Modeling economic impacts of climate change and ocean acidification to fisheries

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Abstract

Ocean acidification appears to have potential to be a significant problem. Past declines in ocean surface pH have been linked to mass extinction events (Guinotte and Fabry, 2008). While I am not an expert in the science, the issue starts with declines in pH (increased acidity) causing a reduction in carbonate ion concentration which in turn causes a reduction in calcium carbonate saturation. This has impacts on marine organisms that are calcifiers and essentially requires marine calcifying organisms to use more energy to form biogenic calcium carbonate (Guinotte and Fabry, 2008). The observable consequences are thought to be hampered reef formation of corals, algaes and hampered shell formation of oysters, clams and crabs (although there are varying consequences on species depending on studies as shown by Dr. Cooley).

There has been little work assessing the economic consequences of ocean acidification. The one notable paper is that of Cooley and Doney (2009). In this paper the authors calculated potential revenue losses for the U.S.A. from decreased mollusk harvests. If reductions of 6%–25% from 2007 level of harvests were to occur in 2009, the authors calculate $75–187 million in direct revenue would be lost each year into the future, with a net NPV loss of $1.7–10 billion through 2060. However it needs to be noted that these values were calculated using what are commonly termed as replacement cost or engineering cost estimates. From an economic viewpoint, there is no direct connection between replacement costs and a useful welfare measure.

From an economic viewpoint, if ocean acidification affects the provisioning of ecosystem services, it can result in lost consumer surplus (which are the opportunity costs to consumers). Consumer surplus is the benefit to consumers of a market outcome and accrue whenever consumers pay less than their maximum willingness to pay for that unit of a good.

Market prices simply capture the relative rate at which the market is willing to exchange one good for another. The method employed by Cooley and Doney (2009) is the product of market price and a change in quantity, or engineering cost estimates. If the reduction in mollusk harvests are given by the difference in harvests from Q_0 to Q_1 as shown in Figure 1 evaluated at the constant price P_0:

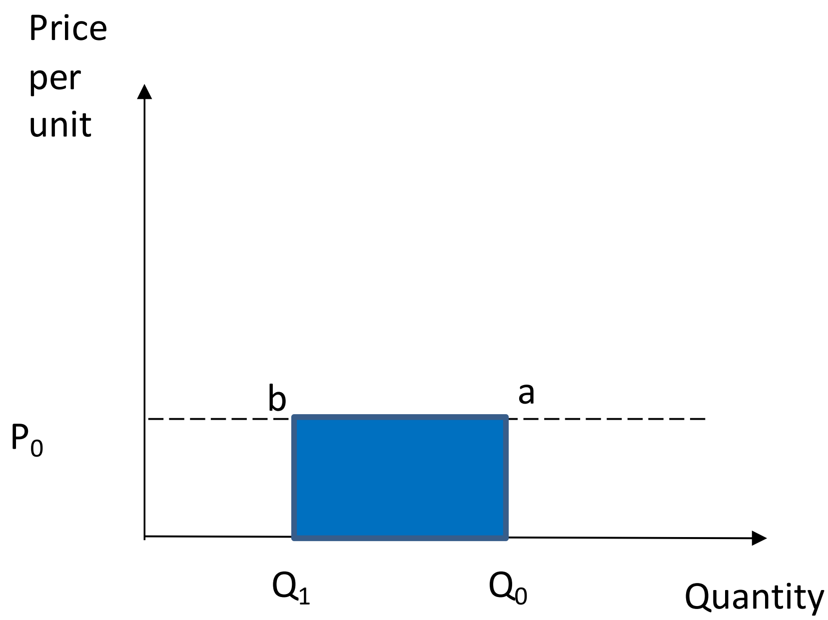

Figure 1 Replacement cost estimates

The lost revenues from ocean acidification are calculated (area Q_1 Q_0ab, shaded area in blue). Values calculated in this manner tend to be rejected as they have no relationship to the economically relevant surplus measures. Figure 2 illustrates the lost consumer surplus (area P_0P_1ca, shaded area in red) associated with the same reduction in harvests if price increases from P_0 to P_1 with the harvest reduction Q_0 to Q_1:

