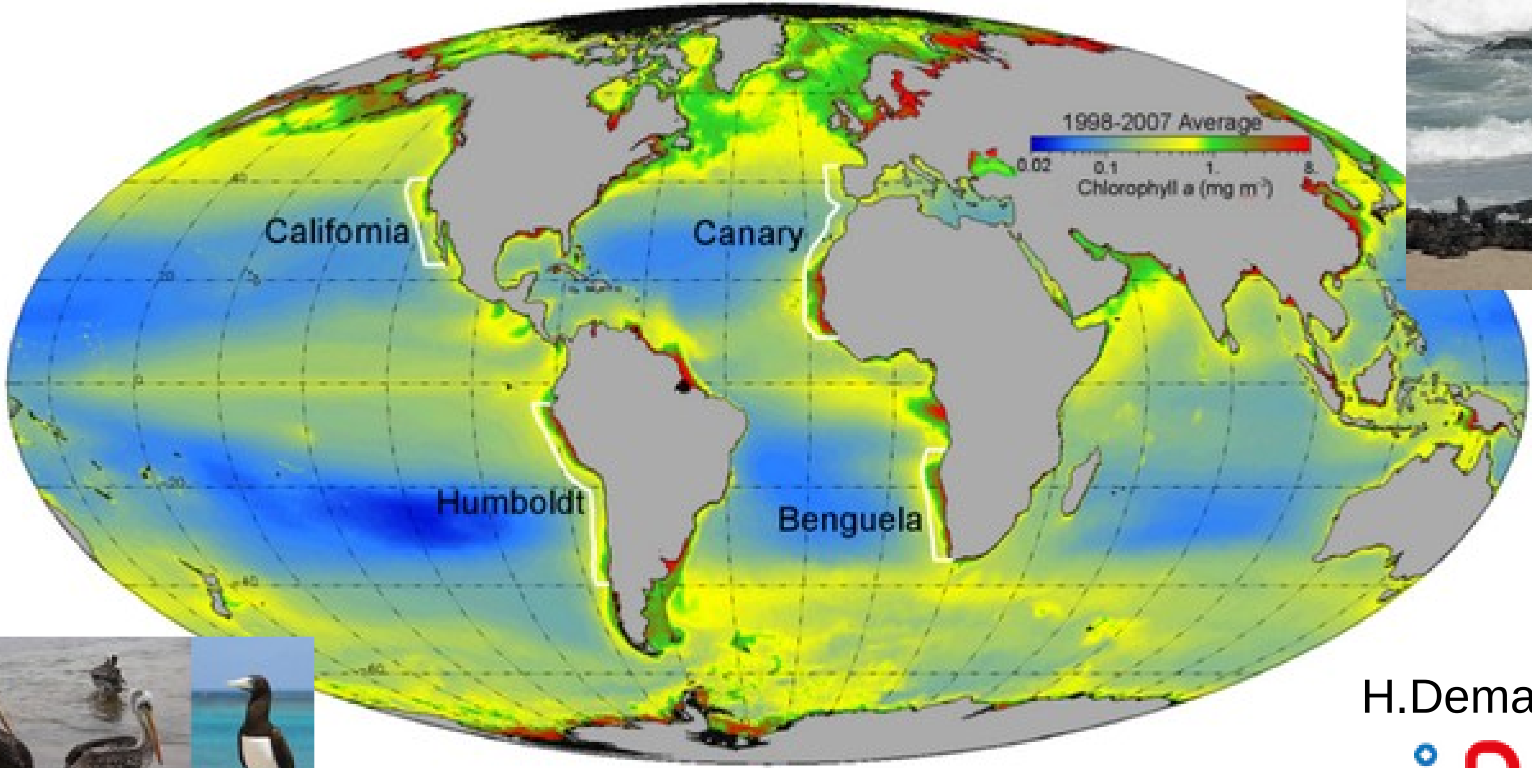
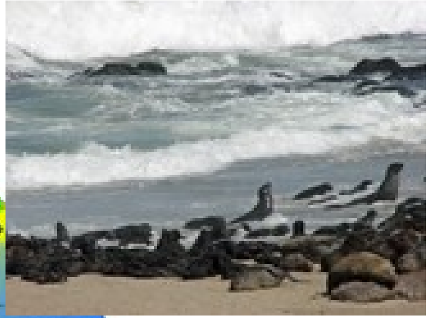
The worldwide importance of Eastern Boundary Upwelling Ecosystems (EBUEs)





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TRAINING WORKSHOP ON “THE CANARY CURRENT EASTERN BOUNDARY UPWELLING SYSTEM”
OCEAN SCIENCE CENTRE MINDELO (OSCM)
C/O INSTITUTO DO MAR MINDELO 10-12 MARCH 2020

Ministério da Economia Marítima

OSCM Ocean Science Centre Mindelo

GOBIERNO DE ESPAÑA

The **Eastern Boundary Upwelling Ecosystems (EBUEs)** are important…

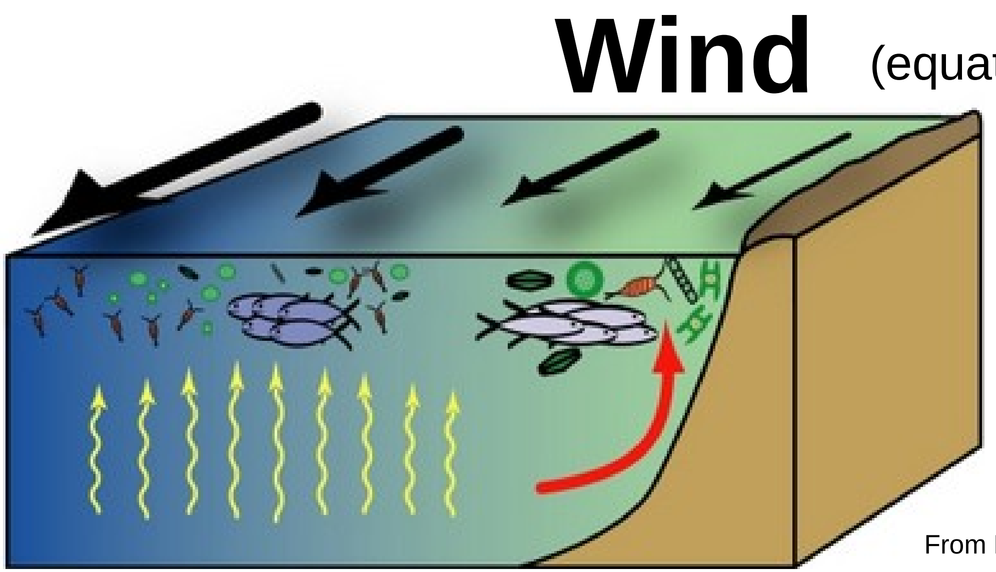
… because they are very productive!

They are some of the most productive marine ecosystems of the world; the four main EBUEs, the **Canary**, **California**, **Humboldt** and **Benguela** Currents provide **one fifth of the marine fish global catch**, and contribute significantly to securing food and livelihood strategies in many developing countries.

