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Restoring and Protecting the world's large marine ecosystems: An engine for job creation and sustainable economic development

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ABSTRACT

Some of the most significant threats to the sustainability of the world's 66 Large Marine Ecosystems (LME) – invasive species, coastal hypoxia, overfishing, marine debris and ocean acidification – are due to a combination of market and/or policy failures which cause these environmental externalities. A concerted global effort to remove these barriers would not only lead to dramatic improvements in ocean health and preservation of trillions of dollars in ocean-related goods and services and hundreds of millions of existing jobs, but also catalyze transformation across a range of ocean using and affecting sectors that would create millions of new, and in many cases, well paying, jobs for people across both the developed and developing world.

1. Introduction

Large Marine Ecosystems (LMEs) are relatively large areas of ocean space of approximately 200,000 km^2 or greater, adjacent to the continents in coastal waters (Sherman and Alexander, 1986) where primary productivity is generally higher than in open ocean areas. Due to their proximity to the continents and the sizeable fraction of the human population that lives near the coasts, the majority of human socioeconomic activity takes place in the world's 66 LMEs that scientists have to date defined (Sherman and Hamukuaya, 2016). The contribution of LME-based economic activity to global GDP is estimated to be between $3 to $6 trillion per year (Hudson, 2012) and overall the ocean is estimated to contribute as much as $27 trillion per year in non-market ecosystem services (Costanza, 2014). The world's LMEs represent a major source of protein for human consumption; LMEs produce about 80% of the world's annual marine wild fisheries catch (NOAA LME Portal) and the fisheries sector directly or indirectly employs over 200 million people. The global shipping industry contributes around $435 billion per year to the global economy and supports nearly 14 million jobs (World Shipping Council, 2009). The tourism industry represents an estimated 9.8% of global GDP, contributing 9% or 284 million global jobs (World Travel and Tourism Council, 2015). While a global figure is not available, coastal tourism is estimated to make up 85% of all US tourism (NOAA Public Affairs) indicating that ocean and coastal tourism likely also represents a sizeable fraction of global tourism on both a GDP and employment basis.

Today, the world's LMEs face unprecedented threats to their long-term health and functioning and the trillions in market and non-market ecosystem services they provide to humanity. These include: invasive species introductions, nutrient over-enrichment, unsustainable fishing, loss/conversion of marine habitat, marine plastics pollution, ocean warming/stratification due to climate change, and ocean acidification. As with most if not all environmental threats to the earth's ecosystems, ocean degradation is driven by a combined suite of market and policy failures that fail to 'internalize' the externality of ocean degradation into the prices of the

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goods and services LMEs and the broader ocean provides to humanity. These market and policy failures are widely understood for each of the key ocean threats; the remaining challenge is much more a political than technical one, to adopt and implement the necessary market and policy reforms to move the world's LMEs on a sustainable path.

The preliminary analysis described in this paper sets forth the initial proposition that a concerted global effort to restore and protect the world's LMEs and broader ocean would not only reap the environmental benefits of a much healthier ocean, and protection of hundreds of millions of ocean-dependent livelihoods and economies, but also lead to sizeable transformations in a number of key ocean using and affecting sectors that would in turn create large numbers of net new jobs, reducing unemployment and therefore stimulating positive economic growth and development. The paper systematically reviews most of the key ocean threats in this context.

1.1. Invasive species

Invasive aquatic species, primarily transferred via ship's ballast water and hulls, and mobile marine infrastructure, have been estimated to cost the world an estimated $100 billion per year in socioeconomic damages to infrastructure and livelihoods (GEF/UNDP/IMO Global Ballast Water Management Programme, 2004). The issue is a particularly pernicious one as, once a given alien marine species has established itself and disrupted the local ecosystem, it is virtually impossible to eradicate. The invasive species externality reflects the lack of internalization of the financial damage of invasive species on aquatic ecosystems and linked economic activity into the design and operations of the shipping industry. As a result, until recently the shipping industry has had no incentive to incorporate the cost of preventing such invasions into shipping operations and to stimulate remedial actions that can ensure ‘clean’ ship ballast water and hulls via treatment and management. However, in 2004 a multi-year negotiation process facilitated by the International Maritime Organization (IMO) led to the adoption of the Global Convention on Ship's Ballast Water and Sediments. This convention sets strict standards on ships above a certain size to effectively treat their ballast water prior to its release at an arrival port. The Convention has already exceeded the required number of ratifying parties and lies within about 2% of ship flag state ‘tonnage’ (35%) ratifications to come into force so this is anticipated shortly (Ship and Bunker News, 2015).

