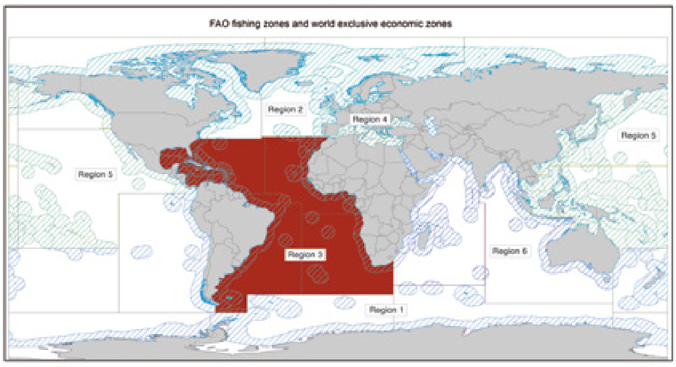
Central and South Atlantic Region

(FAO 31, 34, 41, 47)



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See map in Annex 1, p. 132.

EXECUTIVE SUMMARY

The Central and South Atlantic Oceans can be best characterized as a collection of sub-regions with distinctly different terrestrial influences and oceanographic circulation, as well as different fisheries harvests and human communities that depend on them. Ocean warming and acidification affect the entire region. Coastal waters also experience impacts from nearby landmasses and human communities, such as pollution from agricultural fertilizer, nitrogen and sulfur emissions from fossil fuel combustion and agriculture, and decreasing salinity from Antarctic ice melting. All of these impacts can add to acidification directly or contribute to eutrophication and subsequent deoxygenation, which may worsen the response of marine organisms to acidification. In the four FAO fishing areas that make up this region, 32%-57% of the fish stocks have no room for further expansion by commercial fishing. Overall catch trends across the region have been level or declining in the past two to three decades. Of the taxonomic groups most likely to be directly affected by ocean acidification, finfish, mollusks, crustaceans, and corals provide the most benefits to fisheries in the Central and South Atlantic regions. Given the negative response of bivalve mollusks to ocean acidification in laboratory studies, it seems that artisanal (e.g. yellow clam *M. mactroides*, Uruguay), small scale/semi-industrial (e.g., queen conch *Strombus gigas,* Caribbean) and bivalve aquaculture fisheries (e.g. Eastern oyster *C. virginica,* Brazil) are regional fisheries that are more likely to be impacted by OA. Changes or loss in physical habitat structure as a result of OA could also negatively affect individual species, such as those living among rhodolith beds (i.e., coralline red algae) in the eastern Caribbean and off the coast off Brazil. So far there is no evidence that major open ocean finfish fisheries in this area (e.g. hake, tuna, billfish, sardines, anchovy) will be directly impacted by OA, but current thinking suggests that ocean acidification will most likely affect finfish fisheries through changes in trophic relationships, such as those related to a decrease in overall food availability and/or the flow of energy among trophic levels.

The Central and South Atlantic region is bordered by many nations whose per capita GDP ranks in about the lower two-thirds of the world's nations. Many nations bounding this region also have less resilient human communities for withstanding possible losses of natural resources. Given the strong probability that OA will act hardest on near-shore and smaller scale fisheries in this region, it has the potential to worsen food distribution inequality that already exists and remove an important source of revenue to coastal communities in Central and South Atlantic. If ocean acidification and temperature rise result in range shifts of vulnerable yet economically important species, small-scale fishers will require local management strategies that are flexible enough to allow them to target a changing variety of accessible species using different gear types. Helping subsidize changing gear, retraining local fishers for other occupations, or helping identify and cultivate nutritional alternatives will likely be necessary for many local jurisdictions in the Central and Southern Atlantic, given the relatively low regional income and social resilience in many bordering nations. Large-scale fishers, on the other hand, may need policies that are geographically flexible that allow them to go farther afield for the same species. The dissimilarity of these two fishery categories and their responses points to the need for policy and adaptation research that address different scales. Nevertheless, close coordination among local, regional, and national authorities as well as user groups and researchers has been demonstrated to yield quick, effective responses to ocean acidification events elsewhere. Involving end users in decision-making and governance will lead to more effective outcomes.

1. THE SPECIFICITIES OF THE REGION

1.1. Geography

The Central and South Atlantic Oceans are bordered by the South American and African continents on the east and west sides, which form an irregularly shaped basin. This region (which encompasses FAO areas 31, 34, 41, 47; Figure 1) can be best characterized as a collection of sub-regions that have distinctly different terrestrial influences and oceanographic circulation, as well as different fisheries harvests and human communities that depend on them.

The most northerly sub-region, the north end of the Central Atlantic Ocean, includes the southern half of the North Atlantic Subtropical Gyre, the Caribbean ocean and Gulf of Mexico. This region has an overall wind-driven clockwise circulation and a western boundary current, the Gulf Stream, which transports water and heat from the Caribbean and the Gulf of Mexico northward (Figure 2). On the southeastern side of the North Atlantic gyre, or the northeastern border of the portion of the Central Atlantic under study here, strong upwelling occurs.

The Caribbean Sea and Gulf of Mexico have separate circulation regimes due to their semi-enclosed nature. The Caribbean Sea is characterized by westward currents flowing from the Lesser Antilles to the Gulf of México (Alvera-Azacarate, 2002). These currents are fed by waters of South Atlantic origin entering through southern Lesser Antilles as well as waters of North Atlantic origin that recirculate southwestward and enter the Caribbean through the Lesser Antilles (Johns *et al.,* 2002). The flow enters the Gulf of Mexico as a narrow boundary current that hugs the Yucatan Peninsula (Fratantoni 2001). This Yucatan Current flows into the Gulf of Mexico through the Yucatan Channel. It eventually separates from the Campeche Bank and becomes the Loop Current. The Loop Current then becomes the Florida Current as it exits the Gulf of Mexico through the Straits of Florida (Molinari and Morrison 1998). South of these sub-regions is the Equatorial Atlantic Ocean, which is marked by a complex equatorial current system (Figure 3) and tropical temperatures and ecosystems. The net effect of this is to drive strong seasonal upwelling along the West African coast in boreal summer when alongshore winds are strongest. Seasonal upwelling appears near Dakar, Abidjan, and from Cape Lopez to Cape Frio (Figure 4). Year-round upwelling occurs more to the north, north of Cape Blanc, and more to the south, south of Cape Frio.

The next most southerly sub-region is the South Atlantic Subtropical Gyre, which is marked by temperate conditions and strong upwelling on the eastern boundary at the Benguela Current. Return flow along the southern end of the subtropical region is west to east at the edge of the Southern Ocean as part of the Antarctic Circumpolar Current System.

Several of the largest rivers in the world, including five of the top ten in terms of volume discharge, flow into the Central and Southern Atlantic (Van der Leeden *et al.* 1990). This provides large quantities of fresh water, terrestrial nutrients, and organic material to the nearshore zone. Plumes of very large rivers like the Amazon, Orinoco, and the Congo travel far from the nearshore zone and enrich biological production well offshore (Signorini *et al.,* 1999).

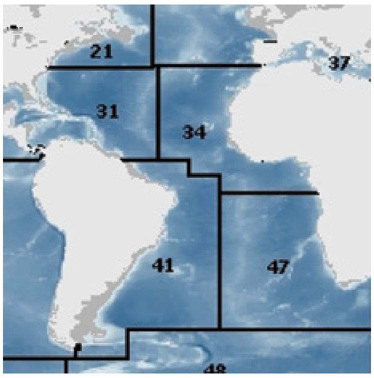

Figure 1:

Central and South Atlantic, with FAO fishing regions marked.

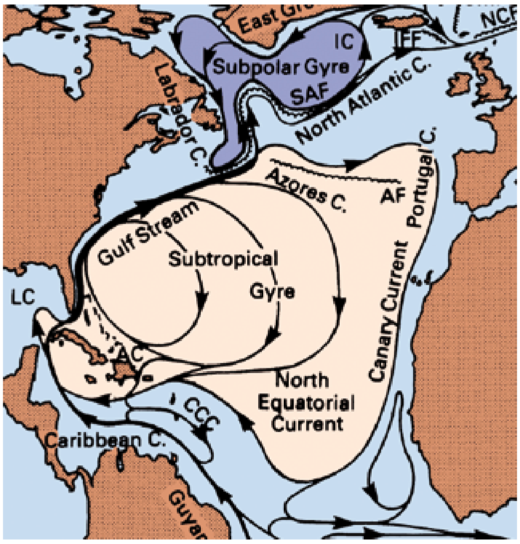

Figure 2:

Overview of the general circulation and major currents in the Central and North Atlantic ocean overlapping with FAO fisheries areas 31 and 34.
From Tomczak and Godfrey (2003).