Sardinellas at Dakar

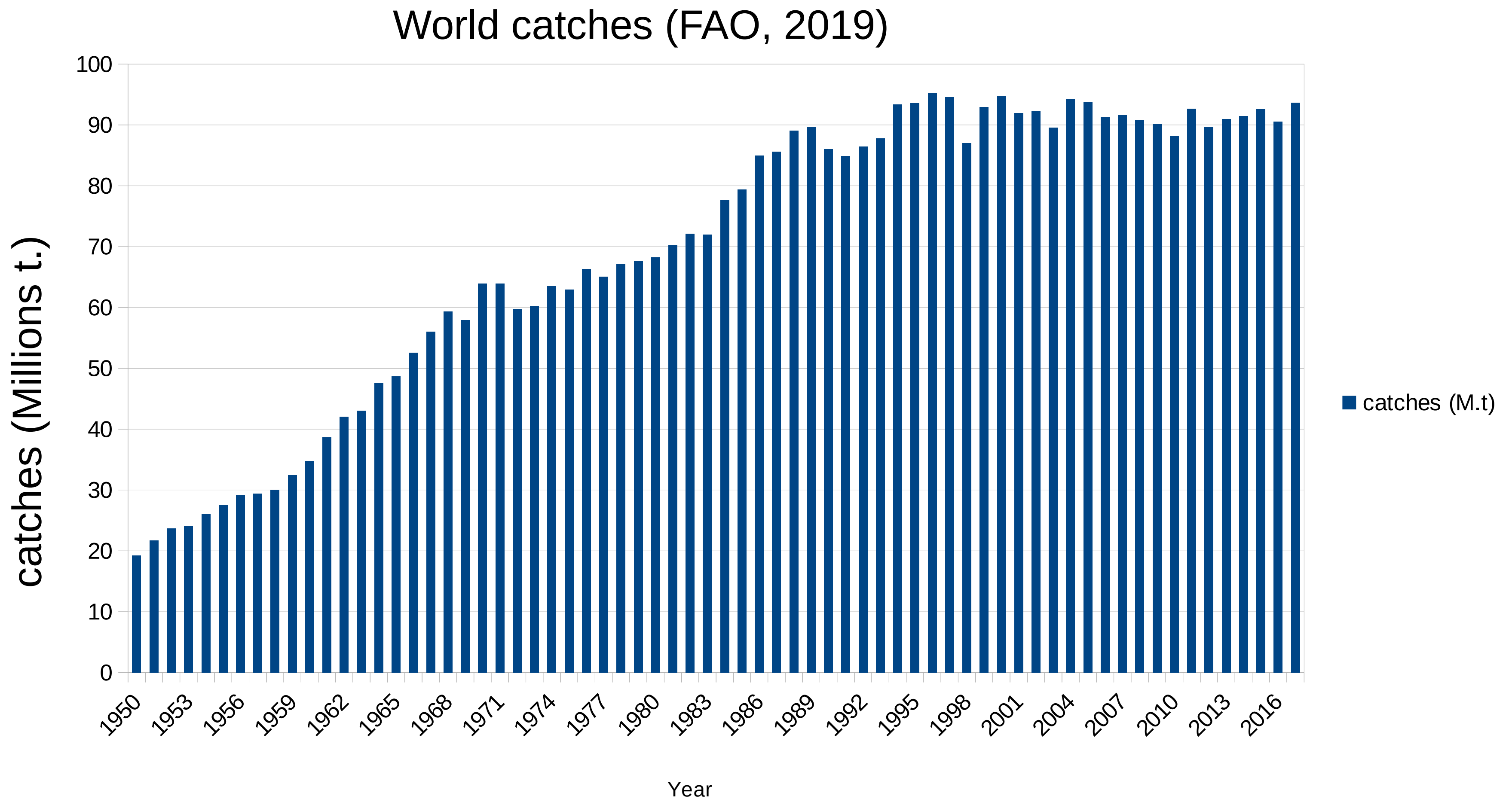
Artisanal fishery in Peru

Hypothesized relationship between wind-forced upwelling and the pelagic ecosystem



From Rykaczewski and Checkley (2008)

Alongshore, equatorward wind stress results in coastal upwelling (red arrow), supporting production of large phytoplankters and zooplankters. Between the coast and the wind-stress maximum, cyclonic wind-stress curl results in curl-driven upwelling (yellow arrows) and production of smaller plankters. Anchovy (gray fish symbols) prey on large plankters, whereas sardine (blue fish symbols) specialize on small plankters. Black arrows represent winds at the ocean surface, and their widths are representative of wind magnitude.

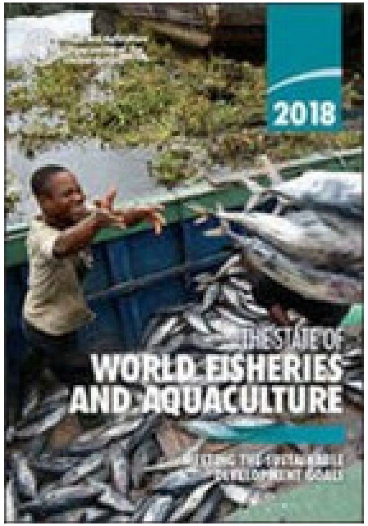

World catches (FAO, 2019)
catches (Millions t.)
100
90
80
70
60
50
40
30
20
10
0
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
Year
catches (M.t)

Estimated average yearly catches (metric tons) by commercial fisheries from different countries operating in the EBUEs during the 2004–2007 period (total catches for these years were 19.7, 18.5, 15.2 and 15.5 million tons respectively).

Source: FAO FishStat

Country	Benguela	California	Canary	Humboldt	Total
Peru				8159,500	8159,500
Chile				3598,488	3598,488
Morocco			842,123		842,123
South Africa	737,250				737,250
Mexico		658,659		684	659,343
United States of America		554,246		519	554,765
Namibia	501,161				501,161
Senegal			306,239		306,239
Mauritania			213,589		213,589
China	283	3450	1400	195,106	200,238
Portugal	1268		181,642		182,909
Russian federation		597	174,254		174,851
Lithuania			114,233	6186	120,419
Spain	6913	5299	101,861	3017	117,090
Netherlands			82,894	7862	90,756
Ukraine			69,078		69,078
Angola	52,518				52,518
Latvia			51,039		51,039
Panama		29,784	4526	6724	41,034
Japan	3311	7711	3652	26,201	40,875
Republic of Korea	2877	4451	9800	11,477	28,605
Gambia			23,866		23,866
Ireland			16,656		16,656
Taiwan, Province of China	2552	7577	1861	452	12,441
Venezuela, Republic of Bolivia		5899		5334	11,233
Germany			7731		7731
France			6834		6834
Liberia			5660		5660
United Kingdom	166		5270		5437
Italy			5351		5351
Greece			2448		2448
Total	1,308,300	1277,672	2,232,005	12,021,549	16,839,525