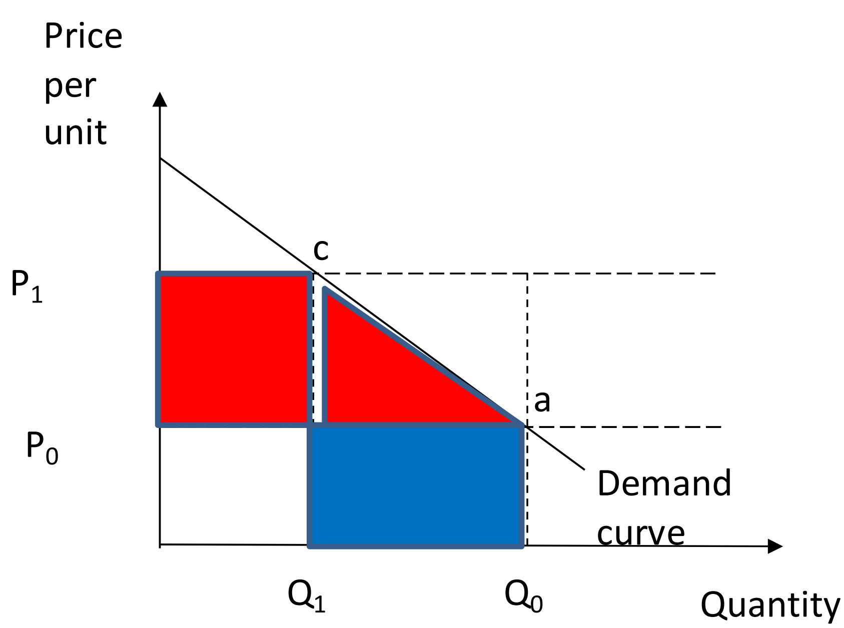

Figure 2 Consumer surplus estimates

As Figure 2 illustrates there is no direction relationship between the replacement cost estimate and the loss in consumer surplus. The replacement cost estimates do not measure or even approximate economic welfare (see Bockstael et al. 2000). In addition, they omit key interactions within the economy and between the economy and nature (Finnoff & Tschirhart 2008). However, applying an economic approach can be a challenge because it requires measuring these surplus measures, which requires more information than just market prices and quantities.

To apply an economic approach to the problem, it helps to consider the problem as one of a class of One of a class of "Materials Damages" problems studied in detail by Tom Crocker 25 years ago (see a review of the research effort for the EPA report archived at http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0043.pdf/$file/EE-0043.pdf). In this work Crocker and his colleagues made the salient point that human welfare is dependent on biological systems (material environment) that provide critical inputs to human activity. If there are damages or improvements in material environment then there will be welfare changes.

Adams and Crocker (1991) laid out three basic steps to assess materials damage from environmental changes. The first step is to provide an understanding of how the environmental change perturbs production and consumption opportunity sets. The second was then to determine the input and output market prices changes in response to the perturbations in opportunity sets. The third was to the document all the adaptations humans can engage in to minimize losses or maximize gains from changes in opportunities and prices.

In general, changes in production opportunities from perturbations in provisioning of ecosystem services (ES) change producers production possibilities by the availability and combinations of ES input sets (i.e. species compositions and densities). In turn this also affects output sets as there may be fewer of some economically relevant species and potentially more of others. If the environmental degradation reduces production possibilities then there will be less choice, higher costs and lower profits. Regardless Adams and Crocker (1991) point out that human objective functions and behavioral conditions remain the same in that firms still choose cost minimizing input combinations.

Similarly in consumption, perturbations in provisioning of ES may change costs facing households directly or indirectly with corresponding welfare consequences. Again the underlying economic problem remains the same with households choosing utility maximizing combinations of goods and services given their income given the perturbations in provisioning of ES.

The implication is that standard economic models can be used if the environmental perturbations can be reliably brought into economic analysis. This is a primary challenge facing research in this area. To bring the environmental changes into economic analysis there is a basic choice in the representation of the natural system. On the one hand the assessment could employ a reduced form representation of the natural system, reducing the entire natural system into one or two indicators (i.e. species). These approaches are commonly seen in the bioeconomic literature (see Massey et al 2006, Smith 2007). They are easy to fit to limited data and are typically thought to give a good overview of general processes. However, it has been shown that aggregation (into a reduced form) can cause errors in economic estimates (Kopp and Smith, 1980). On the other hand the natural system can be represented by a detailed, or structural model (see Finnoff and Tschirhart 2008). Structural representations can represent critical details explicitly and capture the complex adaptive nature of natural systems. However, it has been shown that there are rapidly declining marginal returns to the inclusion of additional natural science information (Adams, Crocker and Katz, 1984). The question then becomes what is the appropriate balance of reality and tractability in the analysis?