1.2. Main stressors

Biogeochemical stressors

All of the sub-regions of the Central and South Atlantic are experiencing major environmental changes due to human activity. Rising temperature and atmospheric carbon dioxide are causing ocean warming and acidification in most places. Coastal waters also experience impacts from nearby landmasses and human communities. Nitrogen and sulfur emissions from fossil fuel combustion and agriculture have been shown to add slightly to ocean acidification, especially in

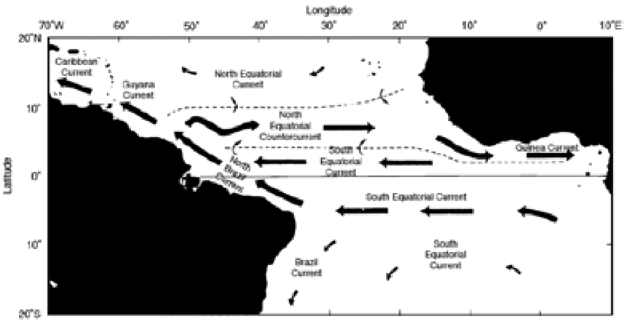

Figure 3:

Schematic of the major surface currents of the equatorial Atlantic Ocean during July-September. From January-May the North Equatorial Countercurrent disappears, causing the surface flow to move westward in the whole region.
From Philander (2001).

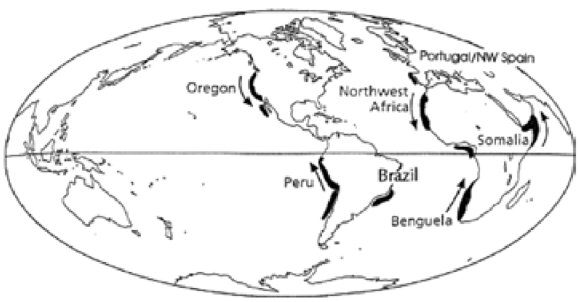

Figure 4:

Major coastal upwelling centers around the world.
From Peterson 1998.

coastal regions and more strongly in the Northern Hemisphere (Doney *et al.* 2007). This can add to acidification in some parts of the region, or it can contribute to eutrophication and subsequent deoxygenation. Other human activities, especially fishing, in the Central and South Atlantic, place a great deal of stress on coastal resources. In the four FAO fishing areas that make up this region, 32%-57% of the fish stocks have no room for further expansion by commercial fishing (FAO, 2005; Freitas *et al.* 2008). Fish stocks are not well quantified in these areas, as it is still unknown whether 39-56% of the fish stocks have room for expansion or not (Freitas *et al.* 2008).

At the same time, these sub-regions also experience various local-scale impacts resulting from human activity, including pollution from agricultural fertilizer or other manmade chemicals, atmospheric ozone depletion, decreasing salinity due to Antarctic ice melting, and overfishing. The type and extent of these impacts varies widely across the Central and South Atlantic region, but most often, these stressors affect the coastal and nearshore zones more heavily than offshore areas. The composite stress on marine ecosystems tends to be greatest for nations along the eastern boundary of this region (i.e., the West Coast of Africa), given the mixture of environmental and human concerns overlapping there (www.oceanhealthindex.org, Halpern *et al.* 2012). In particular, the Ocean Health Index is low for countries in the Central and South Atlantic because of low scores related to food provision, natural products, coastal protection, coastal livelihoods and economies, and sense of place, and in very specific areas along the West African coast, also because of low scores regarding tourism and recreation, and carbon storage (www.oceanhealthindex.org).

Fishing pressure

The FAO's State of Fisheries and Aquaculture publication (FAO 2012) indicates that in terms of overall catch trends, (1) there has been a strong steady decline in the southeast Atlantic; (2) a decline is also evident in the western central Atlantic; (3) the southwest Atlantic, while arguably having somewhat level catches over a 20-year period (at about 2 million tonnes per year), shows indications of a decline in the past 10 years; and (4) the eastern central Atlantic has had steady or slightly increasing (albeit fluctuating) catches over the past 30 years (Figure 5).

FAO (2012, p.58) considers the Southeast Atlantic to be "a typical example of the group of areas that has demonstrated a generally decreasing trend in catches since the early 1970s."

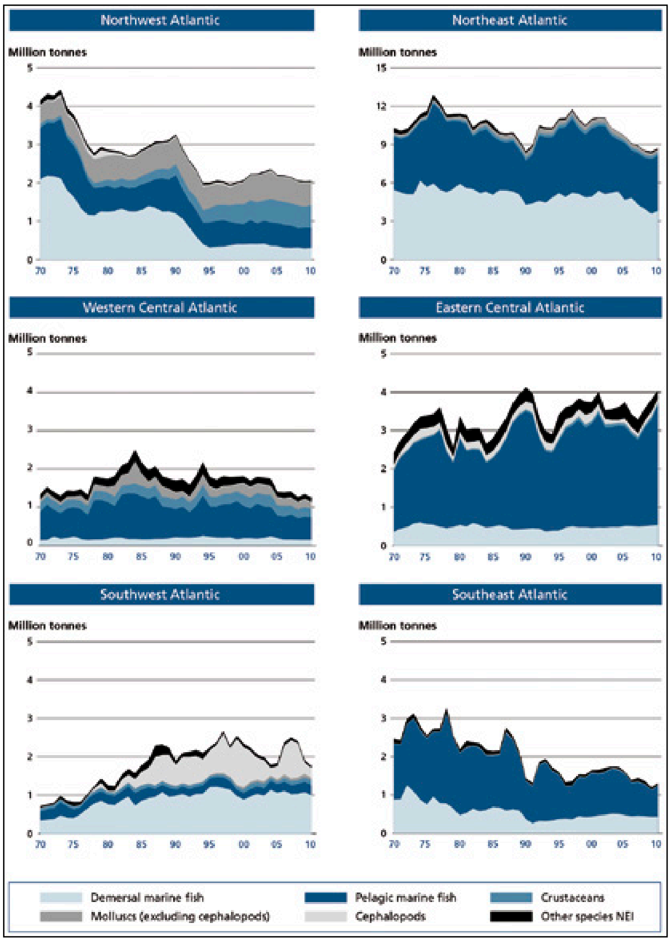

Figure 5:

Capture fisheries production in marine areas.
(Excerpted from FAO 2012).

Specifically, it is noted that the area "produced 3.3 million tonnes in the late 1970, but only 1.2 million tonnes were recorded in 2009." Hake is considered to be "fully exploited to overexploited" despite some improvement in certain stocks. Southern African pilchard has declined, due to "unfavourable environmental conditions," while Southern African anchovy "has continued to improve." FAO (2012) particularly draws attention to Cunene horse mackerel, noting it "has deteriorated, particularly off Namibia and Angola, and it was overexploited in 2009," as well as "the perlemoen abalone stock [which] continues to be worrying, exploited heavily by illegal fishing, and it is currently overexploited and probably depleted."

As noted above, the Eastern Central Atlantic contrasts with the Southeast Atlantic in showing a better overall trend. The increase in the total production in this region in the last 3 years was mainly influenced by the activities of the distant-water fleet. However, FAO (2012, p.57) reports that most stocks are fully exploited or overexploited – specifically that the area "has 43 percent of its assessed stocks fully exploited, 53 percent overexploited and 4 percent non-fully exploited…" In this region, "small pelagic species constitute almost 50 percent of the landings" and "the single most important species in terms of landings is sardine (*Sardina pilchardus*) with landings in the range of 600 000–900 000 tonnes in the last ten years." It is noted that "most of the pelagic stocks are considered fully exploited or overexploited," "demersal fish resources are to a large extent fully exploited to overexploited in most of the area," and "some of the deepwater shrimp stocks seems to have improved and they are now considered fully exploited, whereas the other shrimp stocks in the region range between fully exploited and overexploited."

In Western Central Atlantic, the reduction in catch production in 2010 was mainly attributed to the oil spill in the Gulf of Mexico. Finally, FAO (2012, p.57) notes that in the Southwest Atlantic, "50 percent of the monitored fish stocks were overexploited, 41 percent fully exploited and the remaining 9 percent considered non-fully exploited." Specifically, "major species such as Argentina hake and Brazilian sardinella are still estimated to be overexploited, although there seem to be some signs of recovery for the latter. The catch of Argentina shortfin squid was only one-fourth of its peak level in 2009 and considered fully exploited to overexploited."

1.3. Biological and chemical characteristics

The Central and South Atlantic contains a variety of ecosystems, including pelagic, coastal/near-shore, upwelling, and coral reefs. Each of these have broadly varying biological and chemical characteristics, and the level of understanding about those also varies greatly. Hydrographic and chemical monitoring of many of these environments lag, for example, comparable environments in the North Atlantic, even though two key long-term oceanographic monitoring sites are located in this region. Despite the variety of ecosystems in the region, fishery harvests remain the most economically important service provided by the Central and South Atlantic.