World Fisheries and Aquaculture



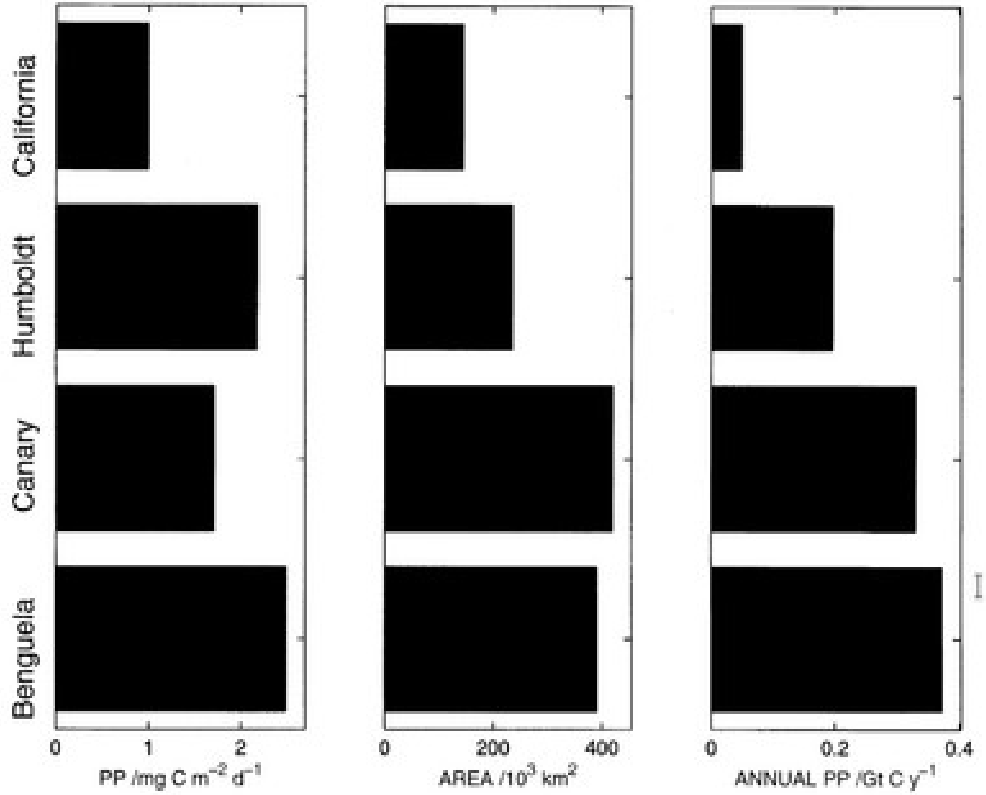
Global production of farmed fish and shellfish has more than doubled in the past 15 years. Many people believe that such growth relieves pressure on ocean fisheries, but farming carnivorous species requires large inputs of wild fish for feed.

On balance, global aquaculture production still adds to world fish supplies!

The strong worldwide demand for Fish meal, oil meal and Omega 3 is mostly supplied by small pelagic fishes, from EBUEs.

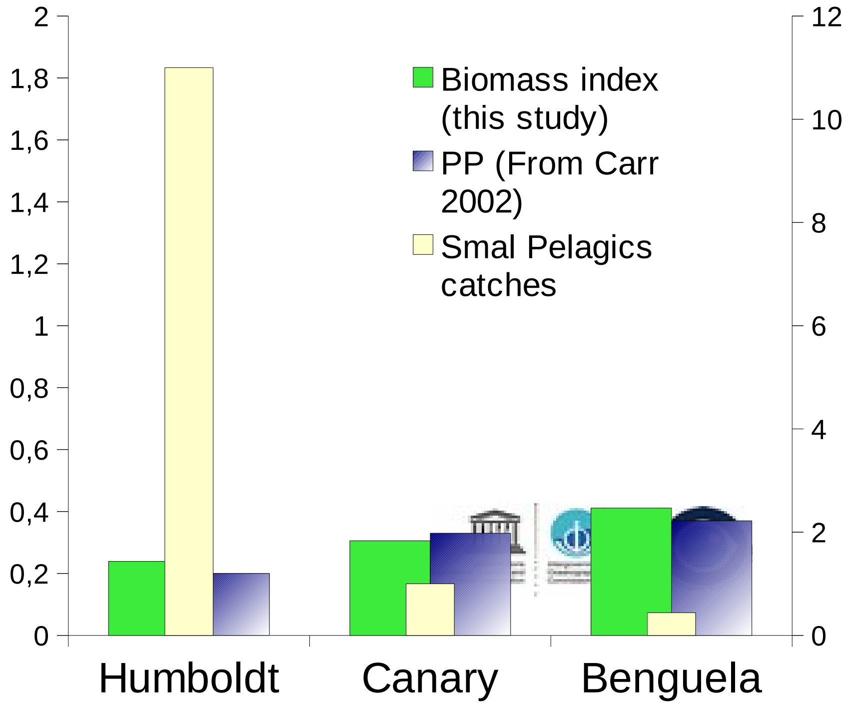
90% of the fish catches from EBUEs is transformed into Fish/oil meal !
(even a large part of the Senegalese Sardinellas)

Regional comparison of primary production, active area and annual production



P.Production Area Annual P.P.

From Carr 2002 (Deep-Sea Research II)



