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Assessing the Economic Impacts of Ocean Acidification on Asia's Mollusk Mariculture

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ABSTRACT

Ocean acidification is coming fast and will exert negative economic impacts on global seawater mollusk fisheries. Asia is by far the top seawater mollusk producer on Earth, therefore, it is more necessary for it to be carried out related researches than the rest of the word. This analysis is an attempt to conduct a regional assessment of the direct economic impacts of ocean acidification on Asia’s mollusk mariculture. The results show that the accelerating ocean acidification poses increasing economic risks to the industry and the total financial losses vary with the degrees of ocean acidification, from 16.08 billion USD to 71.48 billion USD, from 42.66 billion to 189.61 billion USD, and from 121.11 billion USD to 498.28 billion USD, respectively, based on a discount rate of 2%, 3%, and 4%. In addition, we define a microeconomic model to illustrate how ocean acidification affects the mollusk industry’s economy. Considering that economic losses greatly depend on policy effects, it is safe to say that effective polices can reduce the negative impacts of ocean acidification and mitigate the risks of the sudden collapse of the industry as well as the resulting social problems.

Keywords: Mollusks; Ocean acidification; Economic assessment

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1. Introduction

Ocean acidification (OA) is the other CO_2 crisis besides global warming (Doney et al., 2009), attracting increasing attention all over the world (Chen et al., 2018). It is a chemical change that causes declines in ocean pH due to excessive absorption of atmospheric CO_2 by seawater (Caldeira and Wickett, 2003). Since the beginning of the Industrial Revolution, the global ocean pH has dropped by 0.1 units, i.e., decreasing pH from 8.2 to 8.1, and it is estimated to drop by another 0.14-0.35 units by the end of the 21st century (IPCC, 2011). This means that OA is dramatically accelerating (Solomon et al., 2007).

OA reduces the availability of calcium carbonate in the oceans (Ries et al., 2009), which will directly affect the growth and development of marine organisms such as mollusks, crustaceans, and corals (Orr et al., 2005). The problem and threat can also send ripples to other species through food web or niche (Le et al., 2011), thus endangering the entire marine ecosystem and human survival (Kroeker et al., 2010). According to the Conference of the Parties to the Convention on Biological Diversity, global marine species will have reduced by 30% to 40% by 2100 due to the impact of OA, of which, the reduction in seawater mollusk species will probably have been as high as 70% (Xu et al., 2016).

Asia is by far the top seawater mollusk producer on this planet, accounting for more than 90% of the total world production (FAO, 2019). As a direct consequence of the irreversible OA process, Asia’s mollusk mariculture is likely to suffer severe financial losses in the future. Therefore, it is more necessary for Asian countries to conduct research on the economic impacts of OA on mollusk mariculture than the rest of the world. This paper aims to assess the potential economic impacts of OA on the Asian mollusk mariculture, to make early warning on the future development of the industry, and to provide some evidence for decision makers to prevent its excessive expansion or/and timely implement the industrial restructuring.

2. Literature Review

Since Caldeira and Wickett (2003) first put forward and expounded it in the prestigious journal Nature, many studies have found that OA exerts a series of influence on mollusk’s early development (Portner, 2008; Liu et al., 2012), calcification (Felly et al., 2004; Zhang et al., 2011), immunity (Bibby et al., 2008; Liang et al., 2017), physiology (Melzner et al., 2009; Liu et al., 2012; Wang et al,

2014) , reproduction (Kurihara et al., 2009), etc. After Gazeau et al. (2007) proving the relationship between OA and mollusk mortality based on experimental results, researches have expanded into Applied Economics and Management. Some scholars have started studying the economic impacts of OA from the perspective of industrial development.

Cooley and Doney (2009) calculate the potential revenue losses of US mollusk fisheries in 2060 by using three discount rates of 0%, 2%, and 4%. They combine experiment data on the growth rates of mollusks under OA with data on US fisheries harvests and prices, assume that ecological and economic conditions (i.e. catch, prices, and revenues) remain constant. The present value of losses in revenue is estimated to be US$ 2,557 million using the median discount rate of 2%.

