

Economic Effects of an Ocean Acidification Catastrophe

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Acidification from increasing uptake of CO₂ has emerged as a potentially serious threat to ocean health.¹ Here we assess the potential magnitude of the economic effects of an ocean acidification (OA) catastrophe by focusing on key marine ecosystem services most likely to be affected: marine capture fisheries, aquaculture, and coral reefs.

I. Ocean Acidification Catastrophe

Scenario

A. Ocean Conditions

We define an OA catastrophe scenario as a scientifically plausible level of OA and associated biophysical effects that enables an estimate of an approximate upper bound or potential magnitude of economic consequences over the coming two centuries.

Our scenario is based on IPCC RCP 8.5 and its extension to 2300, ECP 8.5 (Riahi et al.

¹ In 2007 IPCC Working Group 1 stated: “Ecological changes due to expected ocean acidification may be severe for corals in tropical and cold waters [] and for pelagic ecosystems []. Acidification can influence the marine food web at higher trophic levels.” (Solomon et al. 2007)

2011). Atmospheric CO₂ concentrations reach 1,000 ppm shortly after 2100 and stabilize at about 2,000 ppm shortly after 2200. Ocean pH levels decline by about 0.3 to about 7.8 in 2100. Because RCP 8.5 CO₂ concentrations are consistent with those from previous high-emission scenarios (e.g. SRES A1F1 and A2), we also incorporate widely-used projections beyond 2100 of pH and ocean conditions, notably Caldeira and Wickett’s (2005) “5,000 Pg C” case, under which pH falls to about 7.5 in 2200. For further details, see the appendix.

B. Biophysical Effects

Natural scientists have run numerous experiments and simulations during the past decade using treatments with seawater pCO₂ equal to 1,000 and 2,000 μ atm.² Gattuso et al. (2015), the National Research Council (2010), the IPCC 5th Assessment Working Group 2 (Pörtner and Karl 2014, Chapter 6,) and Doney et al. (2009) summarize this research. We reviewed these summaries and about 40 individual papers (see appendix for complete list). Several papers are particularly relevant to

² micro-atmospheres of CO₂ partial pressure, which units correspond closely with atmospheric CO₂ in ppm

establishing the biophysical dimensions of an OA catastrophe scenario because they are recent, quantitative, and have clear economic implications.

Punt et al. (2014) coupled experimental data on crab recruitment in low-pH conditions with a bioeconomic model of the Alaska Bristol Bay Red King Crab Fishery. They projected that by 2092, at pH 7.78, relative crab recruit survival would be 20% of year 2000 levels and the maximum economic yield would decline to zero. Their model is noteworthy because it used an empirically-derived link between low pH and economic fish production.

Narita, Rehdanz and Tol (2012) drew on the meta-analysis of Kroeker et al. (2010) showing that mollusks suffer an average 40% reduction in calcification rates under year 2100 ocean conditions when seawater is undersaturated with carbonate ions. They equated this reduction to a 40% leftward shift of the mollusk supply curves for both capture and aquaculture conditions. They used elasticity parameters from the IMPACT model (Rosegrant et al. 2012) to calculate losses of consumer plus producer surplus of ranging from \$6 to 100 billion per year.

Turning to coral reefs, numerous reviews (e.g. Kleypas and Yates 2009, National Research Council 2010), strongly

suggest that they are in grave danger from the combined threats of declining pH and increasing temperature. In a compelling study, Silverman et al. (2009) combined experimental data on reef dissolution with mapping of future ocean conditions. Their conclusion is particularly clear and blunt:

Calcification rates were calculated for more than 9,000 reef locations using model values of Ω_{arag} ³ and sea surface temperature at different levels of atmospheric CO₂. The maps we produced show that by the time atmospheric partial pressure of CO₂ will reach 560 ppm all coral reefs will cease to grow and start to dissolve (Silverman et al. 2009, p. 1).

C. Upper Bound Loss of Ecosystem Services

These examples exemplify recent natural science findings and their increasing inclusion of economic consequences. Of course, we recognize the vast complexity of the systems and linkages involved. We concur with statements such as this one by Manuel Barange:

The scientific community needs to recognise the complexities involved....To extrapolate cell, organism, population, and ecosystem impacts to economic and social consequences, with a significant degree of confidence, is likely to be elusive for some time to come. (Himli et al., 24)

³ Aragonite saturation state, a measure of the abundance of the carbonate ions needed for reef building.

Recognizing these complexities, we conclude that an OA catastrophe scenario based on 2,000 ppm CO₂ and average pH of 7.5 by 2200 plausibly includes the following upper-bound consequences. First, a complete collapse of economically viable commercial marine capture fisheries (MEY goes to zero). Second, an essentially complete collapse of recreational and subsistence marine fish harvests. Third, the essentially complete dissolution all coral reefs. Fourth, a substantial re-arrangement of the ocean ecosystem with an attendant loss of significant biodiversity. We now briefly explore the first three, and also explain why aquaculture is likely to be minimally affected.

