

## The Southern Ocean and South Pacific Region

K. Kelleher (kkelleherWB@gmail.com), Michel Warnau (M.Warnau@iaea.org), Pierre Failler (Pierre.Failler@port.ac.uk), Gretta Pecl (Gretta.Pecl@utas.edu.au), Carol Turley (CT@pml.ac.uk), Gilles Boeuf (gilles.boeuf@mnhn.fr), Dan Laffoley (danlaffoley@btinternet.com), Laura Parker ([L.Parker@uws.edu.au](mailto:L.Parker@uws.edu.au)) and Leigh Gurney.

### EXECUTIVE SUMMARY

The Region comprises three sub-regions (FAO Statistical Areas) with very different characteristics. The South Pacific includes the vast and virtually unpopulated Southern Ocean surrounding the Antarctic. It has the world's largest fisheries off Peru and Chile and some of the world's best managed fisheries in Australia and New Zealand. The Region has over 27% of the world's ocean area and over 98% of the Region's total area of 91 million km<sup>2</sup> is 'open ocean'. The Region contains less than 5% of the global continental shelf area only a fraction of this area is covered by three large marine ecosystems (the New Zealand Shelf, the Humboldt Current and the Antarctic LMEs). The Humboldt Current System (HCS) is the world's largest upwelling which provides nutrients for the world's largest fisheries. The Region also has a high number of seamounts

The marine capture fisheries of the Region produce over 13 million tons annually and an expanding aquaculture industry produces over 1.5 million tons. Peru's anchoveta fishery provides about half the world's supply of fish meal and oil, key ingredients of animal and fish feeds. El Niños, or more generally as El Niño Southern Oscillations (ENSOs) can substantially change the species composition of the key small pelagic catches (anchovy, sardine, horse mackerel and jack mackerel) causing production to fluctuate from about 4-8 million tons. Partly due to the lack of upwellings and shelf areas, fisheries production in the Southern Ocean and Area 81 is relatively small but supports economically important commercial and recreational fisheries and aquaculture in New Zealand and in New South Wales (Australia). Krill remains a major underexploited resource, but is also a keystone species in the Antarctic food web. The Region is home to numerous endangered species of whales, seals and seabirds and has a high number of seamounts, vulnerable ecosystems fished for high-value species such as Orange roughy.

The fisheries and ecosystems of the Region are highly vulnerable to ocean acidification (OA), particularly when associated with the stresses from ocean warming and low oxygen. OA is likely to have negative impacts in the Region, but some opportunities may also arise for culture of seaweeds, or expansion of fisheries for species with higher resilience to OA. Other stresses include commercial fishing, ocean warming, and pollution. As the Southern Ocean and the HCS are areas where OA will have substantial and early impacts, a strong case can be made for the Region to invest in the science of OA and to pilot adaptation and mitigation measures.

Given the economic importance of fisheries in the Region, countries have well-developed fisheries management regimes and a strong marine science capability. The limited number of major industrial fisheries enterprises also suggests opportunities for broad stakeholder dialogue and engagement. Regional fisheries bodies have espoused an ecosystem approach to fisheries which creates the opportunity to include OA considerations in the preparation of scientific advice and the decision-making process.

The long term priority is to move towards reduction in GHG emissions and the Region can play an important role in pursuing an 'OA agenda' in international fora. In the medium term, the Region can envisage a range of actions to mitigate and adapt to the effects of OA. These include actions to enhance knowledge of the impacts and piloting policies and strategies for conservation and sustainable use of marine resources that take account of the impacts of OA. Raising stakeholder and public awareness will be an important step in generating initiatives and financing OA knowledge management and research and developing OA

engagement strategies for the Region's capture fisheries and aquaculture. 'Technical' questions arising in the Region include the impact of OA on the Southern Ocean keystone species – krill; the impact of the combined stressors of OA and low oxygen in the Humboldt Current System; the need to increase understanding of the adaptive capacity of cultured molluscs to OA; and the need for expanded data on OA trends throughout the vast Region. Addressing these and other questions will contribute to the understanding of the economics of ocean acidification in the Region.

## 1 THE SPECIFICITIES OF THE REGION

The Southern Ocean and South Pacific Region comprises three sub-regions (FAO Areas) with very different characteristics. The Region includes the vast and virtually unpopulated Southern Ocean, the world's largest fisheries off Peru and Chile and some of the world's best managed fisheries in Australia and New Zealand. The Region is highly vulnerable to ocean acidification (OA), ocean warming and low oxygen, provides lessons in governance and the limited number of key actors provide basis for dialogue and action. While OA is likely to have primarily negative impacts in the Region, some opportunities may also arise. Targeted actions could be considered on knowledge management and research, management of capture fisheries and aquaculture and OA engagement strategies.

### 1.1 Geography

This chapter focuses on three distinctly different ocean areas comprising five FAO Fisheries Areas (the major geographical units used by FAO to group fisheries statistics). These are: the Southern Ocean (FAO Areas 48, 58, 88) surrounding Antarctica, considered as a single area for the purposes of this report; the Southwest Pacific (FAO Area 81), centred around New Zealand; and the Southeast Pacific (FAO Area 87), dominated by Peru and Chile. The areas are illustrated in figure 1.

There are few similarities between these areas. Peru and Chile are home to the world's largest single-species fisheries, dominated by anchovy and other small pelagic species. These fisheries are heavily influenced by the world's largest upwelling system and changing oceanographic conditions, in particular the decadal oscillation, El Nino. In contrast, Area 81 is the FAO area which consistently reports the lowest catches, attributable partly to the small shelf areas, low population and challenges posed by fishing remote ocean areas. The Southern Ocean is a vast but relatively fragile ecosystem particularly vulnerable to climatic change, with negligible population and low but expanding fishery production.

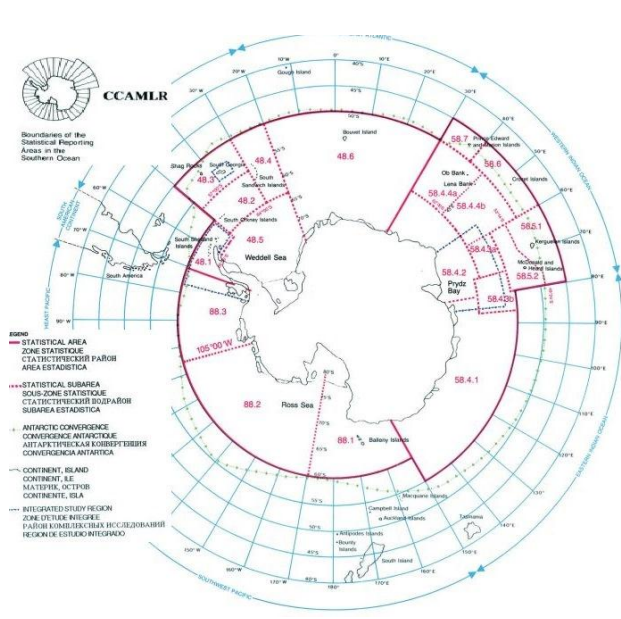
Despite the Region's vast area, only a fraction of this area is covered by three large marine ecosystems (LMEs; the New Zealand Shelf, the Humboldt Current and the Antarctic LMEs), suggesting massive 'open system' drivers of ocean processes, compared to the relatively more 'discrete' drivers in LMEs. The Region's oceanic area is over 98% of the Region's total area (91 million km<sup>2</sup>), which covers over 27% of the world's oceans. However, the Region contains less than 5% of the global continental shelf area.

**Table 1. Surface area of FAO Areas 81, 87 and the three Southern Ocean areas (in km<sup>2</sup>)**

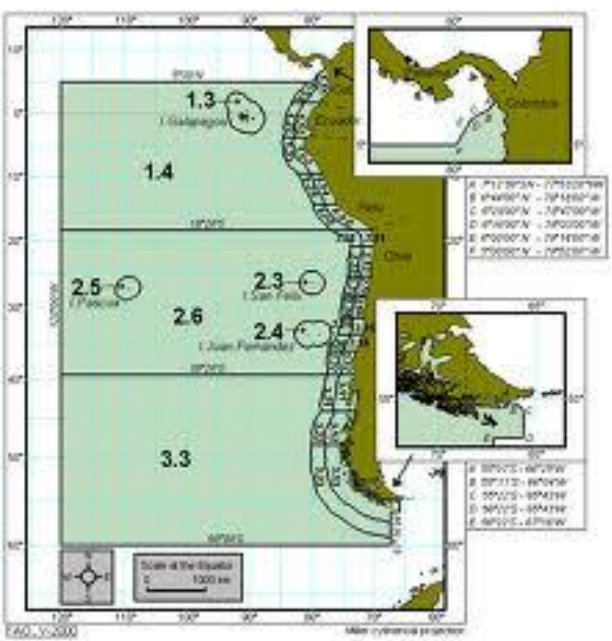
In km <sup>2</sup>	Total area	Continental shelf	Oceanic area
Southern Ocean Areas 48, 58, 88	33.97	0.52	33.45
FAO Area 81	27.66	0.41	27.25
FAO Area 87	30.80	0.57	30.23
Total	92.42	1.50	90.92
% of global	27.8%	4.7%	25.8%

Source FAO.

Coral reefs exist in the Region. They occur, for example, along the coast of Columbia and the Northern Island of New Zealand. However, as coral reef fisheries are discussed extensively in other chapters, the impact of OA on these fisheries is not addressed here.

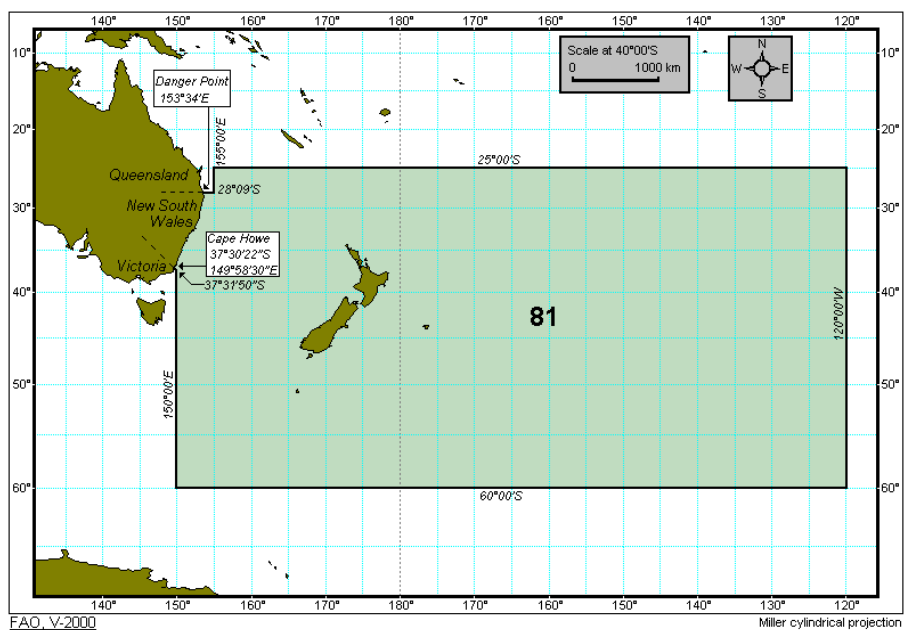


FAO Areas 48, 58, 88



FAO Area 87

Figure 1. The South Pacific Region and Southern Ocean showing the five FAO Statistical Areas.



