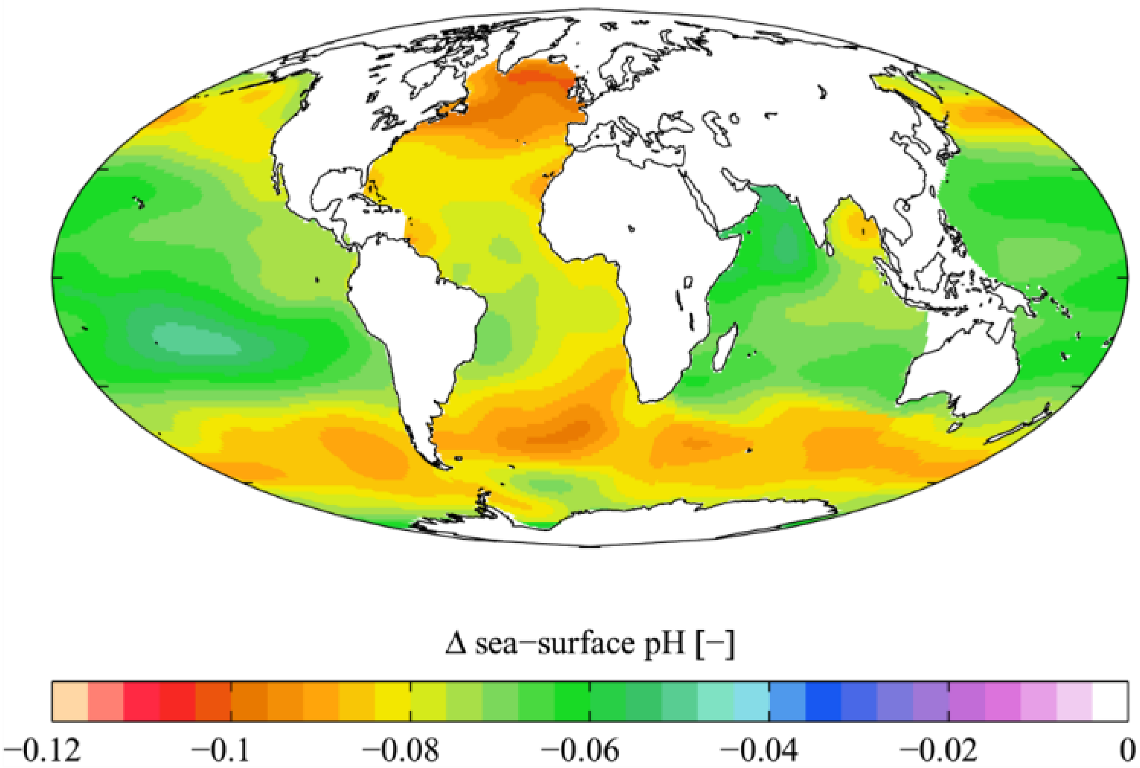
Who are the most vulnerable? – a global assessment of exposure, sensitivity, adaptive capacity and vulnerability to ocean acidification.

John K. Pinnegar, Silvana Birchenough and Nick Dulvy
Marine Climate Change Centre, Cefas, Lowestoft, UK

Session S2, Ocean Acidification, Thurs 26th Mar 2015

Ocean Acidification – what we know already…



Estimated change in sea water pH caused by human created CO_2 between the 1700s and the 1990s, from the Global Ocean Data Analysis Project (GLODAP) and the World Ocean Atlas

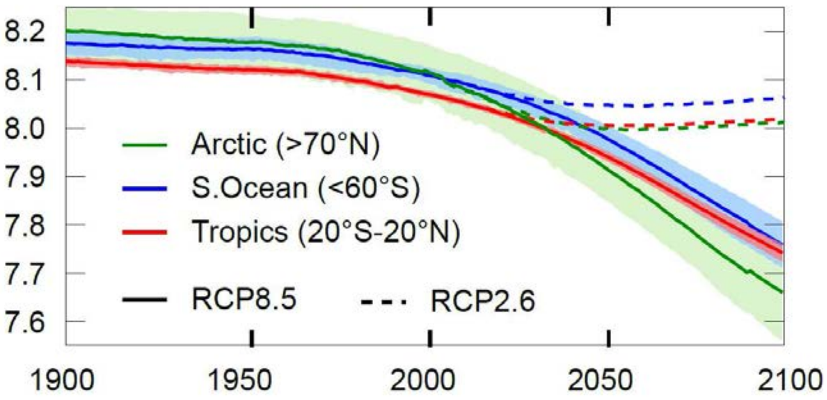
The Ocean has absorbed approximately 30% of atmospheric CO_2 from human activities resulting in decreased pH

Surface ocean pH has declined by approximately 0.1 pH units since the beginning of the Industrial Revolution

Further increases in atmospheric CO_2 are *certain* to further acidify the Ocean and change its carbonate chemistry

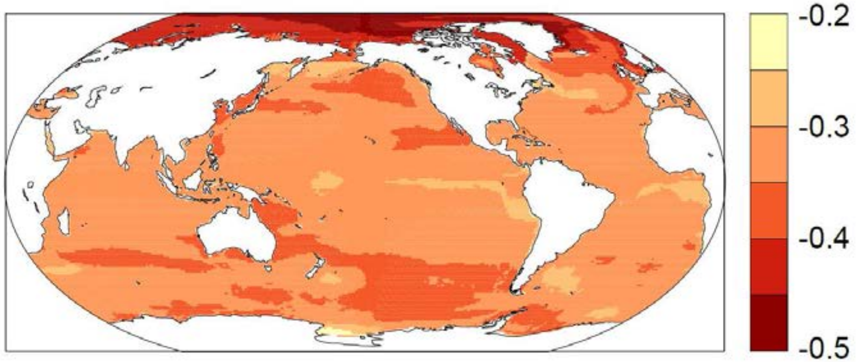
Ocean Acidification – the future…

a. Surface pH



Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6.

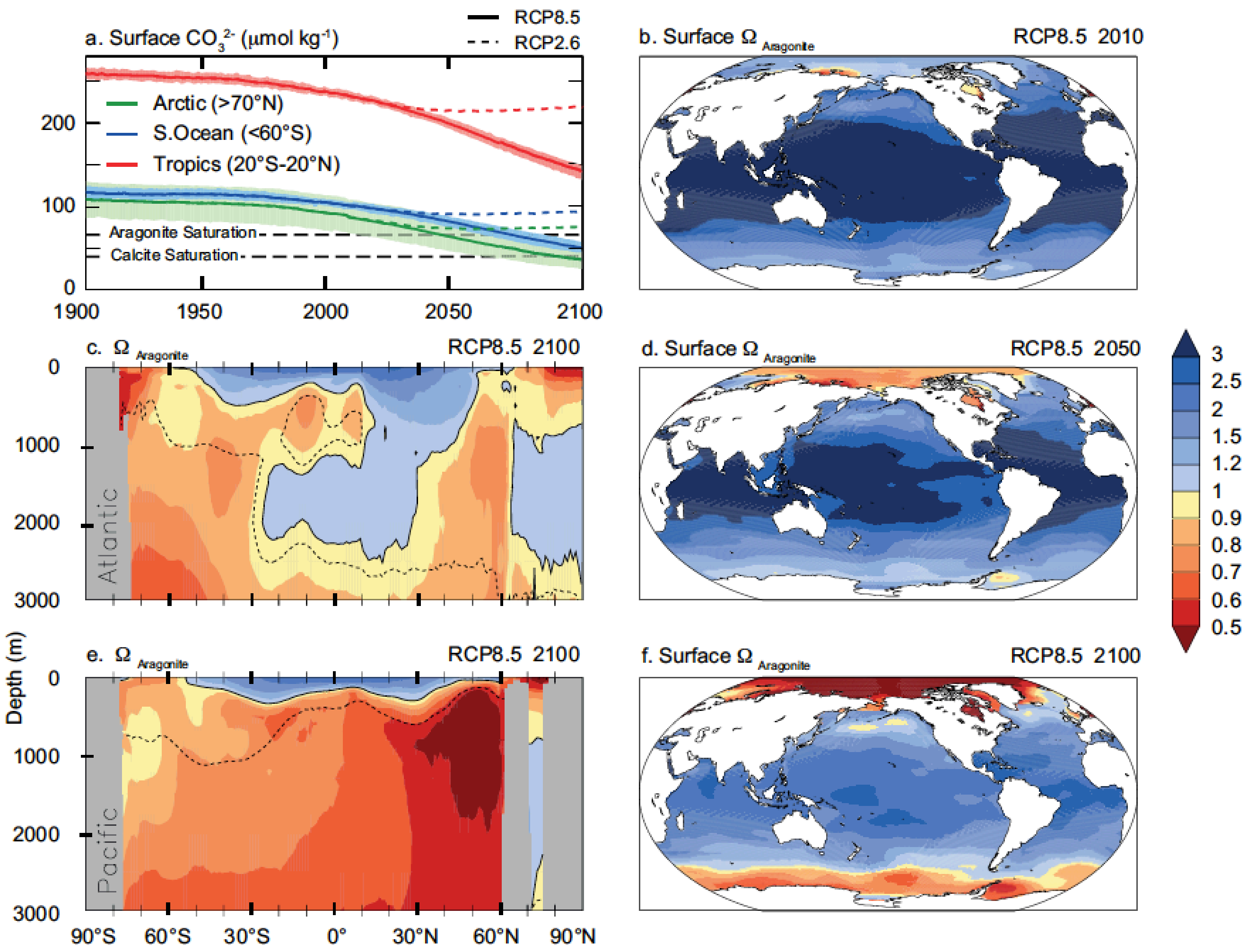
b. Surface pH in 2090s (RCP8.5, changed from 1990s)



Models project that cold waters (particularly in the Arctic) soon become corrosive to aragonite, a ($CaCO_3$) mineral in some marine shells & skeletons

