in West African waters. The total number of years foreign countries signed agreements with West African countries for fishing access added together for each decade have increased significantly since they first started in the 1960s (Alder and Sumaila 2004). The negotiations and agreements are usually made at political levels with almost no involvement of local scientific or community inputs from countries involved. Simultaneously, there was a strong demand for fisheries resources as a source of food, income and livelihoods for coastal West African communities. As a result, fisheries resources in those waters are heavily exploited both by local fleets, which are mainly small-scale artisanal, and foreign vessels starting in the 1960s.

The pressure on fisheries resources of West Africa has caused the decline of fish stocks. However, as the demand for fish keeps increases, fishers use increasingly more sophisticated, sometimes destructive and sometimes illegal fishing methods (Pauly 1990, McClanahan et al. 2005). High-technology fishing techniques with the potential of finding the last remaining fish are being used (Ovetz 2007). Some fishing gears are very destructive to the ecosystem, such as bottom trawl by the industrial fishery, which sweeps the ocean floor and clears everything in its way, or dynamite fishing by small-scale fisheries, such as those near the coast of Dakar (Campredon and Cuq 2001) and in Moree, Ghana, before it was banned through co-management (Overå 2001). In addition, artisanal fishers (e.g. those in Ghana), use very small mesh sizes, which catch very small fish before they become sexually mature. Trawlers sometimes operate close to the shore, destroying coastal habitats and the gear of artisanal fishers (Overå 2001). A global assessment of illegal fishing found West Africa to be an area of high risk with an estimated illegal catch of 40% above the reported catch (Agnew et al. 2009). Together with other problems such as discard of bycatch (Kelleher 2005) and trash-fish trade (Nunoo et al. 2009), all these stresses in the region's fisheries increase the number of people at risk of facing hunger (Brown and Crawford 2008, Shah et al. 2008).

Methods

Projecting fisheries landings under climate change scenarios

We employed a combination of models to project future fisheries catch potential and landings in each country. Essentially, there are two major steps in projecting future maximum catch potential of species: (1) projecting future species distribution ranges under different climate change scenarios using a simulation model approach (Cheung et al. 2009); and (2) calculating maximum catch potential using an empirical model (Cheung et al. 2008a, 2010).

Projecting future species distribution under climate change

The calculation included 128 marine fish and invertebrate species exploited by West African countries in their EEZs. The 'current' (i.e. 1980–2000) distributions of these species were produced using our algorithm, which predicts the occurrence of a species on a half degree latitude × half degree longitude grid of the world ocean based on the species' depth range, latitudinal range, habitat preferences and broad-known occurrence regions (Close et al. 2006, Cheung et al. 2008b). The parameter values of each species were obtained from online databases such as FishBase (www.fishbase.org) and SealifeBase (www.sealifebase.org).

We then simulated future changes in species distribution by using a dynamic bioclimate envelope model (Cheung et al. 2008b, 2009). First, the model identified the current species' preference profiles with the environmental conditions by overlaying environmental data (e.g. sea surface temperature, salinity, etc.) with distribution maps of relative abundance of species. Preference profiles are defined as the suitability, which is represented by the relative density of the species in each environmental condition and habitat type, of each of the environmental conditions to each species (Cheung et al. 2010).

Species' environmental preference profiles were then linked to the expected carrying capacity in a population dynamic model in which growth, mortality and spatial dynamics of adult movement and larval dispersal along ocean currents were explicitly represented (Cheung et al. 2008b, 2009). The model simulated changes in relative abundance of a species in each spatial cell by incorporating the intrinsic population growth and settled larvae and net migration of adults from surrounding cells. Animals are assumed to migrate along the calculated gradient of habitat suitability, so our model assumes that carrying capacity varies positively with habitat suitability of each spatial cell, which is dependent on species' preference profiles to the environmental conditions in each cell. The final carrying capacity value of a cell is calculated from the product of the habitat suitability of all the environmental conditions considered in the model. The details of the algorithm of this model are provided in Cheung et al. (2008a, 2009). With the projected changes in the physical data from the NOAA/Geophysical Fluid Dynamic model (GFDL) ocean–atmosphere-coupled global circulation model (CM 2.1), annual changes in relative abundance of exploited fish and invertebrates from West African waters for the period 2001–2060 were simulated by the model (Cheung et al. 2010).

We examined two emission scenarios, the SRES A1B scenario (Nakicenovic and Swart 2000) and the 'constant 2000 level' scenario, representing high- and low-range greenhouse gas emissions respectively. The projected changes in primary productivity of these scenarios are available in Sarmiento et al. (2004). The SRES A1B scenario assumes that the greenhouse gas concentration was stabilised at 720 ppm by the year 2100. It describes a world of very rapid economic growth, low population growth, rapid introduction of new and more efficient technologies, and moderate use of resources with a balanced use of technologies. Large displacement and migration of population to resource-rich regions are expected from this scenario. SRES A1B scenario is considered to be a conservative scenario compared with other scenarios with higher future greenhouse gas emissions in the Intergovernmental Panel on Climate (IPCC) assessment (e.g. SRES A1F; IPCC 2007), but they are not included here. Thus, the projected impacts on economic, food and nutritional security in this study are also conservative. In contrast, the constant 2000 level scenario assumes that greenhouse gas concentration stabilised at 360 ppm, which is the same as the level in 2000. Changes in environmental conditions in the ocean, including sea temperature, sea ice coverage, salinity and advection from 2001 to 2059 under climate change scenarios were based on outputs from projection from the NOAA/GFDL ocean–atmosphere-coupled global circulation model (CM 2.1) (Delworth et al. 2006). We re-gridded the data with its original resolution on to the half degree in latitude by half degree in longitude spatial cells to match with the species distribution data.

Projecting maximum catch potential and landings

Based on the projections of the future distribution of fish stocks, we calculated the potential change in maximum catch potential by the 2050s (i.e. average of 2050–2059) relative to the 2000s (i.e. average of 2001–2010) in the 14 coastal countries in West Africa. Firstly, we calculated the average catch from 1999 to 2003 by species and country, as estimated by the Sea Around Us Project global catch database (www.seaaroundus.org). The Sea Around Us Project developed an algorithm that disaggregated reported catch data from 1950 to 2006 into a half degree latitude × half degree longitude grid of the world ocean (see Watson et al. 2004 and www.seaaroundus.org for details). The main source of catch data is the fisheries statistics from the Food and Agriculture Organization of the United Nations (FAO), which is modified where more appropriate data are available.

Secondly, we projected primary production from West African waters in the future using various empirical equations described in Sarmiento et al. (2004). With these models, we first predicted surface chlorophyll content in the ocean from ocean–atmosphere-coupled global circulation model (GCM) outputs. In the next step, three algorithms described in

Behrenfeld and Falkowski (1997), Carr (2002) and Marra et al. (2003) were used to calculate the annual phytoplankton primary productivity by using modelled surface chlorophyll content and its distribution, light supply and vertical attenuation, and sea surface temperature (Sarmiento et al. 2004). The annual primary productivity in West African waters was predicted from 2001 to 2060 for the two climate change scenarios.

Finally, we calculated the annual maximum catch potential using the empirical model of Cheung et al. (2008a). This model estimates the species' annual maximum catch potential for each of the spatial cells (30′ × 30′) based on total primary production within its exploitable range, the area of its geographic range, its trophic level and terms correcting the biases from the observed catch potential. This model is detailed in Cheung et al. (2008a, 2010). To minimise the effect of interannual variability of the climate projections, a 10-year running average was applied to the estimated catch potential. The annual maximum catch potential for each species in each EEZ was calculated by summing up all the projected values in the cells within that particular EEZ. We then estimated the percentage change in catch potential of each species in each EEZ between the 2000s and the 2050s, with the mean of catch potential estimated from the three primary production algorithms.

The percentage change in catch potential was then used as a proxy for estimating the potential landings by each of the countries by the 2050s. The current fisheries landings of each country was estimated by aggregating the catch of all species landed in a given country from 1999 to 2003. The projected annual landing for each country in the 2050s was estimated using the projected percentage change in total maximum catch potential of all species caught by a given country and its current landings.