The very clear and strong signal regarding compliance with the anticipated Convention has stimulated hundreds of millions of dollars in new ballast water treatment research and development by existing and new companies keen to capitalize on this new market. Companies have developed and submitted over 65 technologies that have been accepted by the IMO as meeting the provisions of the Convention. With upwards of 68,000 ships requiring systems ranging in price from $0.5–3 million (gCaptain, 2013), the overall costs of industry compliance with the Convention are estimated to be in excess of $40 billion, underscoring the ongoing and expected continued rapid growth of the ballast water treatment industry. Revenues for the global ballast water treatment system market were projected to increase from $466.6 million in 2013 to $3.14 billion by 2023 at a compound annual growth rate of 21% (Environmental Leader, 2013). While no detailed studies have been done yet on the impacts of this new industry on employment, it is clear that a completely new industry of this massive scale is catalyzing the creation of dozens of new companies and divisions in existing companies and likely creating several tens of thousands of new jobs to meet the rapid scaling up of the industry in anticipation of required compliance with the Convention. Given the highly technical nature of ballast water treatment technology, these are likely to be jobs that pay well and are located in coastal areas.

1.2. Nutrient over-enrichment

Due to the massive increase, especially since the ‘green revolution’ of the 1950's, in the industrial production and use of reactive nitrogen as fertilizer in agriculture, and in continued inadequate global levels of wastewater treatment, nitrogen burdens to the world's LMEs have roughly tripled since pre-industrial times and are projected to double or triple again by 2050 in the ‘business as usual’ scenario (Seitzinger et al., 2010; Lee et al., 2016), with the majority of increases occurring in the developing world. Over the last 30 years, the global occurrence of eutrophic/hypoxic areas has increased at an exponential rate, numbering over 500 and costing the global economy an estimated $200 - $800 billion per year (UNDP, 2012).

Nutrient over-enrichment of LMEs and associated coastal eutrophication and hypoxia reflects the lack of internalization of the cost of the nutrient damage to the coastal and ocean environment into the price of industrially produced fertilizer and wastewater treatment. Consequently, the agricultural and wastewater sectors have little financial or policy incentives to invest in improving fertilizer use efficiency or in sufficient levels of human and animal wastewater treatment to remove (and ideally, recover and re-use) most nutrients before they reach the ocean. This issue is further exacerbated in many cases by large subsidies to agriculture including for fertilizer. For example, fertilizer subsidies in India rose 17-fold from 1990 to 2009, to about US $11.4 billion per year (Salunkhe and Deshmush, 2013) and in China, fertilizer subsidies amounted to RMB 20 billion (about US$ $3.2 billion) in 2012 (Li et al., 2014). Internalizing the coastal hypoxia externality would therefore require a range of economic and policy incentives for fertilizer use efficiency, nitrogen recovery from wastewater, and enhancement of nutrient sinks, including wetlands. These could include taxes (on fertilizer and/or wastewater nutrient emissions), nutrient release cap and trade schemes in river basins or coastal areas, promotion and enforcement of best agricultural practices in fertilizer use, application of ‘positive’ subsidies (such as to agricultural and wastewater practices and technologies that reduce emissions and capture and re-use nutrients), and many others. For further detail on such initiatives, see Green Economy in a Blue World, p. 76–93 (Hudson, 2012).