FAO Area 81

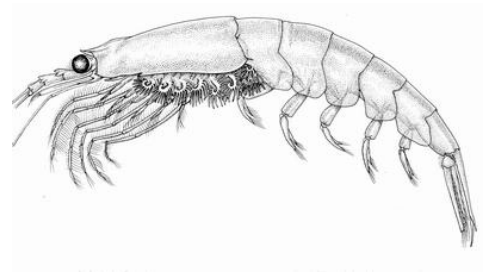
1.2 Overview of fisheries production

The Region has some of the world’s major fisheries, including the world’s largest – Peru’s anchoveta fishery. Chile also has major fisheries for mackerels, anchovy and squid and important coastal aquaculture. The anchoveta fishery provides about half the world’s supply of fish meal and oil, key ingredients of animal and fish feeds. Production varies from about 4-8 million tons in response to ocean temperatures with decadal intrusions of warm tropical waters reducing productivity of the Humboldt Current ecosystem. These events, referred to as El Ninos, or more generally as El Nino Southern Oscillations (ENSOs) can substantially change the species composition of the key small pelagic catches (anchovy, sardine, horse mackerel and jack mackerel).

In contrast to the export driven fisheries of Chile, Peru and Ecuador, the relatively narrow shelf areas off New South Wales<sup>2</sup> (Australia) means that production generally supplies the local markets. New Zealand is a significant producer and exporter of hoki, squid, and shellfish. Extensive offshore deepwater plateaus around New Zealand have fostered important fisheries for Orange roughy, alfonsino and other deepwater species. However, difficulties in managing these fragile deepwater and seamount resources have resulted in declines in the catches of these species. Although production is dominated by industrial fisheries, small scale fisheries are socially and economically important throughout the Region, particularly in Latin America. Recreational fisheries are important in New South Wales and in tourist destinations throughout the Region.

All the countries<sup>3</sup> in the Region have an expanding aquaculture industry. Chile is the world's second largest producer of salmon. New Zealand and Australia also produce salmon (not in NSW). New Zealand is a large producer of green mussels. Most countries produce oysters, and scallops with Chile becoming a global player in shellfish aquaculture.

The Southern Ocean has a relatively modest production in the order of 200,000 tons annually<sup>4</sup>. However species such as Patagonian toothfish, mackerel icefish are among the world's most high priced fish. Only a fraction of the total allowable catch (TAC) for krill (3.7 million tons) (figure 2) is harvested. New technologies are being introduced to profitably harvest krill, one of the few major global fish resources which remains substantially underexploited<sup>5</sup>. Krill is primarily used as a high-value fish feed, but an expanding range of pharmaceuticals and food additives are being developed from krill.



**Figure 2. Krill, *Euphausia superba***

The Region provides a range of lessons on fisheries governance. Australia's fisheries management plans provide useful lessons on applying an ecosystem approach<sup>6</sup> and Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR) has pursued an ecosystem approach for several decades in managing the fisheries of the Southern Ocean. An ecosystem approach to fisheries (EAF) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries. New Zealand's fisheries are well known for a strong economic approach and well-developed rights-based approach. The economic approach to fisheries management focuses on generating economic returns and maintaining the wealth and capital value of fisheries. A rights-based approach draws on the idea that stronger tenure over fisheries resources creates incentives for better management; and where the fishing rights are tradeable, overcapacity will tend to exit the fishery as vessel operators sell their fishing rights. Peru has introduced a range of reforms greatly improving the profitability of the anchoveta fishery. Chile has recently taken steps to reform its aquaculture governance following a collapse in the salmon farming industry.

A range of regional fisheries bodies illustrate various cooperation modalities. These include the South Pacific Regional Fisheries Management Organisation (SPRFMO), responsible for high seas resources, excluding tuna); the Western Central Pacific Fisheries Management Commission (WCPFC), responsible for management of tuna in the Western Pacific; the Inter-American Tropical Tuna Commission (IATTC, responsible for tuna in the Eastern Pacific); the Permanent Commission for the South Pacific (CPPS, responsible for maritime policy in the Southeastern Pacific); and CCAMLR (responsible for management of

<sup>2</sup> Note that effectively only New South Wales is part of Area 81.

<sup>3</sup> The main countries are as follows: Australia, New Zealand, Columbia, Ecuador, Peru and Chile. Other countries have overseas possessions, territories or islands in the region (i.e. the three FAO areas combined), where aquaculture can be considered negligible. These countries include: France, UK and South Africa.

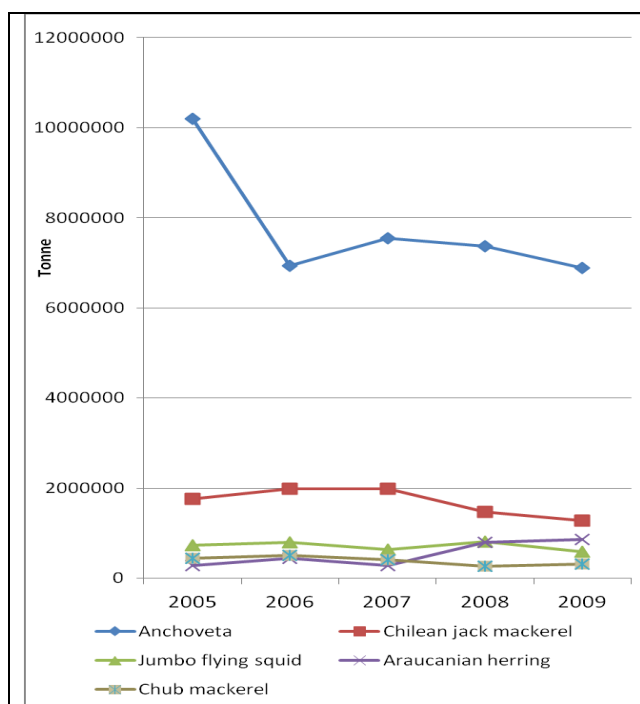
<sup>4</sup> CCAMLR recorded catches.

<sup>5</sup> Nicol, S. and Endo, Y. 1997. Krill fisheries of the world. FAO Fisheries Technical Paper. No. 367. Rome, FAO. 1997. 100p.

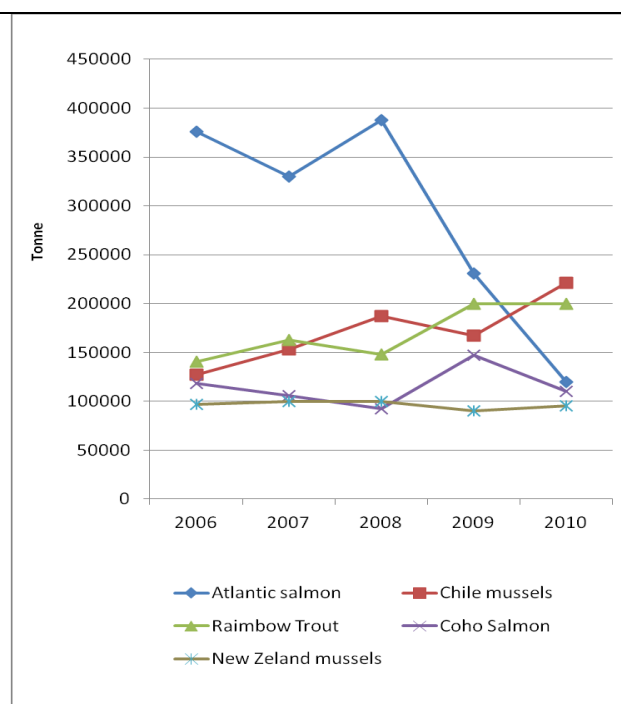
<sup>6</sup> FAO Fisheries Department. 2003. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2. Rome, FAO. 2003. 112 p

Antarctic fisheries and other living marine resources, excluding whales)<sup>7</sup>. Non-governmental organisations also play a role in the conservation and management of the Region. These include Coalition of Legal Toothfish Operators (COLTO) and Birdlife, one of many organizations focused on conservation of albatross and other birds threatened by fisheries and changing ecosystems.

Figures 3 and 4 illustrate the trends in the catches of the top five species and the trends in production of the top five cultured species dominated by anchoveta and salmon respectively. The production trends are dominated by two features. In the case of capture fisheries, it is the influence of El Nino and fishing pressure on the anchoveta fisheries in Peru and Chile. In the case of aquaculture it is the collapse of the salmon industry in Chile (now recovering), due directly to disease and indirectly to weak environmental governance of the industry. The fisheries are of major importance in both Peru and Chile and of considerable socioeconomic importance in New Zealand.



**Figure 3. The top five capture fisheries species(83% of total catches)**



**Figure 4. The top five aquaculture species (87% of total production)**

Source: FAO, FishStat

### 1.3 Main stressors

The fisheries of the Region are subject to multiple stressors including: fishing, OA, changing sea temperatures, salinity and dissolved oxygen. Fisheries production is also subject to the substantial variability of the upwelling of the Humboldt and other currents and their interplay with El Nino's and other climate-driven forces. While the impact of individual stressors can often be projected or modelled, the current understanding of the combined impact of multiple stressors is poor.

<sup>7</sup> The International Whaling Commission has a global mandate.

### 1.3.1 Ocean Acidification

Ocean acidification poses severe potential threats to Southern Ocean ecosystems<sup>8</sup> in particular. The relative undersaturation of calcium carbonate (CaCO<sub>3</sub>) in the Southern Ocean means that ocean acidification is likely to have its greatest initial impacts there if the level of atmospheric CO<sub>2</sub> continues on its projected trajectory.

Even under the more conservative IPCC S650 scenario, which assumes that atmospheric CO<sub>2</sub> will only reach 563 ppm by 2100, aragonite, a form of calcium carbonate essential to shell forming in pteropods, krill and other animals that form the base of the Southern Ocean food chain, will be largely unavailable in deeper areas. For example, aragonite is only likely to be available in the first 60 meters of the water column (currently in the top 730 m of the Southern Ocean). The entire Weddell Sea (an important part of the Antarctic ocean) is projected to be aragonite undersaturated, giving rise to radical change in the Weddell Sea food chain with likely consequences extending to whales, penguins, albatrosses and seals.

The impact of OA in area 87 (Southeast Pacific) is likely to be substantial. Model results (Egger 2011) reveal large regional variability in the Humboldt Current System's (HCS) vulnerability to ocean acidification, which is determined by longterm changes in the carbonate chemistry superimposed on natural regional variations. An initial qualitative assessment of how future ocean acidification in the HCS could affect marine organisms and ecosystems indicates that 'the natural envelope of seasonal variability in aragonite saturation levels is probably larger than the variation between present day and 2050 in the upwelling areas.' However, a bias in the model used possibly underestimated the evolution of ocean acidification in the HCS and its impact on marine organisms and ecosystems. Essentially, it is likely that there will be a progressive reduction in the healthy ocean space available for production of shellfish and other calcifiers (animals that require calcium to form their shells, or skeletons). Figures 5 and 6 illustrate these trends. In addition, the integrity of the fragile and unique Galapagos marine ecosystem is likely to be threatened from a combination of OA, fishing and other stresses associated with population increase, tourism and economic development.

As the geographical range of Area 81 stretches from the Southern Ocean to the sub-tropical seas of Australia, the effects vary widely. The fringes of the area are likely to be influenced by the effects described with respect to the Southern Ocean and the Humboldt Current System. The mix of fisheries ranges from the oceanic jack mackerel and Pacific blue whiting to deepwater Orange roughy and to squid, hoki and lobster. The effects on the pelagic and deepwater resources are not known. The effects on shellfish are likely to include lower growth rates, lower larval survival, lower shell weight, possibly leading to higher levels of predation and greater vulnerability to disease. Where additional stresses exist, these effects are likely to be amplified and the negative impacts on shellfish fisheries increased. These cultured species include green mussels, Pacific oyster and Sydney Rock oyster, scallops and salmon. The capture fisheries species include the pelagic species, the deepwater finfish species, deepwater crab, Wellington squid, hoki and tuna.