One organizing principle that has roots in Tom Crocker's work is the potential for non-convexities in natural system phenomena (see for example Crocker and Forester, 1981 and Brown et al. 2010). If the natural system is reasonably convex, then environmental perturbations will have monotonic effects that can be well represented with a reduced from representation. But if there are pervasive non-convexities then a high level of abstraction may lead to trouble and it may well be necessary for the assessor to know the entire possibilities surface.

The point is rather obvious if one considers the standard way an economist might consider correcting a materials damage problem (to correct the problem one has to understand the welfare consequences making an economic assessment one part of a corrective policy). Figure 3 illustrates a hypothetical setting relating (loosely) to the problem of ocean acidification and a simple adaptation of Crocker and Forester (1981). In the top panel, marginal control costs and marginal damages of acidification are presented as downward and upward sloping functions of pH (acidity increases to the right of the horizontal axis and decreases to the left). Economic theory would dictate that as there are costs of control and damages that there is a single point of balance between the two marginal effects – a point at which the net benefits to society of a plan of action are maximized (bottom panel). To find the optimal point all one needs is information on marginal damages and marginal control costs to determine how to maximize social net benefits.

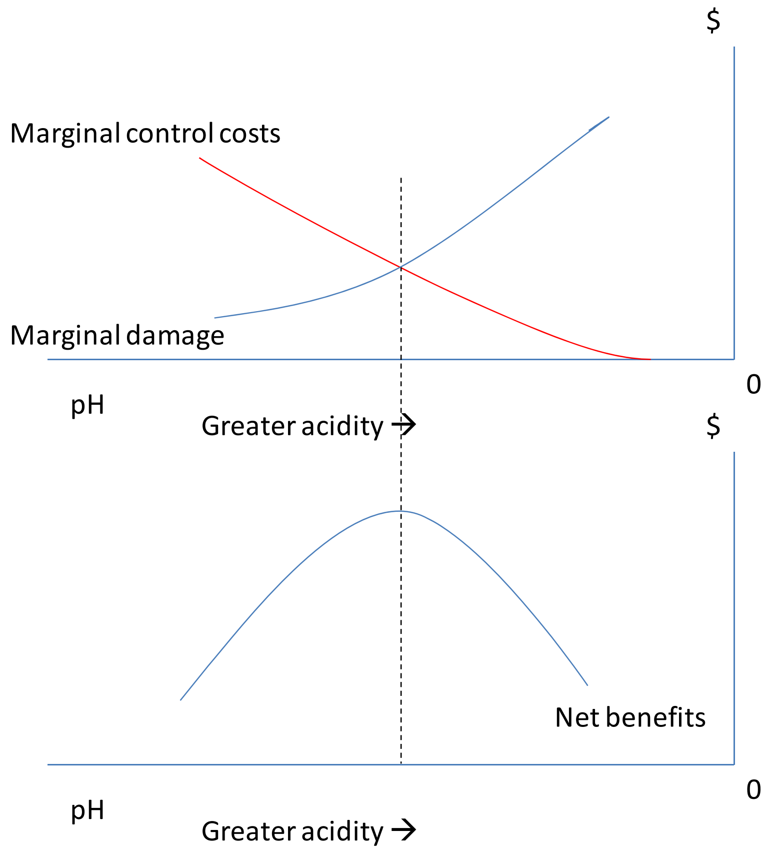

Figure 3. Optimal acidification in the standard setting

However, in many cases (see Crocker and Forester 1981) marginal damages or marginal control costs may not be monotonically related to the environmental state. Figure 4 demonstrates the case Crocker and Forester found for terrestrial acid deposition. Here, there are serious non convexities in marginal damages. The implications are then that there is the possibility for multiple equilibria and having to differentiate between local and global optimal. For example, as shown in Figure 4, without a knowledge of the entire damage and cost functions would the researcher be able to determine which of the equilibrium points A, B, or C would be globally optimal. In addition, unlike the standard setting, how exactly natural and economic adjustments are to be made to bring the system into equilibrium are not as