Moore (2011) develops a biogeochemical-economic model to assess the potential impacts of OA on the US market for oysters, scallops, clams and mussels from 2010 to 2100. His model includes compensation variables representing changes in consumer welfare, and the estimated impact equals the loss in consumer welfare due to rising mollusk prices caused by OA. The present value of lost consumer welfare is calculated to be US$ 735 million in terms of a discount rate of 5%.

Finnoff (2011) argues that the welfare implications of OA need to be measured by changes in consumer and producer surplus rather than changes in gross revenues. Despite no attempt of estimating values for OA impacts, he makes the point that integrating highly complex ecological processes into an economic model is a real challenge. On the one hand, a reduced form model may be overly simplified and miss non-convexities in the ecological system. On the other hand, a detailed structural model may better capture the complexities of the system but become intractable.

Armstrong et al. (2012) analyze global mollusk production under the best and worst OA scenarios up to 2100. Their study not only identifies the marine ecosystem services that are likely to be affected by OA but also shows that OA may have positive and negative effects on the provisioning services of fisheries and aquaculture. In addition, the study considers a discount rate of 4% to be best in the present value calculation for future OA impacts.

Narita et al. (2012) estimate the value of global losses of mollusk production due to OA from 2000 to 2100. They follow the method of Cooley and Doney (2009) but adopt a higher loss rate of calcification and assume that demand for mollusks increases with income. Hence, they figure out worse results, i.e., the annual global costs in 2100 could be over US$ 100 billion, under a business-as-usual emission trend of CO_2. Narita and Rehdanz (2017) even focus their attention on European mollusk production losses, indicating that every year's costs will exceed US$ 1 billion after 2100 and France, Italy and Spain, the current major producers, will be the hard-hit areas.

Onofri and Pald (2017) construct a microeconomic model to evaluate the economic impacts of OA on the world's top ten mollusk and crustacean markets. The yields affected by OA are critical variables in the model that affect three objective functions for consumers, producers, and policymakers. Their results show that OA can both generate gains or losses according to the biological scenarios they embrace for producing predictions.

In summary, though there are very few economic studies that measure the impacts of OA on mollusk mariculture, they provide an effective way to predict the future development trend of the industry from an economic perspective. They are of great practical value, except only focusing on the US or European mollusk industry and no enough attention for Asia’s future.

3. Methodology

3.1 Research design

It is important to note that OA does not directly affect the industrial economy, but affects it by reducing the production of mollusk mariculture. The assessment of OA impacts accordingly requires an integration of research findings that can bridge disciplinary boundaries (Brander et al., 2014).

Assessing the direct economic impacts of OA on Asian mollusk mariculture of the future involves two key steps.

(1) To determine the degree of OA and the relationship between it and seawater mollusk production is the first one. It involves some knowledge of marine chemistry or biogeochemistry. To cross the chasm in this field, we quote the published results of renowned scholars and the research conclusions issued by authoritative organizations such as the Intergovernmental Panel on Climate Change (IPCC).

(2) To estimate the value of the lost production caused by OA is the other one. This step mainly belongs to the research category of microeconomics and is what we focus on in this paper.

In terms of the specific operation, we use a net present value (NPV) method based on different discount rates to assess the economic impacts of OA. The method takes into account essential indicators, e.g., inflation and risk compensation, and eliminates the interference of many variables, e.g., supply and demand, breeding costs and sales prices. Thus, it can present the potential financial loss of the future intuitively and make the estimation feasible and straightforward.

3.2 Data collection

The index and future trends of OA in this paper are quoted from IPCC. IPCC has simulated the best, medium and worst three scenarios of global OA at the beginning of the next century, which predicts that amounts of CO_2 in the ocean are 550ppmv, 700ppmv, and 950ppmv and the corresponding seawater pH balances are 7.95, 7.85, and 7.7.

The mortality of seawater mollusks due to OA is quoted from the experimental findings of Gazeau et al. (2007). Those findings, suggesting that death rates are 9%, 25% and 40% under three scenarios respectively, have been proved by Cooley and Doney (2009) and are also currently recognized by academia.