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<sup>8</sup> Orr et al (2005)

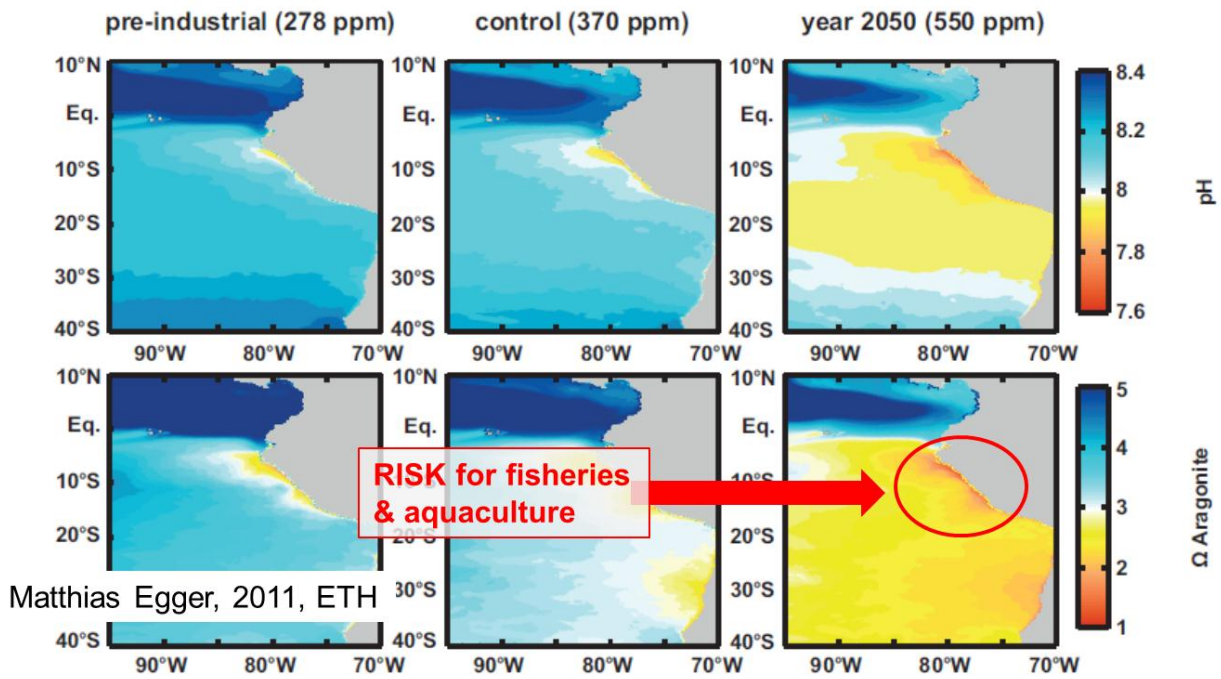


Figure 5. A dramatic decrease in pH and aragonite saturation is projected in the Humboldt Current system (Source: Egger 2011)

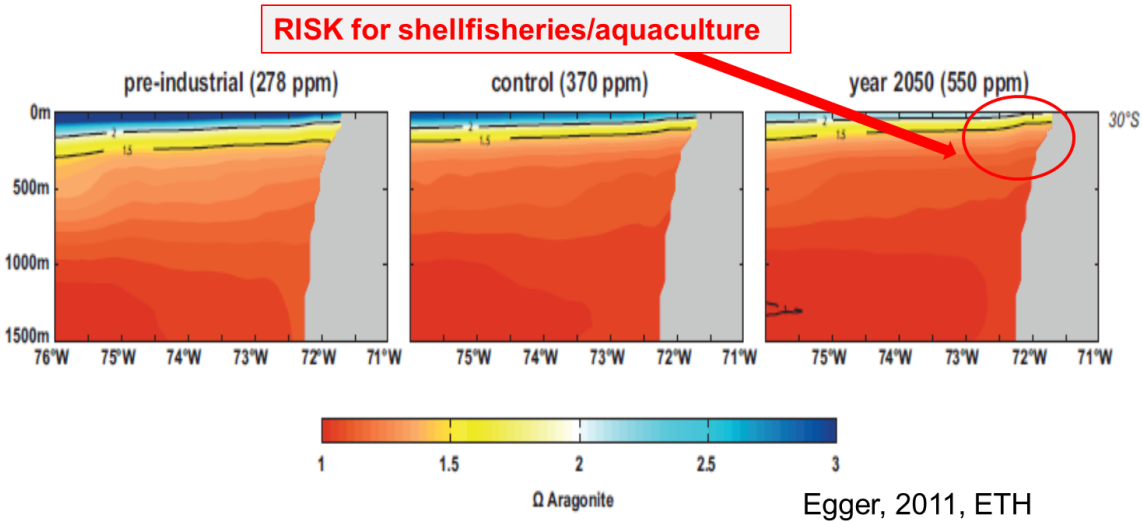


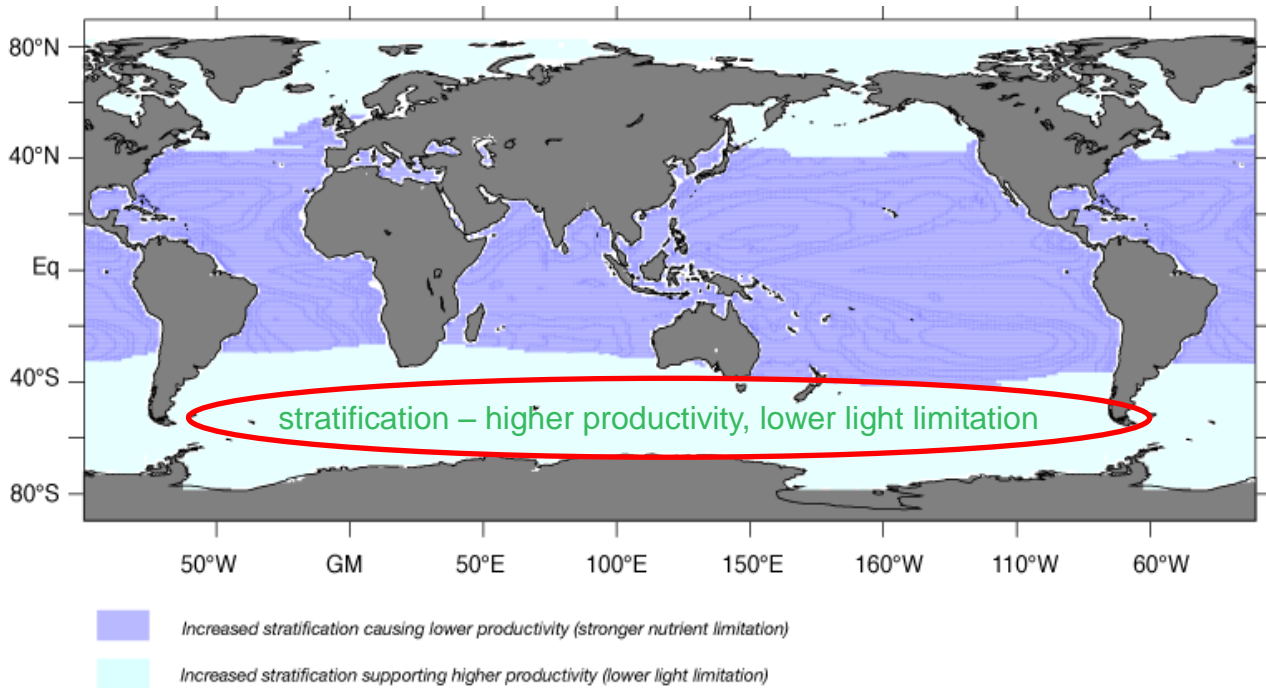
Figure 6. Major reduction in healthy living space by 2050:

### 1.3.2 Changes in ocean temperature and salinity

In addition to significant acidification, the Southern Ocean is also generally warming. This will cause greater stratification of the water column – a more well-defined differential between warmer upper layers and colder deeper waters, which in turn will limit nutrient transfers from the richer deeper waters to the more productive surface layers. On the other hand a warmer Southern Ocean is expected to have higher productivity due to reduced light limitation (Figure 7), but this increase may be modulated by micro- and macro-nutrient

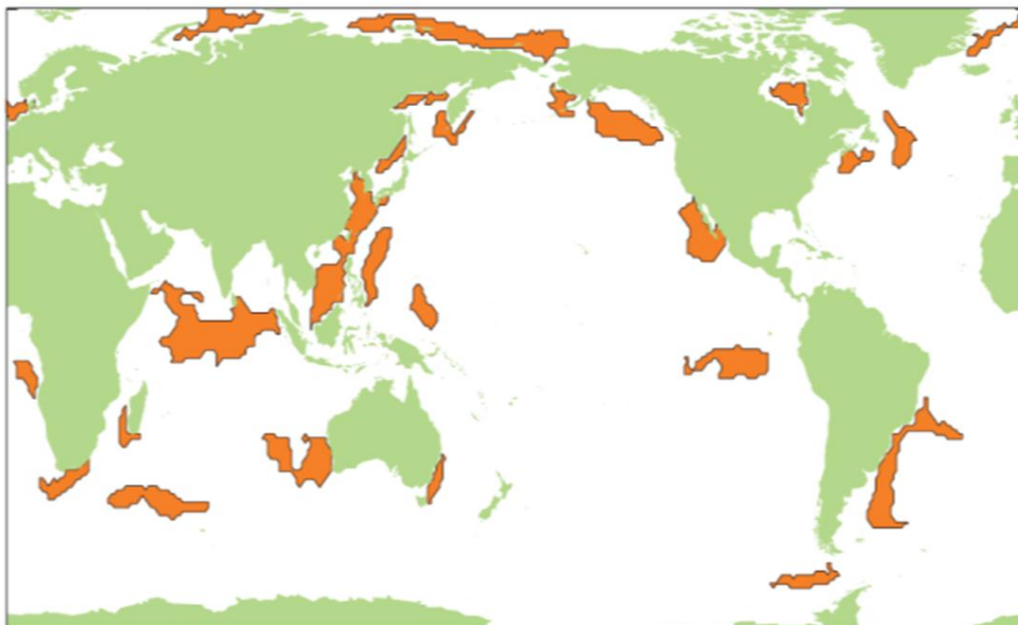


availability. The net outcome of the changes in these driving forces is unclear, in particular the conversion of any increased productivity into commercial fish biomass.



**Figure 7. Stratification resulting from ocean warming may increase productivity in the Southern Ocean**

Moreover, in Southern Ocean and Antarctic waters the warming is occurring throughout the entire water column, that is, it is not limited to surface waters and it is occurring at a high rate in comparison to other ocean areas. It is not only the Southern Ocean that is threatened by increased ocean temperatures as four of the world's ocean warming hotspots are in the South Pacific Region (see figure 8). The salinity of Antarctic waters may also change as a result of ice melting. Salinity gradients are closely related to temperature and stratification and the combined effects of OA, ocean warming and salinity changes are unknown.



**Figure 8. Ocean warming hotspots**  
(Hobday and Pecl, in press)

There is substantial evidence that ocean warming will allow warmer water species to extend their range polewards (Last et al 2010, Johnson et al 2011, Burrow et al 2014). Ocean warming will allow disease organisms and invasive species can extend their range, while the warmer oceans can disrupt life cycles, predator prey relationships and potentially result in ecosystem regime shifts. In addition to ocean acidification, increasing temperatures and expansion of low oxygen zones, many farmed species in the Southwest Pacific and Southeast Pacific face stressors such as salinity fluctuations and disease, particularly in estuarine locations, possibly resulting from sea-level rise and/ or increased, or erratic rainfall causing large freshwater intrusions of flooding of estuarine areas.