The projected change in maximum catch potential from Cheung et al. (2010) was extracted for the two large marine ecosystems (LMEs) (Sherman and Hempel 2008), i.e. Canary Current and Guinea Current, which encompass the 14 countries under study. To better represent the resolution of the projected changes in catch potential, we calculated the relative changes in potential catch in each country EEZs were calculated based on the projected changes at the LME level. Also, the overall changes of the fisheries resources in each country are represented by the results obtained from projections from animal groups that are reported at species level (i.e. those that are included in Cheung et al. 2010).

Estimating forecasted fish demand in the 2050s

The current per capita fish consumption and the forecasted population in each West African country were used to predict the future total fish demand in the region. Because per capita fish consumption depends on several factors, including income, prices of fish and their substitutes, prices of complements, tastes and non-price factors (i.e. health education, urbanisation, distribution, storage capabilities, etc.) (Kinnucan et al. 1993, Delgado and McKenna 1997), there is high uncertainty in projecting future per capita fish consumption. Despite the continuing rise in global per capita consumption of fish projected by the FAO to 2030 (FAO 2002), fish consumption per person in sub-Saharan Africa is expected to stagnate or even decline (FAO 2002, Delgado et al. 2003). Also, the per capita consumption in West Africa remained stagnant historically (1969–1992) (Delgado and McKenna 1997). Therefore, we assume per capita fish supply to be constant over the study period. The per capita fish supply in the 2000s in each West Africa country was estimated using catch, import and export data from the Sea Around Us Project database (www.seaaroundus.org) and national population data from the United Nations (2009). Although FAO (2009) also provides data on fish food supply/consumption, their estimates include fish supplies from aquaculture, inland and marine fisheries, which cannot be easily disaggregated. We therefore computed here the per capita fish supply by including only the capture marine catches of each country (Table 1).

The high projected rate of population growth in West African countries implies an increase in projected overall fish demand when the per capita consumption is assumed to remain constant. We used the projected population in those countries reported in United Nations (2009) to forecast the need for fish to meet their food security needs in 2050 (Figure 2). To maintain the current nutritional level, it is reasonable to forecast the need for fish in 2050 based on current consumption per capita data, using the following equation:

$$D_c = P^c_{2050} \times d^c_{2050} \tag{1}$$

where c denotes country, D_c is the total fish demand in each country in the 2050s, P^c_{2050} represents the projected population in each country in 2050, and d^c_{2050} is the estimated per capita fish demand in the 2050s, which is assumed to be equal to the current per capita fish demand, $d^c_{current}$. We also are aware that people in West Africa may seek protein from other sources when there is a reduction in marine fish production. However, we assume here that there is no substitute for fish and thus the threat to food security posed by the loss in fish supply under climate change can be clearly demonstrated.

We then compared this projected total fish demand in each country with the projected fish production from

Table 1: Annual per capita fish food supply in West African countries in the 2000s

Country	Fish food supply (kg capita^{-1} y^{-1})[b]
Senegal	25.9
Gambia	23.2
Ghana	17.5
Nigeria	14.5
Sierra Leone	14.2
Côte d'Ivoire	12.0
Cape Verde	9.9
Guinea	7.2
Mauritania	5.7
Togo	4.5
Benin	3.9
Liberia	3.1
Guinea-Bissau	1.2
Western Sahara[a]	–

[a] As the estimated catch for Western Sahara in its own EEZ is very low (<1 t), its per capita fish supply is considered to be negligible

[b] The values are calculated using the national populations (United Nations 2009)

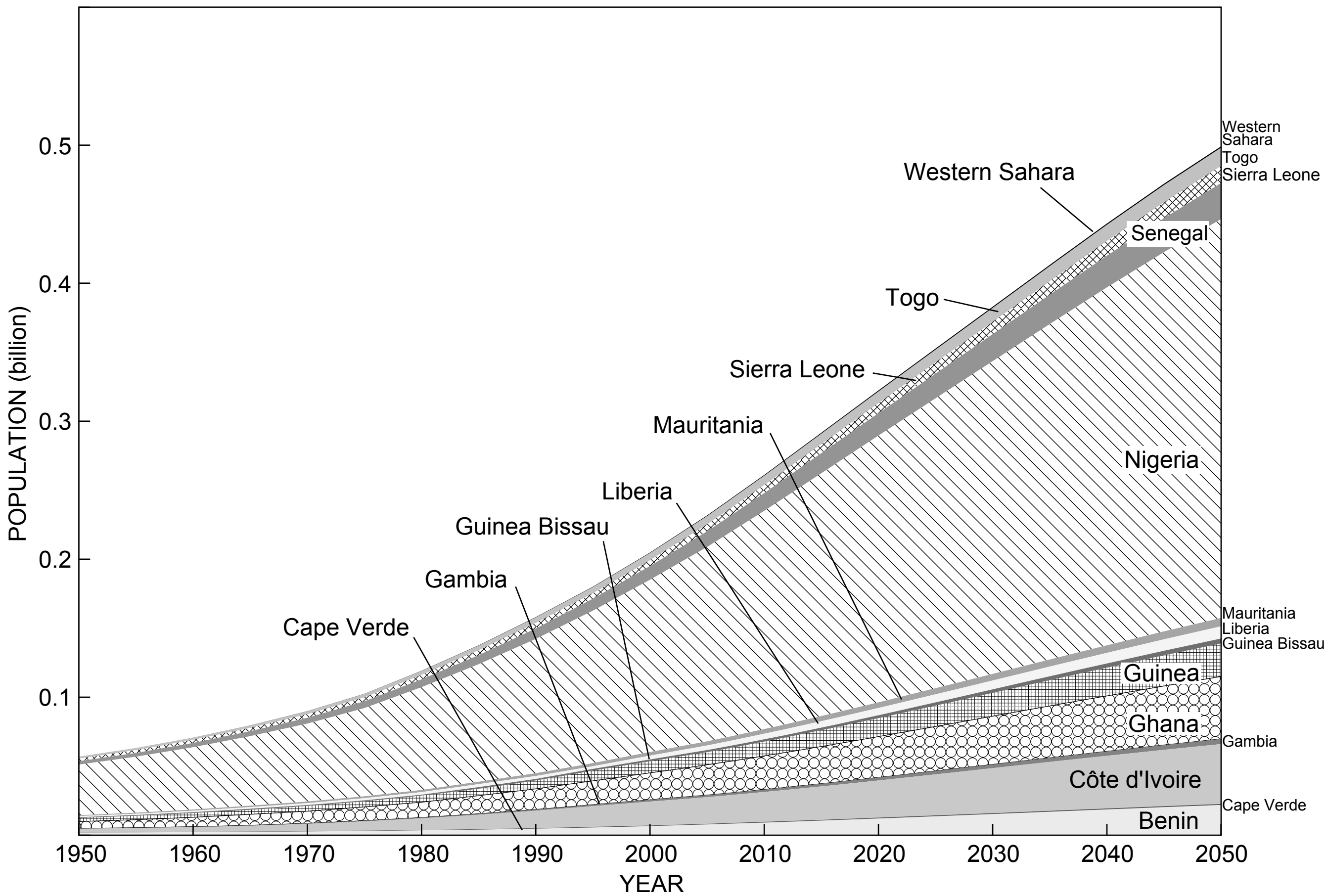

Figure 2: Projection of population in each West African country under study from 1950 to 2050. Data source: *Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2008 Revision*, http://esa.un.org/wpp/JS-Charts/pop-tot_0.htm

captured marine fisheries under the two climate change scenarios by the 2050s, to compute the percentage of projected fish production to the fish demand for each country. If this percentage is equal to or greater than 100%, it implies that the fish production would be enough to meet the total fish demand in a given country.

Estimating potential loss in fish protein under climate change

We analysed the impact of climate change on the protein consumed by West Africans from marine resources under the scenario that fishing efforts were maintained at the current level. To estimate the loss in marine protein, marine fish are assumed to have protein content of about 15–20% by weight (FAO 2005–2009). Then, the potential protein losses due to climate change are compared to the dietary protein consumption (g person^{-1} day^{-1}) in 2003–2005, as reported by the FAO for each country (Table 2). Here, we make the assumption that there is no diet-switching to other sources of protein and micronutrients when the fish supply declines.