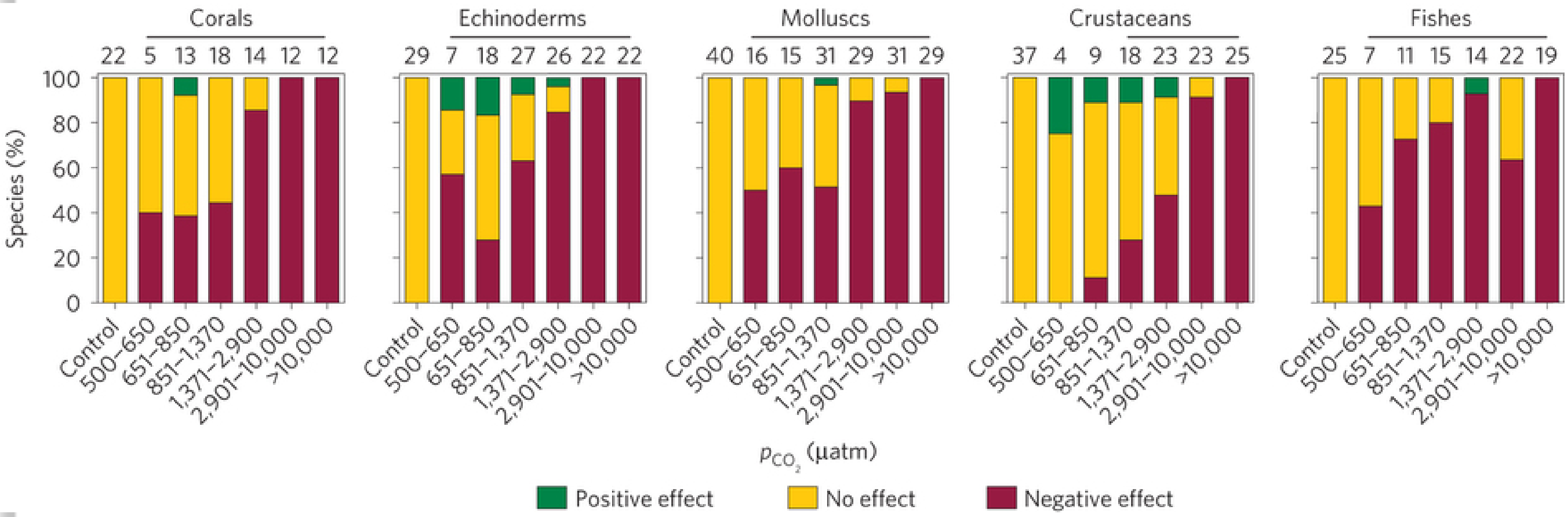
(From IPCC AR5, WGII, Chapter 30)

Ocean Acidification – the future…



IPCC AR5
WG1 Chap. 6

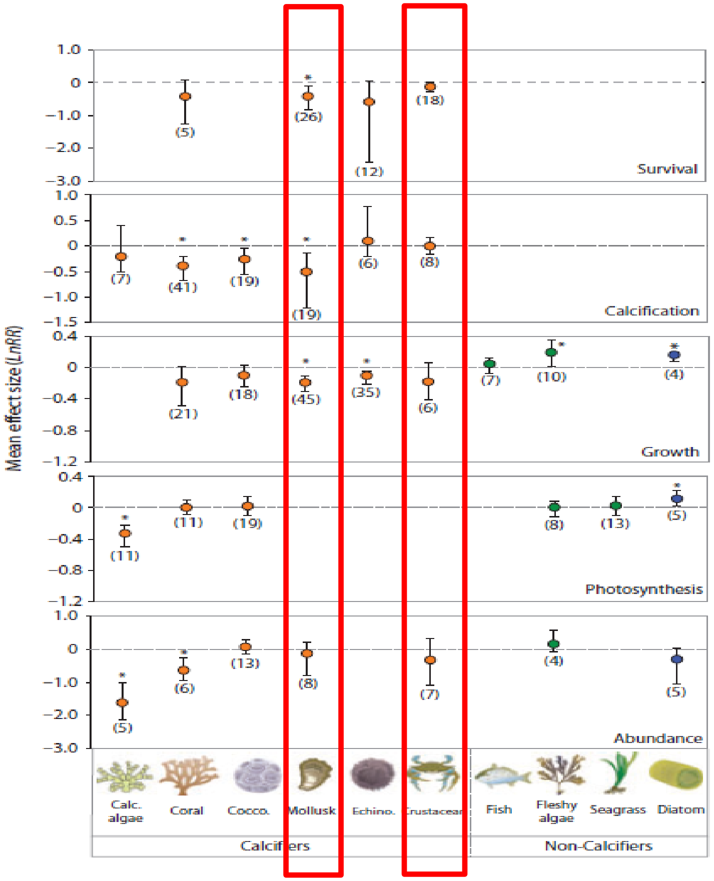
Ocean acidification – sensitivity of species…

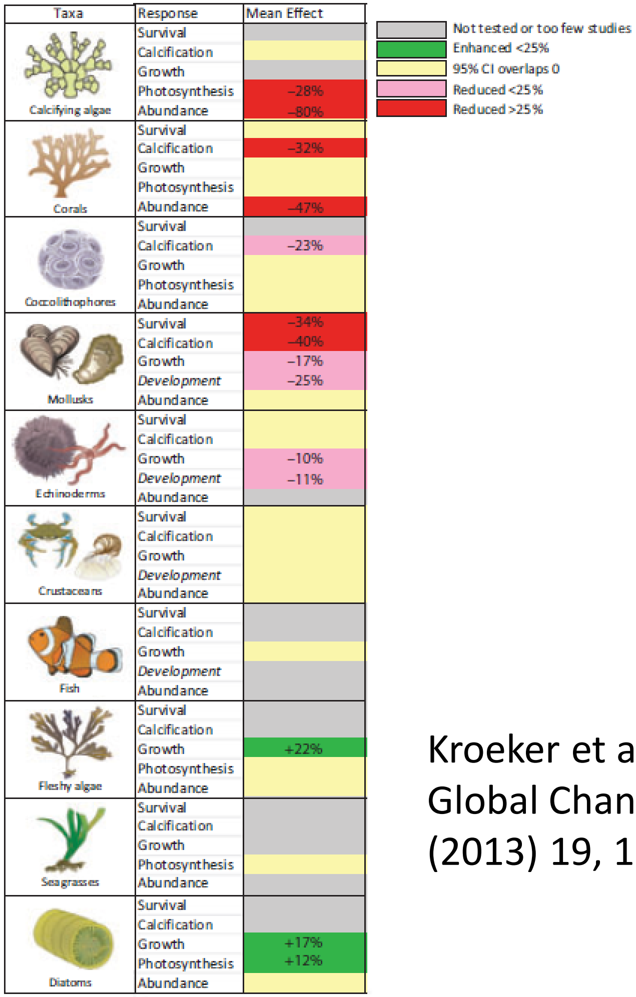


Wittmann & Pörtner (2013) Nature Climate Change 3,995–1001.

Ocean acidification – sensitivity of species…

There have now been several useful meta-analyses and these have yielded useful insights:





Taxa	Response	Mean Effect
Calcifying algae	Survival	⬜
	Calcification	🟨
	Growth	⬜
	Photosynthesis	🟥 –28%
	Abundance	🟥 –80%
Corals	Survival	🟨
	Calcification	🟥 –32%
	Growth	🟨
	Photosynthesis	🟨
	Abundance	🟥 –47%
Coccolithophores	Survival	⬜
	Calcification	🟪 –23%
	Growth	🟨
	Photosynthesis	🟨
	Abundance	🟨
Mollusks	Survival	🟥 –34%
	Calcification	🟥 –40%
	Growth	🟪 –17%
	Development	🟪 –25%
	Abundance	🟨
Echinoderms	Survival	🟨
	Calcification	🟨
	Growth	🟪 –10%
	Development	🟪 –11%
	Abundance	⬜
Crustaceans	Survival	🟨
	Calcification	🟨
	Growth	🟨
	Development	🟨
	Abundance	🟨
Fish	Survival	⬜
	Calcification	⬜
	Growth	🟨
	Development	⬜
	Abundance	⬜
Fleshy algae	Survival	⬜
	Calcification	⬜
	Growth	🟩 +22%
	Photosynthesis	🟨
	Abundance	🟨
Seagrasses	Survival	⬜
	Calcification	⬜
	Growth	⬜
	Photosynthesis	🟨
	Abundance	⬜
Diatoms	Survival	⬜
	Calcification	⬜
	Growth	🟩 +17%
	Photosynthesis	🟩 +12%
	Abundance	🟨

⬜	Not tested or too few studies
🟩	Enhanced <25%
🟨	95% CI overlaps 0
🟪	Reduced <25%
🟥	Reduced >25%

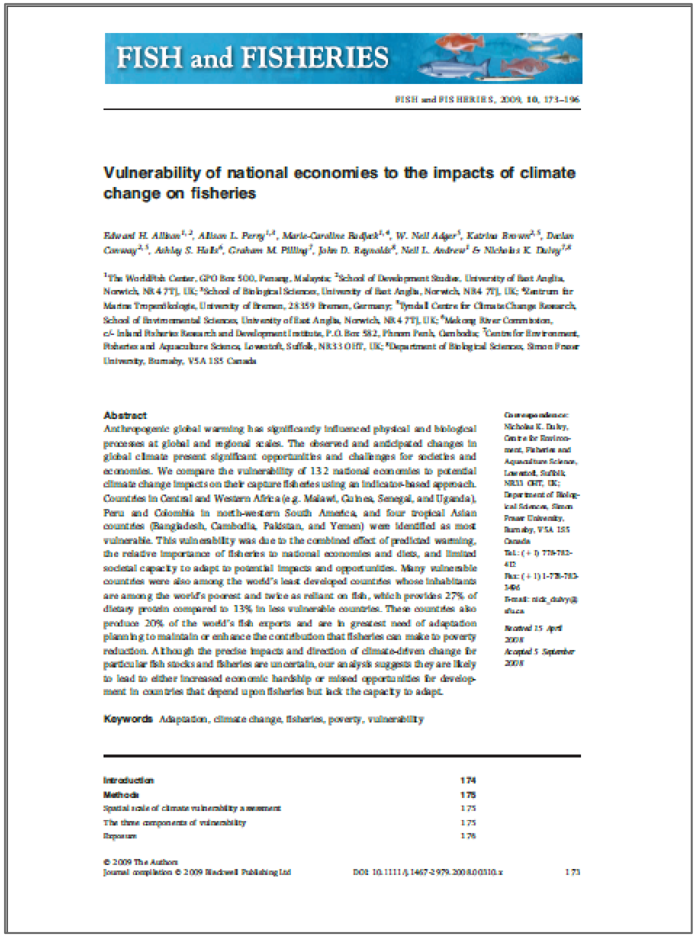
Kroeker et al. (2013)
Global Change Biology
(2013) 19, 1884–1896