In the central and South Atlantic, three long-term time-series datasets have been collected to monitor conditions in the open ocean. Bermuda Atlantic Time Series (BATS), Hydrostation S, and the European Station for Time Series in the Ocean (ESTOC) are located within the region defined as the Central Atlantic, providing extensive data on environmental trends and biogeochemical properties in this region. Hydrostation S was established in 1954 and an almost continuous record of temperature, salinity and dissolved oxygen has been maintained. Sea surface temperature shows large variability on seasonal and decadal timescales, with a small, but detectable secular increase over time (Figure 6).

Seawater CO_2 parameters have been measured at BATS (combined with Hydrostation S) since 1983 and at ESTOC since 1995. The record at BATS shows a consistent increase in surface seawater pCO_2 tracking the observed increase in the atmosphere (Figure 7; Bates *et al*., 2012**).** Surface seawater total dissolved inorganic carbon concentration (DIC) has increased by 1.53±0.12 mmol kg^{-1} yr^{-1}; pH has decreased at a rate of -0.0016±0.00022 pH units per year, and the saturation state with respect to aragonite has decreased at a rate of -0.01±0.0012 units per year (Bates *et al*., 2012). The trends observed at the ESTOC are similar to those observed at BATS. Similar, shorter-term studies in the Caribbean have observed the same trends in this region (e.g., Gledhill *et al*., 2009).

Environmental and chemical conditions in the near-shore regions are known to be more variable due to the effects of upwelling, river plumes, and terrestrial inputs (Doney, 2010). In addition, biological processes in shallow near-shore regions exert a strong effect on the seawater chemistry, which can either alleviate or exacerbate anthropogenic ocean acidification (e.g., Cai *et al*., 2011). Upwelling and river plume-influenced regions in the Central and South Atlantic are characterized by high levels of dissolved nutrients, and host high primary production that attracts zooplankton and finfish. Large fisheries are traditionally located in these regions. In the Central Atlantic, fisheries harvests are especially high in the upwelling regions along the African continent (Figure 5), due primarily to harvests of sardine. In the Southwest Atlantic, major harvests include Argentine hake, Argentine shortfin squid, Patagonian grenadier, hoki and Brazilian sardinella. In the Southeast Atlantic, major exploited species include cape horse mackerel, hake, Pacific sardine and Southern African anchovy.

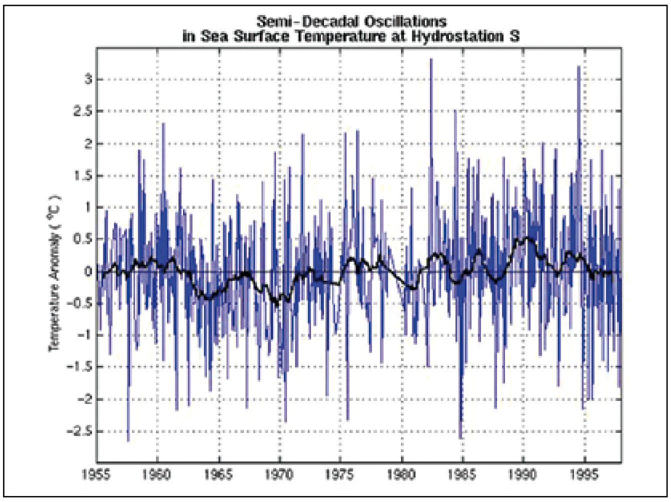

Figure 6:

Sea surface temperature at Hydrostation S between 1955 and 1998. The blue line shows the seasonally normalized SST anomaly and the black line shows the data with a low-pass filter emphasizing the longer term semi-decadal trend.
From http://www.bios.edu/research/hydrodata.html

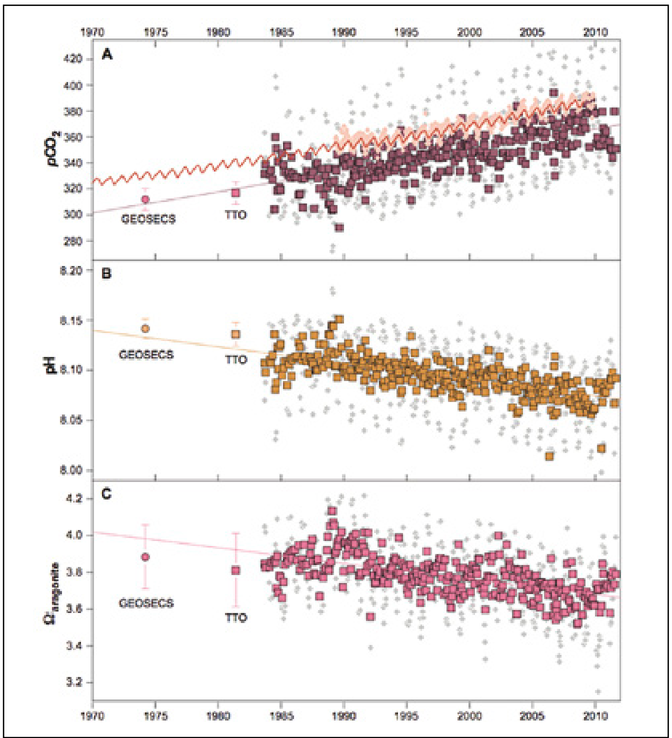

Figure 7:

Trends in atmosphere *p*CO_2 in Hawaii and Bermuda and surface seawater *p*CO_2, pH and saturation state with respect to aragonite measured at the Bermuda Atlantic Time-series Station (BATS) between 1983 until present and nearby measurements during GEOSECS and TTO in the 1970s and 1980s.
From Bates *et al.,* 2012**.**

In the Central Atlantic, tropical coral and mangrove ecosystems with high biodiversity host many nutritionally and economically valuable species. For example, Gulf menhaden and round sardinella are two major exploited fisheries in Central Western Atlantic. In Central Eastern Atlantic, European pilchard and sardine fisheries contribute to about 40% of the total landings in this region in the 2000s (Sea Around Us Project www.seaaroundus.org, Watson *et al.,* 2004). Open waters of the Central Atlantic are the main harvest areas of several species of tuna and swordfish. Frontal zones in the open waters concentrate abundant pelagic squid with commercial potential such as the orangeback squid (*Sthenoteuthis pteropus*) and the flying squid (*Ommastrephes bartrami*).

1.4. General socio-economic aspects of the area

The Central and South Atlantic region is bordered by a range of developing and developed nations, but the majority of bordering nations have smaller economies, and lower scores on social indicators. Per capita GDP based on purchasing power parity (PPP) varies widely for the nations bordering the Central and South Atlantic region. Nations in Eastern South America have somewhat higher GDP than those in West Africa; nevertheless, the nations bordering the entire ocean region have per capita GDP that ranks in about the lower two-thirds of the world's nations. Many nations bounding this region score low on worldwide governance indicators from Kaufmann *et al.* (2010), which indicate characteristics of the social system. Most of these indicators, which include voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption, are in the 0^{th}-50^{th} percentile for nations bordering this ocean region.

2. BIOLOGICAL IMPACTS OF OCEAN ACIDIFICATION

Not many experiments have been performed to examine the effects of ocean acidification on most species native to the Central and South Atlantic regions. However, trends are emerging from the broader ocean acidification literature showing that calcifying algae experience negative effects on photosynthesis and growth; corals experience net negative effects on growth and calcification; mollusks experience net negative effects on survival and calcification; and crustaceans experience net neutral effects on growth, calcification, and slightly negative effects on survival (Kroeker *et al.,* 2010, 2013). In contrast, fleshy algae and seagrass may show positive responses in growth and photosynthesis (Kroeker *et al.,* 2010, 2013). Species from all of these taxonomic groups are socioeconomically important in the Central and South Atlantic regions.

2.1. Impacts at the individual level

2.1.1. Ocean acidification effects on selected species

Of the taxonomic groups most likely to be directly affected, finfish, mollusks (here, referred to as shellfish), crustaceans, and corals provide the most benefits to fisheries in the Central and South Atlantic regions (Sea Around Us Project http://seaaroundus.org/). Given the negative ocean acidification response seen in many experiments on Eastern oyster, *Crassostrea virginica,* and closely related bivalve mollusks, it seems that artisanal (e.g. yellow clam *Mesodesma mactroides*, Uruguay), small scale/semi-industrial (e.g., queen conch *Strombus gigas*, Caribbean) and bivalve aquaculture fisheries (e.g. *C. virginica*, Brazil) are fisheries that are more likely to be impacted by ocean acidification because they focus on a mollusk species.