clear. For example, in the region between A and B the marginal damages of acidification exceed the marginal control costs, signally that a reduction in pH is optimal, directing the situation towards point A. However, to the right of point B the reverse is true, signally that an increase in pH is optimal. This would direct the situation towards point B which would only be appropriate if it were a global maximum. If only a local max this would be problematic (to say nothing of the highly acidic end state). It appears that an expansion of the scope of analysis is necessary as marginal comparisons alone (of marginal damages to marginal control costs) are insufficient to signal how to maximize social net benefits. In these settings it is likely necessary to know the entire surface (across environmental change) to locate the global optimum and understand the signals provided by marginal measures.

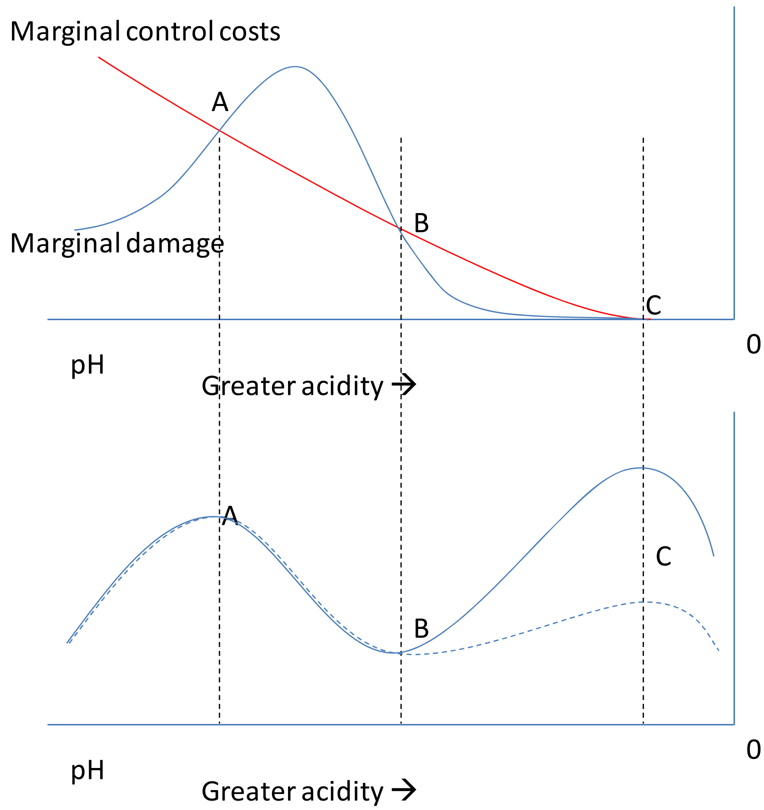

Figure 4. Acidification with non-convexity

Of course then the question becomes is there the potential for non-convexities with ocean acidification?

Using an extension of a Bering Sea ecosystem model developed in Finnoff and Tschirhart (2008) in work for the EPA and National marine fisheries service (illustrated by Figure 5) the consequences of ocean acidification were simulated in a very ad-hoc fashion. Under the assumption that acidification only influenced the commercially important crab stocks, the ad hoc assumption was made in the model that acidification increases variable respiration requirements of crabs for any level of biomass consumption. The process could be expected to directly affect more species but the point is just to illustrate the potential ecosystem consequences.

Using 3 arbitrarily chosen severities (1 being the most severe and 3 the least) and assuming that the full effect would take time to unfold the model was used to generate multi-species growth functions for ecosystem species in the presence of acidification. Figure 6 presents the growth functions generated for three commercially important species, crabs, pacific cod and arrow tooth flounder under a benchmark of no acidification, low acidification, moderate acidification and high acidification. The growth functions simply document the "surplus" production available or growth (vertical axis) at any level of stock (horizontal axis) that could be appropriated by humans and the system remain in equilibrium (a multispecies interpretation of bioeconomic yields)