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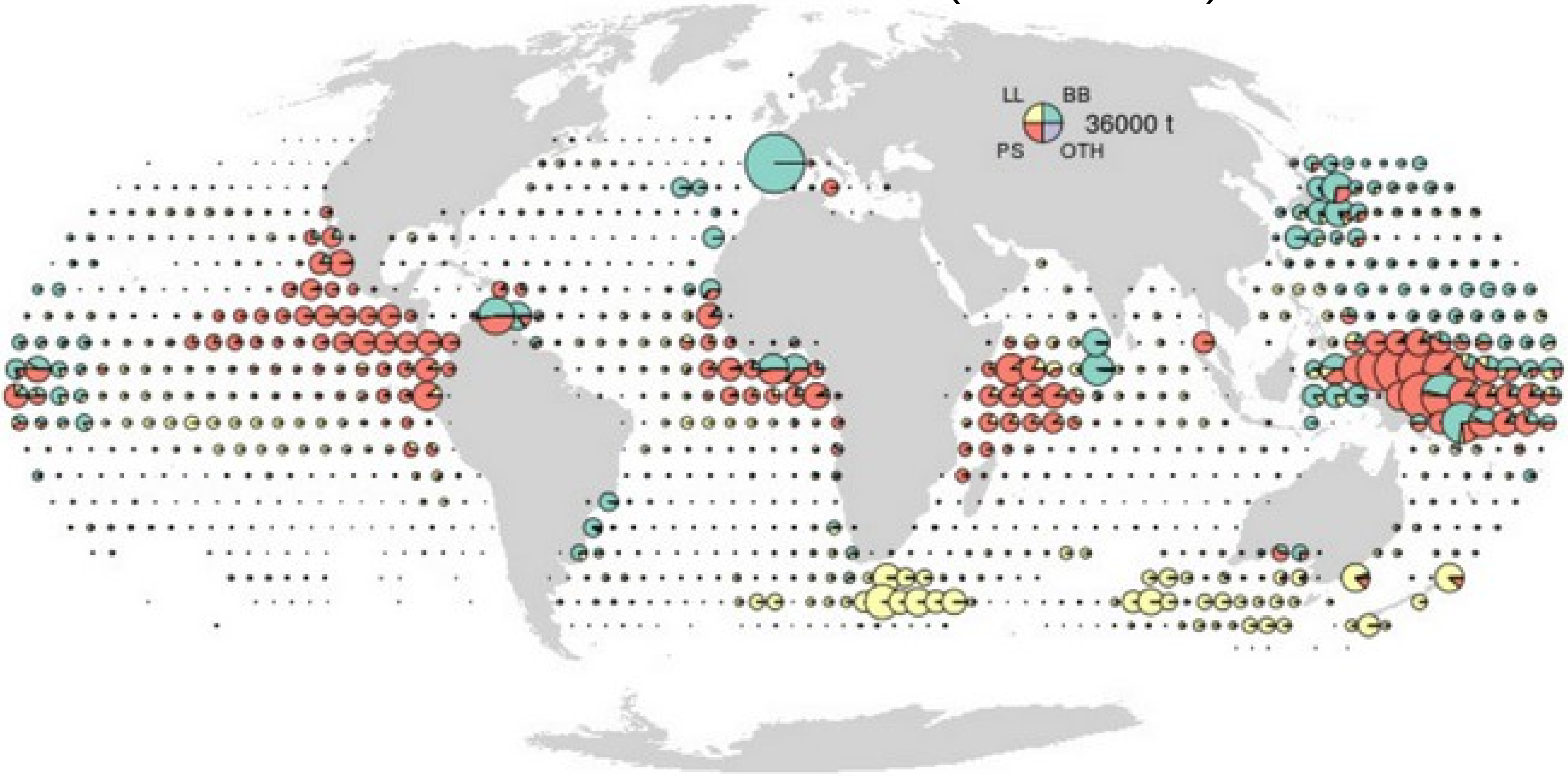
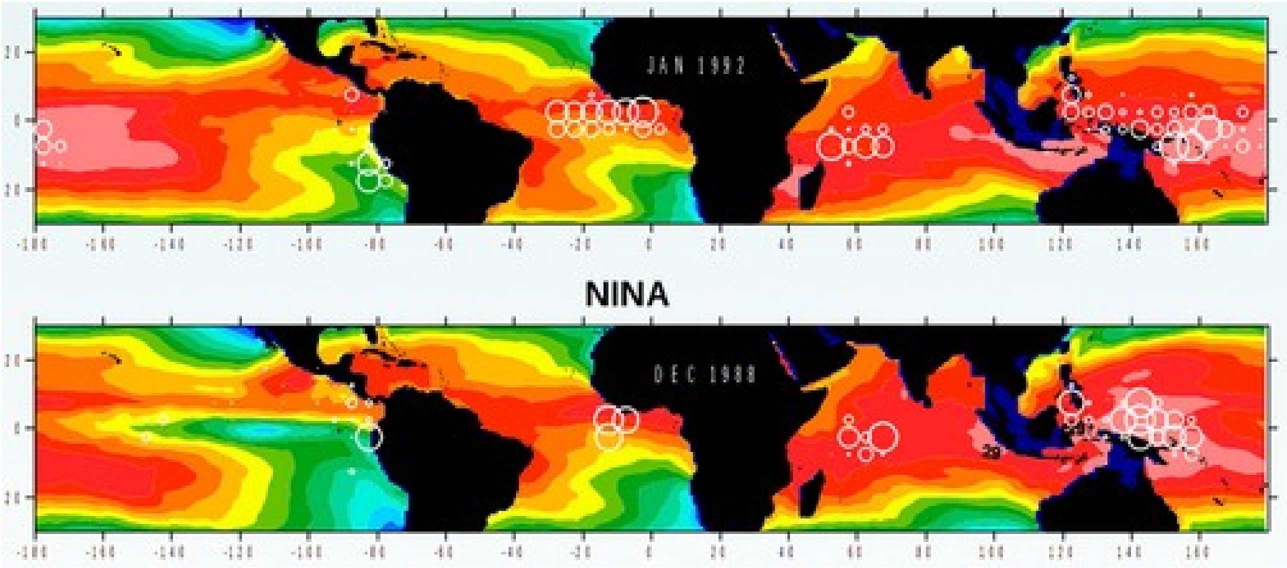
Global distribution of tuna catch (in the 1980s)