Commercial Species Specifically:

Species	Scientific name	pH tested/methods	Duration	Observations for pH decrease up to 0.4 units (effect size)	Other co-stressors	References
Molluscs						
Scallops (King)	*Pecten Maximus*	[8.18, 8.10, 7.81, 7.82] pH meter and tank	11 weeks (77 days)	*Clearance rates, respiration rates, condition index and cellular turn over (DNA:RNA)	Temperature= 15oC	Sanders et al., (2013)
Mussels	*Mytilus edulis*	[8.1, 7.6, 7.4, 7.1, 6.7]	44 days	**Shell growth was significantly affected between pHu 7.1. and 8.1 but was significantly reduced at 7.1 and 6.67pHu. From day 23 mortlaity was observed in this treatment		Berge et al. (2006)
	Mytilus edulis					Gazeau et al. (2010)
	Perumytilus purpuratus					Vargas et al., 2012
Oysters	*Crassostrea gigas*	[8.07,7.55]	2hours	**Significant decreased calcification as a function of increasing CO2 and decreasing pH.		22-Epoca ref. list
	Crassostrea gigas					Lanning et al. (2010)
	Crassostrea virginica	[8.16,8.06,7.91, 7,76]	28 days	**Shell area decreased by 16% and calcium content 42%in the highest CO2 treatment relative to the lowest. Nosignificant difference observe in shell thickness.		54-EPOCA ref. list
Clam	*Ruditapes decussatus*	[8.25,7.85, 7.67]	75 days	*No changes observed in net calcification size or weight of the clams. Mortality reduced in the acidified treatments.		Range et al.(2011)
Clam	*Macoma balthica (eggs, larvae and embrios)*	[8.1, 7.8, 8.5]		Effects observed in fertilization, embryogenesis and reduction of larval development		van Colen et al. (2012)
Cockles	*Ceratodesma edule*	[8.3, 6.7]	55 days	Direct effects: Reductions on shell length, shell weight and cockle flesh over high CO2 increased. Indirect effects: DEB but difficult to differnciate between assimilation, maintenance and growth		Klok et al (2014)
Abalone	*Cocholepas concholepas*	[8.1, 7.8]	?	combined results demostrated that elevated PCO2conditions increase the standard metabolic rates and it is likely to have higher cost of energy		Lardiles et al. (2014)
Mussels	*Mytilus galloprovincialis*	[7.8; 8.0]	10 months	Mussels highly sensitive to waring, high mortalities under elevanted temepratures/Oa may have the potentential to reduce growth rate , especially in summer, there results are not conclusive	Temperature (+3oC, 17-20)	Gazeau et al. 2014
Crustaceans						
Nephrops	*Nephrops norvergicus (eggs)*	[control and -0.4 units]	4 months	Embryonic responses were investigated by quantifying proxies for development rate and fitness including: % yolk consumption, mean heart rate, oxygen comsumption and oxidative stress	Temperature= 5–18°C	Styf et al. (2013)
	Hyas araneus (larvae)	[8.01, 7.71]		Zoea I larvae is able to compesante for higher metabolic costs and survival was not affected by elevanted PCO2 levels	Temperature=6.2oc	Schiffer et al.(2013)
Crabs	*Necora puber*	[8.05, 7.8. 7.6, 7.4, 7.2, 6.8 and 6.0]	30 days			Small et al. (2010)
	Cancer magister					
Shrimps	*Palaemon pacificus (egg, juvenile)*	[7.9, 7.6]	30, 15 wk	**Decreased survival, growth, egg production		Kurihara et al. (2008)
Prawns	*Palamon elegans*		30 days			Kurihara (2008)
	Palamon serratus		30 days			
Lobster (European)	*Hommarus gammarus (larvae)*	[8.10, 7.84] pH meter	5 months (140 days)	**Growth was slow at 10oC and after 5 weeks none of the larvae moulted into Stage 4.Deformities were observed in the larvae (curled carapace, damaged in the tail and bend rostrum)	10- and 18oC	Agnalt et al. (2013)
	Hommarus gammarus (juvenile)	[7.95, 7.96] pH meter	5 months (140 days)	**Deformities were observed in juveniles ~40 in total (mainly claws, twisted legs and puffy carapace)	14oC	Agnalt et al. (2013)

[Fish & Fisheries, 10: 173–196]

Allison et al. (2009)



FISH and FISHERIES

FISH and FISHERIES, 2009, 10, 173–196

Vulnerability of national economies to the impacts of climate change on fisheries

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Abstract

Anthropogenic global warming has significantly influenced physical and biological processes at global and regional scales. The observed and anticipated changes in global climate present significant opportunities and challenges for societies and economies. We compare the vulnerability of 132 national economies to potential climate change impacts on their capture fisheries using an indicator-based approach. Countries in Central and Western Africa (e.g. Malawi, Guinea, Senegal, and Uganda), Peru and Colombia in north-western South America, and four tropical Asian countries (Bangladesh, Cambodia, Pakistan, and Yemen) were identified as most vulnerable. This vulnerability was due to the combined effect of predicted warming, the relative importance of fisheries to national economies and diets, and limited societal capacity to adapt to potential impacts and opportunities. Many vulnerable countries were also among the world's least developed countries whose inhabitants are among the world's poorest and twice as reliant on fish, which provides 27% of dietary protein compared to 13% in less vulnerable countries. These countries also produce 20% of the world's fish exports and are in greatest need of adaptation planning to maintain or enhance the contribution that fisheries can make to poverty reduction. Although the precise impacts and direction of climate-driven change for particular fish stocks and fisheries are uncertain, our analysis suggests they are likely to lead to either increased economic hardship or missed opportunities for development in countries that depend upon fisheries but lack the capacity to adapt.

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Keywords *Adaptation, climate change, fisheries, poverty, vulnerability*

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Compared the vulnerability of 132 national economies to climate change impacts on their capture fisheries using an indicator-based approach.

Assumes: $V = \int(E, S, AC)$

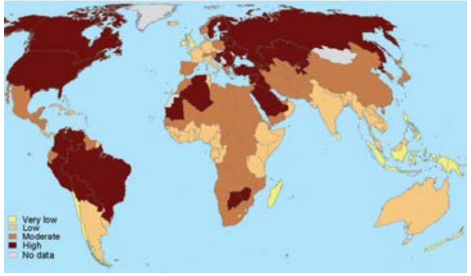
V= Vulnerability, E = Exposure,
S = Sensitivity, AC = Adaptive Capacity

PLACID

Cefas

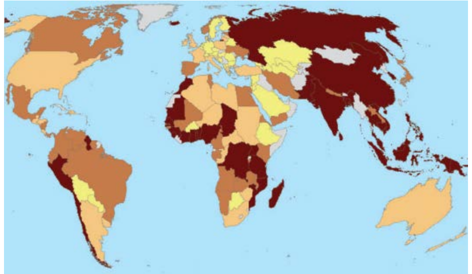
Climate Change Impacts on Fisheries

Exposure (future temperature change)



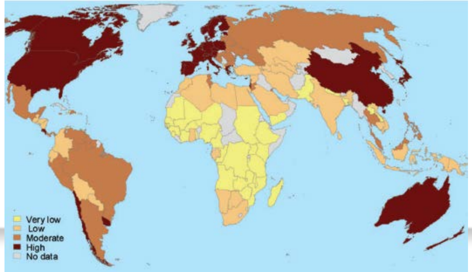
Fisheries Sensitivity

(production, and the contributions of fisheries to employment, export income and dietary protein)

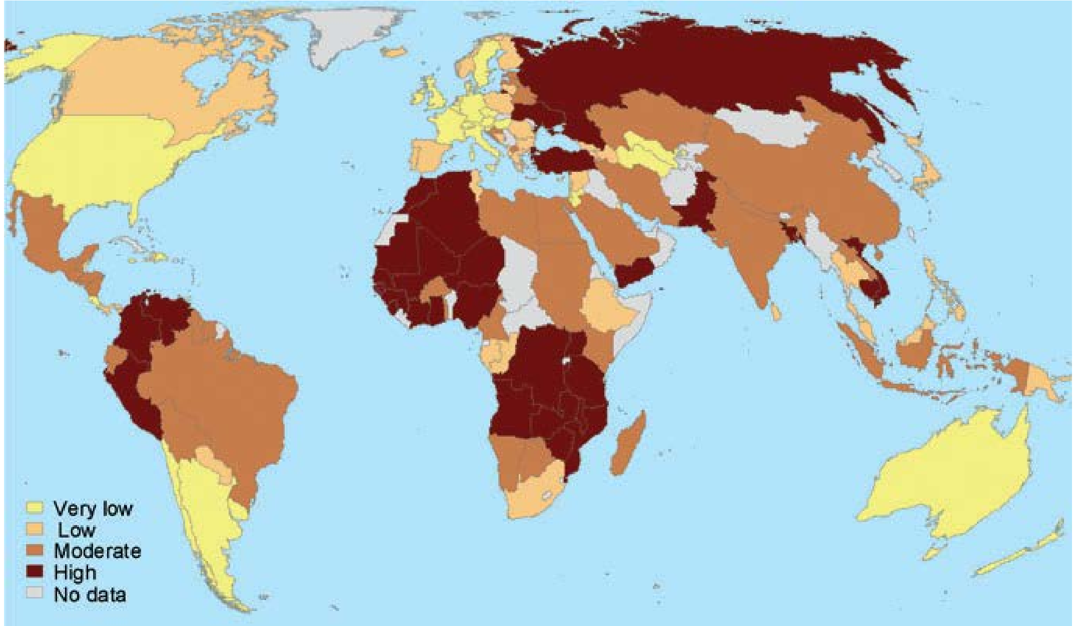


Adaptive Capacity

(life expectancy, education, governance and GDP)



Vulnerability



Vulnerability of national economies of potential climate change impacts on fisheries under IPCC scenario B2 (lower emissions).