Estimating landed values under climate change

The annual total landed values of fish in West African countries was estimated at US$0.7 billion in the 2000s, using ex-vessel prices of each species in 2000 (Sumaila et al. 2007) and the average catch data from the Sea Around Us Project database. The landed values of each country under two climate change scenarios by 2050 are also estimated using ex-vessel prices (in 2000) and the projected fisheries landings. Fish prices are greatly influenced by local markets, global supply of fish, preference of consumers, prices of alternative products on the market, and also abundance of targeted species (Murawski and Serchuk 1989, OECD 1997, Asche et al. 1999, Hannesson 1999, Pinnegar et al. 2006). The projected imbalance between fish supply and demand may lead to increases in fish price (Alexandratos 1995, Sverdrup-Jensen 1997). This study assumes the real ex-vessel price (after adjusting for inflation) to be constant throughout the study period because the projection of future price is limited by data availability and model complexity. Also, the real ex-vessel fish prices have remained relatively stable since 1970 (Delgado and Courbois 1999). Although real fish prices are likely to rise in the future — for example, fish prices were projected to increase by about 6–15% over the 1997 level by 2020 (Delgado et al. 2003) — this assumption allows for quick results of all critical issues, including impacts of climate change based on available data (Delgado and Courbois 1999).

Table 2: Economic impact in West African countries using national multipliers based on fisheries output impact in 2003 (source: Dyck and Sumaila 2010)

Country	Landed value (US$ million)	Economic impact (US$ million)
Benin	5.76	8.78
Cape Verde	3.83	5.84
Côte d'Ivoire	34.57	52.67
Gambia	30.27	46.12
Ghana	67.94	103.51
Guinea	99.43	151.48
Guinea-Bissau	4.80	7.31
Liberia	3.20	4.87
Mauritania	6.18	10.00
Nigeria	195.50	55.52
Senegal	151.77	335.36
Sierra Leone	58.15	88.60
Togo	3.78	5.75
Western Sahara*	–	–

* As the estimated catch for Western Sahara in its own EEZ is very low (<1 t), its landed value is considered to be negligible

Estimating the effect of climate change on fisheries-related jobs

FAO (1999b) provided data on the number of people involved in marine fisheries from 1990 to 1997 for the 14 countries under study. Employment data for 2000 can be obtained from the World Resources Institute (WRI) (http://www.wri.org). However, this data source provided the total number of people employed in both fishing and aquaculture in 2000. Hence, the number of people employed only in marine capture fisheries in the 2000s was estimated by combining the proportion of fishers involved in marine fisheries in the 1990s (FAO 1999b) with the total number of fishers reported by the WRI. These employment data were converted to number of fisheries-related jobs per tonne caught in 2000 by dividing it with the average landings in the 2000s in each country. The number of job losses in marine fisheries was then estimated by using the projected catch loss (as described above) under the climate change scenario by the 2050s.

Estimating the indirect and induced economic impacts of the fisheries sector under climate change

The fisheries sector is a primary or an economic base industry and supports a large number of secondary economic activities, including boat building, fish processing, international transport, etc. We estimated the indirect and induced economic impacts of climate change impacts on the fisheries sector in the countries by applying the national fishing output multipliers reported in Dyck and Sumaila (2010) (Table 2), in which the total current impact of the fisheries sector was calculated by applying the Leontief technological coefficients at current production. The total economic impact of the fisheries sector (E^c_{fish}) using net multipliers is calculated by:

$$E^c_{\text{fish}} = (M^c_{\text{fish}} - 1)\, L^c_{\text{fish}} \tag{2}$$

where c denotes the country and L^c_{fish} is the landed value for the fisheries sector in each country from 1999 to 2003. The Leontief multiplier (M^c_{fish}) for each country minus one represents net multiplier (Dyck and Sumaila 2010). The contribution of fisheries production to other sectors of the economy was assumed to be unchanged over time under climate change scenarios. Therefore, the impact of climate change to the whole economy in West African countries was estimated by applying the fishing output multipliers to the projected landed values in the 2050s.

Results

Fisheries landings under climate change scenarios

According to the FAO (2009), the contribution of fish to total animal protein supplies is around 19% of the total in Africa. In West African coastal countries, the percentage of dietary protein from fish relative to other animal proteins can be very high with some at more than 50%, e.g. 62% in Gambia and 63% in both Ghana and Sierra Leone (Béné and Heck 2005). As such, variation in fisheries landings under climate change would have a direct impact on the protein intake and hence food security in West Africa. Under the constant 2000 level scenario, the annual landings of almost all of the countries in West Africa, except Gambia, Western Sahara, Mauritania and Senegal, are predicted to decline by the 2050s (Table 3). The total annual landings of the 14 countries combined is projected to reduce by 20 000 t (i.e. a reduction of about 8% over current levels) in the 2050s under this scenario.

Under the high-range greenhouse gas emission scenario (SRES A1B), the sum of annual landings in the early 2000s in West African EEZ regions was 2.6 million tonnes (Sea Around Us Project database). By using the percentage change in the maximum catch potential of each species estimated in Cheung et al. (2010), the potential loss in total annual landings from these regions is estimated to be 670 000 t (i.e. a reduction of 26% over current levels) by the 2050s under the SRES A1B scenario. The EEZs of six countries (Ghana, Côte d'Ivoire, Liberia, Togo, Nigeria and Sierra Leone) are projected to suffer substantial reductions in landings, of up to and over 50% of their current production under the SRES AIB scenario (Table 3). These countries with large reductions in landings are located near the equator. Also, some of these countries, such as Sierra Leone, Liberia and Togo, have already had high proportions of their populations in a condition of undernourishment (>40%) (Table 3), so reductions in their landings would have great implications in terms of food security. In addition, some of the West African countries (e.g. Mauritania and Senegal) are currently net exporters of fish. Thus, a drop in landings under the SRES A1B scenario will not only affect the food security in these countries but also greatly impact their economies through reductions in fish exports.

Forecasted fish demand in the 2050s

To maintain the per capita supply of fish at the current level in West Africa to the 2050s, we estimate that the capture marine fish production in this region needs to increase by five times over the current level. As projected by FAO (2002), the

Table 3: Current landings, projected landings, percentage change in landings over current level and the prevalence of undernourishment in the population of each West African country under two different climate change scenarios. GHG = greenhouse gas

EEZ Country	Current landings in the 2000s (t)[a]	Low-range GHG emission scenario (constant 2000)		High-range GHG emission scenario (SRES A1B)		Prevalence of undernourishment in total population (2000–2002) (%)
		Projected landings in the 2050s (t)[b]	Potential percentage change in catch over current level (2000s)	Projected landings in the 2050s (t)[b]	Potential percentage change in catch over current level (2000s)	
Ghana	264 796	154 806	−41.5	119 243	−55.0	12
Côte d'Ivoire	58 268	35 752	−38.6	25 434	−56.4	15
Liberia	22 848	14 599	−36.1	11 318	−50.5	43
Togo	14 907	10 520	−29.4	5 959	−60.0	41
Nigeria	288 140	220 682	−23.4	136 456	−52.6	10
Sierra Leone	59 307	51 000	−14.0	27 723	−53.3	51
Guinea	107 380	97 331	−9.4	79 924	−25.6	18
Benin	8 148	7 456	−8.5	6 172	−24.2	22
Cape Verde	17 007	15 996	−5.9	13 328	−21.6	19
Guinea-Bissau	13 351	12 940	−3.1	10 331	−22.6	29
Gambia	32 147	34 471	7.2	29 637	−7.8	29
Western Sahara	821 642	890 892	8.4	691 230	−15.9	–
Mauritania	293 861	327 211	11.3	251 541	−14.4	7
Senegal	608 982	717 029	17.7	527 598	−13.4	32
West Africa region (14 countries)	2 610 786	2 590 686	−8	1 935 895	−25.9	15