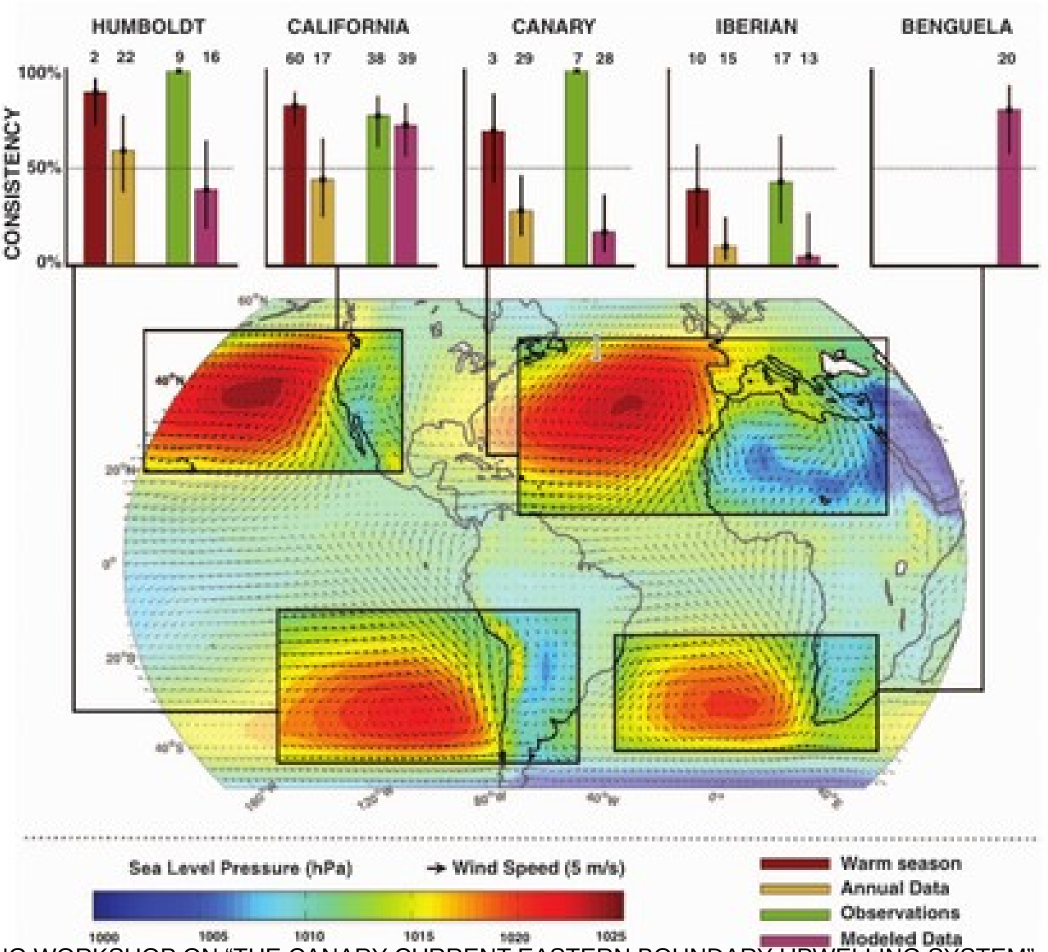


Impact of Nino-Nina events



In anomalous years when the trade winds weaken or reverse, the water that is upwelled is much warmer and low in nutrients, resulting in a sharp reduction in the biomass and phytoplankton productivity. This event is known as the El Nino-Southern Oscillation (ENSO) event. The Peruvian upwelling system is particularly vulnerable to ENSO events, and can cause extreme interannual variability in productivity.

Climate change and wind intensification in coastal upwelling ecosystems



Sydeman et al. 2014 (Science)

Published analyses suggests that **winds have intensified** in the California, Benguela, and Humboldt upwelling systems and weakened in the Iberian system over time scales ranging up to 60 years; wind change is equivocal in the Canary system. Stronger intensification signals are observed at higher latitudes, consistent with the warming pattern associated with climate change. Overall, reported changes in coastal winds, although subtle and spatially variable, support Bakun's hypothesis of upwelling intensification in eastern boundary current systems.

Conjectures on **future climate effects** on marine ecosystems:
1. **Physics**

Changing wind fields

- Increase of coastal winds resulting in stronger upwelling & lower temperature close to shore;
- At the opposite, decrease of trade winds offshore resulting in increased STT offshore leading to stronger gradients;
- The combination of these two process could result in a downwelling favourable wind stress curl
- Change in upwelling seasonality;
- Annual mean decrease in the eddy kinetic energy;

Warmer surface layers, increased stratification due to changes in temperature and salinity

- Southern high latitudes warming less than northern high latitudes. Subtropical regions (high evaporation and salinity) become saltier, whereas waters at higher latitudes and the tropics become fresher.
- Changes in the depth of the thermocline according to latitude and distance from shore
- Likely increase in the frequency and magnitude of occurrences of El Niño (controversed issue)

Conjectures on future climate effects on marine ecosystems:

2. **Productivity**

Bottom-up processes:

Decrease in plankton abundance due to increased stratification in offshore upwelling areas (McGowan et al., 2003), or horizontal input of cooler, fresher, nutrient-rich water from the north at higher latitude (Chelton et al., 1982; Freeland et al., 1997; Overland et al., 1999), perhaps increases close to shore due to increased upwelling.

Ecosystemic processes:

Sardine regimes might be favoured offshore in the Humboldt ecosystem, and possibly in the Californian ecosystem, associated to a lower total pelagic fish production (compared to an anchovy regime), but anchovy favoured closer to shore.

Conjectures on future climate effects on marine ecosystems:

3. **Acidification**

The Southern Ocean surface waters will begin to become undersaturated in aragonite by the year 2050. California and Humboldt ecosystems could be the more affected. Uncertainty regarding the expected detrimental effect of acidification on foraminifera in these upwelling regions.

Large uncertainty regarding the depletion of the ozone layer in response to the increase of CO2 concentrations, the resulting increase in ultraviolet radiation at the ocean surface and possible negative impacts on invertebrate larvae and algae.

Conjectures on future climate effects on marine ecosystems: 4. **Production**

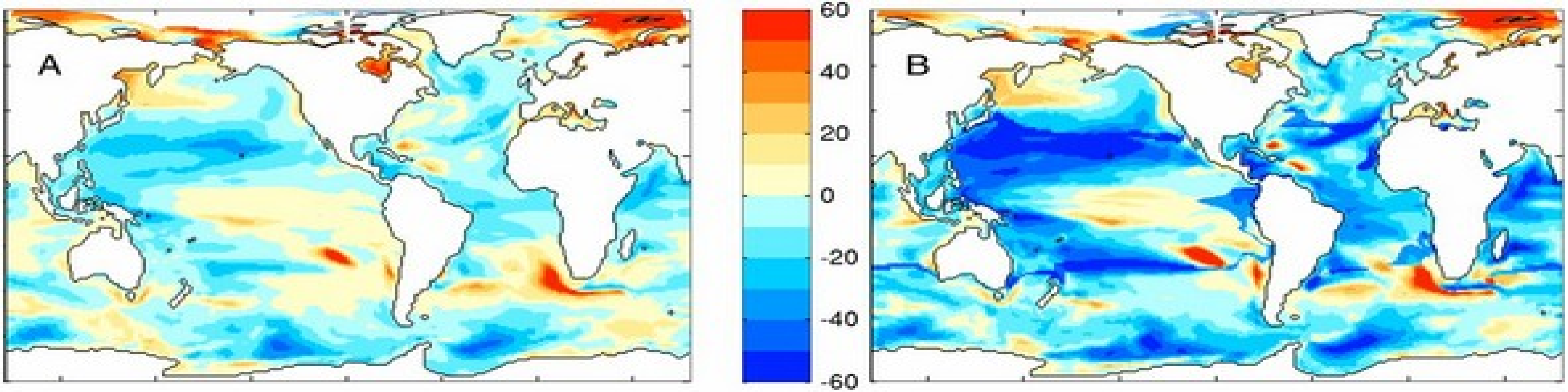
Expected increase of along-shore and offshore transport of fish larvae resulting in higher mortality, not necessarily compensated by enhanced primary production.

Sardine should be more favoured than anchovy.

Exploitation is likely to exacerbate the effects CC. Reduction in marine diversity at the individual, population and ecosystem levels will likely lead to a reduction in the resilience and an increase in the response of populations and ecosystems to future climate variability and change

Projected changes in NPP and catch with Global warming

Projected change in NPP and catch under a high-emissions scenario (RCP8.5) from ESM2M-COBALT (25, 69) between 1951–2000 and 2051–2100 using the best-fit trophodynamic model: (A) percent change in NPP, (B) percent change in fish, (C) percent change...