The top 10 most vulnerable (out of 132) were: Angola, DR Congo, Russia, Mauritania, Senegal, Mali, Sierra Leone, Mozambique, Niger, Peru

Hypotheses & questions…

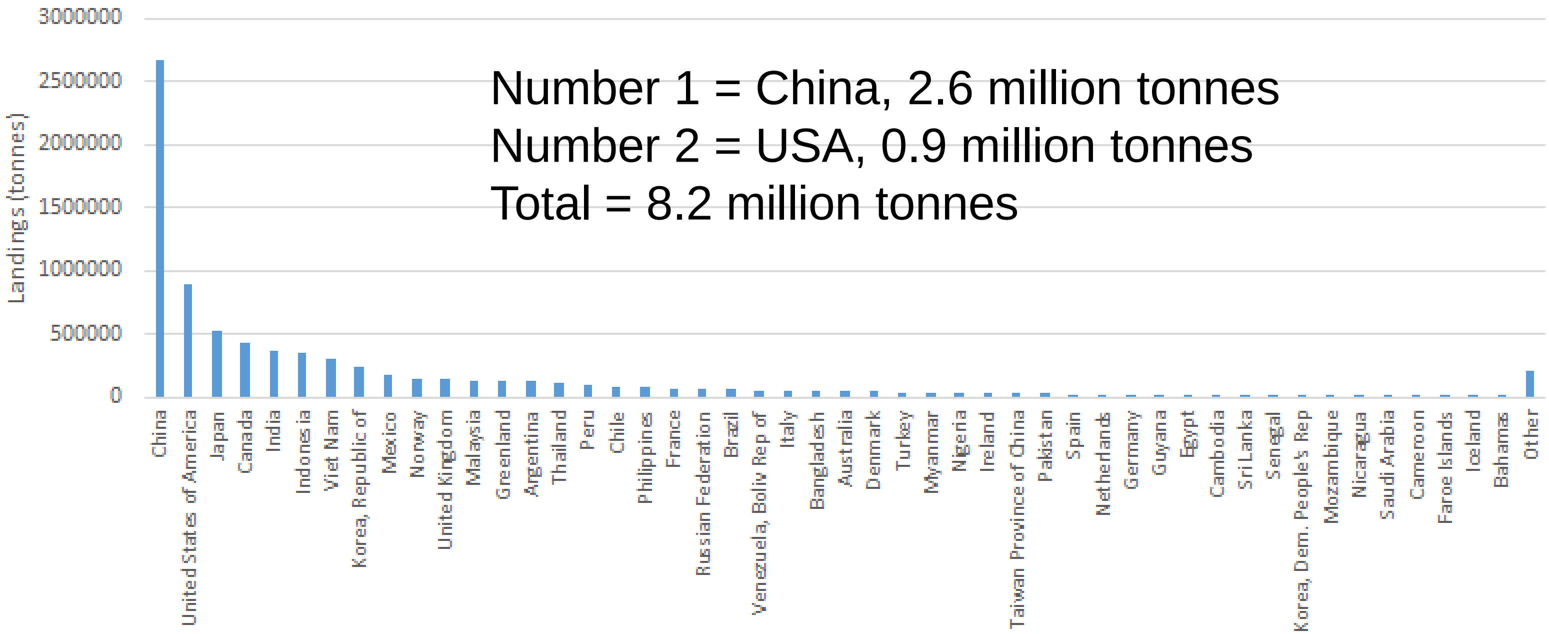
1. Countries that are most reliant on shellfish as a source of income or protein, will be most vulnerable to the effects of ocean acidification.

2. The largest projected decrease in surface pH will occur in warmer, low and mid-latitudes, however it is high latitudes (particularly the Arctic) and upwelling regions that will become under-saturated first with respect to aragonite.

3. The countries highlighted as most vulnerable in this analysis will be very different to those highlighted in previous assessments based on changes in seawater temperature.

Shellfish production, who, what and where?

2010 Wild-capture fisheries (total shellfish)



Number 1 = China, 2.6 million tonnes
Number 2 = USA, 0.9 million tonnes
Total = 8.2 million tonnes

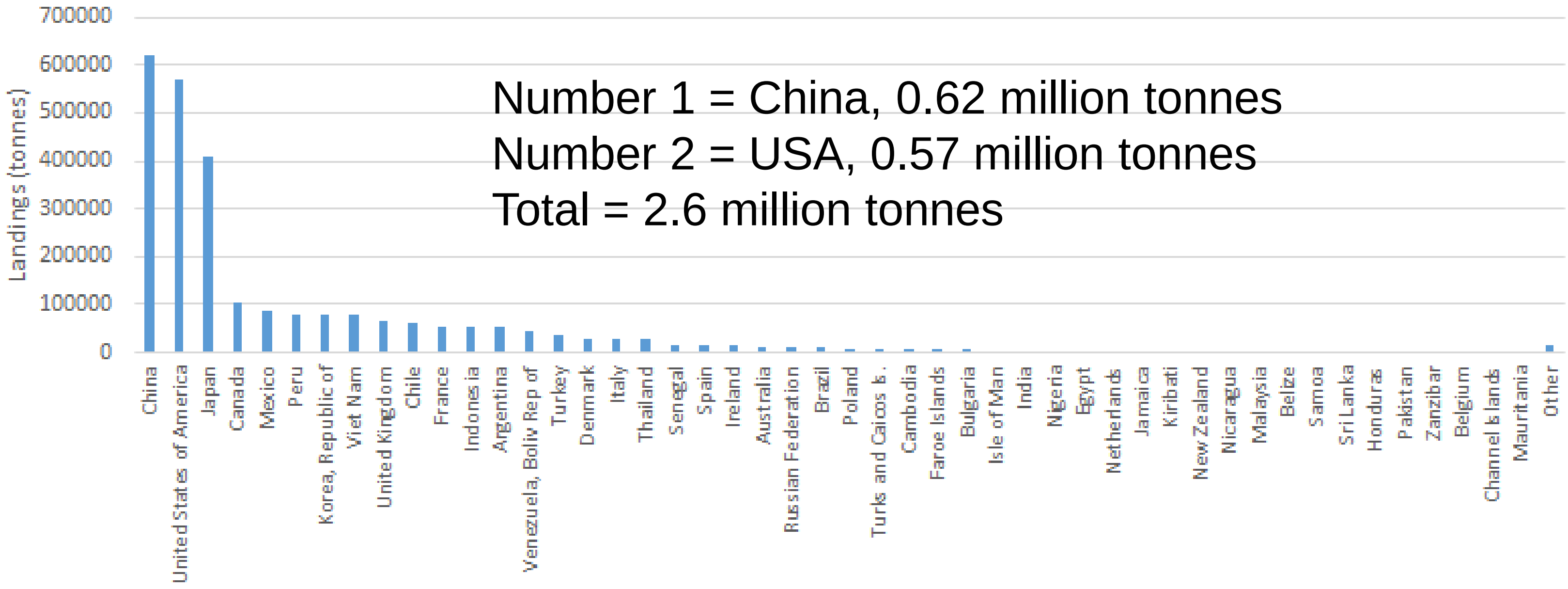
Brazil is #21, 67322 tonnes

UK is #11, 140407 tonnes

FAO FishStat

Shellfish production, who, what and where?

2010 Wild-capture fisheries (molluscs only)



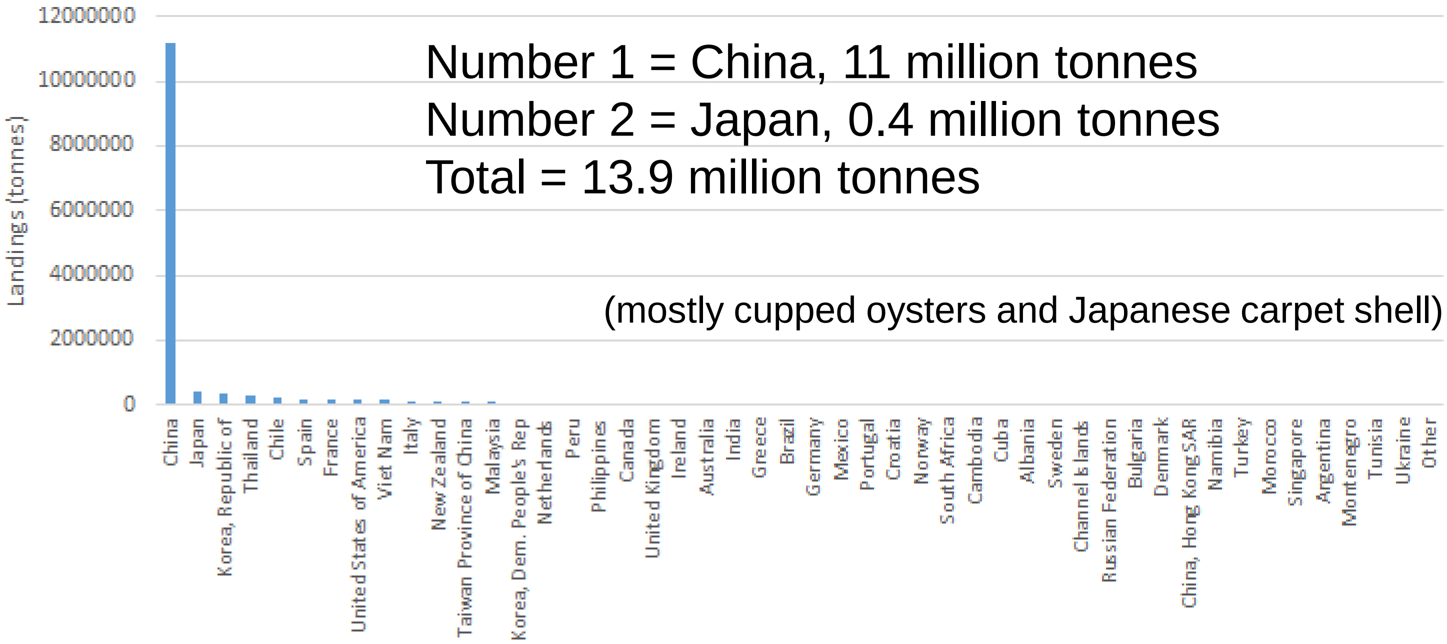
Number 1 = China, 0.62 million tonnes
Number 2 = USA, 0.57 million tonnes
Total = 2.6 million tonnes

Brazil is #24, 10180 tonnes Chile is #10, 62259 tonnes UK is #9, 66765 tonnes

FAO FishStat

Mollusc aquaculture, who, what and where?