Each FAO sub-region in the Central and South Atlantic hosts specific economically important or iconic species that are likely to be especially vulnerable and make up a significant percent of harvest value (Table 1). In FAO area 31, this includes the American cupped oyster, ark clams, and queen conch; in FAO area 34, this includes cuttlefish; in FAO area 41, this could potentially include Argentine shortfin squid, Patagonian squid, Patagonian scallop, and sublittoral bivalve species; in FAO area 47, this includes common squid, arrow squid and cuttlefish (Sea Around Us Project www.seaaroundus.org). This may not be an exhaustive list; additional species may be important for very localized fisheries that are not included here.

2.1.2. Identification of the major threats: pCO_2, Ω

Most ocean acidification studies on individual species have focused primarily on the effects of pH or decreasing calcium carbonate mineral saturation states. Emerging studies suggest that the negative biological consequences of ocean acidification are likely related to energetic consequences (e.g., Navarro *et al.*, 2013), but the exact biochemical mechanism and compound responsible (e.g., CO_3^{2-}, H^+, etc.) for the response are not yet known.

Table 1.

Catch data for potentially ocean acidification-vulnerable species from the Sea Around Us Project (www.seaaroundus.org) for FAO areas 31, 34, 41, 47, covering the Central and South Atlantic.

FAO 31		
Spp	**Country**	**% of total Landed value of that species**
American cupped oyster	Mexico	12.0000
	USA	88.0000
Caribbean spiny lobster	Bahama	39.9315
	Cuba	16.4156
	USA	13.9787
Ark clams	Venezuela	98.0000
	Cuba	2.0000
Blue crab	USA	81.6473
	Mexico	17.7591
	Cuba	0.5483
	Nicaragua	0.0454
Groups	Mexico	46.8524
	USA	38.2338
	Venezuela	9.7884
	Dominican Rp	2.0264
	Bahamas	1.1349
Shrimps	USA	37.7182
	Mexico	34.5184
	Venezuela	12.8547
	Fr Guiana	5.2316
	Nicaragua	2.5955
FAO 34		
Octopuses	Morocco	59.3597
	Mauritania	20.2067
	Senegal	7.6315
	Korea Rep	5.3994
	China Main	2.9161
	Spain	1.7947
	Belize	0.9307
Southern pink shrimp	Nigeria	75.2402
	Senegal	14.1712
	Portugal	4.7708
Cuttlefishes	Morocco	37.5609
	China Main	13.5661

	Spain	9.8517
	Mauritania	8.0809
	Senegal	7.6306
	Italy	7.4921
	Ghana	5.2242
FAO 41		
Argentine shortfin squid	Argentina	38.2947
	Taiwan	18.5608
	Korea Rep	18.4109
	Japan	13.0968
	China Main	4.5593
	Spain	2.6776
	Uruguay	1.7872
	Falkland Is	1.6349
	Ghana	0.1827
	Portugal	0.1517
Patagonian squid	Falkland Is	69.7775
	Spain	8.1688
	France	5.8034
	UK	4.9136
	Australia	3.5514
	St Vincent	2.8238
Patagonian scallop	Argentina	96.0225
	Uruguay	3.9532
	Falkland Is	0.0197
	UK	0.0046
FAO47		
Cape rock lobster	South Africa	87.4203
	Namibia	12.5797

2.1.3. Direct biological responses of the species

Ocean acidification has been shown to alter a variety of life stages, but most often it affects juvenile forms (e.g., larval crabs, bivalves, etc.)(e.g., Long *et al.* 2013; White *et al.* 2013). The processes affected include reproduction, growth, calcification, immunity, olfaction, photosynthesis, etc. (Kroeker *et al.* 2010, 2013; Munday *et al.*, 2012). The population-scale consequences of these individual-based effects are not yet known for most species in most locations. Most importantly for this study, we do not yet know whether ocean acidification will impact market-relevant quantities of specific economically important species, such as meat weight, time to harvestable size, total population numbers, geographic range, etc.

2.1.4. Acclimation and adaptation capacities

The acclimation and adaptation capacities of valuable fisheries in the Central and South Atlantic Oceans are not known. However, upwelling regions on the eastern boundary of this region host high biological productivity and major thriving fin fisheries. These areas routinely experience lower pH and higher CO_2, but the tolerance of finfish living there may have been gained over many generations, and does not necessarily represent an adaptive response that will allow them to tolerate ocean acidification better. At least two hypotheses can be proposed that might explain local species' tolerance of lower-pH, higher-CO_2 conditions: 1) the high level of nutrition provided to the finfish by high biological productivity may provide energy they need to tolerate sub-ideal conditions; or 2) the finfishes' ability to move around may help them control their exposure to adverse conditions. Until more research is completed, it is difficult to propose which changes (e.g., increased variability, change in the mean, etc.) in which factors (whether pCO_2, pH, or CO_3) are biologically relevant for these species, especially because they living in naturally variable or rapidly changing conditions.

2.1.5. Indirect impacts on the species

So far there is no evidence that major open ocean finfish fisheries in this area (e.g. hake, tuna, billfish, sardines, anchovy) will be directly impacted by ocean acidification. The effect of ocean acidification on finfish fisheries is most likely to manifest itself through changes in trophic relationships, such as those related to a decrease in overall food availability and/or the flow of energy among trophic levels (Barry *et al.*, 2011). For example, a main prey species for top fish predators are pelagic squid, which may be affected by ocean acidification (Rosa and Seibel, 2008). A decrease in prey numbers would force predators to find a different food source or decline as well. In some food webs, the demise of one species could benefit others once competition for resources and/or predation pressure decreases, but predicting the outcome and the rate of such a change with high confidence is difficult. Changes in lower trophic levels could impact the abundance of top predators in the food web. Zooplanktivorous fishes may be affected by decrease in abundance of certain species like pteropods or other zooplankton. It is certain that large changes in the relative abundance of species in a given ecosystem as ocean acidification creates "winners" and "losers" will alter the system's role and function (Barry *et al.*, 2011).

Changes or loss in physical habitat structure as a result of ocean acidification could also negatively affect individual species. For example, a reduction in structural complexity of calcium carbonate bioherms and reefs as a result of decreasing calcification and increasing $CaCO_3$ dissolution could increase the competition for space and resources among species. In the Caribbean, coral reefs serve as a critical habitat for many species, but coral health and cover have deteriorated radically in the past several decades owing to a range of factors including overfishing, disease, and warming (Gardner *et al.*, 2003). This decline could intensify as a result of ocean acidification, with negative consequences to those species dependent on the coral reef structure. Similarly, in the eastern Caribbean and off the coast of Brazil, rhodolith beds (i.e., coralline red algae) constitute an important habitat for many species, and may also be at risk from ocean acidification (Amado-Filho *et al.*, 2012). Indeed, several studies have shown that coralline algae may be extremely sensitive to ocean acidification (e.g., Kuffner *et al.*, 2008), potentially leading to significant habitat loss in areas where these organisms serve as ecosystem engineers and builders.

Although carbonate ecosystems are believed to be among the most strongly affected by ocean acidification, changes to non-carbonate dominated ecosystems arising from ocean acidification (positive or negative) or other environmental stressors could also have significant indirect effects on these systems. For example, *Sargassum* seaweed provides a diverse habitat for many species, especially in their early life stages (Laffoley *et al.*, 2011), but the effect of ocean acidification on this habitat is unknown. Nonetheless, if affected at all, this seaweed may benefit from rising CO_2. Regardless of the outcome, both positive and negative indirect effects arising from ocean acidification will likely be difficult to research.

2.2. At population/community level

Fish species that depend highly on habitat provided by coral reefs are also vulnerable via indirect routes. There is a wide array of these reef-associated species, and these typically contribute to smaller-scale fisheries that are nutritionally and economically important. The structural complexity provided by coral reefs is critical in providing a diverse habitat and maintaining high biodiversity. As a result of ocean acidification and other environmental stressors (e.g., overfishing, warming, eutrophication, sedimentation), coral reefs could transition from a state of net accretion to net erosion (Silverman *et al.*, 2009; Andersson and Gledhill, 2013), which would tend to decrease their structural complexity. The result may be a decrease in the abundance and biodiversity of reef-associated species and negative nutritional and economic impacts for the people who depend on them.

For example, the Mesoamerican reef ecosystem is also affected by ocean acidification (Gledhill *et al.* 2008, 2009) and has multiple users and values. They include: (i) commercial fisheries targeting high value gastropods like queen conch (*Strombus gigas*), crustaceans like spiny lobster (*Panulirus argus*) which could be affected by ocean acidification during its long larval stages of 8-10 months, and a diversity of reef dependent fish species like groupers (*Epinephelus spp.*) and snappers (*Lutjanus spp.*); (ii) non-consumptive users like divers who derive satisfaction from observing the reef ecosystem (i.e. eco-tourism); (iii) shoreline residents and users whose interests are partially protected by coral reefs from storm damage caused landfalling hurricanes; (iv) existence values reflected in those who are willing to pay to derive satisfaction by knowing that threatened reefs and reef associated species like the hawksbill turtle (*Eretmochelys imbricata*), and corals in general, are being protected through international organizations, local government institutions, and NGO´s; and (v) option demand values associated to benthic invertebrates which are also rich sources of bioactive compounds with various medical, industrial and commercial applications (Seijo 2007). Because of the above, it is essential to know possible pH reduction consequences on commercially and food security important species (Cooley 2009).