The yield and value data of Asian seawater mollusks are obtained through FishStatJ, which is an official statistical software of the World Food and Agriculture Organization (FAO). According to recent statistics, the Asian mollusk yield is about 15.81 million tonnes, and its value is equivalent to 24.66 billion USD.

3.3 Calculating formula

In terms of yield in the future, the equation is given by:

$$Q_t = Q_0(1-d) \tag{1}$$

where Qt represents the yield of Asian seawater mollusks after t years, here, t is set to 100, Q_0 represents the current yield, and d is the mortality caused by OA, equaling 9%, 25% or 40%.

The lost net present value in the future, is expressed as:

$$NPV = R_t - R_t' \tag{2}$$

where R_t represents the theoretical future revenue of Asian seawater mollusks if free from negative OA impacts, is given by:

$$R_t = R_0(1+r)^t \tag{3}$$

and R_t' represents the actual future revenue of Asian seawater mollusks when subjected to negative OA impacts, is given by:

$$R_t' = R_t(1-d) = R_0(1+r)^t \times (1-d) \tag{4}$$

Combining equation (2) with (3) and (4), we can rewrite the expression as:

$$NPV = R_t \times d = R_0(1 + r)^t \times d \tag{5}$$

all meanings of parameter R_t, R_t', t and d are the same in the above equations, R_0 represents the current revenue of Asian seawater mollusks, r is the discount rate, in this paper, r is set to 2%, 3%, and 4% to calculate the lost present value, respectively.

4. Results

The current yield of Asian seawater mollusks is about 15.81 million tonns in total. No matter which scenario occurs, it will potentially be reduced by OA in the future. As shown in Table 1, the future loss of Asian mollusk mariculture is estimated to be 1.42 million tonnes, 3.95 million tonnes and 6.32 million tonnes under the best, medium and worst scenarios, respectively. In each scenario, the species with the higher yield now are the ones more affected by OA negative impacts in the future. Consequently, clams, oysters, scallops, mussels, abalones, and miscellaneous mollusks are in descending order of the loss in volume.

Table 1. Current yield and future loss of Asian seawater mollusks (Unit: million tonnes)

Species	Yield in 2017	Loss in 2117 (Best Scenario)	Loss in 2117 (Medium Scenario)	Loss in 2117 (Worst Scenario)
Clams	5.58	0.50	1.40	2.23
Oysters	5.44	0.49	1.36	2.17
Scallops	2.16	0.19	0.54	0.87
Mussels	1.17	0.11	0.29	0.47
Abalones	1.03	0.09	0.26	0.41
Miscellanea	0.42	0.04	0.10	0.17
Total	15.81	1.42	3.95	6.32

Sources: own elaboration and calculation from FAO (2019)

Table 2 lists the present value of Asian mollusks in 2017 and that in the next 100 years if the yield maintains the current state and there are no negative OA impacts. According to the NPV method, the present value of Asian mollusks in 2117 will theoretically be 178.69 billion USD, 474.02 billion USD and 1245.7 billion USD at a discount rate of 2%, 3%, and 4%, respectively. Compared with Table 1, mussels make a significant change in rankings. The reason for the dropping of this species, from 4th in yield to 6th in value, is ascribed to its low price per quality unit.

Table 2. Present value of Asian seawater mollusks in current and the future (Unit: billion USD)

Species	Value in 2017	Value in 2117 (r = 2%)	Value in 2117 (r = 3%)	Value 2117 (r = 4%)
Clams	9.47	68.60	181.98	478.22
Oysters	5.98	43.32	114.93	302.03
Scallops	5.53	40.05	106.24	279.20
Abalones	2.06	14.94	39.63	104.14
Miscellanea	1.05	7.57	20.09	52.80
Mussels	0.58	4.20	11.15	29.31
Total	24.66	178.69	474.02	1,245.70

Sources: own elaboration and calculation from FAO (2019)

With the aggravation of OA, direct financial losses of Asia's mollusk mariculture probably will increase and the amounts of the losses will depend on OA levels. If OA can be mitigated by effective polices in the future, i.e., under the "best scenario" simulated by PICC, the total loss in 2117 will be 16.08 billion USD, 42.66 billion USD and 112.11 billion USD. In case of happening the "medium scenario", the total loss of the same year will nearly triple, ranging from 44.67 billion USD to 311.42 billion USD. Once the "worst scenario" comes out in reality, which indicates that the OA crisis will intensify in the future, then the total direct loss will nearly triple again, from 71.48 billion USD to 498.28 billion USD.