2010 Aquaculture Production (molluscs only)



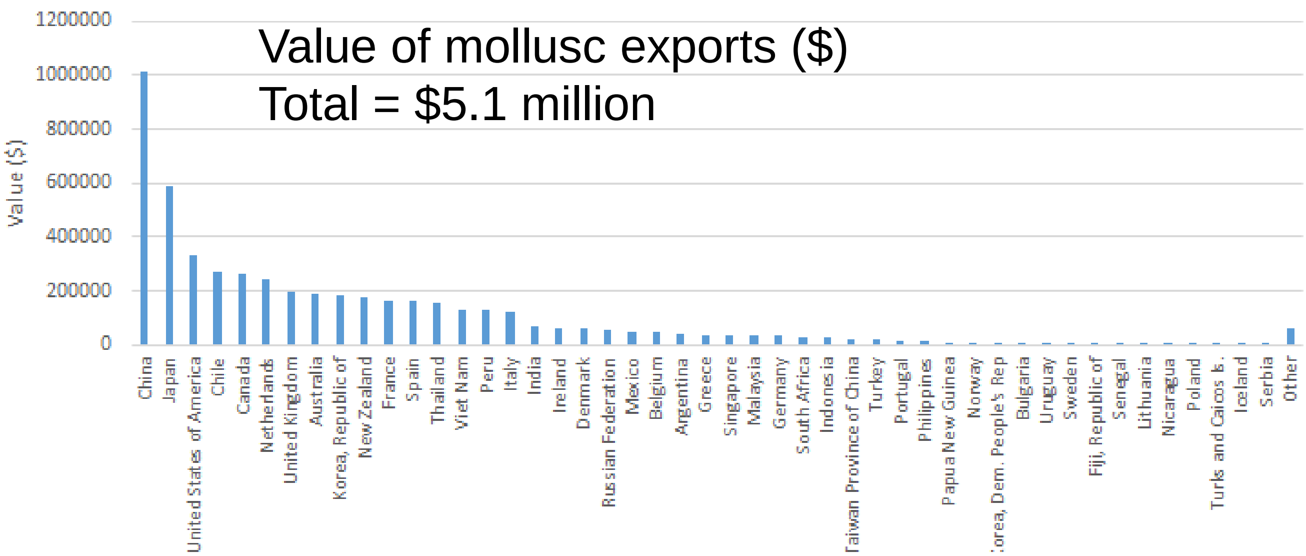
Number 1 = China, 11 million tonnes
Number 2 = Japan, 0.4 million tonnes
Total = 13.9 million tonnes

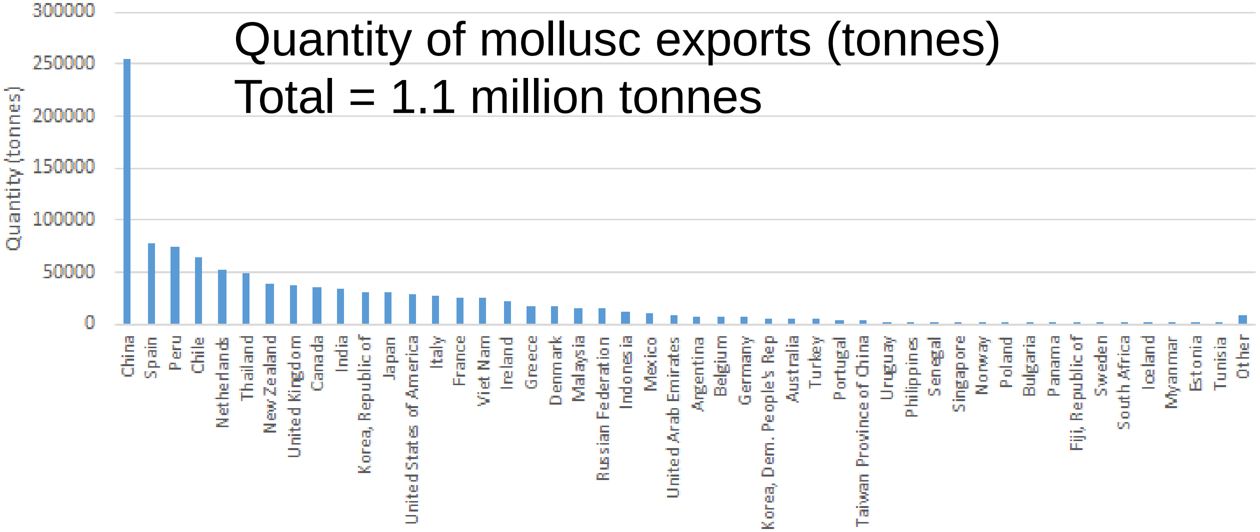
(mostly cupped oysters and Japanese carpet shell)

Brazil is #24, 15636 tonnes Chile is #5, 233906 tonnes UK is #19, 31519 tonnes

FAO FishStat

Total mollusc exports, who, what and where?

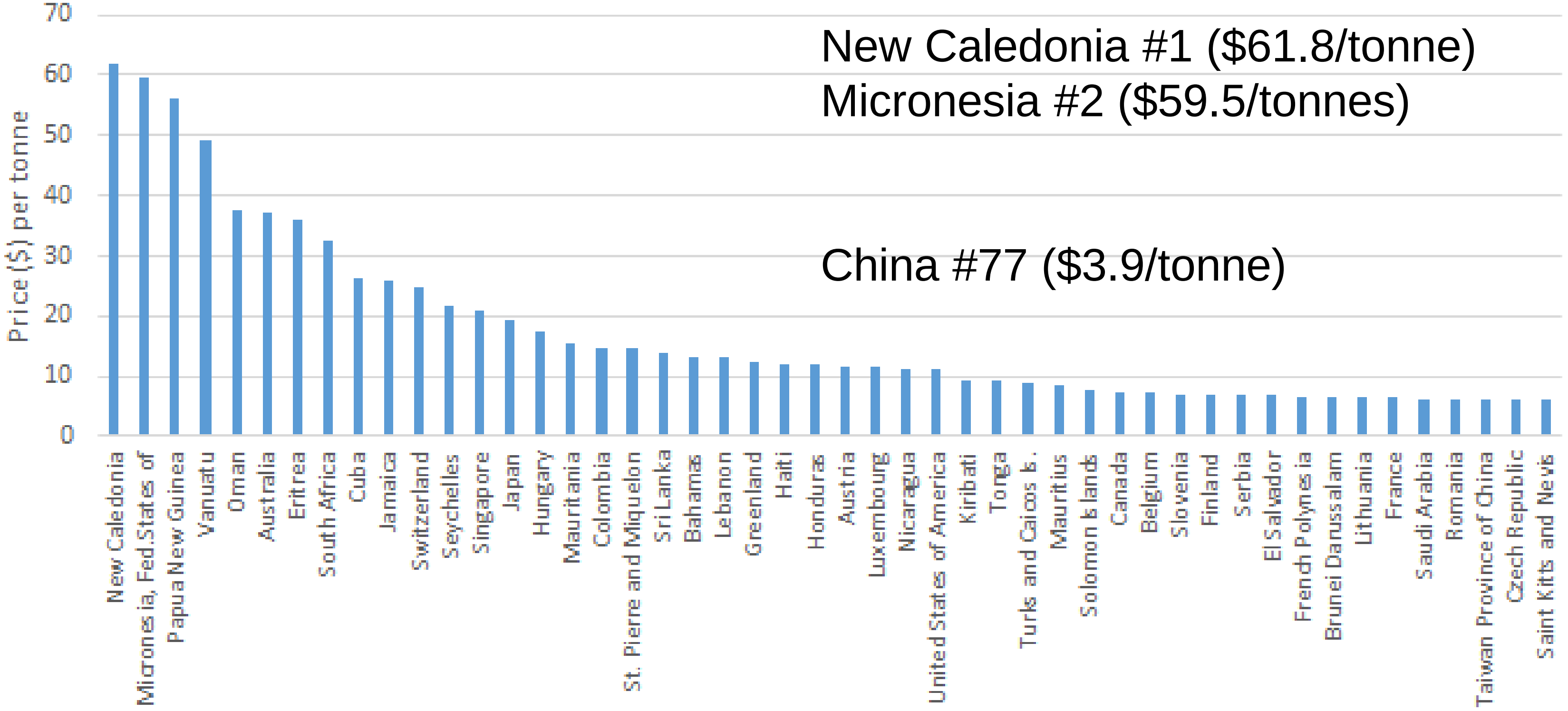

Value of mollusc exports ($)
Total = $5.1 million


Quantity of mollusc exports (tonnes)
Total = 1.1 million tonnes

FAO FishStat

Total mollusc exports, who, what and where?