### **1.3.3 Fishing and other stressors**

Overfishing is a major stressor, largely attributable to weak governance of fisheries involving poorly designed management regimes or failure to effectively apply management measures. Illicit fishing activities are further expression of poor governance. Weak aquaculture governance is also likely to lead to stresses, for example, pollution of down-current fish farms, escapement and interbreeding of escaped fish with wild stock leading to a loss of genetic diversity which may have survival value in increasingly acidic seas.

Pollution is clearly a major stressor and the vast proportion of marine pollution originates from land-based sources<sup>9</sup>. In Peru and Chile mining effluent is a significant pollutant and local pollution from fish meal processing plants and from urban wastes exists. Area 87 is well south of 'the garbage patch', but marine garbage and micropollutants are growing ubiquitous problems. Altered rainfall patterns can have an additional, and sometimes quite serious, polluting effect by washing agricultural fertilizer into rivers. Wind has a significant influence on surface waters and upwelling systems and changing wind patterns may amplify the other stressors such as rainfall or wave action. Areas of low primary production such as off the coast of Columbia and Ecuador and increased UV exposure in the Southern Ocean may also act as stressors for marine species in these areas.

## **1.4 Biological and chemistry characteristics**

### **1.4.1 Southern Ocean**

The sea surface temperature of the Southern Ocean ranges from about -1.8°C near the Antarctic coast to about 3.5°C at the polar front. Despite the cold water, the Southern Ocean is one of the more productive parts of the world ocean. Although chemical reactions and metabolic rates are slower where it is colder, the major limiting factor for marine productivity is not temperature but nutrient availability. Nutrient availability is linked to upwelling and in the Southern Ocean and upwelling is connected to the seasonal formation and melting of sea ice.

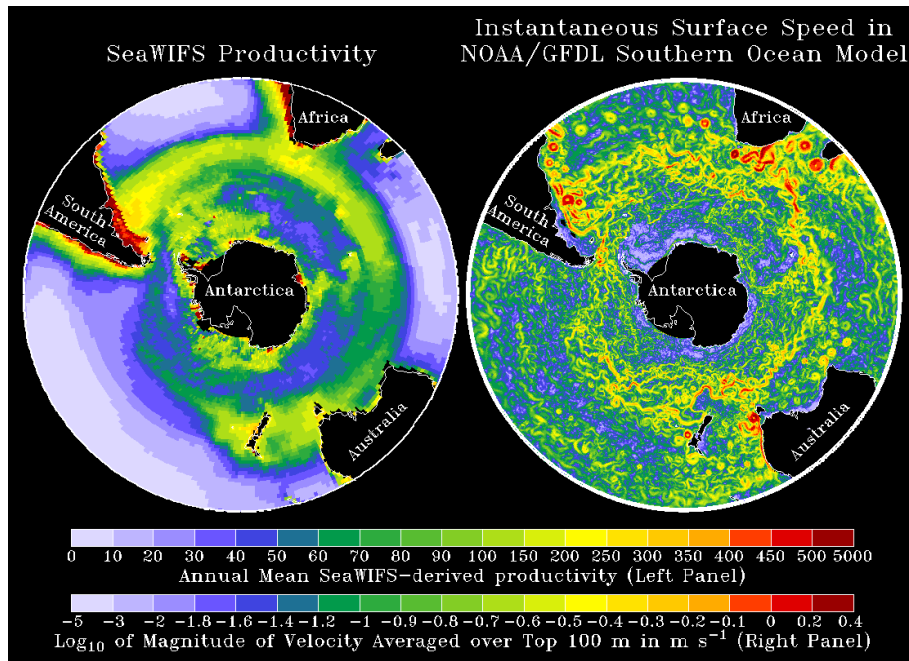
As sea ice forms some salt is expelled into the surrounding water. This increases the salinity causing the sea water to become denser than surrounding water a process aided by the cooling of surface water to subzero temperatures. The colder more saline higher density water sinks and is replaced at the surface by water from deeper in the ocean that is warmer and less dense. Some of the excess salt produced during sea ice formation is also held in pores or spaces inside the sea ice, so the process continues in the spring and summer when meltwater ponds on the surface of the sea ice drain through the ice washing out the salts. This process causes the exchange between surface and deepwater that keeps the surface of the Southern Ocean supplied with nutrients and is also linked to the formation of Antarctic Bottom Water – the deepwater current which is part of the 'global ocean conveyor' system that helps heat from tropical to higher latitudes.

There is considerable variation in productivity throughout the Southern Ocean and throughout the year. On average roughly 50 tonnes of carbon is fixed per 100km<sup>2</sup> of sea by phytoplankton. The location of

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<sup>9</sup> <http://www.gpa.unep.org/>

productivity shifts during the year depending on the distribution of sea ice. As sea ice retreats in summer, centres of productivity move closer to the continent. Nutrients tend not to be completely depleted in the surface zone during the period of phytoplankton growth, due primarily to limitation of the micro-nutrient iron. If iron were more abundant in the Southern Ocean, then phytoplankton production would be even higher. Because of the relatively high ratio of macro-nutrients to phytoplankton abundance, the Southern Ocean is referred to as a 'high nutrient – low chlorophyll environment' - the world's largest high nutrient – low chlorophyll environment area.



**Figure 9. Plankton blooms in the Southern Ocean may also be linked to eddy activity** (Source SeaWiFS. <http://www.gfdl.noaa.gov/visualizations-oceans>)

In a warmer Southern Ocean, primary productivity will increase, but it is uncertain if the productivity will be captured at upper levels in the food chain, i.e., converted into commercial fish biomass. The overall impacts on fisheries are largely unknown. The future vulnerability is likely to be substantially different for the key species – for the planktonic krill, for the benthic toothfish and for a range of animals in higher trophic levels: marine mammals, penguins, albatross and other seabirds. The phytoplankton blooms are the base of the food chain, but the primary productivity is transferred to the upper trophic levels by krill and pteropods which have a unique vulnerability to OA.

#### 1.4.2 Southeast Pacific Area 87

Area 87 is dominated by the Humboldt Current System (HCS), the world's largest Eastern Boundary Upwelling with multiple upwelling cells along the coasts of Peru and Chile. The system is characterized by upwelling of high CO<sub>2</sub>, low pH, low O<sub>2</sub> relatively cold waters, so nutrient upwelling drives productivity but with associated risks of oxygen depletion and 'dead' zones. The El Nino is the dominant influence in the on the Humboldt Current system.

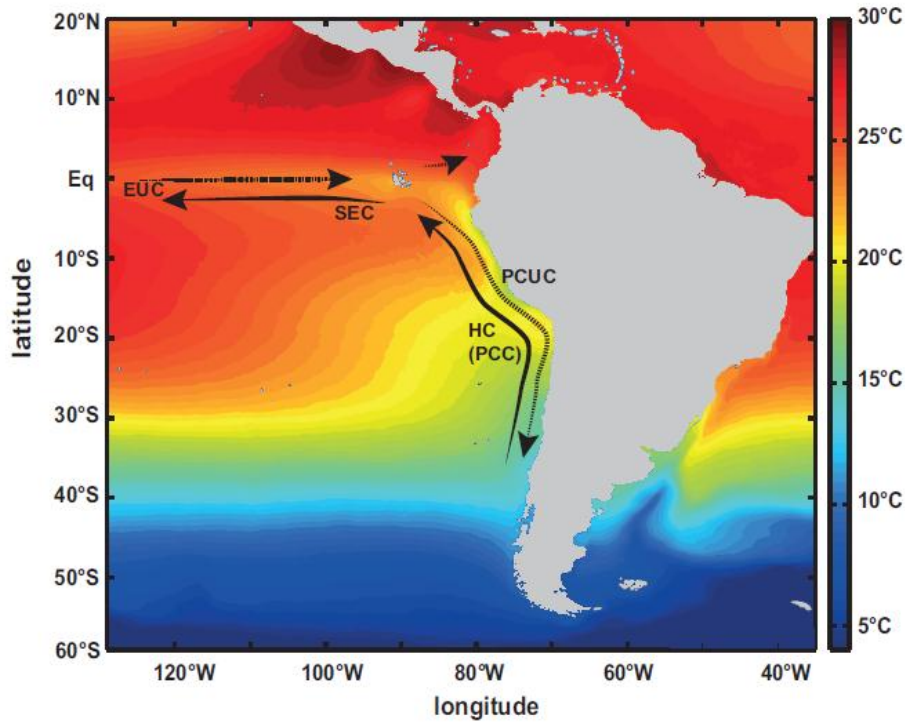
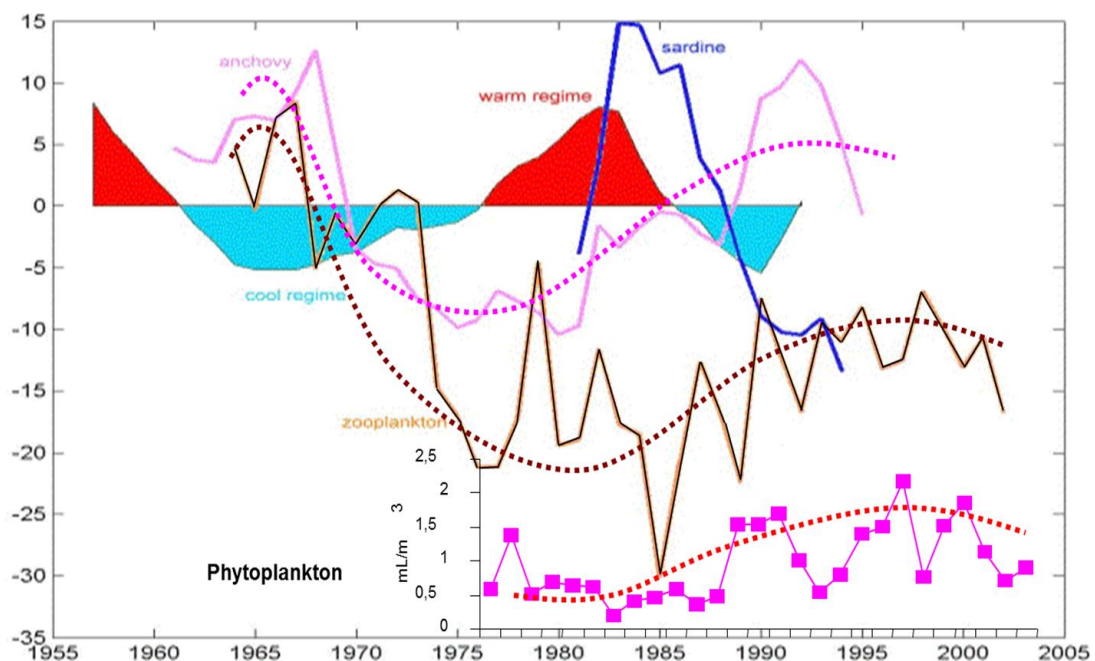
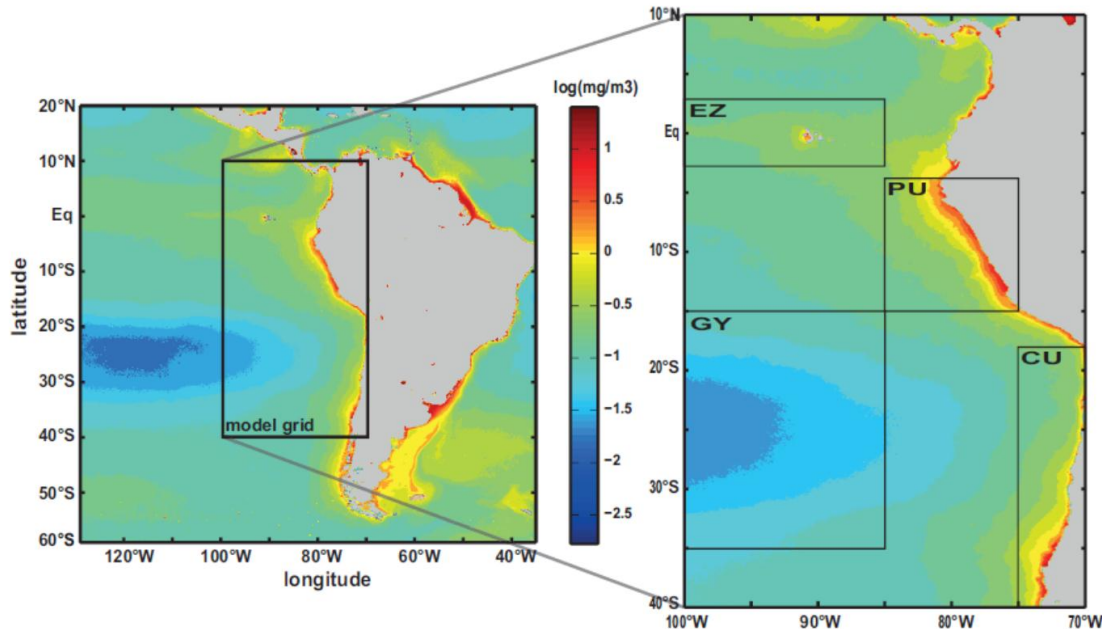