Table 3. Financial losses of Asian seawater mollusks due to ocean acidification in the future

(Unit: billion USD)

Species	Loss in 2117 Best Scenario)			Loss in 2117 Medium Scenario)			Loss in 2117 Worst Scenario)		
	r = 2%	r = 3%	r = 4%	r = 2%	r = 3%	r = 4%	r = 2%	r = 3%	r = 4%
Clams	6.17	16.38	43.04	17.15	45.49	119.56	27.44	72.79	191.29
Oysters	3.90	10.34	27.18	10.83	28.73	75.51	17.33	45.97	120.81
Scallops	3.60	9.56	25.13	10.01	26.56	69.80	16.02	42.50	111.68
Abalones	1.34	3.57	9.37	3.73	9.91	26.03	5.98	15.85	41.66
Miscellanea	0.68	1.81	4.75	1.89	5.02	13.20	3.03	8.04	21.12
Mussels	0.38	1.00	2.64	1.05	2.79	7.33	1.68	4.46	11.72
Total	16.08	42.66	112.11	44.67	118.51	311.42	71.48	189.61	498.28

Sources: own calculation from FAO (2019)

It can be seen from Tables 2-3 that the discount rate has a significant impact on the calculation results. A 2% discount rate, i.e., the liberal IPCC discount rate (much lower than the 7% conservative IPCC discount rate), is usually considered the lower limit to estimate the possible financial losses generated via the NPV equation. A 3% discount rate is argued by some scholars to be the government accepted discount rate for a medium to long-term prediction, which is also a fairly representative rate in economics. While a 4% discount rate is considered by Armstrong et al. (2012) to be the best one for a global forecast.

5. Discussions

5.1 The choice of discount rate

For the above discount rates, we tend to utilize a 4% discount rate to assess the economic impacts for the future basing on the following considerations.

(1) The lower discount rate reflects the more extended periods. Considering that the time set for the "future" in this paper is one hundred years later,

which is equivalent to experiencing about three generations, and US government guidance is to use discount rates of both 3% and 7% for valuing costs and benefits within a single generation (IPCC, 2017), hence, the discount rate should not be set too high, say, over 5%.

(2) The higher discount rate corresponds to faster economic growth. Asia's economic growth is faster than the world average. Notably, Asian newly industrializing economies, which are also the top seawater mollusk producers, are growing at a high rate (6.5 % for the year of 2018). Therefore, the discount rate should be higher than 3% as long as Asia's economic growth remains at a relatively high speed.

Therefore, a 4% discount rate may not only accord with the concept of bounded rationality in mainstream economics but also be helpful to reduce the social cost of OA.

5.2 Revelations for policymaking

Given that consumers, producers, and policymakers jointly determine the development of mollusk mariculture.

The consumers' utility (*U*) depends on the consumed quantity (*Q*), the buying price (*p*) and the ocean environmental quality (*K*), while Q depends on two other variables p and *K*, so the basic equation is mathematically expressed as:

$$U_y = Q(p_y;\ K_y) \tag{6}$$

where subscript y indicates the year. If $\frac{\partial U_y}{\partial Q_y} \cdot \frac{\partial Q_y}{\partial p_y} < 0$, marginal price increase will reduce consumers' spending. Nevertheless, it is not enough to make a quantitative prediction because variable p is not directly affected by OA. Thus, a further assumption of $\frac{\partial U_y}{\partial Q_y} \cdot \frac{\partial Q_y}{\partial K_y} \neq 0$ need making, and in this case, OA will affect *Q* and *U* in turn.