[a] Average annual landing data from 1999 to 2003 obtained from the Sea Around Us Project catch database (www.seaaroundus.org)
[b] Annual landings in the 2050s projected by using the model described in the text

global fish food demand will only be met by continuing the expansion of fish cultivation by 2030. The share of capture fisheries to the world fish production will continue to diminish without the consideration of climate change (FAO 2002). Our results show that climate change will further exacerbate this situation (see Appendix). The percentages of projected fisheries landings to forecasted fish demand in West Africa countries under climate change by the 2050s are shown in Figure 3. Under both climate change scenarios, the projected fish catch in most of the countries cannot meet the forecasted fish demand in the 2050s except for Guinea-Bissau and Mauritania. In these two countries, a large proportion of their marine catches are currently exported. In Guinea-Bissau and Mauritania, 76% and 89% of their exports were fish respectively in the 2000s. Although the projected landings in these two countries under climate change scenarios is predicted to meet the domestic fish demand, the future export strategies may need to be carefully revised to avoid threatening food security in this region. Among the countries under study, Benin, Côte d'Ivoire, Nigeria and Western Sahara show the largest gap between the forecasted demand for fish and the projected fish catch under both climate change scenarios, with the catch providing <10% of the projected demand in some cases. Although three of these countries (Benin, Côte d'Ivoire and Nigeria) mainly rely on imported fish for food consumption in the 2000s, the predicted decline in catch in the 2050s, under climate change scenarios, imply that they will have to increase the amount of imported fish and/or develop sustainable aquacultural potential to meet fish demand in the future.

Potential loss in fish protein under climate change

Sierra Leone and Ghana are projected to lose an average of 7.6% and 7.0% of the protein that they consumed in the 2000s respectively, and they show the largest loss in marine protein among the other countries under the SRES A1B scenario by the 2050s (Table 4). According to Béné and Heck (2005), these two countries are both highly dependent on fish protein relative to other animal proteins (i.e. with a ratio of fish/animal protein at about 63%). Thus, a decline in protein from fish will have large implications for the nutritional quality of people's diets in these countries.

Landed values under climate change

The annual total landed value of West African countries is estimated to drop by 21% (i.e. from the current US$732 to US$577 million in constant 2000 dollars) under SRES A1B scenario from 2000 to 2050 (Table 5). Under the constant 2000 level scenario, decline in the annual total landed value is also predicted but with a lower magnitude of change (8%). Almost all of the countries under study show reductions in their landed values from fish caught in their EEZs under the SRES A1B scenario except Gambia (Figure 4). Côte d'Ivoire, Ghana and Togo will suffer the greatest impact on their landed values, with up to 40% declines under the SRES A1B scenario by the 2050s. All the countries in our study suffer declines in landed values to a lesser extent under the low constant 2000 level except Western Sahara, Mauritania, Senegal and Gambia, which are projected to have an increase in their landed values under this scenario.

The effect of climate change on fisheries-related jobs

The projected change in fisheries-related jobs in the 2050s relative to the number of jobs in the 2000s under the two climate change scenarios is shown in Figure 5. The total number of jobs provided by the fisheries sector in West

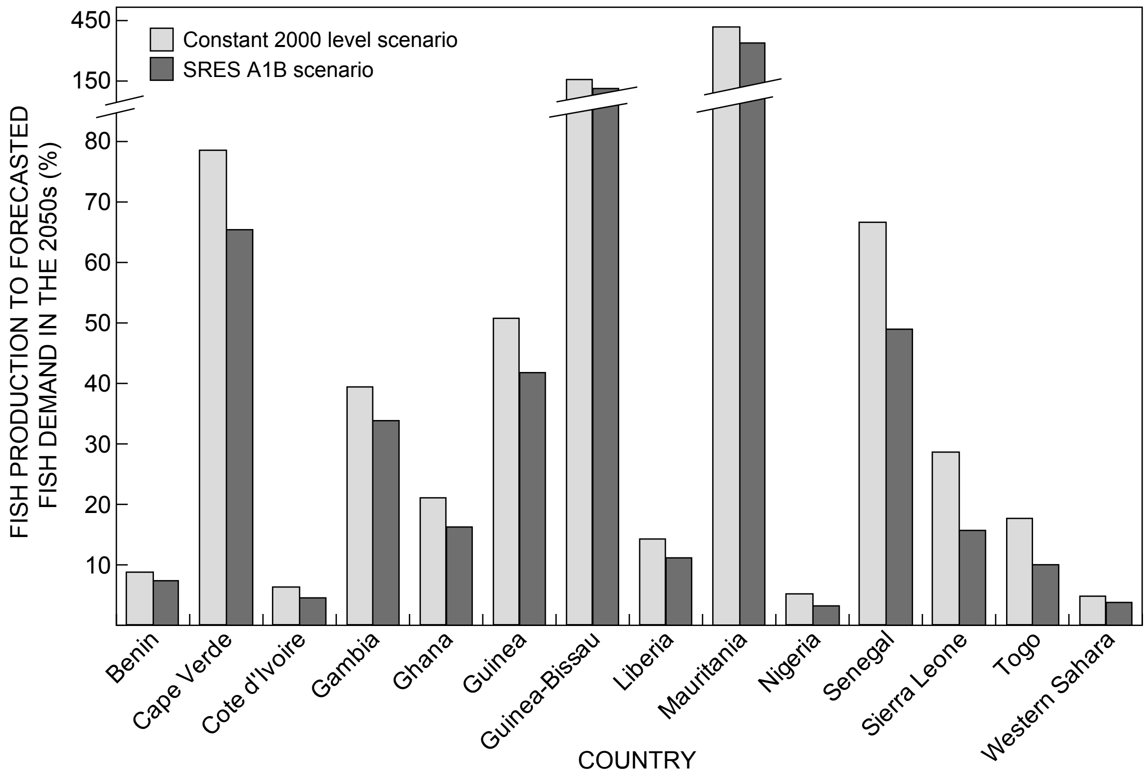

Figure 3: Percentage of fish catch to forecasted fish demand in West African countries by the 2050s under high-range climate change scenario (SRES A1B) and low-range climate change scenario (constant 2000 level). (Note: the forecasted fish demand is estimated using the current per capita fish food consumption and projected national populations (United Nations 2009)

African countries is about 760 000 in 2000. Under the SRES A1B scenario, the total number of fisheries-related jobs is projected to be 390 000 with a job loss of almost 50%, which may lead to serious socio-political problems. By contrast, the total number of jobs associated with fisheries under the constant 2000 level is predicted to be 580 000 with a job loss of only about 23%. Côte d'Ivoire, Ghana, Liberia, Nigeria, Sierra Leone and Togo will also face severe impacts on the number of jobs supported by the fisheries sector with more than 50% of job losses under the SRES A1B scenario (Figure 5).

The indirect and induced economic impacts of the fisheries sector under climate change

Total indirect and induced economic impacts of fisheries in the countries are shown in Table 5. Together with US$155 million loss of annual total landed values (SRES A1B), we estimated that another US$156 million may be lost per year in other economic sectors by the 2050s under high-range greenhouse gas emission scenario (Table 5). This makes up to US$311 million annual loss to the whole economy in West Africa.

Senegal is predicted to have the greatest impact on the direct, indirect or induced economic impact from the fisheries sector under SRES A1B scenario, with a reduction of about US$5 million of landed value but the impact on the secondary activities is double (i.e. a decrease of US$11 million). Ghana and Nigeria are predicted to suffer the greatest loss in the economic output of fisheries in terms of direct, indirect or induced impacts under SRES A1B scenario of US$89 million and US$87 million of their total economic impact from fisheries in the 2050s under climate change respectively.