2.3. Consequences in terms of socio-economics

Thus far, there have been no documented ocean acidification-related losses in economically important species in the Central and South Atlantic Oceans. We can therefore only speculate at which species may be affected by analogy with related species, and we can only identify which communities are strongly dependent now. This approach only provides a small hint at the possible impacts of ocean acidification on the region, and no information on economic consequences beyond the early studies already in the literature (Brander *et al.* 2009, Narita *et al.* 2012, Cooley and Doney 2009, Cooley *et al.* 2012).

3. ECONOMIC IMPACTS OF OCEAN ACIDIFICATION

3.1. Current data

The total landed value of fish in Central and South Atlantic is about USD$14.5 billion in 2005 real dollars and contributes to 14% of the global landed value in 2005 (Swartz *et al.* 2012). In this region, many species that contribute strongly to landed values could be affected by ocean acidification (Table 1).

In the Central Western Atlantic, American cupped oyster (*C. virginica*), Penaeus shrimps and Caribbean spiny lobster (*P. argus*) are three of the species with the highest landed value in the 2000s (Figure 8). In Central Eastern Atlantic, the most economically important species are European pilchard (*S. pilchardus*), Bigeye tuna (*Thunnus obesus*) and Madeiran sardinella (*S. maderensis*) (Sumaila *et al.* 2007; Swartz *et al.* 2012) (Figure 9). These species are not only major sources of food for local communities and fishing countries in these regions, but are also economically important as they act as major trade commodities.

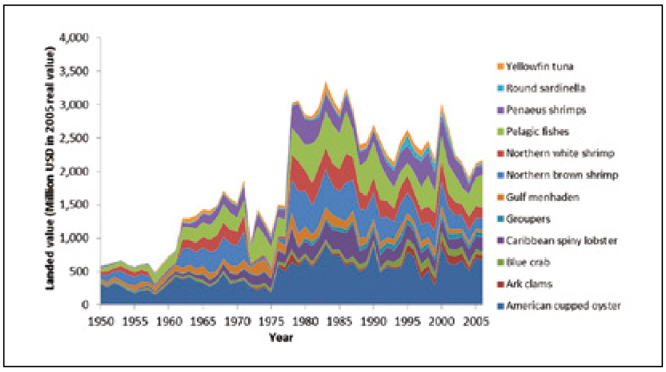

Figure 8:

Historical landed value (in 2005 real value) of top 12 species, which have the highest annual average catches in the 2000s (from 1997 to 2006), in Central Western Atlantic
(Sea Around Us Project).

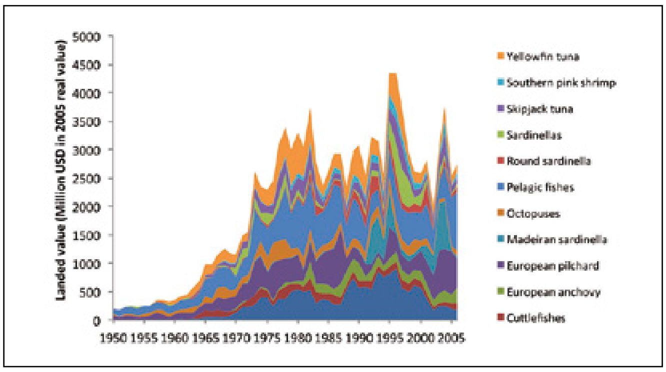

Figure 9:

Historical landed value of 12 species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), in Central Eastern Atlantic
(Sea Around Us Project).

In the South Atlantic, the upwelling systems also support many large and economically important fisheries. In the Southwest Atlantic, Argentine hake and Argentine shortfin squid are the two major exploited species and their landed value contribute to 30% and 20% of the total landed value in this region, respectively (Sumaila *et al.* 2007, Swartz *et al.* 2012) (Figure 10). In Southeast Atlantic, hakes and bigeye tuna are the two most economically important species in this region (Figure 11).

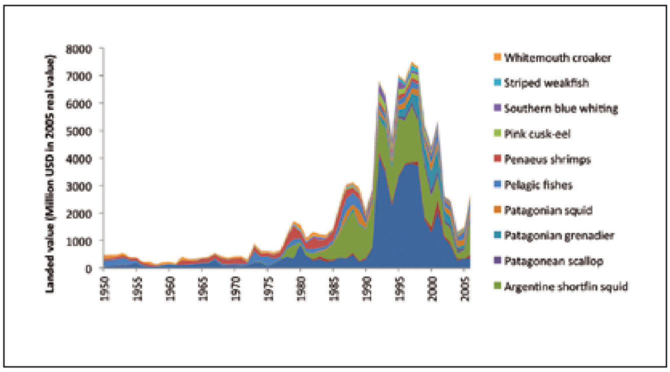

Figure 10:

Historical landed value of 12 species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), in Southwest Atlantic
(Sea Around Us Project).

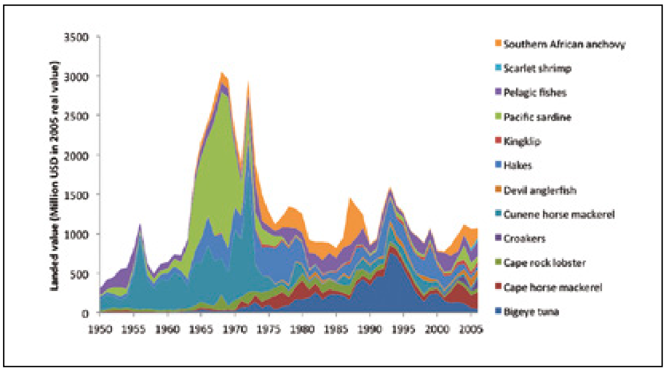

Figure 11:

Historical landed value of 12 species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), in Southeast Atlantic
(Sea Around Us Project).

Most of the countries in the Central and South Atlantic rely on fish and fisheries as major food and income sources. Fish is also the major trade commodity of these countries. For example, Brazil and Mexico are two of the major world's exporters of fish (FAO 2012). FAO (2012) indicates that regional trade in South and Central America continues to be of importance.

Apart from expansion of specific fisheries over time and the introduction of newly exploited species, there have not been marked sudden changes in fishery harvests in South and Central Atlantic Ocean nations (Figures 12-16). Regional trends towards expansion and higher harvests match those observed worldwide.

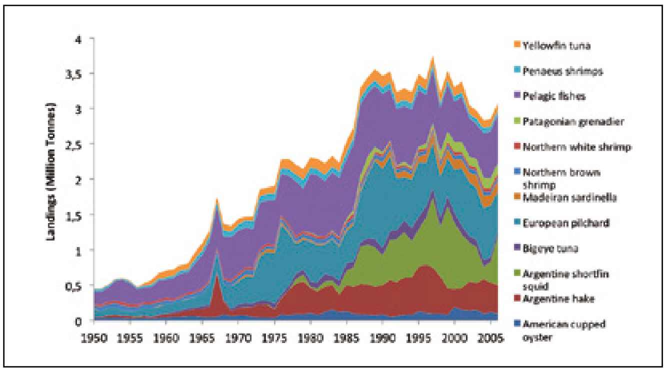

Figure 12:

Landings by economically valuable species in Central and South Atlantic (FAO 31, 34, 41, 47). Historical landings of 12 economically valuable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

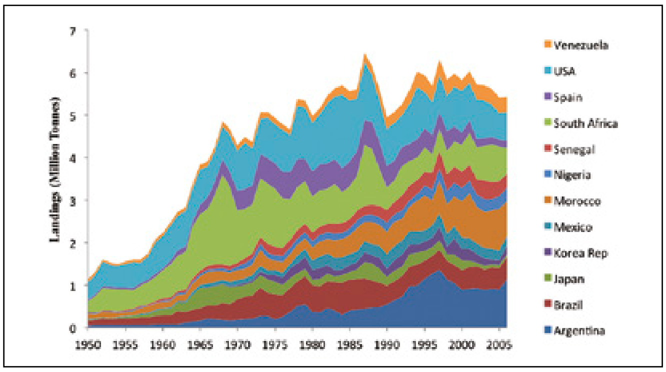

Figure 13:

Landings by countries with high landed values in Central and South Atlantic (FAO 31, 34, 41, 47). Historical landings of 12 countries, which have the highest annual average landed values in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