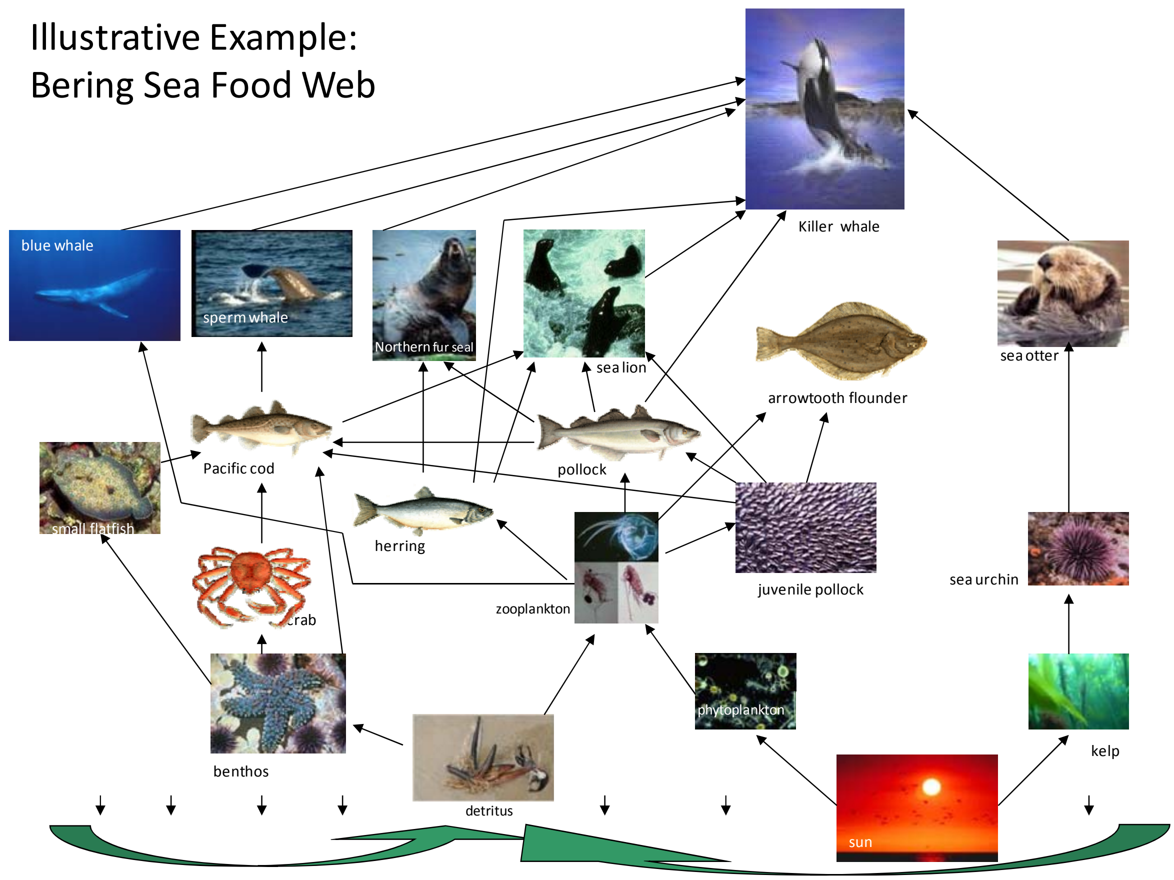

Figure 5

What is striking about Figure 6 is that for crabs alone there are non-monotonic changes from ocean acidification. For the low to moderate levels of acidification (levels 2 and 3) the multispecies carrying capacity of crabs (where the growth curves cut the horizontal axes) increases. In the absence of human harvests crab populations might increase at these low levels of acidification! This is due to the food web repercussions of acidification which see differential effects on predators (cod) and prey (bethos) which reverberate throughout the ecosystem. High levels of acidification (level 1) here would lead to extinction of crabs.

For other commercially exploited species that are directly related through a direct predator prey relationship, such as cod, a low level of acidification finds the carrying capacity only slightly altered but there are significant declines at moderate and high levels (where the moderate and high lines overlay one another). Arrowtooth flounder (ATF) are also commercially exploited yet are more distantly related in the food web. They only experience minor effects on their carrying capacity across the levels of acidification. However, for each of these commercially exploited species there are significant declines in surplus growth (sustainably harvestable biomass).