Figure 10. Sea-surface temperature in the Humboldt Current (°C)

Primary productivity varies between  $150\text{-}300\text{ gCm}^{-2}\text{yr}^{-1}$  driven by the upwelling system and interrupted by EL Nino events. By affecting the planktonic food sources for fish, and in particular for juvenile anchovy and sardine, the El Nino causes regime shift in the species composition of the main small pelagic fisheries alternating between anchovy and sardine dominated regimes and shifts in the horse mackerel and chub mackerel populations. The anchovy and sardine populations however do not always vary synchronously. These species changes can have negative consequences for the fishing industry and the economies of the countries that fish the system. Around 19% of the world's catches are from Peruvian and Chilean waters. The fluctuations in the biomass also affect the megafauna of the area, including pelicans, seals and whales.



**Figure 11. Decadal' shifts in the mix of small pelagic species in the Humboldt Current system in response to El Ninos**



**Figure 12. Highly productive upwelling in Peru and Chile**  
(Chlorophyll – SeaWiF's Satellite Remote Sensing, Source Egger, 2011)

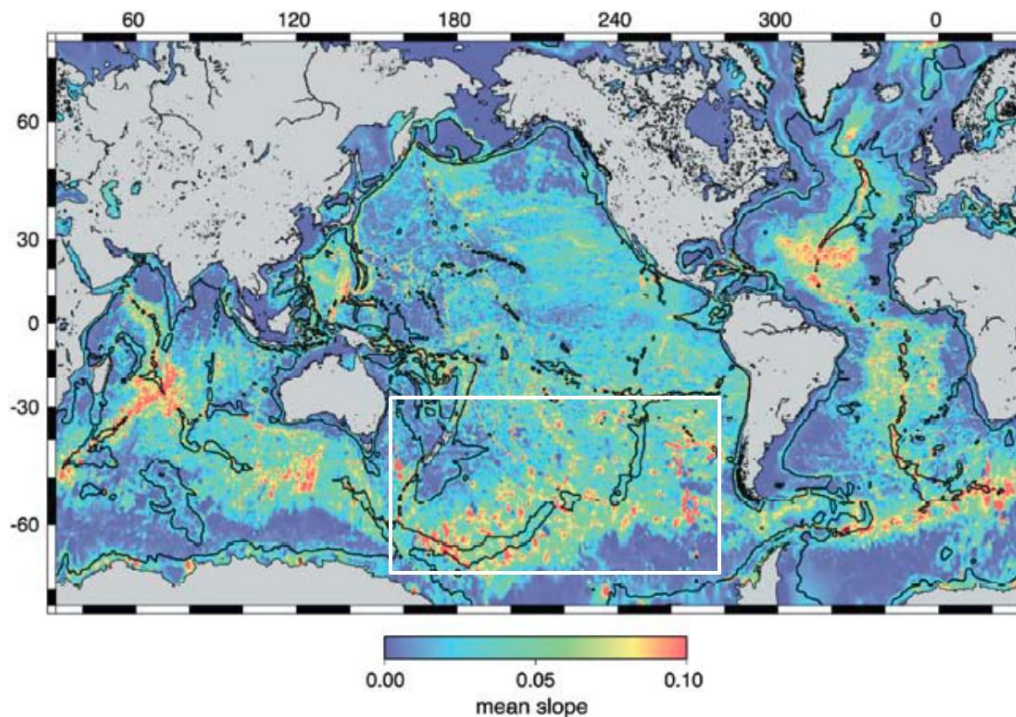
Several areas of the HCS have intense oxygen minimum zones (OMZs), known to significantly contribute to the oceanic production of  $N_2O$ , a greenhouse gas. The contribution of the OMZs on the oceanic sources and sinks budget of  $CO_2$ , the main GHG, still remains to be established<sup>10</sup>. However the occurrence of low oxygen conditions can have a devastating effect on aquaculture production.

### 1.4.3 Southwest Pacific Area 81

This vast oceanic area has a total surface area of 27.7 million  $km^2$  with only 0.4 million  $km^2$  of shelf area. It ranges from the sub-tropical waters of northern New South Wales in Australia to the northern fringes of the Southern Ocean. Several relatively weak current systems include the East Australian Current which flows south along the east coast of Australia, part of which turns east after coming in contact with the West Wind Drift along the northern edges of the Southern Ocean and southern margin of the Tasman Sea and blends with the East Cape Current to form to form the Wairarapa Gyre in the area of the Chatham Rise. Within the Region, there are two shallower plateaus of about 200–1000 m in depth. The largest is the Campbell Plateau, which occurs to the southeast of New Zealand below 46°S. The second, the Lord Howe Rise, is shallower and extends from the centre of New Zealand in a northwesterly direction. The types of habitats are very varied, supporting a wide range of fisheries, from coastal continental to deep-water seamount fisheries. The Region is mostly deep oceanic water, with many seamounts<sup>11</sup> where bathypelagic fish resources such as orange roughy and oreos are exploited.

<sup>10</sup> A. Paulmier et al. 2011.  $CO_2$  maximum in the oxygen minimum zone (OMZ) *Biogeosciences*, 8, 239–252, 2011.

<sup>11</sup> Wessel, P., D.T. Sandwell, and S.-S. Kim. 2010. The global seamount census. *Oceanography* 23(1):24–33.



**Figure 13. The concentration of seamounts in the South Pacific Region**

## 1.5 General socio-economic aspects of the Region

This section focuses principally on describing<sup>12</sup> the fisheries of the Region, which are of global importance and of great economic significance particularly to Peru, Chile and New Zealand. Despite its diversity, the Region has several common fisheries characteristics.

- relatively low population pressure throughout the Region and relatively low fish consumption
- a major net exporter of seafood – fishmeal, small pelagics, salmon, mussels
- the vast majority of the production is industrial, or large scale fishing and aquaculture
- a number of distant water fishing nations (DWFN), or flag states which are not among the coastal states of the Region, have a significant fishing presence
- there are important small-scale fisheries and aquaculture operations, particularly in Latin America
- the Region has the world’s largest single species fishery (Humboldt anchoveta)
- the Region contains a fishery resource with high future potential (Antarctic krill 5.6 million ton precautionary TAC of which about 0.25 million tons is currently harvested)
- the Region offers a range of fisheries governance lessons.

The countries fishing in the Region include: Canada, China, the Cook Islands, Netherlands, Estonia, Georgia, Japan, the Republic of Korea, Latvia, Lithuania, Norway, Poland, the Russian Federation, Spain, Taiwan Province of China, Ukraine, Uruguay, Argentina, and the United States of America. As indicated in Table 2, aquaculture is of growing importance

<sup>12</sup> Information in this section drawn mainly from: FAO. 2011. *Review of the state of world marine fishery resources*. FAO Fisheries and Aquaculture Technical Paper No. 569. Rome, FAO. 2011. 334 pp.

**Table 2. Main marine and brackish-water aquaculture production in 2011 in the Region by species group (tons)**

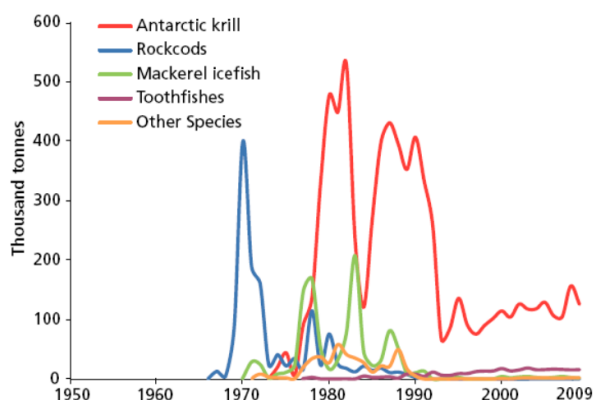
Country/ species group	tons
<b>Chile</b>	245,274
algae	12,162
salmonids	608,266
molluscs	233,112
<b>Ecuador</b>	223,315
shrimp	223,313
<b>New Zealand</b>	109,967
salmonids	12,280
molluscs	97,687
<b>Peru</b>	58,103
molluscs	58,101

Source: FAO, FishStatJ.

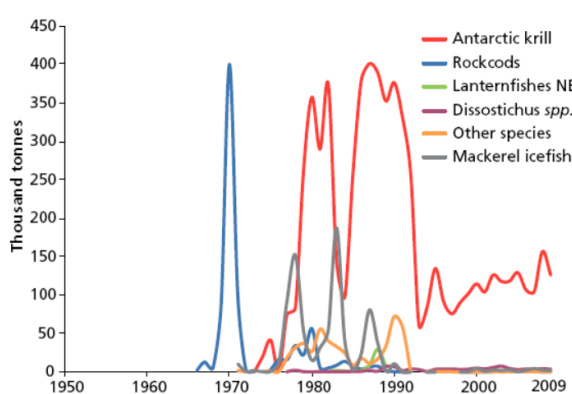
### 1.5.1 Southern Ocean

The Southern Ocean represents about 15 percent of the world’s ocean area. A number of countries, including Australia, France, UK and South Africa have island territories in the Southern Ocean. The Antarctic Convergence (50°S - 60°S) formed by cold, northward-flowing Antarctic waters separates two hydrological regions with distinctive marine life and krill as a keystone species. Catches from the Southern Ocean are dominated by those from the Antarctic Atlantic with 90 percent of the total recorded catches from the Southern Ocean in 2009. The overall catch of the Antarctic Atlantic (Area 48) has shown a steadily increasing trend to 131,700 tonnes in 2009.

**Annual nominal catches of selected species in Areas 48, 58 and 88**



**Annual nominal catches of selected species in Area 48**



**Figure 14. Trends in catches in the Southern Ocean illustrating the dominance of Area 48.**

In the 1980s and 1990s (see Figure 14), fishing focused on krill, mackerel, icefish and, to a limited extent, squid and crab. The development of new harvesting technology and markets in recent years has seen growing interest in fisheries targeting Antarctic toothfish (*Dissostichus mawsoni*) Patagonian toothfish (*Dissostichus eleginoides*) adjacent to the Antarctic continent, and renewed interest in krill fishing. In the 1990s and early 2000s, unreported catches of toothfish and related high-value demersals may have exceeded the reported catch by five to six times. At its peak in 1982, the krill fishery contributed about 13 percent of the global annual catches of crustaceans. Commercial whaling ceased in 1987 and there has been no commercial sealing since the 1950s.