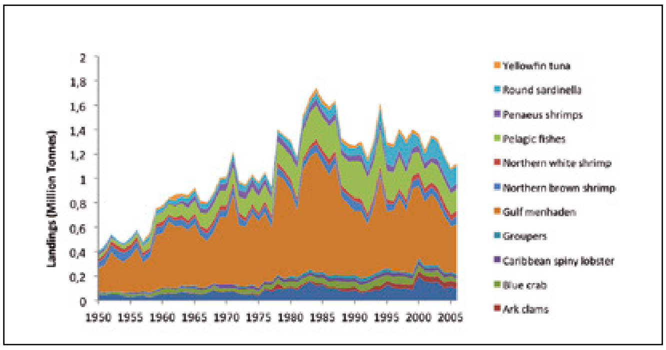

Figure 14:

Landings by economically valuable species in Western Central Atlantic (FAO 31). Historical landings of 12 economically valuable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

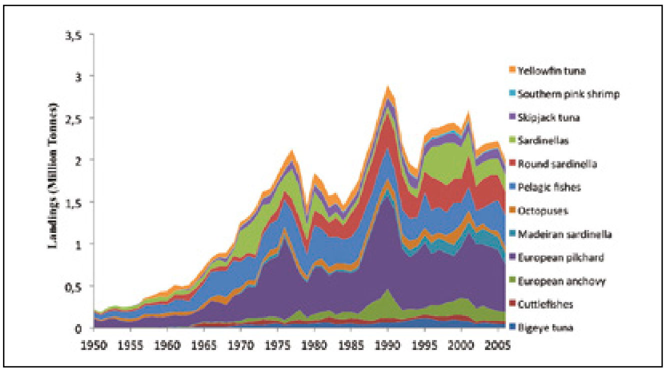

Figure 15:

Landings by economically valuable species in Eastern Central Atlantic (FAO 34). Historical landings of 12 economically valuable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

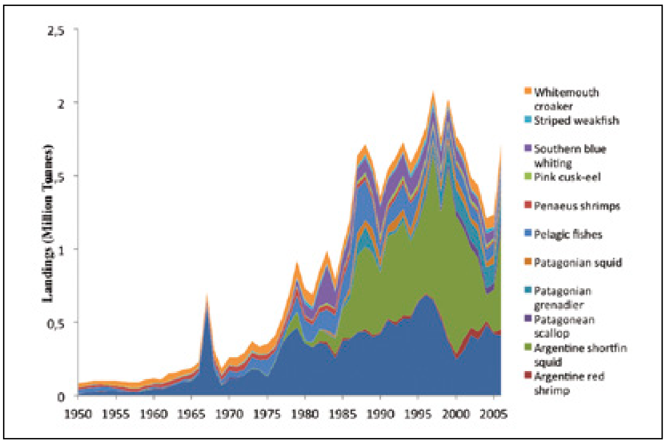

Figure 16:

Landings by economically valuable species in Southwest Atlantic (FAO 41). Historical landings of 12 economically aluable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

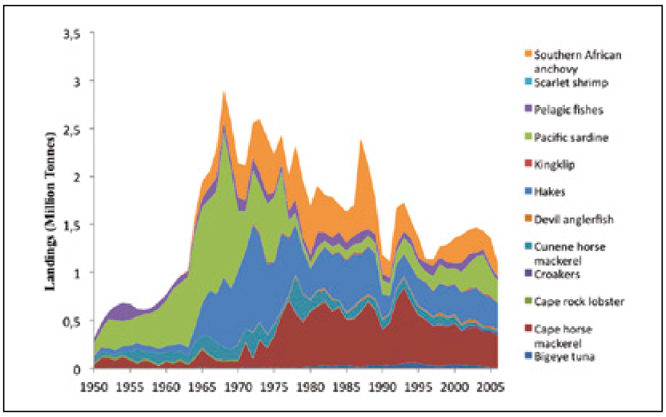

Figure 17:

Landings by economically valuable species in Southwest Atlantic (FAO 41). Historical landings of 12 economically valuable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

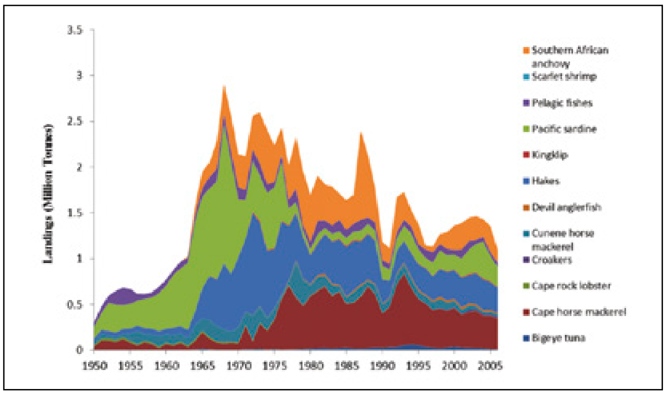

Figure 18:

Landings by economically valuable species in Southeast Atlantic (FAO 47). Historical landings of 12 economically valuable species, which have the highest annual average landed value in the 2000s (from 1997 to 2006), from the Sea Around Us Project (www.seaaroundus.org).

3.2. Role of fisheries in the economy

Commercial fishing brings significant annual revenues for nations bordering the Central and South Atlantic Ocean (Tables 2-3). Many of the most economically important species are finfish and top predators (Tables 4-7), making the links between ocean acidification and large economically important commercial activities difficult to trace since these species have not demonstrated major ocean acidification responses yet.

Table 3:

Countries with the highest total annual landed values (10-year average from 1997 to 2006) in Central and South Atlantic (FAO 31, 34, 41, 47) from the Sea Around Us Project (www.seaaroundus.org)

Country	Landed values (USD million)
Argentina	2,724
USA	1,411
Morocco	918
Spain	798
Brazil	766
Mexico	617
Japan	580
Korea Rep	562
Venezuela	553
Nigeria	547
Senegal	461
South Africa	402

Table 2:

Species with the highest annual average landed values (10-year average from 1997 to 2006) in Central and South Atlantic (FAO 31, 34, 41, 47) from the Sea Around Us Project (www.seaaroundus.org).

Taxon Name	Common Name	Landed values (USD million)
Merluccius hubbsi	Argentine hake	1,560
Marine fishes not identified	Pelagic fishes	1,341
Illex argentinus	Argentine shortfin squid	1,008
Thunnus obesus	Bigeye tuna	595
Crassostrea virginica	American cupped oyster	584
Sardina pilchardus	European pilchard	469
Macruronus magellanicus	Patagonian grenadier	422
Penaeus	Penaeus shrimps	360
Thunnus albacares	Yellowfin tuna	311
Sardinella maderensis	Madeiran sardinella	272
Farfantepenaeus aztecus	Northern brown shrimp	236
Litopenaeus setiferus	Northern white shrimp	216

Table 4:

Species with the highest annual average landed value (10-year average from 1997 to 2006) in Western Central Atlantic (FAO 31) from the Sea Around Us Project (www.seaaroundus.org)

Taxon Name	Common Name	Landed values (USD million)
Crassostrea virginica	American cupped oyster	584
Marine fishes not identified	Pelagic fishes	381
Penaeus	Penaeus shrimps	267
Farfantepenaeus aztecus	Northern brown shrimp	236
Litopenaeus setiferus	Northern white shrimp	216
Panulirus argus	Caribbean spiny lobster	175
Arca	Ark clams	96
Callinectes sapidus	Blue crab	91
Epinephelus	Groupers	74
Brevoortia patronus	Gulf menhaden	71
Sardinella aurita	Round sardinella	67
Thunnus albacares	Yellowfin tuna	62

Table 5:

Species with the highest annual average landed value (10-year average from 1997 to 2006) in Eastern Central Atlantic (FAO 34) from the Sea Around Us Project
(www.seaaroundus.org)

Taxon Name	Common Name	Landed values (USD million)
Marine fishes not identified	Pelagic fishes	578
Sardina pilchardus	European pilchard	469
Thunnus obesus	Bigeye tuna	364
Sardinella maderensis	Madeiran sardinella	272
Thunnus albacares	Yellowfin tuna	215
Sardinella	Sardinellas	181
Katsuwonus pelamis	Skipjack tuna	180
Engraulis encrasicolus	European anchovy	167
Octopoda	Octopuses	120
Sardinella aurita	Round sardinella	117
Farfantepenaeus notialis	Southern pink shrimp	110
Sepiidae	Cuttlefishes	105

Table 6: Species with the highest annual average landed value (10-year average from 1997 to 2006) in Southwest Atlantic (FAO 41) from the Sea Around Us Project
(www.seaaroundus.org)