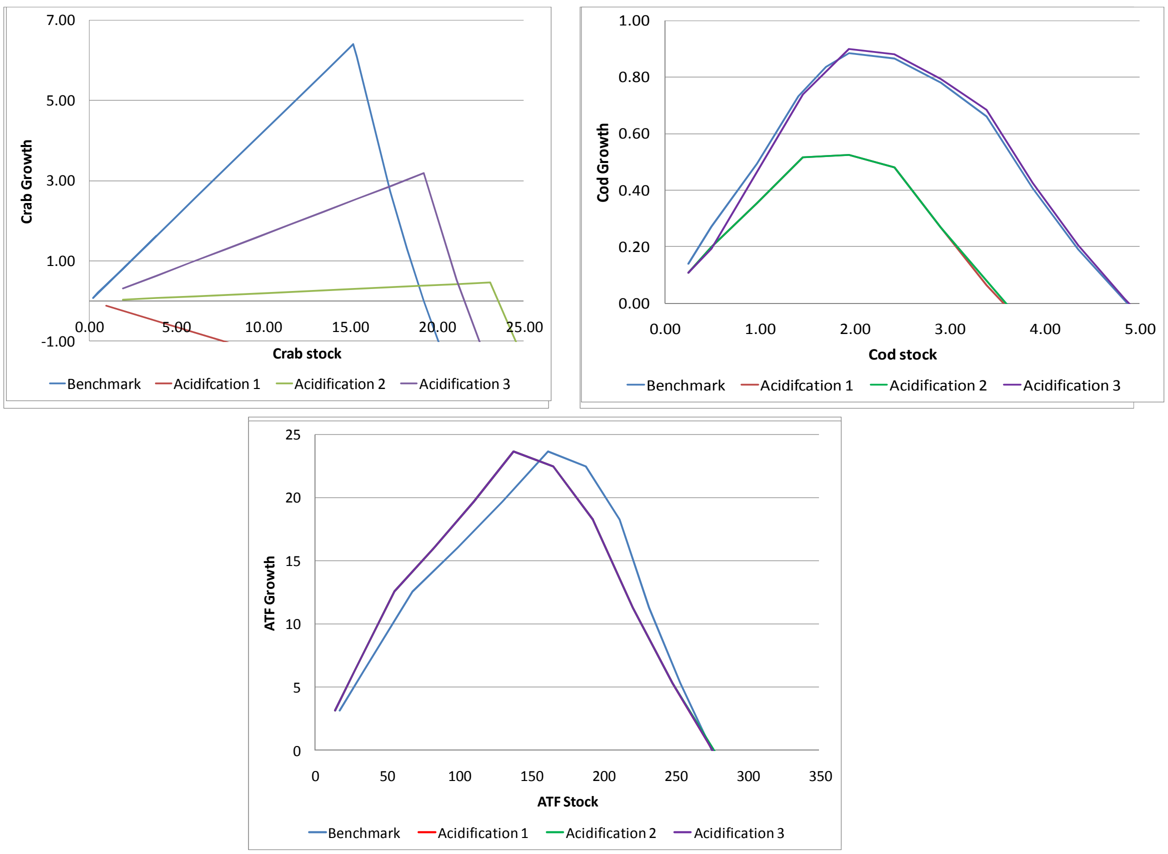

Figure 6 Selected growth curves for commercially exploited species

There are also effects on charismatic mammals that could be expected to have significant non-market values (Finnoff and Tschirhart, 2008) yet are only indirectly related to crabs in the ecosystem. Figure 7 presents growth curves for stellar sea lions (SSL) and sperm whales (SW). Sperm whales are more directly related to the effects on crabs than sea lions yet both have effects on their carrying capacities and growth (the moderate and high acidification curves overlay one another).