### 1.5.2 Southeast Pacific Area 87

Ecuador’s aquaculture is particularly important with production of about 300,000 tons worth \$1.4 billion (2011) comprising mainly shrimp and tilapia. Ecuador also has an important tuna fleet and tuna processing industry and the Galapagos biodiversity hotspot is also in Ecuador waters. There are about 250,000 fisheries jobs – approximately 4% of the workforce and Ecuador has the largest artisanal fishing fleet in all the

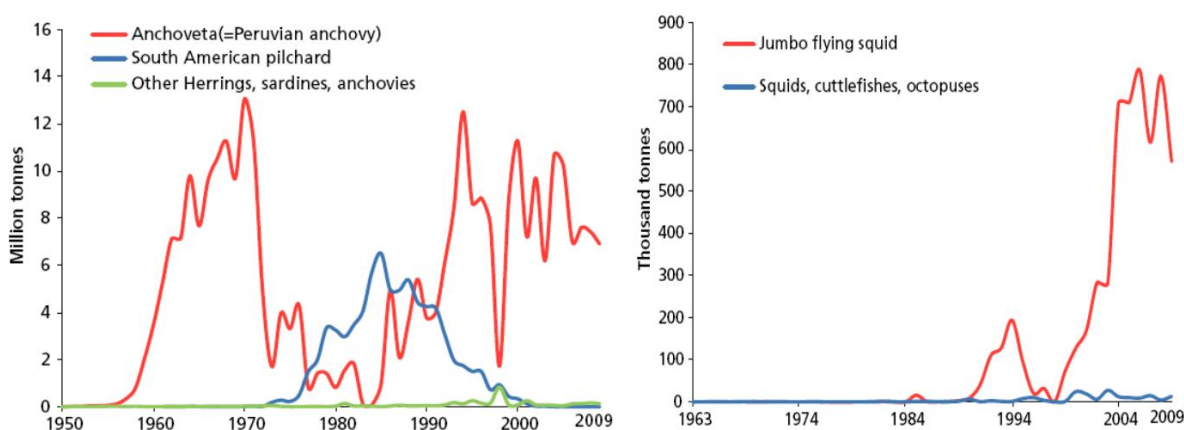
Southeast Pacific countries. The large industrial tuna purse seine vessels can fish in more distant waters of the Central Pacific. Total fisheries production is in the order of 400,000 tons per year.

**Table 3. Recorded capture fisheries production ('000 tons)**

	2005	2006	2007	2008	2009	2010	2011
Peru	9,350	6,983	7,177	7,360	6,873	4,220	8,216
Chile	4,698	4,421	4,087	3,897	3,782	3,015	3,431
Ecuador	430	415	362	447	449	340	452
Columbia	-	-	80	70	45	52	52
Venezuela	19	34	27	37	27	12	31
Total	14,497	11,854	11,733	11,811	11,175	7,638	12,181

Source: FAO, FishstatJ.

Between 150,000 and 170,000 people depend directly on Peru's fisheries for employment and income. The large-scale industrial fishery dedicated to export production provides about 30,000 jobs and the artisanal fishery employs about 65,500 engaged directly in fishing operations and a further 19,200 employed by fishery-based food processing for direct human consumption. The artisanal fisheries use about 10,000 vessels and contribute greatly to the country's food security by producing between 200,000 and 400,000 tons per year. The challenges facing Peru's fisheries include: maintaining sustainable levels of exploitation in the face of El Nino-driven fish stock variability; pollution, mainly associated with a lack of or inadequate treatment of sewage, waste waters and solid waste generated by coastal cities, poorly controlled mining operations and pollution from activities such as oil and gas production, transport and storage, fish processing and aquaculture, agriculture and several other manufacturing activities.



**Figure 15. Variability in the anchovy fishery and the rise of the cephalopod fisheries**

Chile's fisheries are dominated by the industrial fisheries, but are also the basis for the livelihoods of about 85,000 artisanal fishers. Declining catches in key resources have generated conflicts between the sub-sectors. Almost all the fisheries are considered<sup>13</sup> either fully, or over-exploited and three out of the 33 main fisheries are considered collapsed. Until 2007 Chile experienced rapid growth in its salmon aquaculture becoming the second largest salmon and trout producer after Norway, contributing 38% of the world's salmon supply. Salmon was the third largest export product in terms value (3.9% of Chile's exports). A severe outbreak of infectious salmon anaemia in 2007 caused salmon production to fall from 400,000 to 100,000 tons in 2010. Chile also grows turbot, mussels, scallops, oysters and algae. Key species for aquaculture include Atlantic salmon and Rainbow trout, Whiteleg shrimp, Coho salmon, Chilean mussels, Gracilaria seaweed and Peruvian calico scallops.

### 1.5.3 Southwest Pacific Area 81

<sup>13</sup> Subpesca 2013. Estado de situación de las principales pesqueras Chilenas 2012



Catches reached a peak of about 900,000 tons in the 1990s and have now stabilized at around 600,000 tonnes (2009). Five taxonomic groups account for 81 percent of the catches: gadids (cods, hakes, haddocks, 30 percent), squids, cuttlefishes and octopuses (10 percent), tunas, bonitos and billfishes (8 percent) other bottom fish (21 percent), other pelagic species (11 percent).

There are only two countries in Area 81, Australia and New Zealand. New Zealand has the largest landings, with a peak of 650 000 tonnes in 1998 and 420 000 tonnes in 2009. Japan caught the second-largest volume in Area 81 and landed 300 000 tonnes in 1988, but withdrew after 2006. Australia's landings from Area 81 increased gradually from 10,000 tonnes in 1950 to 30,000 tonnes in 1985, and then experienced a rapid growth to a peak of 80,000 tonnes in 1990. The total catch then fell sharply to about 20,000 tonnes in 2009. Recreational fisheries are important in Australia and New Zealand. The Republic of Korea also has a strong presence in Area 81, with catches of about 50,000 tonnes in 2009.

Orange roughy, snoek, oreo dories and similar species make up the 'other demersal species' (21% of catches). Orange roughy increased rapidly to reach a record high of more than 80,000 tonnes in 1990 with a dramatic decline to about 10,000 tonnes landed in 2009. Snoek catch has increased quite steadily to 25 000 tonnes in 2009. New Zealand and Australia have been pioneers in developing profitable and sustainable deepwater (> 600 m) trawl fisheries. These fisheries include fisheries off New South Wales. For New Zealand the targets include the pelagic resources in the Southwest Pacific and the bathypelagic species associated with the sea bottom rises from the Tasman Sea east to the south, and east of the South Island of New Zealand. The most important species caught in these fisheries are orange roughy (*Hoplostethus atlanticus*) and hoki (*Macruronus novaezelandiae*).

Wellington "flying squid" and various other squids make the third-largest contribution to catches in Area 81. The landings of Wellington flying squid have varied greatly between 20,000 tonnes and 100,000 tonnes, and were about 50,000 tonnes in 2009. The catch of other squids have fluctuated widely and declined overall from a peak of 70,000 tonnes in 1980 to 20,000 tonnes in 2009. Horse mackerel is the most important pelagic species with an average catch of 100,000 tonnes in the 1990s.

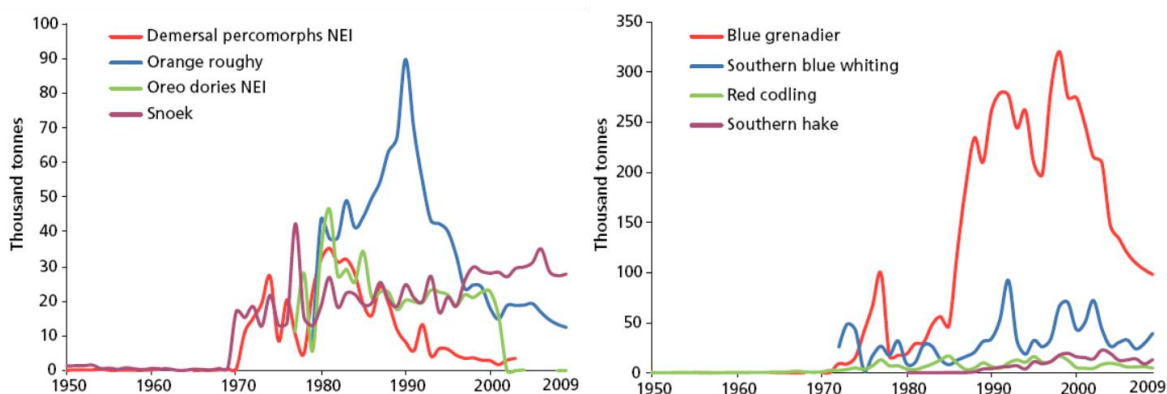


Figure 16. Trends in the catches of major species in Area 81

Sydney rock oyster *Saccostrea glomerata* (native) and Pacific oyster *Crassostrea gigas* (introduced) are both important species in Australia. In addition, the Pacific oyster is also farmed in parts of New Zealand. The annual value of these species to the Region's fisheries is approximately \$40 million for the Sydney rock oyster and \$22 million for the Pacific oyster. They also have ecological significance providing habitat structure for benthic organisms in the region, acting as a biological purifier for polluted estuarine water and a food source for other organisms (Gutiérrez et al. 2003). Other key aquaculture species include: New Zealand mussel, Sydney cupped oyster, Atlantic salmon and Rainbow trout.

For Australia (New South Wales) ocean warming is a major driver of regime shifts as tropical species move south<sup>14</sup>. There is also evidence of temperature stresses on bivalves and *in vitro* evidence of OA stresses on

<sup>14</sup> Figueira and Booth 2010.

cultured species. If acclimation across multiple generational does not occur, selective breeding of oysters (and potentially other molluscs) may be an avenue for aquaculture to reduce the impacts of ocean acidification on stocks. However, this will come at an additional cost to production.

## 2 BIOLOGICAL IMPACTS OF OA

The biological impacts of OA need to be taken into account in the fisheries management regimes and an overview of these regimes and approaches provides a useful framework for action. The fisheries management regimes can be considered at two levels: national management and regional management. At both levels the Region provides some lessons in fisheries governance. Throughout the Region, a limited number of key actors facilitate dialogue and action. This includes a limited number of industrial fisheries ‘giants’ in most countries and a consolidated aquaculture industry and aquafeeds industry. However, there are also large numbers of small-scale fishers in Latin America.

### 2.1.1 National fisheries management regimes

Australia and New Zealand have robust governance of fisheries and despite some setbacks their fisheries are largely sustainable. Introduction of an ecosystem approach has grounded management advice in a more holistic science base. Attention to the political economy of fisheries has led to the issue of fishing rights creating incentives for rights-holders to conserve and value the resource base. In some cases this may have come at the cost of a concentration of wealth, in others (such as in New Zealand) the benefits have been spread through community ownership of fishing rights. Peru has had a major governance reform in the anchoveta fishery with economic rents increasing by up to \$0.5 billion per annum. Chile is benefiting from lessons from a collapse in salmon aquaculture due partly to poor aquaculture governance, concentration of farms and failure to enforce disease controls. Chile also has strong small-scale cooperative movement, but conflicts between industrial and small-scale fishers are ongoing.

Australia, New Zealand, Chile and Peru all have well developed and resourced fisheries research and management institutions, produce regular ‘state of the fisheries resources’ analyses and are actively studying climate change adaptation options for fisheries and their marine economies. Australia has created the Heard and McDonald Islands Marine Reserve<sup>15</sup>, a 65,000 km<sup>2</sup> area around the uninhabited Heard and McDonald Islands and includes two large zones of the Southern Ocean. The reserve is intended to protect the habitat and food sources of seals, penguins, albatrosses and ensure that this pristine ecosystem remains intact. Ecuador manages the 133,000 km<sup>2</sup> Galapagos Marine Reserve.