Price ($) per tonne



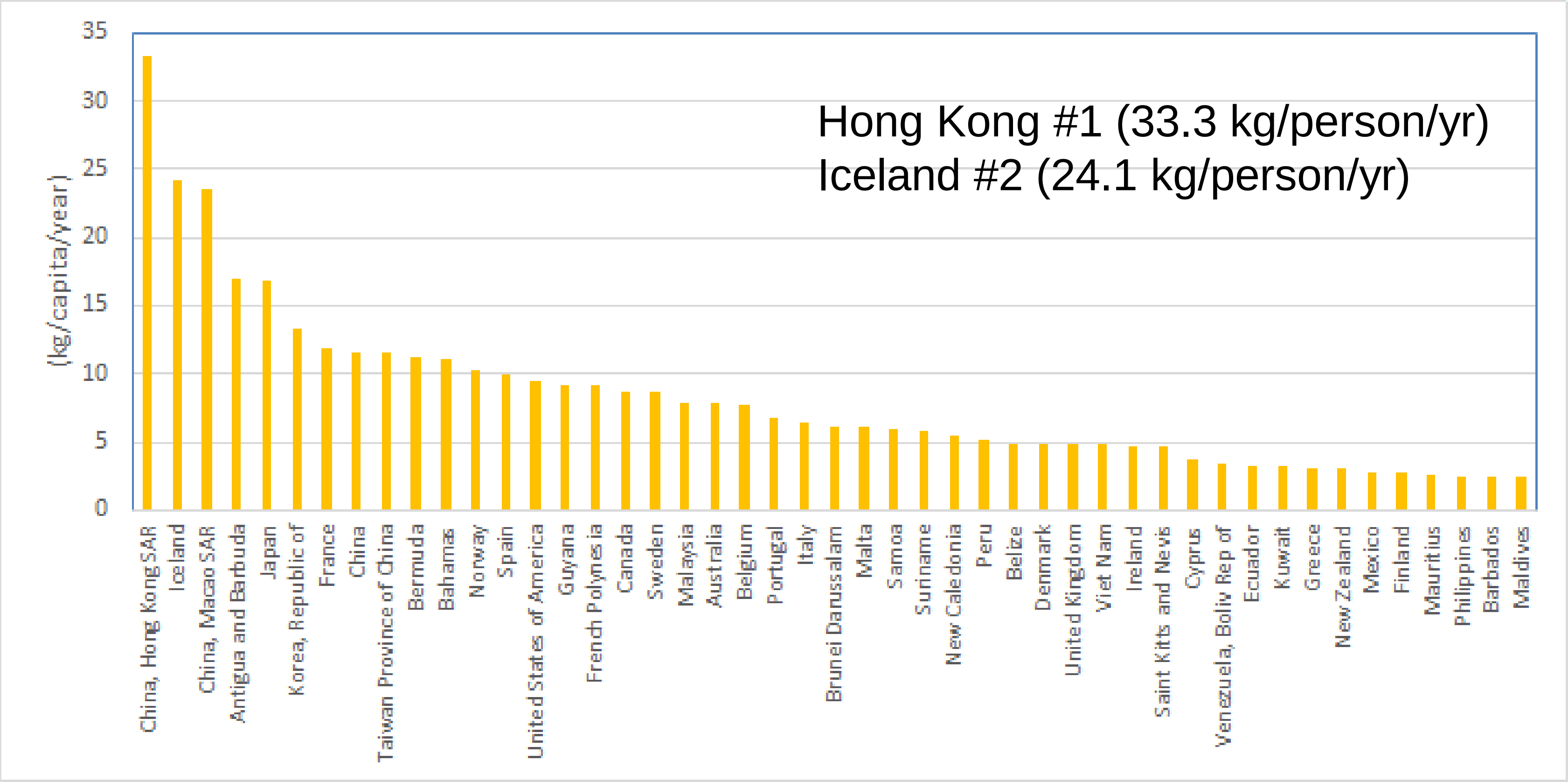
New Caledonia #1 ($61.8/tonne)
Micronesia #2 ($59.5/tonnes)

China #77 ($3.9/tonne)

FAO FishStat

Shellfish consumption, who, what and where?

Per capita shellfish (mollusc + crustacean) consumption

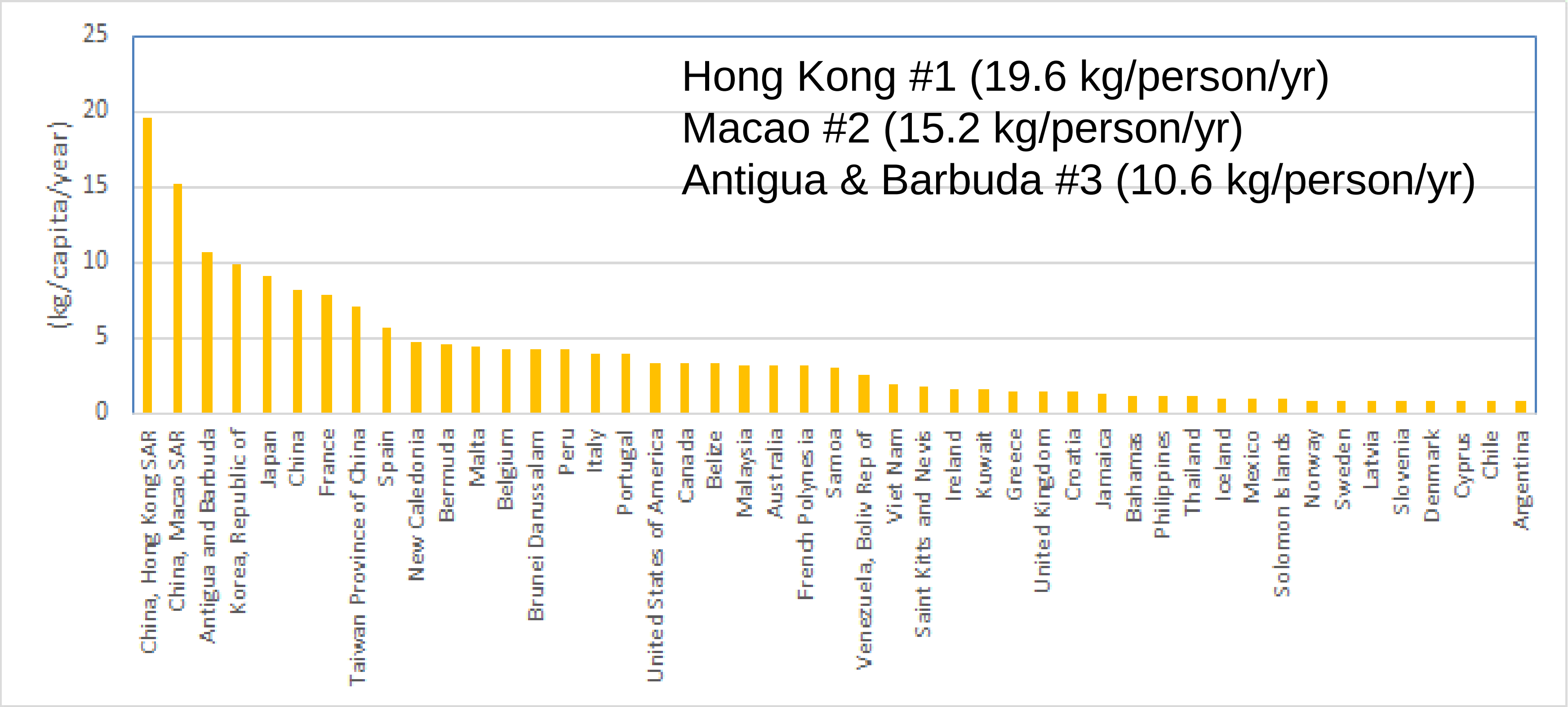


Hong Kong #1 (33.3 kg/person/yr)
Iceland #2 (24.1 kg/person/yr)

FAO FishStat

Shellfish consumption, who, what and where?

Per capita mollusc consumption

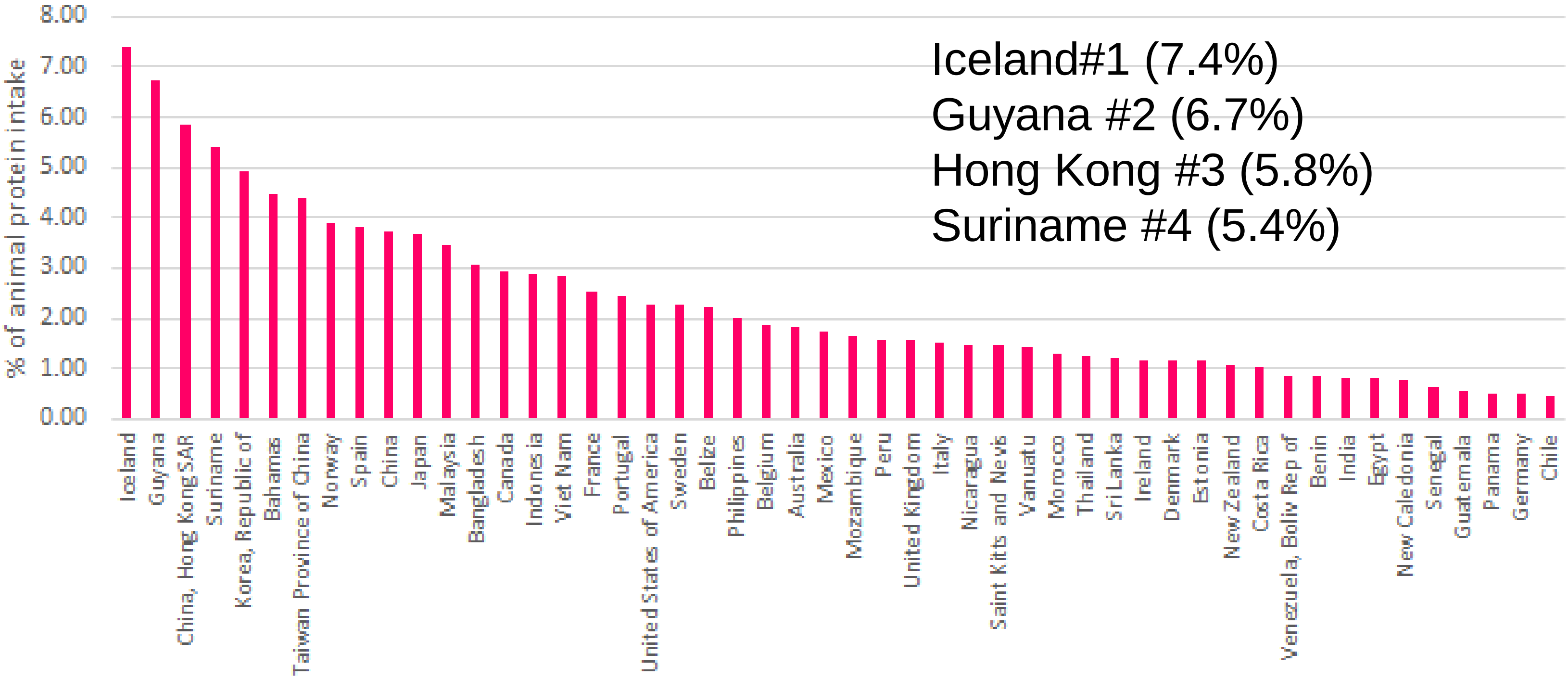


Hong Kong #1 (19.6 kg/person/yr)
Macao #2 (15.2 kg/person/yr)
Antigua & Barbuda #3 (10.6 kg/person/yr)

FAO FishStat

In terms of protein supply?