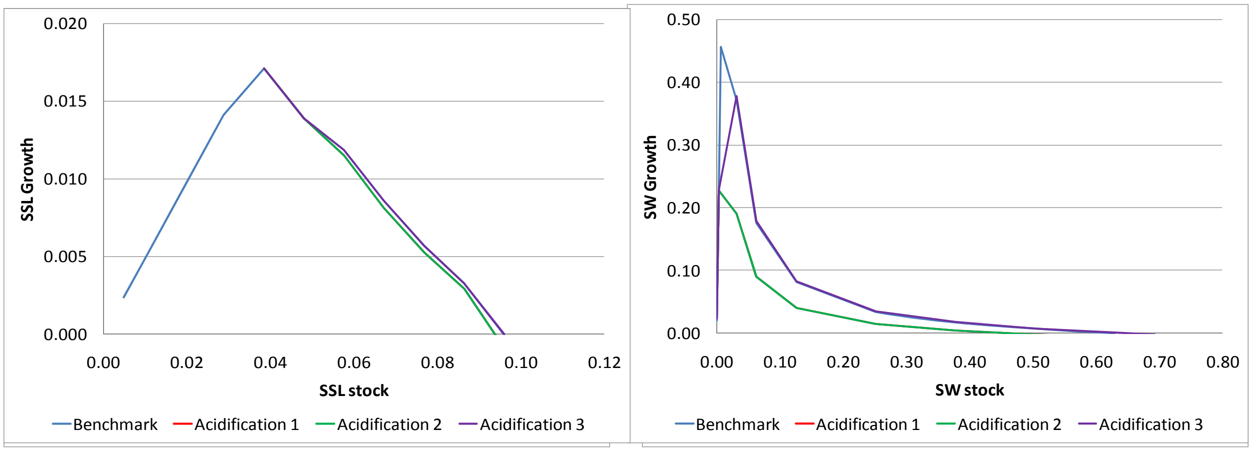

Figure 7 Selected growth curves for charismatic mammals

In sum, the consequences from acidification reverberate across system in varying degrees and magnitudes. There definitely seems to be the potential for non-convexities. As shown in the above figures, the negative shock of acidification on the crab optimization problem can result in higher carrying capacities yet less surplus growth. The changes are not typically monotonic. The implications for bioeconomic harvests of fish and crab is that they will likely be affected in varying degrees and magnitudes depending on their location in the food web. There are also perturbations in non-harvested stocks in varying degrees depending on their location in the foodweb.

Regardless of the accuracy of these results, they point to the complexity in assessing the changes in opportunity sets posed by acidification. To assess these or similar consequences an evaluation mechanism would need to be able to assess changes in flows (harvests of commercially exploited species) and stocks (changes in charismatic mammals) simultaneously. There is much the same reality versus tractability debate in the assessment mechanism as in the inclusion of ecological detail.

One organizing lens is whether a reduced form (partial equilibrium) representation is sufficient for accurate assessment or whether a structural form (general equilibrium) representation is required. Partial equilibrium approaches are the bioeconomic standard (for example see Smith, 2007) for small scale policies and welfare changes, while general equilibrium approaches are the public finance standard (for example see Carbone and Smith, 2008) for larger scale policies and welfare changes.

Partial equilibrium approaches are typically easy to implement as they hold all other economic activity constant (taking other prices and incomes as exogenous). They allow an uncluttered view of the economic activity directly affected by the acidification and a clear representation of optimal planning over long time horizons through the effect of environmental dynamics on choices. In addition they typically require few parameters. However they only provide a narrow viewpoint, they omit all other human adaptation and often omit a connection to welfare economics.

In contrast a general equilibrium representation allows the adaptations in the economic system to be represented. Prices and incomes are endogenous, there is an inclusion of producer and consumer behavior throughout an economic and allow a clear link to the principles of welfare economics. However these methods require numerous parameters, they are exceedingly hard to dynamically optimize, their broad viewpoint makes decomposing welfare effects impossible and can obscure the influence of environmental dynamics by economic responses.

Both methodologies have pros and cons, the question boiling down to a determination of the the appropriate balance. For the problem of ocean acidification this would tend to depends on the setting. For example, when considering the consequences on aquaculture a partial equilibrium approach may suffice, especially if the consequences are confined to the near shore and few other exploited (or non-market) populations.   Regardless the lack of scientific research into this issue from an economic viewpoint is glaring. To say much more requires some hard scientific effort.

In conclusion, the point of my talk is that welfare measurement of materials damages has some well known characteristics but for this problem a lot remains unresolved and work remains. There is a high likelihood in my opinion that generating accurate assessments will be tricky and generalities seem to be lacking. A necessary first step is a a clear understanding of how production and consumption possibilities are affected by the problem in a consistent setting. While dose response relationships of environmental change from the natural sciences are key, but how much detail is necessary for a good understanding remains to be resolved in this context.

The implications from this brief review are obvious. If problems are convex or well behaved then aggregate representations of the natural science may be sufficient for good economic assessments. But if these problems have pervasive non-convexities then policy makers must expand the scope of their analysis for good economic assessments. Marginal assessments on their own may lead to trouble.

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