Table 4: Percentage loss in marine protein relative to current protein consumption in each West African country under the two climate change scenarios. GHG = greenhouse gas

Country	Percentage loss	
	Low-range GHG emission scenario (constant 2000)	High-range GHG emission scenario (SRES A1B)
Sierra Leone	1.7–2.3	6.5–8.7
Ghana	4.5–6.0	6.0–8.0
Senegal	**	3.9–5.2
Mauritania	**	3.6–4.8
Guinea	0.8–1.1	2.3–3.0
Cape Verde	0.5–0.7	1.9–2.5
Togo	0.8–1.0	1.5–2.0
Gambia	**	1.6–2.1
Côte d'Ivoire	1.0–1.3	1.4–1.9
Liberia	1.0–1.3	1.4–1.8
Guinea-Bissau	0.15–0.2	1.1–1.5
Nigeria	0.4–0.5	0.9–1.1
Benin	0.08–0.1	0.2–0.3
Western Sahara *	–	–

* Western Sahara has no data on the dietary protein consumption (g person^{-1} day^{-1})

** No marine protein loss because of increase in catch under this scenario

Table 5: Landed values and total economic impact (US$ million y[−1]) from the fisheries sector in the 2000s and under the two climate change scenarios

Country	Current (2000s)		Constant 2000 level scenario		SRES A1B scenario	
	Landed value	Economic impact	Landed value	Economic impact	Landed value	Economic impact
Benin	3.49	5.32	3.20	4.89	2.95	4.50
Cape Verde	3.34	5.09	3.10	4.73	2.90	4.43
Côte d'Ivoire	34.93	53.22	26.81	40.85	20.92	31.88
Gambia	28.57	43.53	30.66	46.72	29.29	44.62
Ghana	84.66	128.98	61.85	94.23	49.51	75.43
Guinea	77.10	117.46	70.29	107.09	63.96	97.44
Guinea-Bissau	5.07	7.72	4.87	7.42	4.54	6.91
Liberia	3.10	4.72	2.50	3.80	1.99	3.03
Mauritania	107.64	174.17	114.52	185.31	102.37	165.65
Nigeria	188.07	53.41	150.79	42.82	120.00	34.08
Senegal	150.46	332.47	167.22	369.50	145.44	321.38
Sierra Leone	42.43	64.65	37.42	57.01	31.30	47.69
Togo	3.02	4.59	2.23	3.39	1.79	2.72
Western Sahara*	–	–	–	–	–	–
West Africa region	731.88	995.35	675.46	967.74	576.96	839.75

* As the estimated catch for Western Sahara in its own EEZ is very low (<1 t), its landed value is considered to be negligible

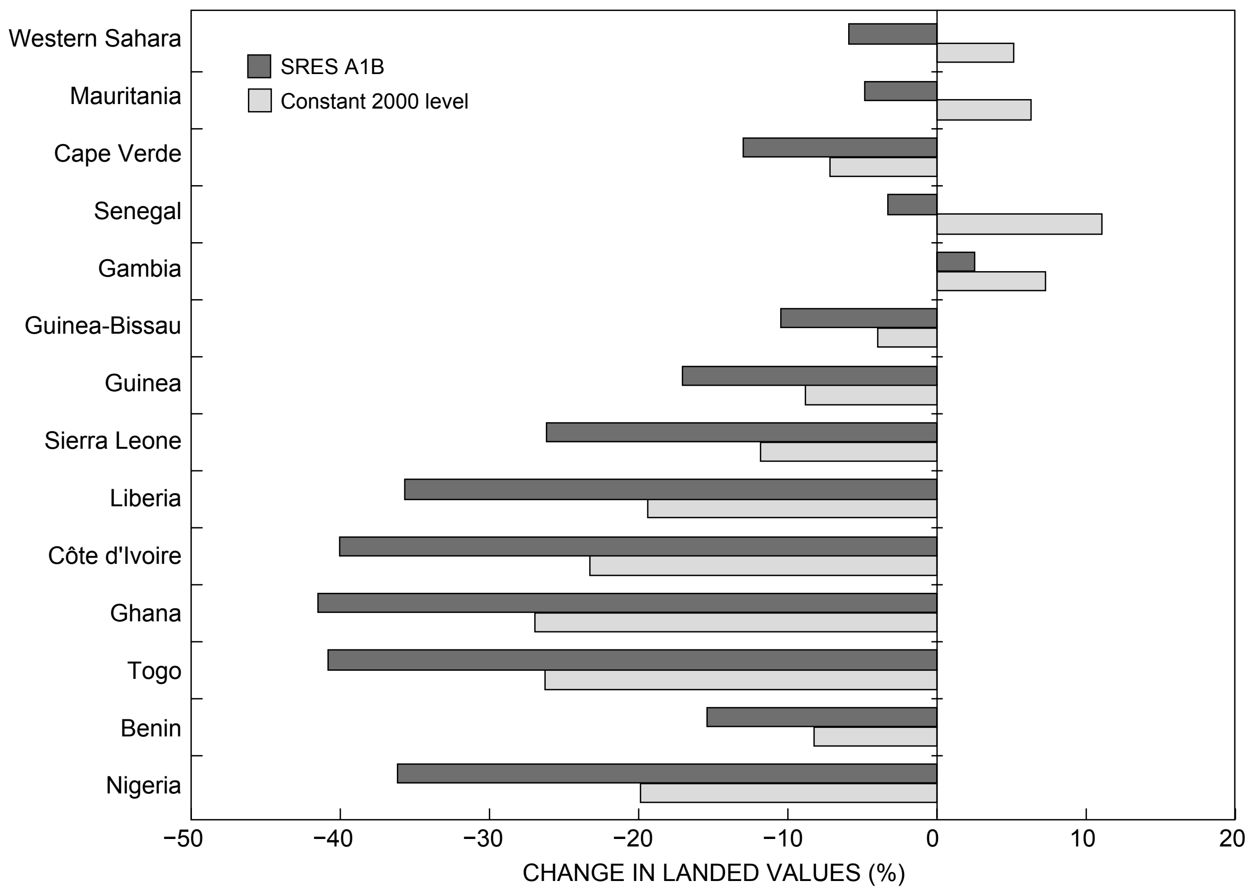

Figure 4: Percentage change in landed value of fishing countries in West Africa from 2000 to 2050 under high-range climate change scenario (SRES A1B) and low-range climate change scenario (constant 2000 level)

Discussion and conclusion

The decline in marine fish landings and the huge discrepancy between the projected supply and demand imply that climate change may worsen the food security issue in coastal West African countries by the 2050s, especially if the predicted decline in the agricultural sector under climate change materialises (Kurukulasuriya et al. 2008, Shah et