II. Value of Lost Ecosystem Services

A. Commercial Marine Capture Fishing

Producer Rents. — Assessing the loss of producer rents associated with a potential complete collapse of marine capture fisheries is complicated by the fact that rents are currently far below their potential levels if fishery resources were to be efficiently utilized. Rent dissipation occurs through multiple mechanisms associated with how fisheries have been and are managed and subsidized. Paradoxically, the economic losses attributable to catastrophic OA would

be reduced to the extent that potential rents continue to be dissipated without OA. The less rent we capture from commercial fisheries, the less we lose if they collapse.

Estimates of economic rents from commercial fisheries vary widely. A lower limit is zero or negative: The World Bank (2009) estimated global net income from fish harvesting to be negative \$5 billion in 2004, when ex-vessel value was \$79 billion. Based on estimates of limited entry permit prices, the authors estimate that annual rents from Alaska salmon fisheries are approximately 5-6% of ex-vessel value (see appendix for calculations).

An upper bound for producer rents (if costs were zero) would be total ex-vessel value, which was approximately \$100 billion for world marine capture fisheries in 2012.⁴ Harvest volumes have been stable or declining for the past two decades and are unlikely to increase significantly. Over the long term, if real prices doubled or tripled, ex-vessel value could potentially grow to \$200 or \$300 billion over the long term.

A more recent World Bank estimate is that global capture fisheries have a current (circa 2012) capitalized value of *potential* rents,

⁴ [= \$115 billion total ex-vessel value x 87% (marine fisheries share of total capture fisheries). Data from FAO <ftp://ftp.fao.org/FI/STAT/summary/a1a.pdf> and <ftp://ftp.fao.org/FI/STAT/summary/app1lybc.pdf>

assuming continued progress toward an efficient level of fishing effort and fish stocks, ranging from \$942 billion to \$1,451 billion, depending on the number of years required to reach a sustainable optimum, and using a discount rate of 5% (World Bank 2015). Their estimated potential range of annual rents is therefore \$47 – 73 billion per year in 2012 dollars, or \$49 – 75 billion in 2014 dollars (note that the costs do not take account of public management costs, estimated as between 1 and 14 percent of ex-vessel value). We use this estimate as an approximate range of the producer rent impacts of a catastrophic complete collapse of marine capture fisheries.

Consumer Surplus. — Narita, Rehdanz and Tol (2012) estimate lost CS to be equal to about 1.4 times lost producer surplus in their study of global mollusk capture fishery decline wherein supply contracts by about 40%. Applying this multiplier to the rents estimate of \$49-75 billion yields CS losses ranging from \$68 billion to \$105 billion. CS losses could be lower if aquaculture provides close substitutes for disappearing wild fish. Or they could be higher if increasingly rich consumers are willing to pay more and more for increasingly rare wild fish. The evaluation of potential CS losses from a collapse of capture fisheries is an important topic for additional research.

B. Marine Aquaculture

Marine aquaculture accounted for about 24% of world marine fish and shellfish production in 2013, with an estimated value of production of \$72 billion in 2013. Production doubled between 1999 and 2013⁵ and there is enormous potential for future growth, particularly as technologies for offshore aquaculture develop. Molluscs—which in their larval stages are particularly vulnerable to OA—account for more than half of production. Thus it might seem that the potential economic implications of OA for aquaculture would be large and important.

However, while OA certainly has significant potential to disrupt current aquaculture operations, its long-term economic effects on aquaculture are likely to be minimal, for several reasons. First, unlike capture fisheries, aquaculture is not dependent on and is far less vulnerable to changes in the ocean ecosystem. Second, and also unlike capture fisheries, aquaculture has the capacity to adapt and change. Aquaculture is a largely private industry in which producers can control almost all the inputs, monitor production, and reap the benefits of technological innovation and cost-saving or quality improvements--as

demonstrated by the rapid and continuing change which has been occurring throughout the industry—in species, farming locations, feeds, gear, juvenile production, and many other ways. Finally, about two-thirds of aquaculture takes place in inland waters, which are less vulnerable to OA than the oceans.

Shellfish hatcheries in Washington and Oregon, which have faced significant challenges due to OA provide instructive examples of adaptation to these challenges. Properly buffered water is a crucial input to aquaculture, just as fertilizer and water are to agriculture. It can be provided as an input. Shellfish hatcheries in Washington and Oregon are already doing this, mitigating OA's effects on calcifying clams and mussels through plant-level monitoring and carbonate injection (Geiling 2015, Oliver 2015). They have also adapted by moving hatchery operations to Hawaii (Welch 2012).

Based on this assessment, we suggest that the best current approximation of the *long-run* loss future rents from aquaculture under our OA scenario is zero.