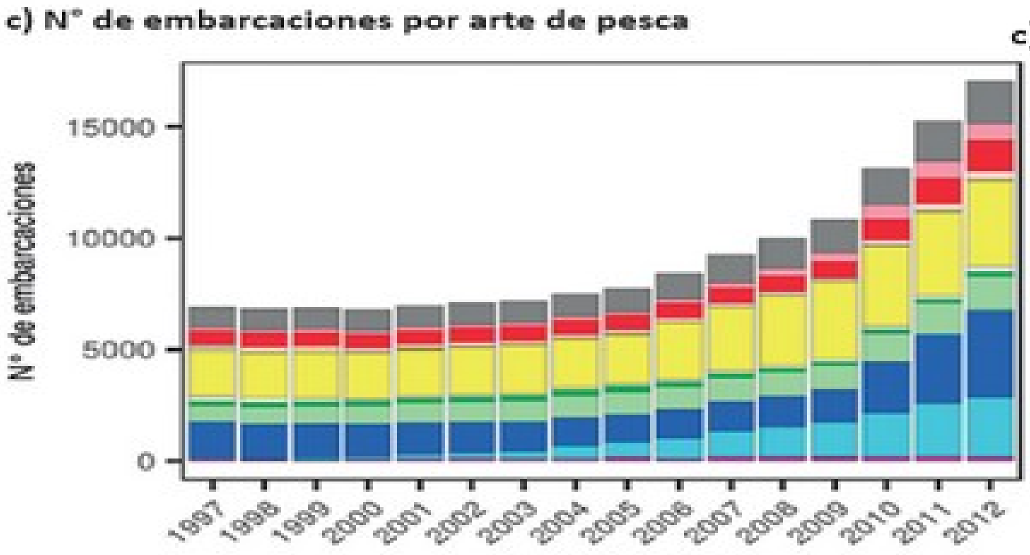


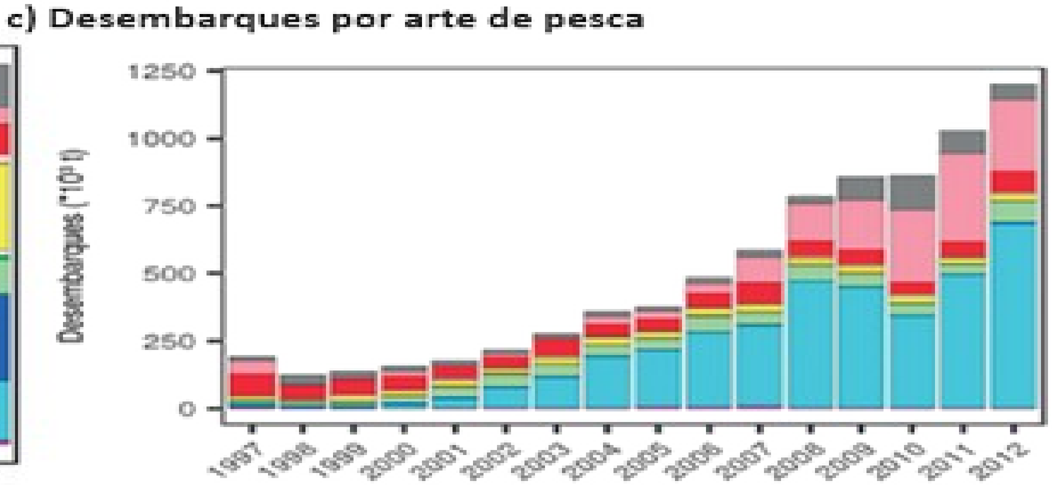
percent change in NPP **% of change** **percent change in fish**

Charles A. Stock et al. PNAS 2017;114:8:E1441-E1449 PNAS

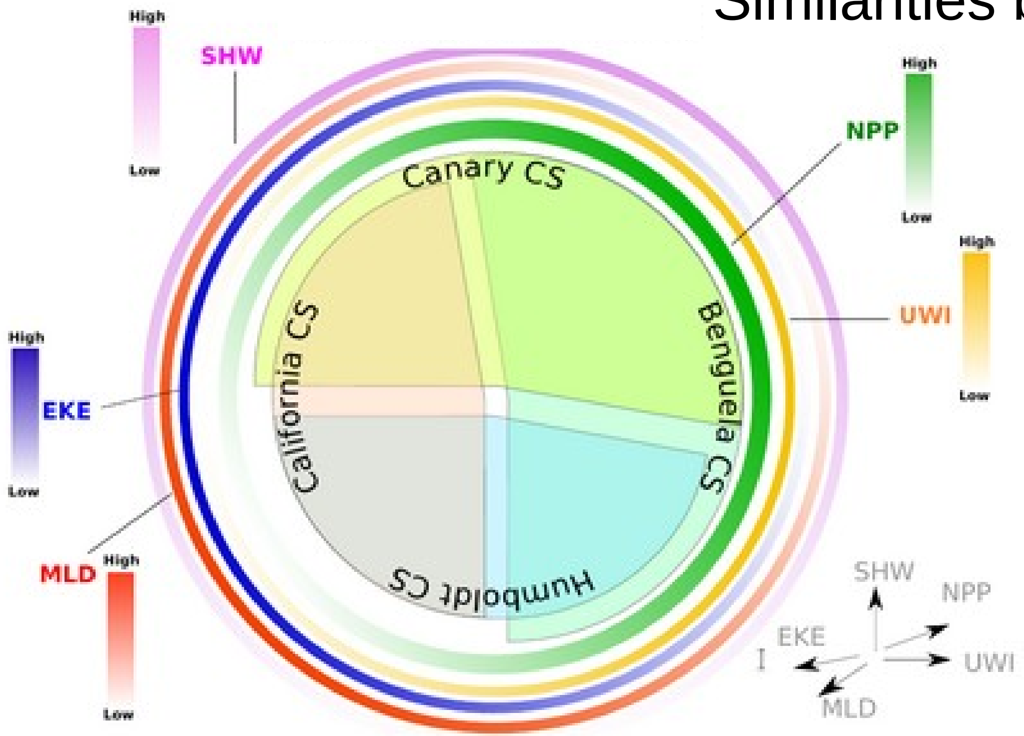
Importance of the artisanal fisheries in EBUEs

Artisanal fisheries are a major component of most EBUEs. They dominate the fisheries in Sénégal in the coastal upwelling domain and are a major component even in Peru.