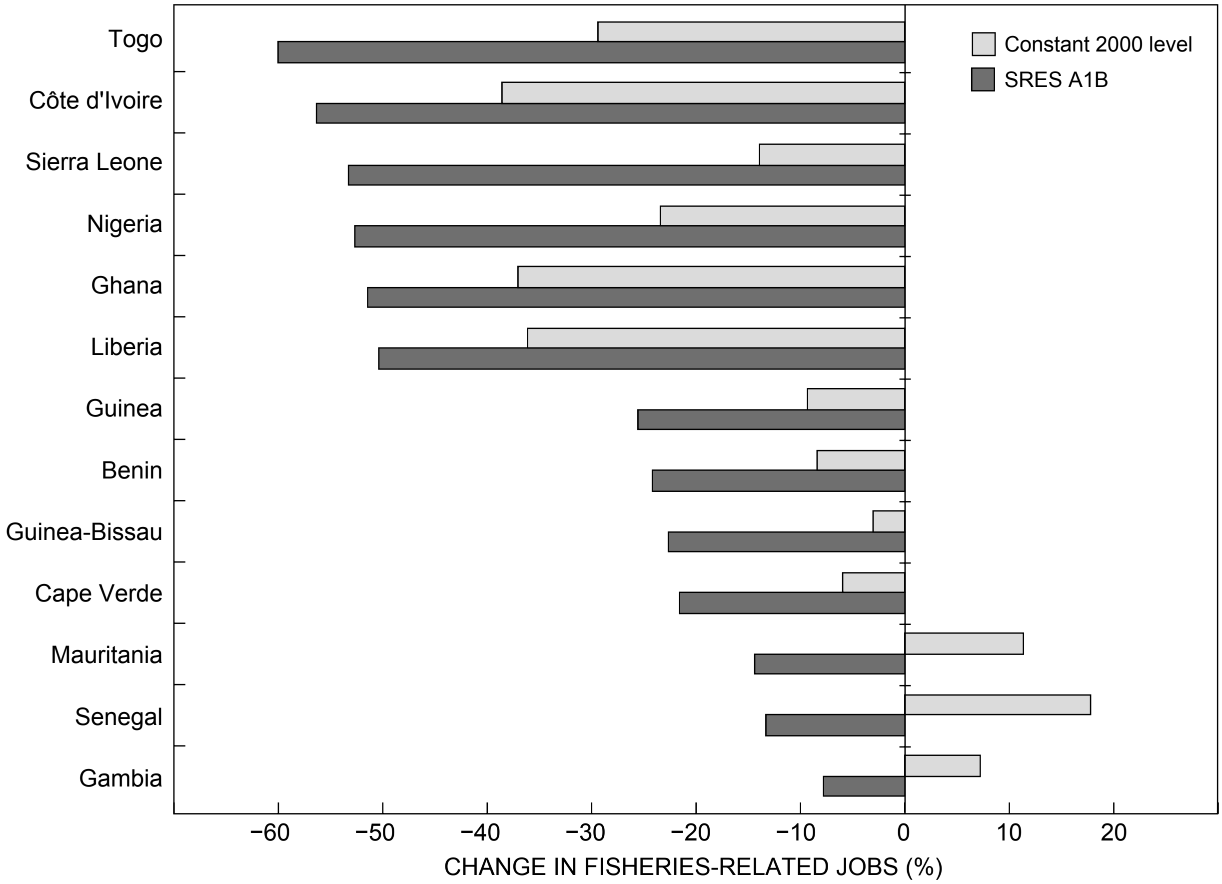

Figure 5: Projected annual average change in fisheries-related jobs in the 2050s relative to number of jobs in the 2000s under high-range climate change scenario (SRES A1B) and the low-range climate change scenario (constant 2000 level). (Note: Western Sahara is not included in this analysis because no employment data are available)

al. 2008). Forecasted fish demand for these countries alert governments to the amounts of fish that will be required by the 2050s to meet the needs of their populations. The difference between the forecasted demand for fish and the projected fish catch makes the risk of insufficient fish supply under climate change and unsustainable fishing practices apparent. This should provide decision-makers and fisheries managers with useful information to help derive appropriate policy to meet the challenges ahead. The projected high demand and low supply of fish may likely cause fish prices to increase by the 2050s, further hindering the ability of the poor communities to access the limited fish supply and thereby aggravating the already difficult food security situation under climate change. In order to maintain and improve the current nutritional level and reduce the risk of hunger, decision makers and fisheries managers have to find ways of minimising the gap between the forecasted fish demand and the catch by exploring some adaptive strategies.

The reduction in landed values and fisheries-related jobs under climate change may have indirect impact on food security by reducing the purchasing power of people to buy both fish and other food with higher calories. It is known that the consumption of non-staple food such as fish increases rapidly with income on a percentage basis (Bouis 2000). The linkage of employment to food security is based on the assumption that the earning of the household from fisheries-related jobs is related to the purchasing power of the household members for staple and non-staple food. With limited alternative employment opportunities in West Africa, a 50% drop in the fisheries-related jobs in this region under high-range climate change scenario implies that the standard of living and food purchasing power will be greatly degraded. Therefore, the impact of climate change on landed values and employment would not only affect the livelihoods of small-scale fishers, but would also affect the food security in West Africa indirectly.

Aquaculture is considered as one of the possible solutions to reduce the risks and uncertainties of capture fisheries, and fill the gap between the fish supply and demand. Globally, aquaculture provides about 19% of total fish production (excluding China) in 2006 with an increase from 14% only in 2002 (FAO 2009). The annual average growth rate of aquacultural production is 8.4% between 1970 and 2008 (Hall et al. 2011). However, the total output from the aquaculture sector is very low relative to the capture sector in West Africa, contributing only about 2% of total fish supply. In 2000, the Nigerian aquaculture sector only contributed about 0.01% of the national catch (Anetekhai et al. 2004). Although aquaculture has been growing rapidly in some countries such as China over the past decade

(Ahmed and Lorica 2002), the growth rate of aquaculture in West Africa lags far behind. A GIS model developed by FAO estimated that 37% of sub-Saharan Africa is suitable for small-scale artisanal fish farming (Kapetsky 1994, Aguilar-Manjarrez and Nath 1998). However, the development of aquaculture in West Africa is limited by many factors including very low production base, inefficient and poorly developed value chains, substantial resources demand (Hall et al. 2011), poor infrastructure, political instability and poor market development (Brummett et al. 2008). Although aquaculture production in Africa is growing fast, it will not be able to fill the gap between fish supply and demand over the next decade (Hall et al. 2011). As such, aquaculture is not seen as a viable alternative source of fish.

The broader impact of climate change on marine resources is evaluated by applying the national net multiplier. The full impact of the fisheries sector in West Africa is much greater than the value of the initial activity. In the 2000s, the total economic impact of the fisheries sector contributes about 2% of the total GDP in West Africa. Our results suggest that climate change not only affects the economic of the fisheries sector, but also has the same extent of impact on the whole economy of the region by the 2050s.

Many of the West Africa countries are already facing high levels of poverty, and their marine resources are also threatened by overfishing, both by local and distant-water fishing fleets (Alder and Sumaila 2004). These countries should focus more on developing adaptation strategies to reduce climate change impacts (Dulvy and Allison 2009). The results of this analysis have important implications for the planning processes of both national and international institutions with respect to the policies they put in place to combat climate change. Our study also underlines the importance of building the adaptive capacity of West African countries in coping with climate change impacts on fisheries.

To begin to tackle current problems and prepare for the impending challenges from climate change, West African countries need to (1) know the state of their fish stocks and ecosystems; (2) know the value (in a broad sense) of their fishery resources; and (3) strengthen fisheries management, especially monitoring, control and surveillance. Without these three foundations, these countries should not engage in global fish trade, sign access agreements and/or provide subsidies that are ecologically sustainable, and economically and socially beneficial to their coastal communities (Sumaila 2007).

Currently, the status of fisheries in West Africa is sub-optimal in terms of helping the region achieve its food security (with respect to catches, incomes and profits) and ecological sustainability objectives. There is ample room for these countries to improve the conservation status of their marine fish stocks without compromising the overall long-term economic benefits or food security from the fisheries (Cheung and Sumaila 2007). Such improvements could be achieved by reducing fishing effort now and rebuilding depleted stocks, which will also help to make the marine ecosystems of West Africa more resilient and capable of absorbing impacts of climate change. Fisheries that have been successfully managed to achieve resource sustainability will probably have a higher capacity and be a better positioned to respond to the unpredictability of climate change. On the contrary, fisheries with current catch above maximum sustainable yield may be more sensitive to shifts in climatic, oceanographic and biological conditions. These fisheries would also need to respond much more proactively to disruptive changes resulting from climate change (Sumaila et al. 2011). To increase the robustness of fish stocks to climate change, there may be short-term costs. However, the medium and long-term negative implications for food security in the region would likely be minimised.

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References

Agnew DJ, Pearce J, Pramod G, Peatman T, Watson R, Beddington JR, Pitcher T. 2009. Estimating the worldwide extent of illegal fishing. *PLoS ONE* 4: e4570. doi:10.1371/journal.pone.0004570.

Aguilar-Manjarrez J, Nath SS. 1998. *A strategic reassessment of fish farming potential in Africa*. CIFA [Committee for Inland Fisheries of Africa] Technical Paper 32. Rome: Food and Agriculture Organization of the United Nations.

Ahmed M, Lorica MH. 2002. Improving developing country food security through aquaculture development – lessons from Asia. *Food Policy* 27: 125–141.

Alder J, Sumaila UR. 2004. Western Africa: a fish basket of Europe past and present. *Journal of Environment and Development* 13: 156–178.

Alexandratos N (ed.). 1995. *World agriculture: towards 2010: an FAO study*. Rome and Chichester: Food and Agricultural Organization of the United Nations and John Wiley.