Taxon Name	Common Name	Landed values (USD million)
Merluccius hubbsi	Argentine hake	1,560
Illex argentinus	Argentine shortfin squid	1,008
Macruronus magellanicus	Patagonian grenadier	422
Marine fishes not identified	Pelagic fishes	226
Loligo gahi	Patagonian squid	216
Zygochlamys patagonica	Patagonian scallop	135
Pleoticus muelleri	Argentine red shrimp	123
Genypterus blacodes	Pink cusk-eel	106
Micromesistius australis	Southern blue whiting	71
Penaeus	Penaeus shrimps	68
Cynoscion striatus	Striped weakfish	59
Micropogonias furnieri	Whitemouth croaker	48

Table 7:

Species with the highest annual average landed value (10-year average from 1997 to 2006) in Southest Atlantic (FAO 47) from the Sea Around Us Project
(www.seaaroundus.org)

Taxon Name	Common Name	Landed values (USD million)
Merluccius	Hakes	157
Marine fishes not identified	Pelagic fishes	156
Thunnus obesus	Bigeye tuna	150
Trachurus capensis	Cape horse mackerel	126
Engraulis capensis	Southern African anchovy	91
Trachurus trecae	Cunene horse mackerel	64
Sardinops sagax	Pacific sardine	62
Lophius vomerinus	Devil anglerfish	43
Plesiopenaeus edwardsianus	Scarlet shrimp	42
Genypterus capensis	Kingklip	35
Jasus lalandii	Cape rock lobster	35
Pseudotolithus	Croakers	32

Case study: West African nations

The east side of the Central Atlantic region is bounded by West African countries. West Africa is highly dependent on fish and fisheries as source of food and income. The average annual per capita food fish consumption of West Africa 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 1999–2003) (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 from 1999 to 2003, FAO, 2011), West Africans generally eat less animal protein than 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, vitamin A and vitamin B that 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, 2006). 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 are worth 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 West African 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 to be African exports, because the value of license agreement fees is counted in another category. Furthermore, the fisheries sector, particularly the artisanal sector, is a major source of employment and income for unskilled young men and women of coastal communities through direct and ancillary activities (FAO, 2006).

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 of Western Africa. Currently, fish stocks in West African waters are already overexploited, driven to a large extent by the dominance of foreign distant water fleets in the Exclusive Economic Zones (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 Sea (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; the former Soviet Union and China were also strongly involved. Moreover, some EU countries found an indirect way to fish in West African waters through joint ventures with local businesses. The total number of years foreign countries signed agreements with Western Africa 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 West Africa countries. Simultaneously, there was a strong demand for fisheries resources as source of food, income and livelihoods for coastal Western African communities. As a result, fisheries resources in West African waters are heavily exploited both by local fleets, which are mainly small scale artisanal, and foreign vessels starting in the 1960s.

This pressure has caused the decline of fish stocks; however, the demand for fish keeps increasing, as a result, fishers are using more and more sophisticated, sometimes destructive methods and illegal means, to fish (Pauly, 1990; McClanahan *et al.,* 2005). High-technology fishing techniques with the potential of finding the last remaining fish, which do not leave part of the stock to reproduce, are being used (Ovetz, 2007). Some fishing gears are simply destructive to the ecosystem, such as bottom trawling 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 dynamite fishing was banned through co-management (Overå, 2001). In addition, artisanal fishers, for example, 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 by-catch (Kelleher, 2005) and the 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). Therefore, the impacts of climate change (Lam *et al.,* 2012) and ocean acidification may add further stresses to the fisheries, economic and food security issue to this region.

3.3. Forecast (or scenarios)

Until now, the potential impacts of ocean acidification on marine species and their subsequent economic impacts in Central and South Atlantic are still not well-studied. However, some modeling studies have been already conducted in other regions. Although one global model (e.g., Cheung *et al.,* 2010) suggest that climate change may lead to increases in the potential fisheries catch in higher-latitude regions, follow-up studies with a model that accounts for hypothesized physiological effects of ocean acidification suggest that there may be a substantial reduction in potential fisheries catch in more acidic water in the North Atlantic (Cheung *et al.,* 2011). These potential changes are expected to have direct implications for fisheries and economies through changes in the quantity, quality and predictability of catches (Sumaila *et al.,* 2011).

Studies have shown that ocean acidification reduces coral calcification and favors invasive non-native algal species (Hoegh-Guldberg *et al.*,2007) and negatively affected shellfish and fish (e.g., Kroeker *et al.,* 2010, 2013). Hence, the diversity of coral ecosystems is likely to decrease. In one study by Brander *et al.* (2009), the loss in coral reef area was projected to range from 16% to 27% under different scenarios and the annual economic loss was estimated to be $870 billion in the A1 scenario in 2100. Cooley & Doney *et al.* (2009) also estimated that a substantial loss in revenue, job losses and indirect economic costs may occur in the United States because of ocean acidification, which may have serious impact on marine habitats and hence mollusk fisheries. As some countries depend heavily on mollusks for food and economics, countries with high vulnerability to ocean acidification were also identified in Cooley et al (2012). Although there is still no detailed study on the economic impact of ocean acidification on global fisheries, it seems reasonable to assume that the direct impacts associated with ocean acidification might eventually impose costs on the order of 10% of marine fishery production, perhaps something on the order of $10 billion/year (Kite-Powell, 2009). Moreover, given the strong probability that ocean acidification will act hardest on near-shore and smaller scale fisheries in this region, it has the potential to worsen food distribution inequality that already exists and remove an important source of revenue to coastal communities in Central and South Atlantic.

4. CASE STUDIES

Several iconic species and environments were identified that, if negatively impacted by ocean acidification, would immediately have socioeconomic effects because they are important to a range of human communities and span the full range of environments in the Central and South Atlantic Ocean. These might include: 1) Queen conch (*S. gigas*) in the Caribbean, which is commercially and nutritionally important, and governed over multiple boundaries through large marine ecosystem boundaries. 2) The Mesoamerican barrier reef, which has been the subject of a great deal of research. 3) Oysters, including aquaculture in Brazil and wild harvest in the United States. 4) Yellow clams (*M. mactroides*) along the South American coastline, which are fished in an artisanal scale fishery and are important to human communities for subsistence and identity. However, ocean acidification responses and effects on human communities for these case studies have not been determined yet. We can only infer possible responses based on those of closely related species (c.f. Kroeker *et al.*, 2013), underscoring the need for more research on these regionally critical species.

Of these species, the ocean acidification response of the Eastern oyster (*Crassostrea virginica*) has been best studied. Chapman *et al.* (2011) reported that the two environmental factors that dominate physiological effects for eastern oyster (*Crassostrea virginica*) are temperature and pH, which interact in a dynamic and nonlinear fashion to impact gene expression. Transcriptomic data obtained in their study provide insights into the mechanisms of physiological responses to temperature and pH in oysters that are consistent with the known effects of these factors on physiological functions of ectotherms and indicate important linkages between transcriptomics and physiological outcomes. Furthermore, Talmage and Gobler (2011) report negative effects on survival and growth (both speed and shell thickness) of *C. virginica* larvae.

5. POLICY RECOMMENDATIONS

It is widely acknowledged that the most important policy action that can be taken to mitigate ocean acidification is cutting atmospheric carbon dioxide levels, most effectively by addressing CO_2 emissions rates. Until that occurs, more regional policies will need to be implemented to encourage local mitigation or adaptation efforts responding to ocean acidification.

In the Central and Southern Atlantic Ocean, both small- and large-scale fisheries depend on species that could be harmed by ocean acidification. Marine management policies designed to regulate the location and quantities of marine harvests, or preserve vulnerable species, are most likely the first response that communities will take in the face of ocean acidification (e.g., Washington State Blue Ribbon Panel Report, 2012). If ocean acidification and temperature rise result in range shifts of vulnerable yet economically important species (Cheung *et al.* 2010), small-scale fishers will require local management strategies that are flexible enough to allow them to target a changing variety of species using different gear types. It is more likely that small-scale fishers will be able to change their fishing methods than their locations or ranges of fishing. Therefore, helping subsidize changing gear, retraining local fishers for other occupations, or helping identify and cultivate nutritional alternatives will likely be necessary for many local jurisdictions in the Central and Southern Atlantic, given the relatively low regional income and social resilience in many bordering nations. Large-scale fishers, on the other hand, may need policies that are geographically flexible (e.g. larger fishing areas) that allow them to go farther afield for the same species as long as it is economically feasible.

Lack of consideration for the potential future consequences of ocean acidification in this region by policymakers could result in policies that are appropriate at present but do not build a resiliency “cushion” into ecosystems that will prepare them to withstand chronic temperature and acidification stresses coming in the next several decades. For example, policies that permit destructive use of coral reefs could decrease coral habitat and structure enough that the system is closer to a “tipping point” (Hoegh-Guldberg *et al.* 2007) and more likely to become irrevocably damaged by acidification in the near future. Eliminating dynamite fishing, as several nations already have, is a good example of one possible way to build additional resiliency into marine ecosystems by not wasting extra natural resources.