The result of a truly global scaling up of nutrient pollution reduction policy and economic incentives would catalyze a sizeable transformation in both the agriculture and wastewater sectors as the sectors respond with technological and management innovations and associated new business lines. Whereas industrial scale fertilizer production and application are very capital intensive, reforms of the type listed above promoting nutrient use efficiency, recovery and re-use would be far more labor intensive, likely leading to net job creation both in the private sector but also in the public sector institutions required to oversee implementation of such programs. Similarly, reforms and incentives promoting recovery and re-use of wastewater (such as retrofitting homes and apartment buildings for composting, collection and re-use of human waste as fertilizer) would be much more labor intensive than current/traditional 'linear' municipal wastewater collection, treatment and disposal systems, leading to net job creation in both the private and public sectors. Already, 40 million farm homes in China have holding tanks for human and animal waste that is ultimately used as fertilizer; such schemes are now starting to appear in Chinese urban settings such as Beijing which converts about 6800 t per day of human excrement into fertilizer and biogas (Khan, 2015). Another good case study in this respect is the example of Israel which, recognizing in the 1960's that it faced extreme water scarcity, innovated extensively on both water use efficiency (especially drip irrigation) and wastewater reuse in agriculture. Today, Israel reuses 80% of its wastewater as water – and fertilizer – into agricultural production, far higher than the second ranked country in this area, Spain, at about 17%. Over 280 water technology companies in Israel have increased their exports 5-fold to $2 billion between 2008 and 2013 (Booth, 2013). In the same context that the global Ballast Water convention created a completely new ballast water treatment industry, Israel's water scarcity challenge was responded to through business and technology innovation that in turn created a new 'high tech' industry with jobs that presumably pay well.

1.3. Unsustainable fishing

As much as 80% of the world's fish stocks are fully exploited or overexploited; wild fish yields have been flat for over 30 years with the deficit largely filled by a rapid (9% p.a. since 1980) growth in aquaculture which now provides about 46% of all consumed seafood. FAO and the World Bank estimate that the social and environmental costs of overfishing are $50 billion per year (Arnason et al., 2008).

The global externality of unsustainable fishing principally reflects the lack of internalizing the social and environmental costs of overfishing into (sustainable) fisheries management. This market failure is compounded by policy failures including 'negative' global subsidies of about $16 billion per year (Sumaila, 2010) to the fishing industry (e.g. fuel subsidies, tax breaks) leading to fleet over-capitalization and overexploitation. Illegal, Unregulated and Unreported (IUU) fishing, estimated to amount to twenty percent of annual global fish yields valued at $23 billion, further exacerbates the overfishing externality (FAO, 2013). Other key drivers include destructive fishing methods, poor regulation of the fisheries sector, loss of key fish stock spawning and nursery habitat, weak fisheries management institutions and insufficient application of ecosystem approaches and innovative economic instruments to fisheries management. A comprehensive approach to addressing the global fisheries crisis is required (Hudson and Glemarec, 2012):

- Reduce negative fisheries subsidies, redirect same financial resources to improved fisheries management, sustainable aquaculture, expand Marine Protected Areas;
- Scale up properly designed ITQ allocation to small scale fisheries with market-based mechanisms such as ITQs (up to $40 billion/year), direct portion of new financial flows to marine protected areas, sustainable aquaculture, improved fisheries management;
- Achieve or exceed Sustainable Development Goal 14, Target 14.5, place ten percent of the oceans under marine protected areas (MPA) by 2020;
- Ensure use and application of sound science, ecosystem-based approaches, data sharing, and precautionary principle in regional and national fisheries management organizations including LME institutions;
- Effective implementation and compliance with UN Fish Stocks Agreement, FAO Code of Conduct, Port State Measures Agreement (FAO, 2016).

As a result of subsidies, illegal and unregulated fishing activity, often weak to non-existent tenure rights for small scale fishers (SSF), and other factors, the global fishing industry is not at present a very 'level playing field' between large and small scale fisheries, particularly in the developing world where external fishing fleets extract (or exceed) fish quotas based on often unbalanced licensing agreements with coastal governments, or fish illegally. Recent analyses (Jacquet and Pauly, 2008) demonstrate that, by eliminating many of the policy and market failures (such as subsidies, lack of SSF access to markets, lack of SSF capacity and finance) that favor large scale over small scale fishers, a sizeable transformation in the distribution of benefits realized across the sector between large scale and small scale fishers could be realized, this is summarized in Table 1. It is also important to note that SSF play a major role in generating employment for women especially in developing countries.

Table 1
Fish yields and employment comparison, Small Scale vs. Large Scale Fisheries & Aquaculture (Jacquet and Pauly, 2008).