Shellfish (crustacean + mollusc) as a % of animal protein intake

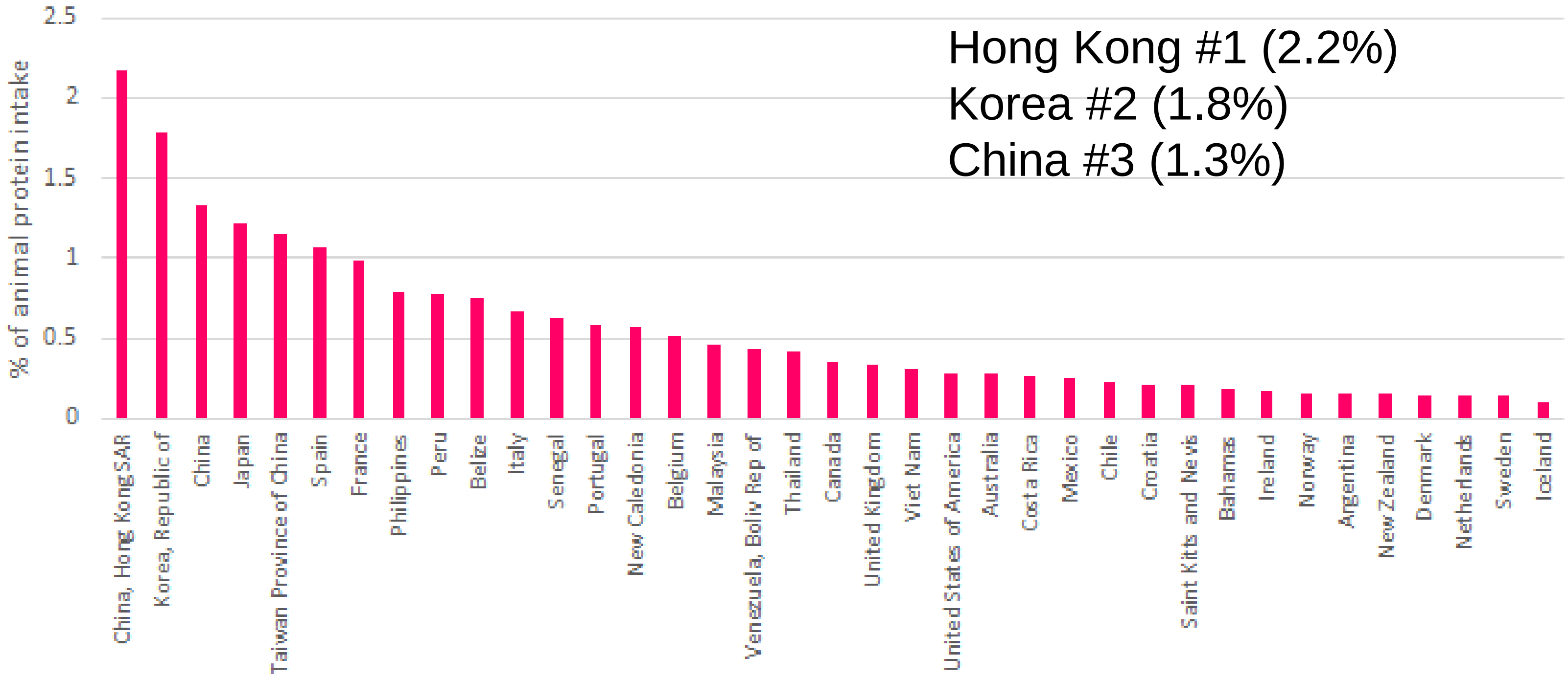


Iceland#1 (7.4%)
Guyana #2 (6.7%)
Hong Kong #3 (5.8%)
Suriname #4 (5.4%)

FAO FishStat

In terms of protein supply?

Molluscs as a % of animal protein intake



Hong Kong #1 (2.2%)
Korea #2 (1.8%)
China #3 (1.3%)

FAO Balance Sheets

Beaten to it….

FISH and FISHERIES

FISH and FISHERIES, 2012, 13, 182–215

Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow

Sarah R Cooley[1], *Noelle Lucey*[2,3], *Hauke Kite-Powell*[2] & *Scott C Doney*[1]

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Abstract

Atmospheric carbon dioxide (CO_2) emissions from human industrial activities are causing a progressive alteration of seawater chemistry, termed ocean acidification, which has decreased seawater pH and carbonate ion concentration markedly since the Industrial Revolution. Many marine organisms, like molluscs and corals, build hard shells and skeletons using carbonate ions, and they exhibit negative overall responses to ocean acidification. This adds to other chronic and acute environmental pressures and promotes shifts away from calcifier-rich communities. In this study, we examine the possible implications of ocean acidification on mollusc harvests worldwide by examining present production, consumption and export and by relating those data to present and future surface ocean chemistry forecast by a coupled climate-ocean model (Community Climate System 3.1; CCSM3). We identify the 'transition decade' when future ocean chemistry will distinctly differ from that of today (2010), and when mollusc harvest levels similar to those of the present cannot be guaranteed if present ocean chemistry is a significant determinant of today's mollusc production. We assess nations' vulnerability to ocean acidification-driven decreases in mollusc harvests by comparing nutritional and economic dependences on mollusc harvests, overall societal adaptability, and the amount of time until the transition decade. Projected transition decades for individual countries will occur 10–50 years after 2010. Countries with low adaptability, high nutritional or economic dependence on molluscs, rapidly approaching transition decades or rapidly growing populations will therefore be most vulnerable to ocean acidification-driven mollusc harvest decreases. These transition decades suggest how soon nations should implement strategies, such as increased aquaculture of resilient species, to help maintain current per capita mollusc harvests.

Keywords *Adaptability, aquaculture, food security, mollusc harvests, Ocean acidification, population growth*

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[1]This included the following nations: Djibouti, Ecuador, Eritrea, Estonia, Fiji, Finland, Iran, Laos, Latvia, Lithuania, Luxembourg, Maldives, Malta, Marshall Islands, Mauritius, Morocco, Mozambique, Myanmar, Namibia, Netherlands, Pakistan, Peru, Poland, Romania, Saudi Arabia, Singapore, Slovak Republic, Somalia, Switzerland, Togo, Tonga, United Arab Emirates, Uruguay, Yemen.

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Sarah Cooley (Woods Hole Oceanographic Institution)

Fish & Fisheries (2012), 13:182–215

Some innovative features of the paper….

1. Looked at protein insufficiency (grams/day/capita), or the additional protein required for citizens to receive the US DoA recommendation of 65 grams per day per capita

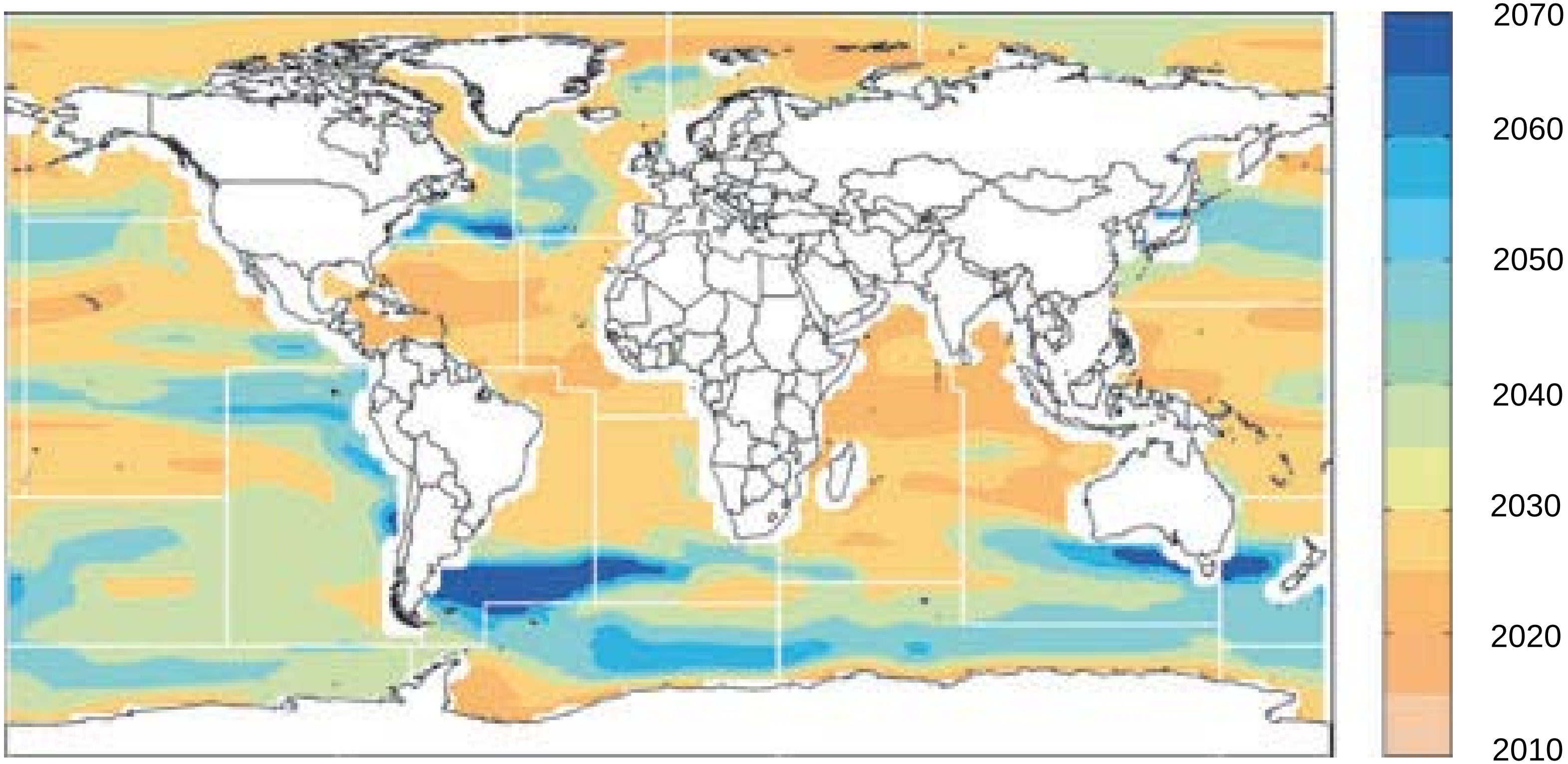
2. Calculated future mollusc production requirements by multiplying production per capita by projected human population growth

3. Developed a scale to rank nations' vulnerability to decreased mollusc harvests from ocean acidification. Countries were grouped by net import/ export status and then were given one point for each of the following conditions:

- (a) if molluscs provide more than 0.001% of the GDP (sensitivity);
- (b) if the country is protein insufficient (sensitivity);
- (c) if molluscs provide more than 1% of citizens' protein (sensitivity);
- (d) if the required increase in production by 2050 is more than 100% (adaptive capacity).
- (e) if the country currently does not have mollusc aquaculture (adaptive capacity).
- (f) the rank of their average adaptabilities (adaptive capacity)
- (g) the number of years until the Ωar transition decade (exposure):