Allison EH, Ellis F. 2001. The livelihoods approach and management of small-scale fisheries. *Marine Policy* 25: 377–388.

Allison EH, Perry AL, Badjeck M-C, Adger WN, Brown K, Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK. 2009. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* 10: 173–196.

Anetekhai MA, Akin-Oriola, GA, Aderinola OJ, Akintola SL. 2004. Steps ahead for aquaculture development in Sub-Saharan Africa – the case of Nigeria. *Aquaculture* 239: 237–248.

Arnason R. 2007. Climate change and fisheries: assessing the economic impact in Iceland and Greenland. *Natural Resource Modeling*, 20: 163–197.

Asche F, Bremnes H, Wessells CR. 1999. Product aggregation, market integration, and relationships between prices: an application to world salmon markets. *American Journal of Agricultural Economics* 81: 568–581.

Atta-Mills J, Alder J, Sumaila UR. 2004. The decline of a regional fishing nation: the case of Ghana and West Africa. *Natural Resources Forum* 28: 13–21.

Behrenfeld MJ, Falkowski PG. 1997. A consumer's guide to phytoplankton primary production models. *Limnology and Oceanography* 42: 1479–1491.

Béné C, Heck S. 2005. Fish and food security in Africa. *Naga, WorldFish Center Quarterly* 28: 8–13.

Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany, M. 2007. Africa. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds), *Climate change 2007: impacts, adaptation, vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. pp 433–467.

Bouis H. 2000. Commercial vegetable and polyculture fish production in Bangladesh: their impacts on household income and dietary quality. *Food and Nutrition Bulletin* 21: 482–487.

Brown O, Crawford A. 2008. *Assessing the security implications of* *climate change for West Africa: country case studies of Ghana and Burkina Faso*. Winnipeg: International Institute for Sustainable Development.

Brummett RE, Lazard J, Moehl J. 2008. African aquaculture: realizing the potential. *Food Policy* 33: 371–385.

Campredon P, Cuq F. 2001. Artisanal fishing and coastal conservation in West Africa. *Journal of Coastal Conservation* 7: 91–100.

Carr ME. 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep-Sea Research II* 49: 59–80.

Cheung WWL, Close C, Kearney K, Lam V, Sarmiento J, Watson R, Pauly D. 2009 Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10: 235–151.

Cheung WWL, Close C, Lam VWY, Watson R, Pauly D. 2008a. Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series* 365: 187–197.

Cheung WWL, Dunne J, Sarmiento JL, Pauly D. 2011. Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic. *ICES Journal of Marine Science* 68: 1008–1018.

Cheung WWL, Lam VWY, Pauly D. 2008b. Dynamic bioclimate envelope model to predict climate-induced changes in distribution of marine fishes and invertebrates. In: Cheung WWL, Lam VWY, Pauly D (eds), *Modelling present and climate-shifted distributions of marine fishes and invertebrates*. Fisheries Centre Research Reports 16. Vancouver: University of British Columbia. pp 5–50.

Cheung WWL, Lam VWY, Sarmiento JL, Kelly K, Watson R, Zeller D, Pauly D. 2010. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology* 16: 24–35.

Cheung WWL, Sumaila UR. 2007. Trade-offs between conservation and socio-economic objectives in managing a tropical marine ecosystem. *Ecological Economics* 66: 193–210.

Cinner JE, Daw T, McClanahan TR. 2008. Socioeconomic factors that affect artisanal fishers' readiness to exit a declining fishery. *Conservation Biology* 23: 124–130.

Close C, Cheung WWL, Hodgson S, Lam V, Watson R, Pauly D. 2006. Distribution ranges of commercial fishes and invertebrates. In: Palomares MLD, Stergiou KI, Pauly D (eds), *Fishes in databases and ecosystems*. Fisheries Centre Research Reports 14. Vancouver: University of British Columbia. pp 27–37.

Delgado CL, Courbois C. 1999. Changing fish trade and demand patterns in developing countries and their significance for policy research. In: Ahmed M, Delgado CD, Sverdrup-Jensen S, Santos RAV (eds), *Fisheries policy research in developing countries: issues, priorities and needs. ICLARM Conference Proceedings* 60: 21–32.

Delgado CL, McKenna AA. 1997. Demand for fish in sub-Saharan Africa: the past and the future. *Naga, the ICLARM Quarterly* 20: 79–82.

Delgado CL, Wada N, Rosegrant MW, Meijer S, Ahmed M. 2003. *Fish to 2020: supply and demand in changing global markets*. Washington, DC, and Penang: International Food Policy Research Institute and WorldFish Centre.

Delworth TL, Broccoli AJ, Rosati A, Stouffer RJ, Balaji V, Beesley JA, Cooke WF, Dixon KW, Dunne J, Durachta JW et al. 2006. GFDL's CM2 global coupled climate models. Part I: formulation and simulation characteristics. *Journal of Climate* 19: 643–674.

Dyck AJ, Sumaila UR. 2010. Economic impact of ocean fish populations in the global fishery. *Journal of Bioeconomics* 12: 227–243.

Dulvy N, Allison E. 2009. A place at the table? *Nature* 3: 68–70.

FAO (Food and Agriculture Organization). 1999a. *The state of food insecurity in the world*. Rome: FAO.

FAO (Food and Agriculture Organization). 1999b. *Numbers of fishers*. FAO Fisheries Circular No. 929, Revision 2. Rome: FAO Fisheries Department.

FAO (Food and Agriculture Organization). 2002. *World agriculture towards 2015/2030 – summary report*. Rome: FAO.

FAO (Food and Agriculture Organization). 2005–2009. Fisheries and aquaculture topics. Nutritional elements of fish. Topics fact sheets. Text by Lahsen Ababouch. In: *FAO Fisheries and Aquaculture Department [online]*. Rome. Updated 27 May 2005. Available at http://www.fao.org/fishery/topic/12319/en [accessed 16 March 2010].

FAO (Food and Agriculture Organization). 2006a. *World agriculture: toward 2030/2050, interim report – prospect for food, nutrition, agriculture and major commodity groups*. Rome: FAO Fisheries Department.

FAO (Food and Agriculture Organization). 2006b. *Contribution of fisheries to national economies in West and Central Africa: policies to increase the wealth generated by small-scale fisheries. New directions in fisheries – a series of policy briefs on development issues*. Rome: FAO Fisheries Department.

FAO (Food and Agriculture Organization). 2007. *FAO yearbook of fisheries statistics summary tables*. Rome: FAO Fisheries Department. Available at http://www.fao.org/fishery/statistics/global-commodities-production/en [accessed 14 January 2010].

FAO (Food and Agriculture Organization). 2009. *The state of world fisheries and aquaculture 2008*. Rome: FAO Fisheries Department.

FAO (Food and Agriculture Organization). 2011. *FAOSTAT*. Rome: FAO Fisheries Department on-line statistical service. Available at http://www.fao.org/fishery/topic/16140/en [accessed 15 January 2011].

Garza-Gil AD, Torralba-Cano J, Varela-Lafuente MM. 2010. Evaluating the economic effects of climate change on the European sardine fishery. *Regional Environmental Change* 11: 87–95.

Hall SJ, Delaporte A, Phillips MJ, Beveridge M, O'Keefe M. 2011. *Blue frontiers: managing the environmental costs of aquaculture*. Penang: The WorldFish Center.

Hannesson R. 1999. Globalisation of seafood prices: some examples. *ACP-EU Fisheries Research Report* 5: 15–16.

Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg R, Hoegh-Guldberg O, Jackson JBC, Kleypas J, Lough JM, Marshall P, Nyström M, Palumbi SR, Pandolfi JM, Rosen B, Roughgarden J. 2003. Climate change, human impacts and the resilience of coral reefs. *Science* 301: 929–933.

IPCC (Intergovernmental Panel and Climate Change). 2007. Summary for policymakers. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds.), *Climate change 2007: the physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press. pp 1–18.