C. Recreational Fishing

The World Bank (2012) estimates that 225 million recreational anglers spend about \$200 billion per year on recreational fishing

worldwide. In the U.S., saltwater fishing accounts for 18% of total angler days (U.S. Fish and Wildlife Service 2012); the global average saltwater fraction is likely higher, perhaps 25%. Using a travel cost model based on a survey of more than 5,000 anglers fishing in Alaska, Haley et al. (1999) estimated that the ratio of consumer surplus to reported expenditures was about 0.35. Applying these parameters to global spending yields a total net annual value of \$17.5 billion.

D. Subsistence Fishing

Subsistence fishing is critically important to those who do it. In developed countries the aggregate values of harvested amounts are likely to be minimal compared to the commercial catch. (Even in Alaska, with relatively high subsistence use, only 0.4% of salmon are caught for subsistence.) In developing countries, subsistence capture fishing appears to largely occur in inland waters. A notable exception is Vietnam, where household surveys revealed an additional 1 million tons of marine capture fish production for subsistence use (World Bank 2012). Assuming that the global total subsistence catch of marine capture fish equals 2 million tons and valuing it at \$2.50 per kg yields an estimate of \$5 billion in net annual economic

value from subsistence capture marine fisheries.

E. Coral Reef Recreation and Tourism

DeGroot et al. (2012) present a recreation service value of \$96,302 per coral reef hectare, but this would yield the unreasonably large value of \$3 trillion per year when applied to the 28 million hectares of reef documented by Costanza et al. (2014). We suggest as a low value the estimate of \$1.5 billion based on the travel cost analysis \$54 per hectare in 2014 dollars (Carr and Mendelsohn 2003). For a high value we adopt Cesar's (2003) estimates of recreation plus coastal protection values. This sum is \$24 billion in 2014 dollars.

The Appendix contains further discussion of the wide range of coral reef values. This is clearly a topic for geographically explicit future research.

III. Summary and Discussion

The sum of annual ecosystem service values assessed above ranges from \$141 to 227 billion.

[Insert Table 1 Here –]

The physical science literature supports the hypothesis that future OA could cause or contribute to substantial or even complete loss of marine capture fisheries and coral reefs. Complete loss provides the upper bound appropriate for this analysis. The annual rents and net use values associated with these losses are small – between 0.09% and 0.21% of current global GDP. These losses will develop over 100-200 years, allowing ample time for the major reallocations of economic resources that will occur as rents decline and fish prices rise. Permanent biodiversity losses are potentially larger when measured by the existence values held by people alive today, but these losses will likely occur over many generations of people who will increasingly grow up without experiencing what has been lost.

One basic reason why OA does not pose an existential threat to global economic output is, perhaps, because it will primarily affect ecosystem services that are already fully- or over-exploited. A second reason is that the ecosystem services of coral reefs and free-swimming fish are combined with many other inputs to produce pleasant recreation experiences. The scope for substitution is vast; witness the many producer and consumer responses to reduced snowfall.

Ocean acidification may well inflict significant long-run welfare losses on people. Short-run effects on capture fisheries could be quite harmful. Should OA continue unabated, the greatest economic challenge posed appears to be how to manage a slow but significant reallocation of resources away from capture fisheries and coral reef tourism.

REFERENCES

- Caldeira, Ken, and Michael. E. Wickett. 2005. Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. *Journal of Geophysical Research* 110: C09S04, doi: 10.1029/2004JC002671.
- Carr, L. and Robert. Mendelsohn. 2003. Valuing coral reefs: a travel cost analysis of the Great Barrier Reef. *Ambio* 32(5): 353-357.
- Cesar, Herman, Laretta Burke, Lida. Pet-Soede. 2003. The Economics of Worldwide Coral Reef Degradation. Arnhem: Cesar Environmental Economics Consulting (CEEC),
- Costanza, Robert, Rudolf de Groot, Paul Sutton, Sander van der Ploeg, Sharolyn J. Anderson, Ida Kubiszewski, Stephen Farber, and R. Kerry Turner. 2014. "Changes in the Global Value of Ecosystem Services." *Global Environmental Change* 26 (May): 152–58.
- Doney, S.C., W.M. Balch, Victoria .J. Fabry, and Richard .A. Feely. 2009. Ocean acidification: A critical emerging problem for the ocean sciences. *Oceanography* 22(4):16–25
- Gattuso, J.-P., A. Magnan, R. Billé, W. W. L. Cheung, E. L. Howes, F. Joos, D. Allemand, et al. 2015. "Contrasting Futures for Ocean and Society from Different Anthropogenic CO2 Emissions Scenarios." *Science* 349 (6243)
- Geiling, Natasha. 2015. How Washington Transformed Its Dying Oyster Industry Into A Climate Success Story. Thinkprogress.org. October 28. <http://thinkprogress.org/climate/2015/10/28/3713061/washington-oregon-ocean-acidification/>
- Haley, Sharman, Matthew Berman, Scott Goldsmith, Alexandra Hill, and Hongjin Kim. 1997. Economics of Sport Fishing in Alaska. Anchorage: Institute of Social and Economic Research. http://www.iser.uaa.alaska.edu/Publications/1999_12-EconomicsSportFishingAlaska.pdf
- Hilmi, Nathalie., Denis Allemand, Christopher. Kavanagh, Dan Laffoley, Marc Metian, David. Osborn, and Stephanie. Reynaud, eds. 2015. *Bridging the Gap Between Ocean Acidification Impacts and*