### International management

The international fisheries bodies include CCAMLR, IWC, SPRFMO and CCPS. Three RFMOs, WCPFC, IATTC and CCSBT are charged with tuna management and their role is addressed in other chapters where the tuna fisheries are of more importance.

#### *Commission for the Conservation of Antarctic Marine Living Resources*

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)<sup>16</sup> was established by international convention in 1982 with the objective of conserving Antarctic marine life in the 32 million km<sup>2</sup> area of jurisdiction (see map Figure 1), including seabirds and the management of fisheries in the Southern Ocean. CCAMLR is an international commission with 25 Members, and a further 11 countries have acceded to the Convention. With responsibility for the conservation of Antarctic marine ecosystems, CCAMLR practices an ecosystem-based management approach and has adopted principles that aim: to balance harvesting and conservation; to protect the needs of dependent species, and to avoid irreversible ecosystem changes. CCAMLR has pioneered ecosystem approaches to fishery and environmental

<sup>15</sup> [www.environment.gov.au/coasts/mpa/heard/](http://www.environment.gov.au/coasts/mpa/heard/)

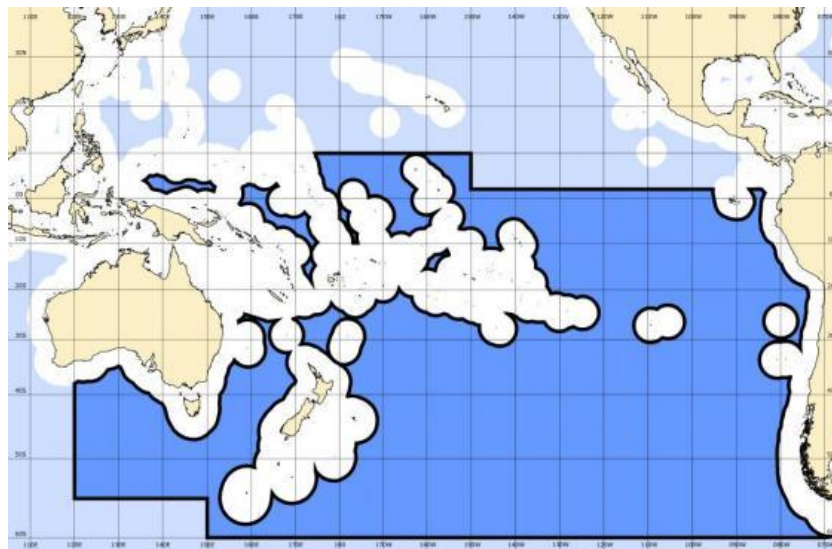
<sup>16</sup> [www.ccamlr.org](http://www.ccamlr.org)

management, through the incorporation of precaution and uncertainty into its management procedures and by establishing an ecosystem monitoring programme using indicator species and processes. This approach permits harvesting, as long as such harvesting is carried out in a sustainable manner and takes account of the effects of fishing on other components of the ecosystem. Based on the best available scientific information, the Commission agrees a set of conservation measures that determine the use of marine living resources in the Antarctic. It has met with some success, notably in applying conservative yield models for toothfish and krill stocks and in establishing strict rules for undertaking new and exploratory fisheries.

The International Whaling Commission has responsibility for the conservation of whales. A related convention, The Convention for the Conservation of Antarctic Seals, ratified in 1978, reports to the Scientific Committee on Antarctic Research, which undertakes the tasks requested of it in the convention.

#### *South Pacific Regional Fisheries Management Organization (SPRFMO)*

The South Pacific Regional Fisheries Management Organization (SPRFMO) was established in response to growing concern over the over-exploitation of seamounts and the jack mackerel and ‘jumbo’ squid fisheries in the high seas off the coast of Chile and Peru. The objective is the conservation and sustainable use of fishery resources and to safeguard the marine ecosystems in this area (Figure 17). SPRFMO has set a limit of 360,000 tons for *Trachurus murphyi* in the convention area and prohibited the use of large gillnets.



**Figure 17. SPRFMO Convention area (note exclusion of EEZs)**

#### *Permanent Commission for the South Pacific (CPPS)*

The CPPS coordinates regional maritime policies in order to adopt concerted positions of its Member States (Chile, Colombia, Ecuador and Peru) in international negotiations, development of the Law of the Sea, International Environmental Law and other multilateral initiatives. CPPS is engaged in a capacity-building process at the national and regional levels in the areas of science, socio-economic policy and the environment. CPPS promote linkages between marine research and regional policies. It coordinates and fosters research activities related to the ecosystem approach, variability and climate change, operational oceanography, natural disaster mitigation, living and non-living resources, as well as issues associated with fishing and aquaculture, including economic and social aspects and related activities. Its area of competence has no specific geographical coordinates.

## 2.2 OA effects on the selected species

There are few studies of the effects of OA on the Region's species. Only three species have been used in laboratory studies on ocean acidification: Sydney rock oyster *Saccostrea glomerata* (Area 81), Pacific (cupped) oyster *Crassostrea gigas* (Areas 81, 87) and Jumbo flying squid *Dosidicus gigas* (Area 87). Of these species two were from populations within FAO Area 81. No studies on populations from Areas 87, 88, 58 or 48 were identified.

### *Finfish*

The sensitivity of finfish to OA is largely unknown but recruitment success may be impacted, there may be a reduction in metabolic rate, growth, in reproduction and survival, or impacts on larval development and hatching success. There may also be indirect impacts on finfish, through the vulnerability of key food species, such as pteropods and krill to ocean acidification, or through destruction of key habitats (such as ice, cold water corals, or shellfish beds). There are likely to be increased energetic requirements. The cumulative impacts of OA and other stressors, such as ocean warming is not well understood. The effects on key mariculture species (Rainbow Trout, Atlantic salmon) is not known, but impacts on anchovy and krill fisheries could affect supply of key feed ingredients such as fish oil and amino acids.

### *Crustacea*

Preliminary results of one study on krill indicated that elevated seawater pCO<sub>2</sub> is likely to increase mortality, reduce activity levels and fitness, and cause moult cycle irregularities on post-larval krill. No significant effects on growth rates and intermoult period were observed under experimental conditions in this study. A workshop in 2011 concluded that the cumulative impact of climate change on krill is probably negative (IMARES 2011). The evaluation focused on major agents of climate change, such as ocean warming, sea ice loss, and ocean acidification. Exposure of Antarctic krill to elevated CO<sub>2</sub> of 1000 ppm and 2000 ppm (pH 7.7 and 7.4, respectively) for 26 days, led to a significant decrease in hatching success of the crustacean species (Kurihara et al. 2008).

### *Shelled molluscs*

A number of laboratory studies have shown that a species response to ocean acidification can vary significantly across different populations (Berge et al. 2006; Gazeau et al. 2007; Kurihara et al. 2007; Havenhand and Schlegel 2009; Parker et al. 2010; Thomsen and Melzner 2010). It is therefore important to assess the impacts of ocean acidification on specific populations within the different FAO Areas before any realistic predictions of socio-economic impacts on the regions can be made.

Studies on the early-life history stages of Australian populations of oysters have shown that they are extremely vulnerable to elevated CO<sub>2</sub> (Parker et al. 2009; Watson et al. 2009; Parker et al. 2010; Parker et al. 2012). At elevated CO<sub>2</sub> there is a reduction in the fertilisation success of gametes, a reduction in the development of embryos and size of larvae and spat and an increase in abnormal morphology and development time of larvae for both species. These effects are greater for the native *S. glomerata* than the introduced *C. gigas*. Combined, elevations in pCO<sub>2</sub> of 750–1000 ppm and temperature (+4 °C) resulted in 100% mortality of D-veliger larvae of *S. glomerata*. In contrast, the same pCO<sub>2</sub> and temperature combination resulted in only 26% mortality of D-veliger larvae of *C. gigas*. In adults of the Sydney rock oyster, exposure to elevated CO<sub>2</sub> caused a significant increase in standard metabolic rate (SMR), suggesting a higher energetic cost of routine metabolism as our oceans continue to acidify (Parker et al. 2012). In Pacific oyster populations outside of FAO Area 81, ocean acidification caused a significant reduction in shell calcification (Gazeau et al. 2007) and an increase in SMR (when ocean acidification was combined with elevated temperature) (Thomsen and Melzner 2010). Further, in the Pacific Northwest coast of the United States, there have already been year-by-year declines in the survival of juvenile 'seeds' of the Pacific oyster due to the upwelling of acidified water (Barton et al. 2012).

Smaller larvae with thinner weaker shells may require a longer length of time in the plankton to have sufficient energy for metamorphosis. A longer larval life may also decrease survival due to the increased risk of predation and exposure to other environmental stressors. In addition, reduced calcification in adults may

lead to reduced protection from predators, parasites and unfavourable environmental conditions (Beniash et al. 2010).

While studies on the native Sydney rock oyster have suggested that it is extremely vulnerable to ocean acidification, particularly during the early-life history stages, there is evidence that some populations of this species may have the potential to acclimate or adapt. For example, Sydney rock oyster populations that have been selectively bred by industry to grow faster and have resistance to disease are more resilient to elevated CO<sub>2</sub> than the wild population, with newly metamorphosed spat from selectively bred populations experiencing only a 25% reduction in shell growth after 4 days at elevated CO<sub>2</sub> compared to the 64% reduction in shell growth experienced by the wild population (Parker et al. 2011). In addition, a recent longer term study has found that positive carryover effects may be passed from adults to their offspring during exposure to elevated CO<sub>2</sub>. Larvae produced from parents reared at elevated CO<sub>2</sub> were larger in size and developed at a faster rate under elevated CO<sub>2</sub> when compared to larvae produced from parents conditioned under ambient CO<sub>2</sub> conditions (Parker et al. 2012)

Similar studies could be envisaged for other commercially important molluscs such as, abalone, New Zealand mussel, Peruvian scallop, loco and other species. In addition, possible increased vulnerability of shellfish populations to disease (such as the protozoan QX disease or Ostreid herpes) as a result of OA could be explored.

#### *Cephalopods*

The jumbo flying squid *Dosidicus gigas* is widely distributed in the Southeast Pacific and supports an important fishery (Lui 2010). Peru and Chile have the largest landings of *D. gigas* in the Pacific Ocean with landings over 0.5 million tons in 2011 in Area 87. *D. gigas* is a large pelagic top predator which already occupies habitats at the upper and lower extremes of its temperature and oxygen threshold limits. A study assessed the impacts of ocean acidification (in combination with elevated temperature) on *D. gigas* populations outside of FAO Area 87 (Rosa and Seibel 2008). During acute exposure to elevated CO<sub>2</sub>, *D. gigas* experienced a significant reduction in SMR(31%) and activity levels (45%). When temperature was elevated past the threshold limit of the squid, the effects of ocean acidification on SMR and activity levels were exacerbated. This suggests that in a high-CO<sub>2</sub>, high-temperature ocean, this reduction in SMR and activity levels will impair predator-prey interactions and have consequences for growth, reproduction and survival and distribution of the species (Rosa and Seibel 2008). Further, expansion of the OMZ in the region will mean that, in the absence of acclimation, *D. gigas* will have to horizontally migrate to shallower, less hospitable waters at night to feed and repay any oxygen debt which has accumulated during their diel vertical migration to the oxygen OMZ (Rosa and Seibel 2008).