Similarities between EBUEs

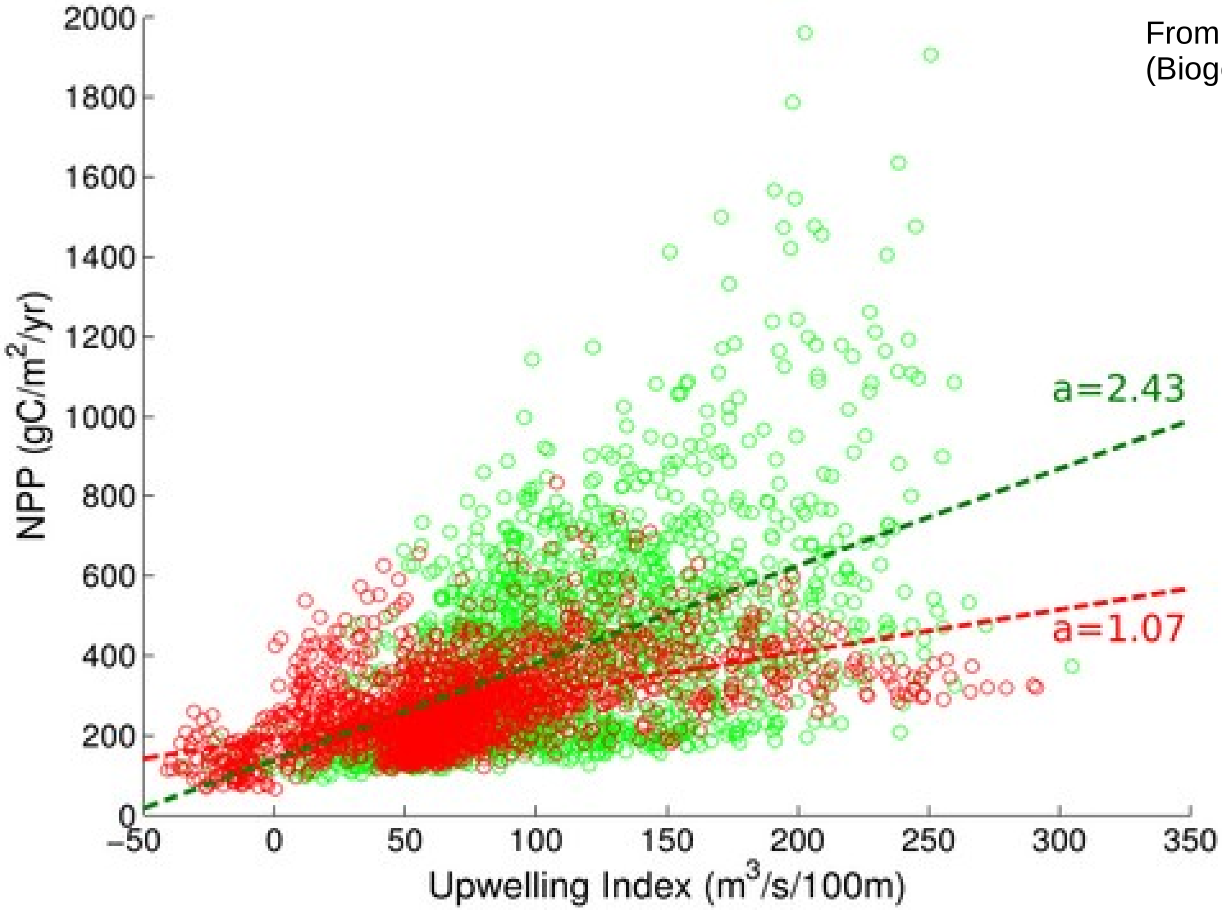


From Lachkar and Gruber 2011 (Biogeosciences)

Canary - Humboldt / California - Benguela are complementary (each pair represents most of the variability of the 4 EBUS)
Canary - Benguela and California - Humboldt are the most similar systems.
Canary and Benguela are both very productive (driven by strong alongshore wind + relatively wide continental shelf, low eddy activity and shallow mixed layer)

Finally, the region of overlap between the Canary and California current systems indicates similar conditions in the two systems characterized by relatively wide shelf and moderate to high eddy activity. Similarly, the overlapping area between the Benguela and Humboldt current systems illustrates common observations between these two systems characterized by narrow shelf and moderate alongshore wind.

From Lachkar and Gruber, 2011 (Biogeosciences)

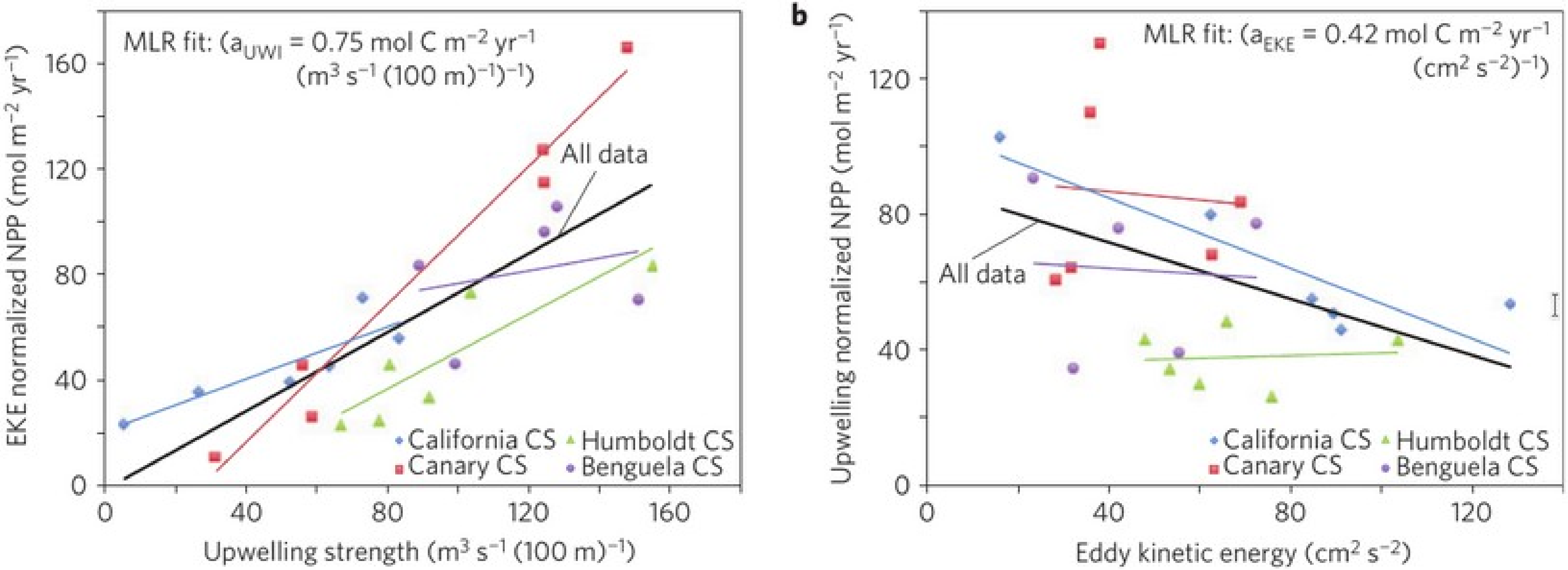


Atlantic

Pacific

The relationship between NPP and upwelling index (UWI) for the Pacific (red circles) and the Atlantic (green circles) EBUS **observations**.