- Economic Valuation: Regional Impacts of Ocean Acidification on Fisheries and Aquaculture*. International Union for Conservation of Nature.
- Kleypas, Joan, and Kimberly K. Yates. 2009. Coral reefs and ocean acidification. *Oceanography* 22(4):108–117
- Kroeker Kristy, Rebecca L. Kordas, Ryan N. Crim and Gerald G. Singh. 2010. Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. *Ecology Letters* 13(11):1419–1434
- Narita, Daiju., Katrin Rehdanz and Richard S. Tol. 2012. Economic costs of ocean acidification: a look into the impacts on global shellfish production. *Climate Change* 113 (3–4), 1049–1063.
- National Research Council. 2010. *Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean*. Washington, D.C.: National Academies Press.
- Oliver, Shady Grove. 2015. Lessons for Alaska: Oregon Shellfish Hatchery Tackles Ocean Acidification. Radio spot on KBBI Homer, aired July 13. <http://www.alaskapublic.org/2015/07/13/lessons-for-alaska-oregon-shellfish-hatchery-tackles-ocean-acidification/>
- Punt, André E., Dusanka Poljak, Michael G. Dalton, and Robert J. Foy. 2014. “Evaluating the Impact of Ocean Acidification on Fishery Yields and Profits: The Example of Red King Crab in Bristol Bay.” *Ecological Modelling* 285 (August): 39–53
- Riahi, Keywan, Shilpa Rao, Volker Krey, Cheolhung Cho, et al. 2011. “RCP 8.5—A Scenario of Comparatively High Greenhouse Gas Emissions.” *Climatic Change* 109 (1-2): 33–57
- Rosegrant, M.W. and the IMPACT Development Team. 2012. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description. International Food Policy Research Institute (IFPRI), Washington, D.C.
- Silverman, Jacob, Boaz Lazar, Long Cao, Ken Caldeira, and Jonathan Erez. 2009. Coral reefs may start dissolving when atmospheric CO₂ doubles. *Geophysical Research Letters* 36, L05606, doi:10.1029/2008GL036282.
- Solomon, Susan, and Intergovernmental Panel on Climate Change, eds. 2007. *Climate Change 2007: The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.
- U.S. Fish and Wildlife Service. 2012. 2011

National Survey of Fishing, Hunting, and
Wildlife-Associated Recreation.
[http://www.census.gov/prod/2012pubs/fhw1
1-nat.pdf](http://www.census.gov/prod/2012pubs/fhw11-nat.pdf)

Welch, Craig. 2012. Willapa Bay oyster
grower sounds alarm, starts hatchery in
Hawaii. Seattle Times. June 21.
[http://www.seattletimes.com/seattle-
news/willapa-bay-oyster-grower-sounds-
alarm-starts-hatchery-in-hawaii/](http://www.seattletimes.com/seattle-news/willapa-bay-oyster-grower-sounds-alarm-starts-hatchery-in-hawaii/)

World Bank. 2012. "Hidden Harvest: the
global contribution of capture fisheries."
Report number 66469-GLB.

World Bank and Food and Agriculture
Organization. 2009. *The Sunken Billions :
The Economic Justification for Fisheries
Reform*. Washington, D.C.

For readers of the Jan 31 posted draft:

Table 1 -- Easier to read:

Summary of rents and surplus that would be destroyed
billions of 2014 dollars per year

	low	high
Capture fisheries		
Producer rents	49	75
Consumer surplus	68	105
Aquaculture	0	0
Recreational fisheries	17.5	17.5
Subsistence fisheries	5	5
Coral reef tourism	1.2	24
Total	141	227
% of world GDP	0.13%	0.21%

TABLE 1— SUMMARY OF POTENTIAL ECOSYSTEM SERVICE
LOSSES FROM OCEAN ACIDIFICATION (BILLION 2014\$)

	low	high
Capture fisheries		
Producer rents	49	75
Consumer surplus	68	105
Recreational fisheries	17.5	17.5
Subsistence fisheries	5	5
Coral reefs	1.2	24
Total	141	227
percent of world GDP (\$110 trillion)	0.13%	0.21%