#### *Other organisms*

Ocean acidification is also a threat to cold water corals and the management of vulnerable marine ecosystems (VMEs).. OA may have additional indirect effects by promotion of biofouling organisms or spread of undesirable invasive species.

In summary, there is limited empirical information on the effects of OA on commercial species in the South Pacific Region and negligible information on the impacts at the population and ecosystem level.

### **3 ECONOMIC IMPACTS OF OA**

It is difficult to estimate the economic impact of OA for several reasons.

- the direct impact on many commercial species is unknown, let alone the indirect effects via impacts on other important linked ecosystem components
- the capability of species and ecosystems to adapt is not well understood
- other commercial species may substitute stressed species
- the impact of other stressors varies widely and the combined impacts are not well understood.

If the export commodities are assumed to be a representative mix of products then 25% of the Region's fish products by value are crustacea and (shelled) molluscs which are the most vulnerable to OA. However, given that the balance of the commodities is largely finfish, most of which depends on crustacea at different stages of their life cycle, the entire fishery economy may be subject to negative economic impacts. The following tables provide an order of magnitude of the Region's fishery economy.

Local consumption or contribution to trade and industry, employment and level of intermediate/final product (including a regional food security dimension and distributional effects).

**Table 4. Balance of fish trade and domestic fish supply 2007**

	Fish imports (tons) 2007	Fish exports (tons) 2007	Domestic supply (tons)
Australia	572,821	157,285	743,594
New Zealand	45,974	585,466	112,782
Colombia	230,538	107,966	305,216
Ecuador	79,500	542,062	174,778
Peru	58,873	10,562,956	1,138,704
Chile	240,028	3,356,023	1,491,640

**Table 5. Economic, nutritional and environmental indicators**

	Fish as % protein supply	Fisheries employment (%)	Fisheries % GDP	EPI Trend
Australia	8.29%	0.72	0.13%	No change
New Zealand	13.78%	0.5	0.79%	No change
Colombia	4.94%	3.1	0.12%	Modest improver
Ecuador	5.40%	13.24	2.72%	No change
Peru	23.39%	2.59	2.06%	Declining performers
Chile	20.17%	3.3	2.51%	Declining performers

**Table 6. Exports of the Region by commodity and country (2011)**

Commodity	Value (\$)	Country	Value (\$)
Fish meal/ oil	2,493,143	Australia	829,684
Finfish	2,182,787	Chile	3,692,739
Crustacea (14%)	1,354,614	Colombia	209,084
Salmonids	1,142,060	Ecuador	1,612,094
Molluscs (excl. cephalopods) (11%)	998,737	New Zealand	906,019
Tuna	635,294	Peru	2,218,406
Small pelagics	263,942	Total	9,477,932
Cephalopods	162,071		
Miscellaneous	152,645		
Seaweeds	33,210		
Sharks	19,356		
Other invertebrates	4,301		
Total	9,442,160		

Source: FishStatJ. Note that values include total Australian exports (i.e. not only Area 81) and also all Columbia exports.

**Table 7. Value of aquaculture production 2009**

Country	Value \$
Chile	6,004,147
Ecuador	1,287,000
Peru	474,025
Australia*	461,489
New Zealand	274,297
Total	8,500,958

Source: FishStatJ. Note that values include total Australian production (i.e. not only Area 81)

It is not only the coastal states of the Region which may be impacted. The trading partners and product users, particularly the aquaculture industry (a major fishmeal/ oil user) could be impacted by higher prices. Approximately 17 Distant Water Fishing Nations that catch over 0.75 million tons in the Region could also be impacted (Table 8).

**Table 8. Recorded catches by coastal states and Distant Water Fishing Nations in the Region (2011) (tons)**

Coastal states (9)	2011 catch	DWFN (17)	2011 catch
Peru	8,217,517	China	302,635
Chile	3,466,611	Norway	102,460
Ecuador	451,589	Korea, Republic of	97,160
New Zealand	420,039	Ukraine	65,018
Colombia	51,586	Japan	55,169
Australia	23,206	Taiwan Province of China	40,195
France	7,434	Panama	38,288
United Kingdom	1,597	Venezuela	30,608
South Africa	162	Spain	25,212
		Vanuatu	7,771
		Nicaragua	6,070
		Poland	3,713
		Netherlands	1,145
		Portugal	638
		Germany	471
		Russian Federation	467
		Uruguay	39
	12,639,741		777,059

Source: FishstatJ

**Table 9. New South Wales reported commercial wild harvest for 2006/2007**

Species/ fishery	Reported Gross Tons	Estimated Value Aus\$'000
Abalone	121.8	4,980
Estuary General	3,657	20,831
Estuary Prawn Trawl	522	3,905
Lobster	109.4	5,200
Ocean Hauling	6,045	16,152
Ocean Trap and Line	1,854	10,556
Ocean Trawl	3,476	21,501
Sea Urchin and Turban Shell	55	86
Inland	25	46
<b>Total</b>	<b>15,865</b>	<b>93,813</b>

#### 4 FORECASTS AND SCENARIOS

The most critical scenarios identified are: (i) the major reduction in healthy living space for marine species by 2050 in the Humboldt Current upwelling system due to aragonite saturation and the shrinking aragonite window; and (ii) the projected aragonite undersaturation in the Southern Ocean. Both have been described above and are likely to lead to major changes in these ecosystems. These scenarios strongly suggest that the South Pacific will be the earliest area in this Region to experience large-scale OA impacts.

Current information suggests that for existing ecosystems and the majority of commercial species in the South Pacific Region, the outlook is negative. However, for some species including seaweeds and cephalopods the perspective appears plausibly more favourable although it is important to acknowledge significant knowledge gaps even for these groups. It could also be speculated that species with an r-selection strategy (short life cycle, high fecundity), a changing environment may favour their adaptation to a more acid ocean.

The combination of stressors, including acidification and warming oceans, and fishing pressure and the responses of species through adaptation or changing distribution and life cycles, makes forecasts of ecosystem changes tenuous and at this stage the socio-economic impacts cannot readily be assessed.

## **5 POLICY RECOMMENDATIONS**

### **5.1 Mainstreaming knowledge and actions**

The generic mainstreaming process requires raising awareness at all levels with a focus on policy makers, scientific priorities and international processes. Strategic pathways should be identified with clearly articulated goals in order to build political support for priority actions. It means harnessing a realistic OA agenda to global processes and fora (e.g. UNGA, G8, OECD, SIDs,). In the South Pacific Region the entry points would include the regional fisheries bodies and the Antarctic treaties and conventions processes, the fishing, fishmeal and aquaculture production and feeds industry organizations and the major conservation NGOs.

The mainstreaming process requires that OA is an active item on the relevant agendas, that appropriate information packages are made available and that a coherent ‘story line’ is prepared in terms of actions requested from the various fora. In general it may be useful to target key fisheries (the largest, most valuable, or where there is the highest level of social dependence). The OA issue needs to be integrated within actions for conservation, sustainable use, poverty reduction, climate change adaptation and mitigation agendas. Public understanding of OA is generally poor and the OA messaging may need to be tailored to the interests of different stakeholders and recognition that they are stakeholders. A relatively coarse segmentation of stakeholders can identify, for example: industrial players - aqua feeds, krill producers, small pelagics companies (among the largest fishing companies in the world); indigenous people and cooperatives in Chile, New Zealand and elsewhere; the aquaculture insurance industry.

### **5.2 Building consensus science**

A major challenge will be to build scientific consensus on key ‘unknowns’ trends, orders of magnitude, geographies, underlying assumptions and quantifying uncertainties. While progress has been made on integration of OA into the UNFCCC processes, further institutional mechanisms may be required to rapidly filter and synthesise the science. It may be necessary to prioritise the scientific questions, for example with a focus on (i) keystone calcifiers; (ii) on the main commercial species; (iii) on the cumulative impacts OA and other stressors; (iv) on the adaptation capacity in species such as corals; and (v) on the possibility of local mitigation through seaweed culture or other means. Ecosystem level impacts may require a long-term research framework to be identified as it will be a challenging long-term research area.

### **5.3 Identifying actions**

It will be important to identify priority mitigation and adaptation actions, their costs, and costs of inaction, and who pays the costs. Many of these actions will involve the application of known best practices of sustainable development, such as responsible fisheries and application of the Code of Conduct for Responsible Fisheries, use of integrated coastal management ICM, or pollution reduction initiatives. Ideally these actions would be accompanied by financing for a sound business case, with a possible expansion of blue carbon markets.

The level of and trends in OA in many major fishing areas is unknown, so efforts to monitor OA levels in key fisheries areas and to include vulnerability to OA in mapping multiple marine stresses (acidification, warming, deoxygenation, pollution, fishing) will be important, as the key mitigation actions are likely to be directed at reducing the other stressors. A minimum level of information on impacts will be required to include OA risk in fisheries advice and models while selective breeding for OA resilience could be a useful approach for commercial aquaculture species.

In order to finance an action agenda it will be useful to prepare a strategic plan with associated costs, allocation of responsibilities and an institutional framework in order to invite funding and coordinate activities at various levels. The South Pacific Region may offer some opportunities for several reasons: the early advent of the OA impacts; the quality of marine science in the area; the presence of pristine marine



parks; comparatively well-managed fisheries; potential for a strong business case and integration with existing pollution control and climate change agendas; and a limited number of major players in fisheries and aquaculture.

## 6 SUGGESTIONS FOR FURTHER RESEARCH NEEDED TO FILL THE GAP BETWEEN NATURAL SCIENCES AND ECONOMICS

At the **process** level several questions may be considered:

- what is the consensus scientific knowledge required to complete basic estimates of economic impacts, estimates of losses, risks to economies?
- what would a focused major awareness effort need?
- what are the costs of defined priority actions – national and/ or global?
- who can support the costs of priority actions/ how will this be financed?
- what is the shape of an OA agenda – is it best to split or lump/ work with or in parallel to main climate change processes or other agendas. What are the advantages, disadvantages, alternatives?
- who can take responsibility for/ coordination of OA agenda and under what mandate?

At the **policy** and strategic levels advice may be usefully developed on the following questions:

- how to build the business case for action on OA
- how to link OA to the poverty and growth agendas
- how to target major concerns, such as jobs, food security, natural disasters
- how to engage private sector and civil society
- how to prioritize an OA action agenda

Building on approaches to **adaptation** to climate change the following questions are applicable to OA adaptation:

- how to increase the resilience of most vulnerable people
- identifying the synergies between adaptation and mitigation
- specifying ‘no-regrets’ or ‘low-regrets’ actions and reversible and flexible options
- identifying safety margins for more informed investments later
- how to link to other agendas – green accounts, payment for ecosystem services

A number of specific or **technical** research questions arise from the examination of the South Pacific Region:

- Studies are needed on the variability of the depth of the upper limit and thickness of the Oxygen Minimum Zone (OMZ), the depth of low pH and high CO<sub>2</sub> waters and depth of the aragonite saturation horizon in the Humboldt Current upwelling system, all likely to be key compounding factors in OA impacts.
- CCAMLR will need to develop research programs to fill in the gaps of current research on Southern Ocean impacts as soon as possible. Longer-term studies of acidification for the entire lifecycle of important species are needed, including implications for non-calcifying organisms and impacts of ocean acidification on other biological processes besides calcification in invertebrates and vertebrates. In particular critical knowledge gaps in the biology and ecology of Antarctic krill need to be closed, including on recruitment processes, under-ice and benthic habitat use, their capacity to adapt to environmental change, their ecosystem function, as well as the energy demand and food consumption of krill-dependent predators.
- If acclimation does not occur, selective breeding of oysters (and potentially other molluscs and corals) may be an avenue for aquaculture to reduce the impacts of ocean acidification on stocks. However, this will come at an additional cost to production.

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