The producers' profit (π) depends on the produced quantity (*Q*), the selling price (*p*), the production cost (*c*) and the ocean environmental quality (*K*) that affected by OA, while Q depends on *p*, *c*, and *K*. The objective function for producers is expressed as:

$$\pi_y = Q(p_y; c_y; K_y) \tag{7}$$

If $\frac{\partial \pi_y}{\partial Q_y} \cdot \frac{\partial Q_y}{\partial p_y} = \frac{\partial \pi_y}{\partial Q_y} \cdot \frac{\partial Q_y}{\partial c_y}$, i.e., the marginal cost is equal to the marginal revenue, π will be maximized. In this case, π is also affected by $\frac{\partial \pi_y}{\partial Q_y} \cdot \frac{\partial Q_y}{\partial K_y} \neq 0$, which means that OA will affect Q and π in turn through the direct impacts on K.

Policymakers have to consider the total social welfare (W) in the future, i.e., the sum of the consumers' surplus and the producers' surplus. The objective function for policymakers is expressed as:

$$W_y = U_y + \pi_y = Q(p_y;\ K_y) + Q(p_y; c_y; K_y) \tag{8}$$

It is evident that W much depends on variable Q that affected by OA. Therefore, the variation of OA in the future can ultimately determine social welfare, which also suggests that understanding what potential losses OA will bring to social welfare helps in making policies.

5.3 The cost of inaction

Generally speaking, for policymakers, only when the social welfare of implementing policies is higher than the cost of making them, they have the willingness to do so. According to our estimation based on a 4% discount rate, the financial losses of Asia's mollusk mariculture due to OA in 2117 will range from 112.11 billion USD to 498.28 billion USD. It also means that the losses will be as high as 498.28 billion USD if we neglect the problem or pay attention but fail in implementing effective polices.

However, a key thing worth emphasizing is that these figures may even underestimate the real losses for the following reasons.

(1) Due to the absence of a better solution, we have to estimate the potential losses in yield by multiplying the current volume by the experimental mortality. Though the inflection-point yield for the future is hardly predictable, facts show that the scale of Asia's mollusk mariculture stays expanding. Thus, from this angle, the yield losses in the future may be more than what we estimated, as well as the financial losses.

(2) We assume a linear relationship between the yield losses and the degrees of OA from a biochemical perspective to make the assessment more workable. But it is also possible that producers may accelerate their departure due to reduced production and financial results. In such a circumstance, the yield losses will be the resultants of both natural changes and human activities. That might further cause an extreme situation, i.e., even though the total yields decline significantly, the total value perhaps create new high because the prices increase more significantly due to supply shortages during a certain period of time.

6. Conclusion

With the increased combustion of fossil fuels due to rapid industrialization, urbanization, and population growth, oceans have begun to taken up excessive amounts of CO_2, resulting in an acceleration of OA. This irreversible trend can make serious economic impacts on the global mollusk mariculture. As the top mollusk producer by far, Asia may well bear the brunt of the crisis.

In this paper, we have empirically analyzed the potential economic impacts of OA on Asia's mollusk mariculture by using the net present value method. According to our estimation, the direct financial losses of the industry vary with the changes of OA degree and they can exponentially increase under the best, medium and worst scenarios simulated by IPCC. Once the worst scenario occurs in the future, Asia will trigger a total financial loss of 4.5 times higher than that under the best scenario. The potential hazard implies that it is urgent for Asia to establish a set of risk prevention system.

The microeconomic model applied in this paper further help us understand the mechanism of OA action on the mollusk economy and let us get clear about what policymakers really consider. It is obvious that the losses of the Asian mollusk mariculture may be incredibly huge-up to nearly 500 billion USD in 2117 unless effective measures are taken in time.

Furthermore, the final financial losses of the Asian mollusk mariculture greatly depend on policy effects. If policies are effective, the losses of the industry can be small -- and vice versa.

Therefore, it can be concluded that even though formulating and implementing targeted policies cannot completely eliminate the negative impacts of OA, at least it can mitigate the risks of the sudden collapses of the industry as well as some resulting social problems.

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