Exposure

Date when Ω_{ar} envelope entirely different from 2010



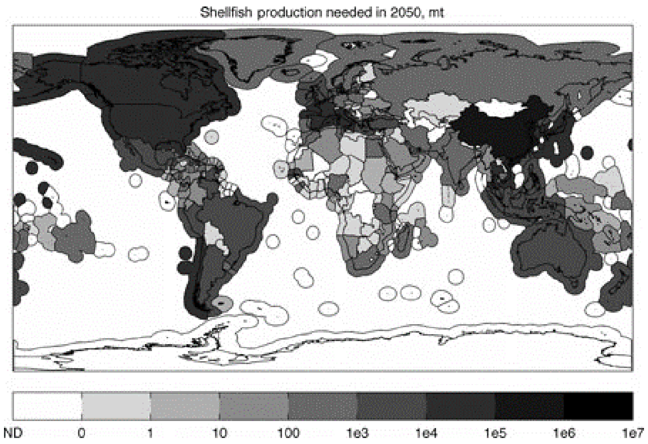
Cooley et al. (2012)

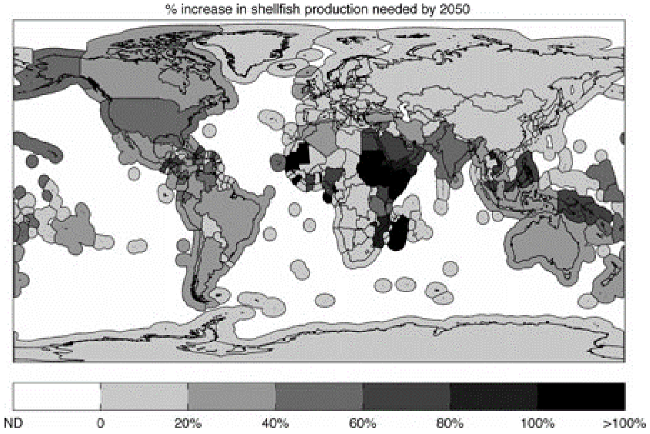
Future Demand for Shellfish

Seafood and mollusc harvests are likely to be affected by national development patterns, changing preferences among consumers, changing trade patterns and management

To forecast future mollusc requirements, This study multiplied the current production rate per capita by future projected human population.

It assumed that nations will maintain approximately the same protein and mollusc consumption per capita patterns in the future.


Shellfish production needed in 2050, mt

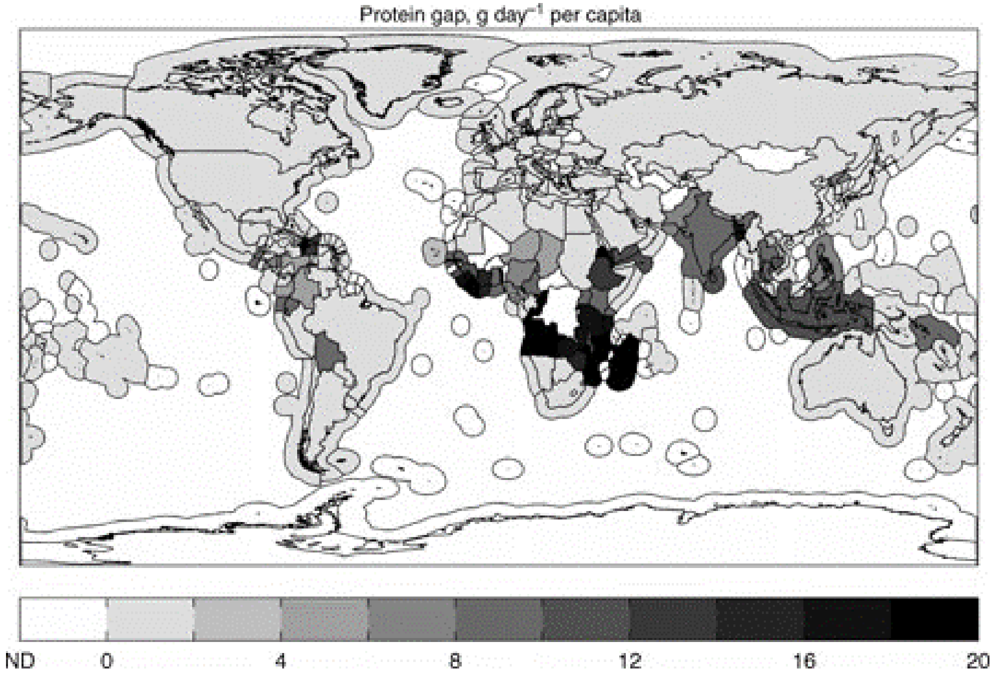

% increase in shellfish production needed by 2050

Cooley et al. (2012)

Protein insufficiency

Looked at protein insufficiency (grams/day/capita), or the additional protein required for citizens to receive the US DoA recommendation of 65 grams per day per capita

The protein gap, was greatest in the Republic of Congo, Liberia, Mozambique, Haiti and Angola



Some countries with high protein insufficiency produced moderate amounts of molluscs per capita (e.g., Mozambique, Haiti, Togo, Madagascar, Eritrea, Tanzania, Dominican Republic, Solomon Islands, Nigeria, Nicaragua, Cape Verde, Vanuatu)

The quantities of molluscs exported from India, Yemen, Mozambique, Togo, Eritrea, Pakistan, Djibouti and Bangladesh equalled the total amounts produced nationally, yet more than 20% of these populations were undernourished

Adaptive Capacity

National adaptability indices were calculated as the average of four socioeconomic indicators (Allison et al. 2009):

- GDP adjusted for purchasing power parity
- governance
- literacy
- life expectancy

The exporting countries with the lowest adaptability were: Mozambique, Somalia, Nigeria, Togo, Papua New Guinea

The importing countries with the lowest adaptability were: Ivory Coast, Sudan, Laos, Solomon Islands

Cooley et al. (2012)

Conclusions

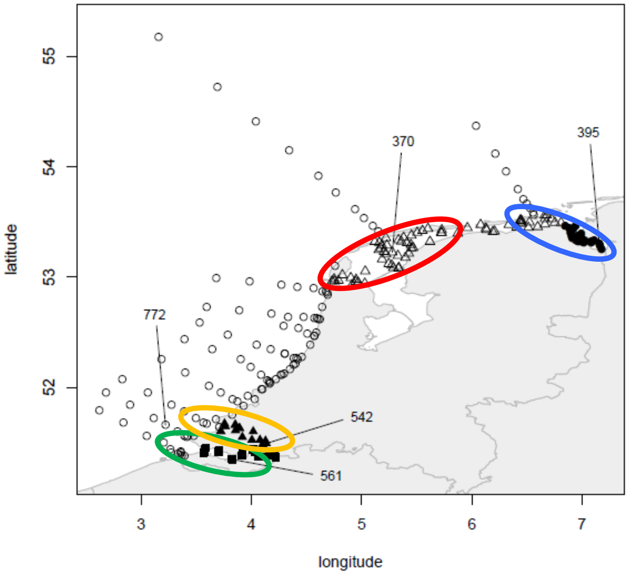
- Molluscs are never a major component of protein intake
- Countries' relative susceptibilities varied greatly. The five exporting nations most susceptible to mollusc harvest declines included: Senegal, Madagascar, Gambia, Mozambique and Haiti.
- Excluding the net importing nations with zero mollusc production and approximately zero consumption, the five most susceptible importing nations included: Solomon Islands, Jamaica, Belize, Cook Islands and Sudan.
- Countries likely to suffer the least from ocean acidification-related mollusc harvest declines included: Austria, Hong Kong and United Kingdom (net exporters); and Slovenia, Switzerland, Sweden, Germany and Finland (net importers).

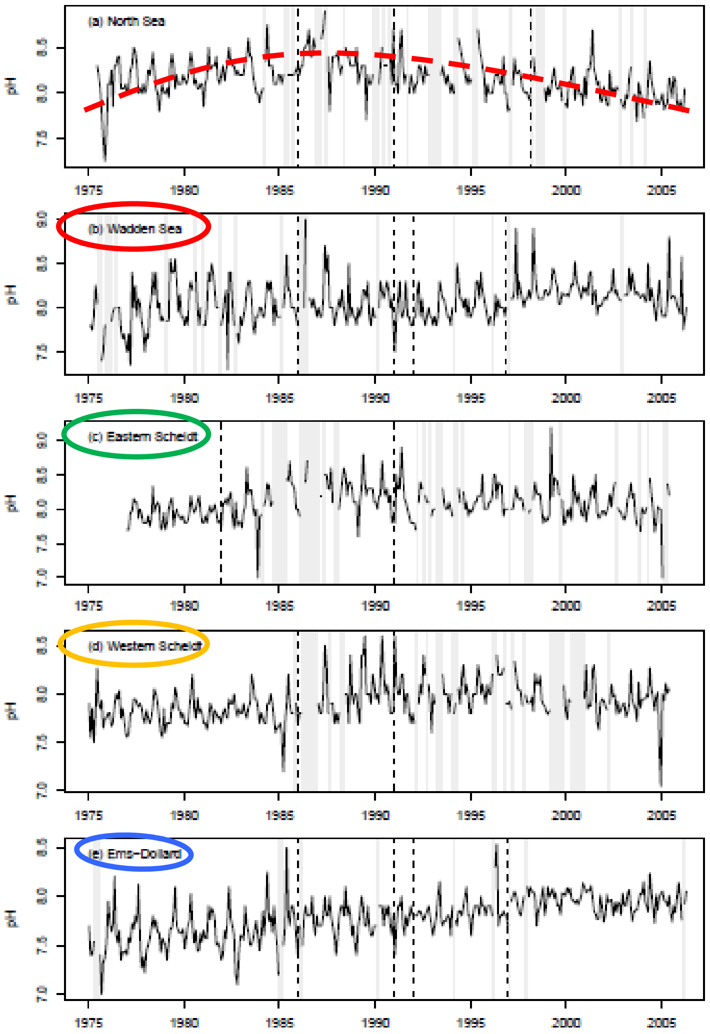
Cooley et al. (2012)

A word of warning…

Many important shellfish species exist in shallow coastal systems that are already subject to considerable natural variability…

Netherlands coastal waters





Are they pre-adapted to withstand some pretty extreme pH conditions? (pH <7.0)

Questions ????

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