	Small scale fisheries	Large scale fisheries	Aquaculture
Annual catch/production for human consumption (mt)	30,000,000	30,000,000	51,650,000
Annual catch to meals & oils (mt)	0	25,000,000	0
By-catch (mt)	0	8–20,000,000	0
Number employed	12,000,000	500,000	10,793,000
Jobs/mt fish product	0.400	0.009	0.209

Notably, this data demonstrates that, globally, small scale fisheries create 44 times more jobs per metric ton of fish harvested than large scale, and aquaculture creates 23 times more jobs per metric ton than large scale. This analysis strongly suggests that a concerted global effort to implement the required suite of policy and market reforms for sustainable fisheries would not only deliver much healthier and robust fisheries in the world's LMEs, but also, via leveling the playing field for small scale fishers, lead to sizeable net job creation in the small scale fisheries sector, particularly in the developing world where systemic unemployment represents one of the most important challenges to development and poverty reduction.

1.4. Marine debris/plastics pollution

Plastics are now ubiquitous in the world, featuring in a vast variety of products consumed by people and societies across all socioeconomic levels. Today, about 300 million metric tonnes of plastic are produced each year (Statista, 2014). Unfortunately, due to ineffective waste management, much of this plastic escapes into the environment; recent estimates are that between 5 and 12 million metric tonnes enters the ocean each year (Jambeck et al., 2015), leading to its accumulation not only in coastal waters but also in the large central gyres of all the world oceans. Plastics impact marine ecosystems from the largest macro (marine mammal and bird ingestion and entanglement) to the micro (ingestion of micro-plastics by plankton, accumulation of micro-plastics and the contaminants they contain up the food chain) levels and the overall impacts are still being intensively studied. A recent UNEP study estimated the annual economic damage of marine debris at $13 billion per year (UNEP, 2014). In addition, the production (energy, raw materials) and disposal of plastic has a sizeable carbon footprint (http://timeforchange.org). The policy and market failure behind the marine debris externality is of course the lack of sufficient internalization of these costs into effective plastic waste minimization, recovery and re-use.

Many countries, particularly in the more industrialized world, have had plastics and other solid waste recovery and recycling programs for several decades. Despite this progress, the global plastics recycling rate is estimated at about 14% (World Economic Forum, 2016). At the same time, there are examples, including 8 European countries such as Sweden and Switzerland that, through aggressive waste management policies and incentives have reduced the proportion of solid waste going to landfill to only 2% of that generated, with roughly equal portions of the 98% going to recycling and incineration, often as waste-to-energy. These examples underscore that it is possible, through effective policy development and implementation, to dramatically reduce the volume of plastics that can escape into the environment and to the world's LMEs and broader ocean. A global scaling up of such proven mechanisms, such as bottle bills, selected bans (e.g. shopping bags), incentives for producers to recover and re-use plastics, and others, could have a sizeable impact on the marine debris challenge.

Furthermore, a number of studies provide evidence that plastics recycling efforts can create sizeable numbers of good quality jobs. In the United States, revenue realized by recycling and re-use programs exceeds that from traditional waste management by 6.4 times ($236 billion vs. $37 billion) (Beck, 2001). The US recycling and re-use industry employs over 4 times as many people as the waste management industry (1.1 million vs. 250,000), 200,000 of these for plastics alone (Beck, 2001). While traditional waste disposal generates around 0.1 job per 1000 t of waste, recycled plastics manufacturing delivers 10 jobs per 1000 t. Average recycling and re-use wages are 10% higher than those for traditional waste management (US EPA, 2002). Lastly, one study (Tellus Institute, 2010) showed that if the United States could achieve a municipal solid waste diversion rate of 75% by 2030, it would create 1.1 million additional jobs and avoid 515 million mt of CO_2 emissions (equivalent to that from 72 coal plants). These and similar studies provide strong evidence that a concerted global effort to put in place the necessary suite of solid waste management policy and market reforms would not only improve global ocean health by reducing marine plastics pollution, but also lead to the creation of sizeable numbers of new jobs that often pay well.