Kapetsky JM. 1994. *A strategic assessment of warm-water fish farming potential in Africa*. CIFA [Committee for Inland Fisheries of Africa] Technical Paper 27. Rome: Food and Agriculture Organization of the United Nations.

Kawarazuka N. 2010. The contribution of fish intake, aquaculture, and small-scale fisheries to improving nutrition: a literature review. The WorldFish Center Working Paper No. 2106. Penang: The WorldFish Center.

Kelleher K. 2005. *Discards in the world's marine fisheries. An update*. FAO Fisheries Technical Paper No. 470. Rome: Food and Agriculture Organization of the United Nations.

Kinnucan HW, Nelson RG, Hiariey J. 1993. US preferences for fish and seafood: an evoked set analysis. *Marine Resource Economics* 8: 273–291.

Kurukulasuriya P, Mendelsohn RO, Hassan R, Benhib J, Deressa T, Diop M, Eid HM, Fosu KY, Gbetibouo G, Jain S, Mahamadou A, Mano R, Kabubo-Mariara J, El-Marsafawy S, Molua E, Ouda S, Ouedraogo M, Sene I, Maddison DJ, Niggel Seo S, Dinar A.

2006. Will African agriculture survive climate change? *World Bank Economic Review* 20: 367–388.
Marra J, Ho C, Trees CC. 2003. *An algorithm for the calculation of primary productivity from remote sensing data*. Palisades, New York: Lamont-Doherty Earth Observatory.
McClanahan TR, Maina J, Davies J. 2005. Perceptions of resource users and managers towards fisheries management options in Kenyan coral reefs. *Fisheries Management and Ecology*: 12: 105–112.
Murawski SA, Serchuk FM. 1989. Mechanized shellfish harvesting and its management: the offshore clam fishery of the eastern United States. In: Caddy JF (ed.), *Marine invertebrate fisheries: their assessment and management.* New York: John Wiley & Sons. pp 479–506.
Nakicenovic N, Swart R (eds). 2000. *IPCC special report on emissions scenarios*. Cambridge: Cambridge University Press.
Nunoo FKE, Boateng JO, Ahulu AM, Agyekum KA, Sumaila UR. 2009. When trash fish is treasure: the case of Ghana in West Africa. *Fisheries Research* 96: 167–172.
OECD (Organization for Economic Co-operation and Development). 1997. *Towards sustainable fisheries: economic aspects of the management of living marine resources*. Paris: Organisation for Economic Co-operation and Development.
Overå R. 2001. Institutions, mobility and resilience in the Fante migratory fisheries of West Africa. CMI Working Paper 2001: 2. Bergen: Christian Michelsen Institute.
Ovetz R. 2007. The bottom line: an investigation of the economic, cultural and social costs of high seas industrial longline fishing in the Pacific and the benefits of conservation. *Marine Policy* 31: 217–228.
Pauly D. 1990. On Malthusian overfishing. *Naga, the ICLARM Quarterly* 13: 3–4.
Perry AL, Low PJ, Ellis JR, Reynolds JD. 2005. Climate change and distribution shifts in marine fishes. *Nature* 308: 1912–1915.
Perry RI, Sumaila UR. 2007. Marine ecosystem variability and human community responses: the example of Ghana, West Africa. *Marine Policy* 31: 125–134.
Pinnegar J, Hutton T, Placenti V. 2006. What relative seafood prices can tell us about the status of stocks. *Fish and Fisheries* 7: 219–226.
Roos N, Wahab MA, Chamnan C, Thilsted SH. 2007. The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. *The Journal of Nutrition* 137: 1106–1109.
Sarmiento JL, Slater R, Barber R, Bopp L, Doney SC, Hirst AC, Kleypas J, Matear R, Mikolajewicz U, Monfray P, Soldatov V, Spall SA, Stouffer R. 2004. Response of ocean ecosystems to climate warming. *Global Biogeochemical Cycles* 18: GB3003, doi:10.1029/2003GB002134.
Shah MM, Fischer G, Velthuizen H, 2008. Food security and sustainable agriculture – the challenges of climate change in sub-Saharan Africa. Commission of Sustainable Development (CSD), CSD–16 Review Session (5–16 May, 2008), United Nations, New York.
Sherman K, Hempel G (eds.). 2008. *The UNEP Large Marine Ecosystem Report: a perspective on changing conditions in LMEs of the world's regional seas, UNEP Regional Seas Report and Studies* No. 182. Nairobi: United Nations Environment Programme.
Smith MD, Roheim CA, Crowder LB, Halpern BS, Turnipseed M, Anderson JL, Asche F, Bourillón L, Guttormsen AG, Khan A, Liguori LA, McNevin A, O'Connor MI, Squires D, Tyedmers P, Brownstein C, Carden K, Klinger DH, Sagarin R, Selkoe KA. 2010. Sustainability and global seafood. *Science* 327: 784–786.
Sumaila UR. 2007. Briefing at the United Nations on global fisheries. *SAUP [Sea Around Us Project] Newsletter*, Issue 42, July/August 2007: 1–2.
Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S. 2011. Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change* 1: 449–456.
Sumaila UR, Marsden AD, Watson R, Pauly D. 2007. A global ex-vessel fish price database: construction and applications. *Journal of Bioeconomics* 9: 39–51.
Sverdrup-Jensen S. 1997. Fish demand and supply projections. *Naga, the ICLARM Quarterly* 20: 77–79.
United Nations. 2009. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2008 Revision. Available at http://esa.un.org/unpp [accessed 15 January 2010].
Watson R, Kitchingman A, Gelchu A, Pauly D. 2004. Mapping global fisheries: sharpening our focus. *Fish and Fisheries* 5: 168–177.
World Bank. 2007. *World development report 2008: agriculture for development*. Washington, DC: World Bank.
World Food Summit. 1996. Rome Declaration on World Food Security. Rome: Food and Agriculture Organization of the United Nations.

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Appendix: Current and projected fish production and fish demand in West Africa

Country	Annual captured marine fish production (1 000 t)			Per capita fish food consumption in the 2000s (kg $capita^{-1}$ y^{-1})[c]	Population (1 000)		Projected fish demand in the 2050s (1 000 t)[e]
	Current[a]	Projected in the 2050s (under constant 2000 level scenario)[b]	Projected in the 2050s (under SRES A1B scenario)[b]		Current (2000)[d]	Projected (2050)[d]	
Benin	8.1	7.4	6.1	3.85	6 659	21 982	84.5
Cape Verde	5.8	5.5	4.6	9.92	439	703	7.0
Côte d'Ivoire	53.6	32.9	23.4	12.01	17 281	43 373	520.8
Gambia	32.1	34.4	29.6	23.23	1 302	3 763	87.4
Ghana	284.4	166.3	128.1	17.54	19 529	45 213	793.0
Guinea	97.0	87.9	72.2	7.21	8 384	23 975	173.0
Guinea-Bissau	6.2	6.0	4.8	1.20	1 304	3 555	4.3
Liberia	6.1	3.9	3.0	3.10	2 824	8 841	27.4
Mauritania	130.0	144.7	111.2	5.70	2 604	6 061	34.6
Nigeria	287.9	220.5	136.3	14.51	124 842	289 083	4 195.0
Senegal	382.8	450.7	331.6	25.93	9 902	26 102	676.8
Sierra Leone	59.0	50.7	27.6	14.21	4 228	12 446	176.9
Togo	14.9	10.5	5.9	4.50	5 247	13 196	59.4
Western Sahara	<0.001	<0.001	<0.001	0.02	315	938	0.017
West Africa region	1 368	1 221	885	14	204 860	499 231	6 840

[a] Average annual landing data from 1999 to 2003 obtained from the Sea Around Us Project catch database (www.seaaroundus.org)

[b] Annual landings in the 2050s projected by using the model described in the text

[c] The per capita food consumption is calculated by dividing the total fish food consumption (i.e. sum of landing values and the imported fish) by the population in 2000

[d] Population data obtained from Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2008 Revision*, available at http://esa.un.org/wpp/JS-Charts/pop-tot_0.htm

[e] The projected fish demand is calculated by using the prevailing per capita fish consumption and the forecasted population in each country