5.1. Survey of policy mechanisms

Because the Central and South Atlantic has not experienced demonstrated negative consequences from ocean acidification yet, it is difficult to predict what policies or governance approaches will be most appropriate. However, there are some general principles that have been successful elsewhere that will likely be useful here as well. Close coordination among local, regional, and national authorities as well as user groups and researchers has been demonstrated to yield quick, effective responses to ocean acidification events elsewhere (Washington State Blue Ribbon Panel, 2012). Involving end-users in decision-making and governance leads to more effective outcomes. Support for social systems is needed to facilitate shifts within the human community that may become necessary, such as livelihood diversification and education, due to changes in marine benefits from acidification or other environmental changes. All of these principles can be more challenging in nations like those bordering the Central and South Atlantic, which are less wealthy and less well developed, and which depend more heavily on local fisheries for animal protein and family income.

6. Suggestions for further research needed to fill the gap between natural sciences and economics

Several general knowledge gaps exist in the natural science that could provide economically relevant information. In most of the Central and South Atlantic (especially FAO regions 31, 41, and 47), commercial harvests of crustaceans (lobster, crabs, shrimp) provide high commercial revenue, yet more research is needed to verify whether or not they are vulnerable to ocean acidification. Furthermore, an understanding of baseline ocean chemistry and community conditions is needed, especially in coastal zones where more vulnerable species (like bivalve mollusks) are harvested. This understanding will allow later assessments of change in regional ecosystems relative to today's baseline. Future global change studies should be integrated to address the effects of multiple stressors including ocean acidification, change in surface temperature, sea-ice extent, and decrease in dissolved oxygen concentrations (and the increase oxygen minimum zones (hypoxia)) on marine ecosystems, rather than individual species. Multiple stressor research is important at all scales, from large marine ecosystems (LMEs) to small-scale fisheries. Most economically important for the Central and South Atlantic region are studies determining how or whether ocean acidification will affect the harvest of significant quantities of top predatory finfish or iconic local species.

From a policy standpoint, several opportunities exist at local to basin scales. A regional fisheries management organization in FAO area 41 is needed to address ocean acidification as well as other regional issues in fisheries planning, especially for management of squid and other transboundary species. In smaller-scale fisheries, local community-focused adaptation policies are likely to be most effective for responding to changing conditions caused by ocean acidification there. However, these are most effective for overall management of small-scale fisheries, and developing these policies does not represent a major shift; rather, it represents a slight expansion of the breadth of issues being presently considered and the timescale of their action.

Depending on how ocean acidification manifests in the Central and South Atlantic Ocean, it has the potential to worsen social inequalities that already exist. The strong economic importance of finfish fisheries in the central and south Atlantic Ocean that will likely not be directly affected by ocean acidification could partially obscure the large potential for certain communities and sub-regions to be affected by ocean acidification. Many commercially and culturally important mollusk species and reef-habitat-dependent fish species may be affected by ocean acidification, given the negative response of closely related mollusk and coral species investigated in other studies. These species are usually harvested by smaller scale and artisanal fishers, in contrast to the large industrialized finfish fisheries in the Central and South Atlantic. The dissimilarity of these two fishery categories and their responses points to the need for policy and adaptation research that address different scales: industrial and large scale vs. artisanal and small scale. It may be worthwhile to frame this work in these two major categories to organize impacts and responses.

The possible effect on fisheries targeting commercially important and or food security species call for answering to essential questions: (i) How could we incorporate ocean acidification effects in the bio-economics of mollusks and crustacean fisheries?, and (ii) How can we deal with new uncertainties inherent to the effects of ocean acidification on calcifying species and coral reef ecosystems in the absence of probabilities of occurrence of possible states of nature (i.e. possible ocean pH changes)? In seeking to address these questions and put answers into action, we must keep in mind realistic use patterns and human behavior. For example, it is important to rebuild sustainable fishing and resilient populations, but to do so in the most suitable places, for example, shallower and more productive marine ecosystems. Adaptive responses to these changes should include 1. technological (e.g. modification of fishing gear), 2. behavioral (e.g. choice of fishing grounds and/or target species), 3. managerial (e.g. human resources management) and 4. policy (e.g. fisheries management) components to be most effective.

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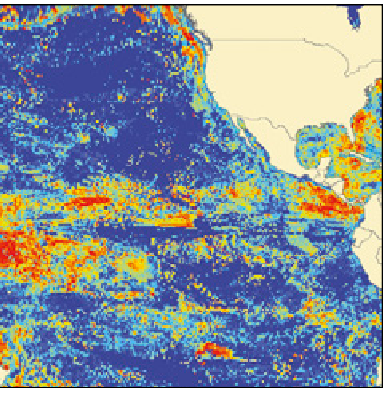
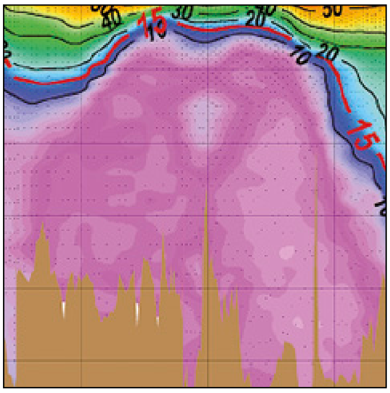
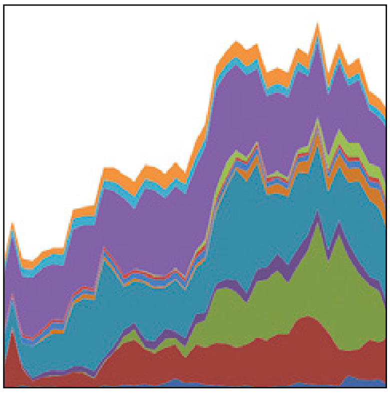
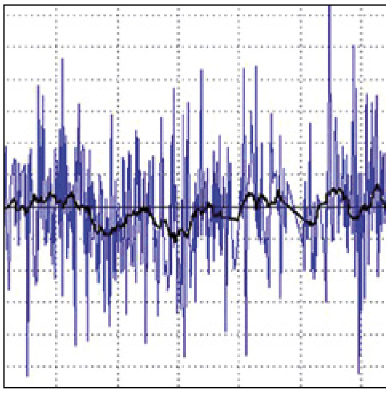
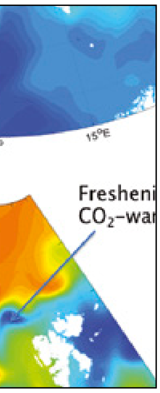


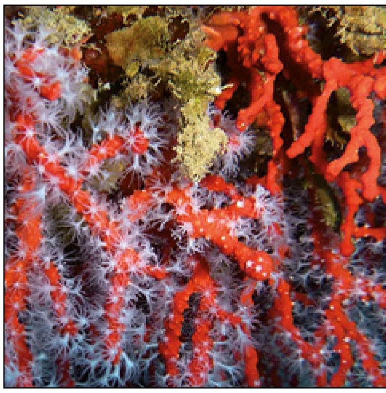
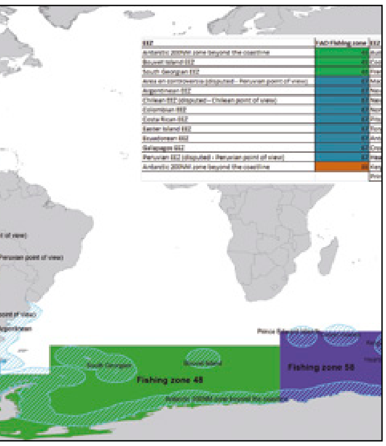
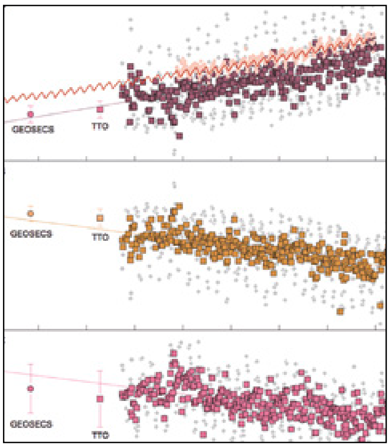

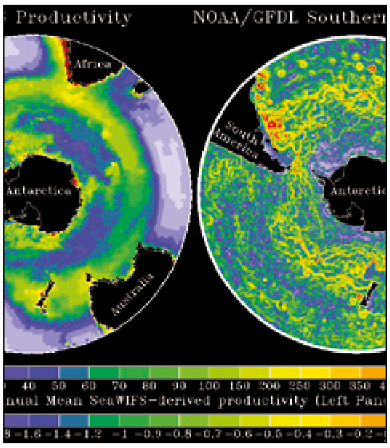

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