1.5. Ocean acidification

An estimated 25–30% of the anthropogenic carbon dioxide emissions from the combustion of fossil fuels over the last 200 years or so has dissolved in the ocean as carbonic acid (Brewer and Barry, 2008). While uptake by the ocean has helped to delay and mitigate the impacts of climate change on the atmosphere to a sizeable degree, it has resulted in a change to ocean carbonate chemistry through lowering the average pH of the ocean by 0.1 units, this represents an increase in ocean acidity of about 30% (pH uses a logarithmic scale). This increased acidity in turn reduces the availability of carbonate (CO_3^{-2}) ions needed by the numerous marine organisms that fix calcium carbonate for their shells or skeletons. In a business as usual fossil fuel use scenario, by the late 21st century ocean pH would drop by another 0.3–0.4 pH units, or an increase in acidity of over 250%. In addition to the aforementioned effects on organisms that fix calcium carbonate, marine organisms spend a lot of their energy maintaining their internal pH and as external seawater pH decreases, they will likely have to divert more of the energy away from other parts of their physiology (e.g., growth and reproduction) to continue to do this. Ocean pH is changing at a rate not seen on earth for at least 60 *million* years and in the earth's geological record there is a strong correlation between mass extinctions and major ocean acidification events.

Initial estimates of the economic costs of ocean acidification by 2100 amount to $1.2 trillion per year (Brander, 2011)), about 0.16% of global GDP, and represent about 10% of the overall projected damages due to climate change. However, these preliminary estimates only include impacts on coral reefs and mollusks and don’t begin to account for the potentially catastrophic impacts on ocean ecosystems if the functioning and survival of calcareous plankton, the basis of much of the oceanic food chain, is impacted. The policy and market failure that is driving ocean acidification is the failure to internalize the environmental and socioeconomic damage of ocean acidification into the production of energy. The solution to address ocean acidification is the same as that for climate change overall: put a proper price on carbon emissions that would catalyze massive additional investment in renewable energy and energy efficiency, and remove the trillions in fossil fuel subsidies that presently make the energy production playing field a very non-level one.

Comprehensive reforms in global energy policy and markets such as those described above would lead to a major transformation in energy markets. Collectively, wind, solar and biomass generate 2.5–9.2 times as many jobs as fossil fuels for every $1 million contribution to GDP (UK Energy Research Centre, 2014). While fossil fuels create 0.1–0.2 jobs per gigawatt-hour of energy generated, renewables contribute 0.5 jobs per gigawatt-hour (UK Energy Research Centre, 2014). In the US, median wages for green energy jobs are $46,303, 13% higher than in the broader economy (Muro et al., 2011). Globally, there were 6.5 million renewable energy jobs in 2014, with solar photovoltaic (PV) as the top employer. 69% of the new electricity generating capacity installed in the US in 2015 was solar and wind (Muncell, 2016). In the UK, the installed capacity of renewables tripled from 2006 to 2012 to almost 16,000 MW and as of 2014 accounted for 19.4% of electricity generation in the UK (UK National Statistics). In summary, moving from heavy reliance on far more capital intensive fossil fuels to much more labor intensive renewable energy sources and energy efficiency would create substantial net new jobs that pay well, catalyzing economic growth and poverty reduction in both developed and developing regions of the world.

2. Conclusion

The world's 66 LMEs and the broader open ocean ecosystem face a range of key threats to their health and functioning which in turn threaten food security and safety, livelihoods and socioeconomic development in most if not all of the world's coastal nations. The suite of policy and market failures driving each of these threats is well understood; what's largely missing is the political and institutional will and commitment to adopt and implement the necessary range of market and policy reforms to internalize these environmental externalities and reverse ocean degradation. This paper presents an initial analysis of how a concerted global effort to address most of the key threats to LMEs – invasive species, coastal hypoxia, overfishing, marine debris and ocean acidification – would, by removing these barriers, not only lead to dramatic improvements in ocean health and preservation of trillions of dollars in ocean-related goods and services and hundreds of millions of existing jobs, but also catalyze transformation across a range of ocean using and affecting sectors that would create millions of new, and in many cases, well paying, jobs for people across both the developed and developing world. This work provides impetus for more in-depth studies of the ocean restoration/job creation nexus across the described ocean challenges and involved sectors.

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