From Gruber et al. 2011 Nature geoscience



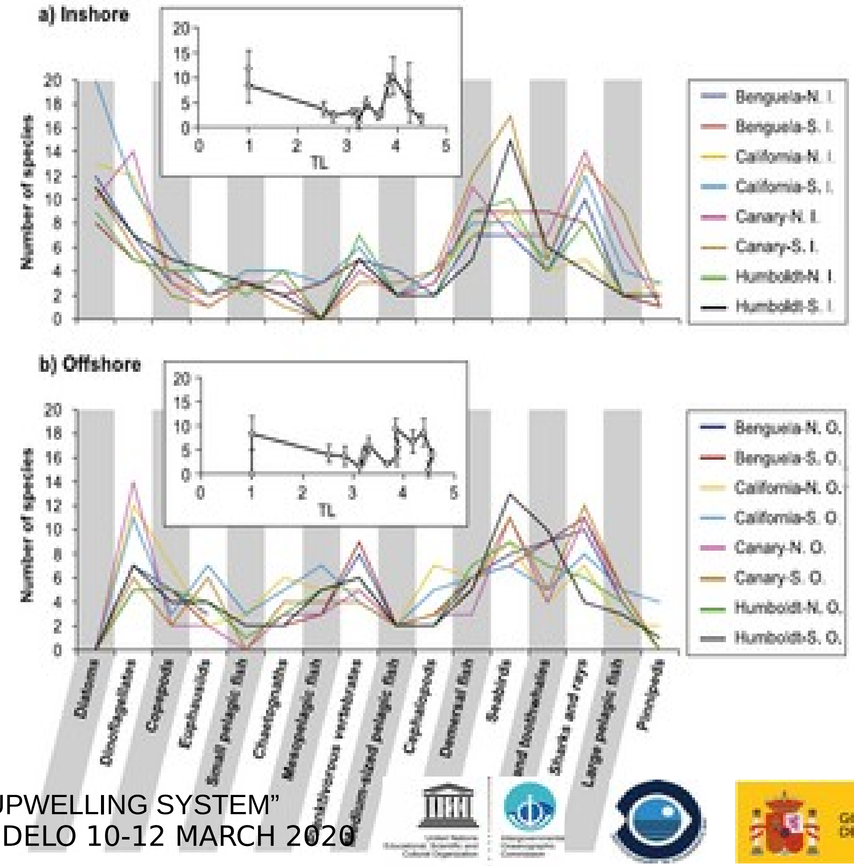
Relationship of observationally based estimates of NPP to upwelling strength and EKE in the four major EBUS

Functional group biodiversity in Eastern Boundary Upwelling Ecosystems

From Fréon et al. 2009 (Progress in O.)

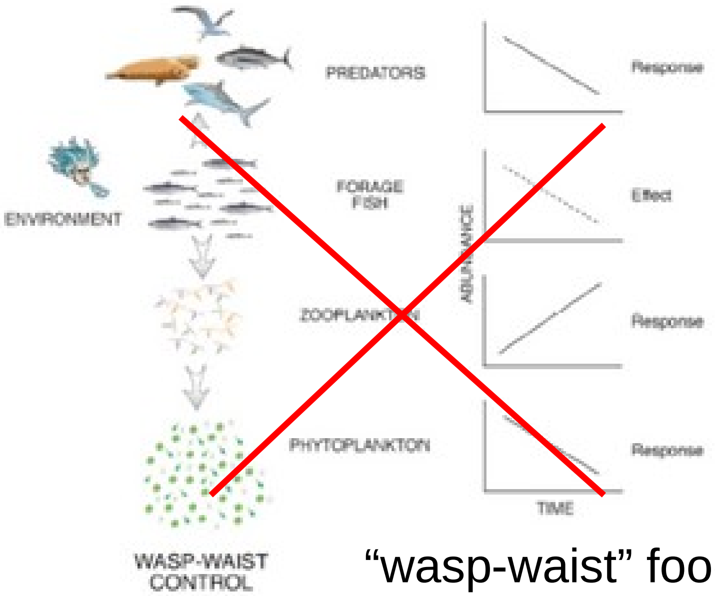
The species diversity in EBUEs is low compared to other ecosystems (despite their unstable environment at different scales) and they are very similar between systems

FG	Overall R	Mean R	TL	Log_{10} (Lm)
Diatoms	36	11.8	1.0	−2.3
Dinoflagellates	24	8.4	1.0	−2.1
Copepods	28	3.8	2.5	−0.6
Euphausiids	26	2.3	2.7	0.2
Small pelagic fish	12	3.1	3.0	1.2
Chaetognaths	13	2.8	3.2	0.3
Meso-pelagic fish	18	1.1	3.2	0.7
Planktivorous vertebrates[a]	17	4.9	3.4	3.2
Medium-sized pelagic fish	9	2.4	3.6	1.3
Cephalopods	19	3.0	3.8	1.4
Demersal fish	67	8.5	3.8	1.5
Seabirds	67	10.3	3.9	1.7
Dolphins & toothwhales	19	5.5	4.2	2.6
Sharks & rays[b]	43	9.3	4.3	2.3
Large pelagic fish	25	3.6	4.3	1.8
Pinnipeds	11	1.8	4.5	2.3
Total	434	11.8	-	-

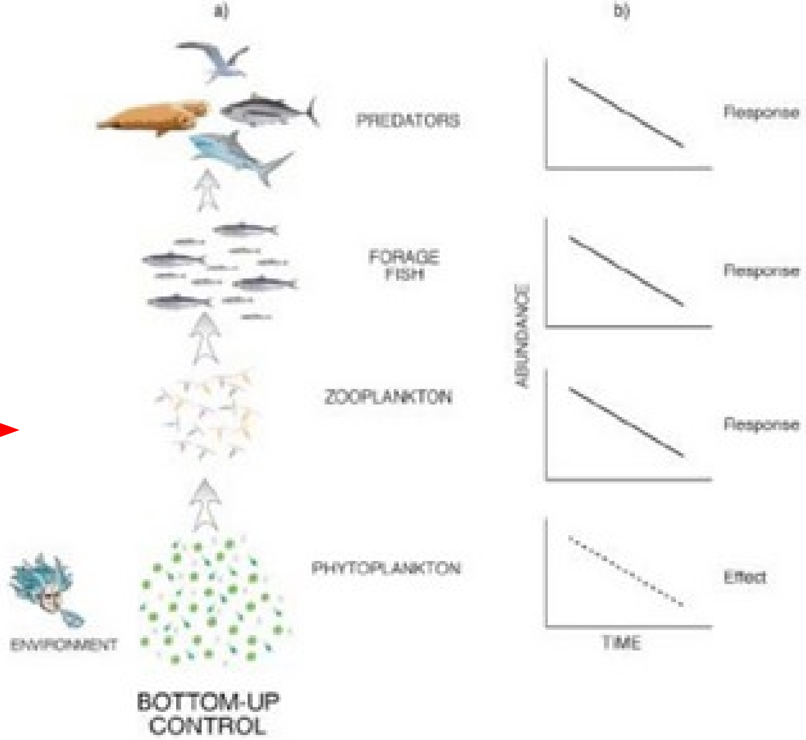


Richness according Functional groups in the four EBUEs (coastal/Offshore)

Furthermore, this contradicts the “wasp-waist” food web hypothesis done by Bakun (1996) an quantified in the Benguela (Cury et al. 2000), confirming that all EBUEs are clearly bottom-up structured



“wasp-waist” food web



Bottom-Up Controlled food web

Thank you