

Reconsidering Ocean Calamities

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The proliferation of a number of pressures affecting the ocean is leading to a growing concern that the state of the ocean is compromised, which is driving society into pessimism. Ocean calamities are disruptive changes to ocean ecosystems that have profound impacts and that are widespread or global in scope. However, scrutiny of ocean calamities to ensure that they can be confidently attributed to human drivers, operate at widespread or global scales, and cause severe disruptions of marine social-ecosystems shows that some of the problems fail to meet these requirements or that the evidence is equivocal. A number of biases internal and external to the scientific community contribute to perpetuating the perception of ocean calamities in the absence of robust evidence. An organized auditing of ocean calamities may deliver a more precise diagnosis of the status of the oceans, which may help to identify the most pressing problems that need be addressed to conserve a healthy ocean.

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Science is a social enterprise, we communicate through the scientific literature, and we must do nothing to undermine the integrity of that communication. Both in sending and in receiving information, we must remain skeptical. (Scott W. Nixon)

There is a growing concern that the health of the ocean is increasingly compromised because of cumulative pressures (Jackson et al. 2001). For example, in a global synthesis of human pressures on the marine environment, Halpern and colleagues (2008) concluded that “no area (of the ocean) is unaffected by human influence and that a large fraction (41%) is strongly affected by multiple drivers” (p. 948). Indeed, the number of environmental problems reported for the coastal ocean and the level of public alarm about their severity has increased over the past decade. As a result, news headlines convey the notion that the ocean is in imminent risk of ecological collapse (e.g., table 1).

Indeed, contemporary narratives on the state of the ocean often enumerate a number of widespread calamities affecting the oceans that have resulted from human pressures. One of the most quoted accounts of these problems is that of Jackson and colleagues (2001), one of the most cited papers in marine ecology (cited 3945 times as of 3 December 2014 according to Google Scholar). The quote reads

Overfishing precedes all other pervasive human disturbance to coastal ecosystems, including pollution, degradation of water quality, and anthropogenic climate change. . . The litany of changes includes increased sedimentation and turbidity; enhanced episodes of hypoxia or anoxia; loss of seagrasses and dominant

suspension feeders, with a general loss of oyster reef habitat; shifts from ecosystems once dominated by benthic primary production to those dominated by planktonic primary production; eutrophication and enhanced microbial production; and higher frequency and duration of nuisance algal and toxic dinoflagellate blooms, outbreaks of jellyfish, and fish kills. (Jackson et al. 2001, pp. 629, 634)

This quote has been paraphrased repeatedly, in various forms, in the scientific literature (e.g., Jackson 2008, Mooney et al. 2009), as well as in policy statements, such as that in UN Secretary-General Ban Ki-moon’s oceans compact statement that

Humans, however, have put the oceans under risk of irreversible damage by overfishing, climate change and ocean acidification (from absorbed carbon emissions), increasing pollution, unsustainable coastal area development, and unwanted impacts from resource extraction, resulting in loss of biodiversity, decreased abundance of species, damage to habitats and loss of ecological functions. (www.un.org/depts/los/ocean_compact/oceans_compact.htm)

Indeed, such narrative has been so often repeated as to qualify as a “litany”, a term used in the quote above from Jackson and colleagues (2001).

Such accounts of the deterioration of the oceans stemming from the scientific community run the risk of conveying the hopeless notion to managers and the public that we are confronted with an insurmountable environmental crisis of gigantic proportions. Although emphasizing problems

Table 1. Examples excessive media headlines emphasizing the collapse of marine ecosystems due to ocean calamities.

Headline	Source	Dates	Plagues referred to
Jellyfish are taking over the oceans: Population surge as rising acidity of the world's seas kills predators	Mail online UK	03-Dec-11	Jellyfish blooms, Decline of calcifiers, Overfishing
<i>Caulerpa taxifolia</i> : The silent killer	Reportage/Enviro, Australia	06-Jun-11	Invasive species
The Green Monster: Why a giant seaweed is taking over the bottom of the Mediterranean	New York Times, USA	12-Dec-99	Invasive species
DEAD ZONE: Runoff from Midwest farms plagues Gulf	New Star, USA	12-Nov-12	Decline of fish stocks
Ocean acidification is killing sea life, and we are the culprits	Los Angeles Times	28-Nov-12	Decline of fish stocks and calcifiers
The slippery slope to slime	Australian Broadcasting Corporation	15-Apr-13	Decline of biota
Overfished and under-protected: Oceans on the brink of catastrophic collapse	CNN, USA	27-Mar-13	Decline of fish and all plagues
Ocean acidification may weaken or kill plankton, responsible for half of world's oxygen production	DGR News Service, USA	04-May-12	Decline of calcifiers
Big increase in jellyfish blooms around the world (watch https://www.youtube.com/watch?v=x43805RX4u0)	CNN, USA	06-Nov-13	Global jellyfish blooms
Ocean acidification, the lesser-known twin of climate change, threatens to scramble marine life on a scale almost too big to fathom (http://apps.seattletimes.com/reports/sea-change/2013/sep/11/pacific-ocean-perilous-turn-overview/)	The Seattle Times	12-Sep-13	Ocean acidification

may be intended to propel remedial action, it may achieve the contrary, because an overly negative message may lead society into pessimism or the belief that the ocean is beyond restoration. Indeed, recent media reports on problems in the ocean do not leave much room for optimism (table 1). However, an analysis of some of the calamities reported in doom and gloom media accounts (e.g., table 1) shows some—at times, severe—disconnect with actual observations. For instance, there is no evidence that ocean acidification has killed jellyfish predators, nor that jellyfish are taking over the ocean, and predictions that the killer algae, *Caulerpa taxifolia*, was going to devastate the Mediterranean ecosystem have not been realized, despite claims to the contrary from the media (table 1). It may be, therefore, that some of the calamities composing the syndrome of collapse of coastal ecosystems may not be as severe as is portrayed in some accounts.

Referring to the epigraph of this article, we contend that the marine research community may not have remained sufficiently skeptical in sending and receiving information on the problems caused by human pressures in the ocean and that there is a need to revisit the process by which potential or isolated problems escalate to the status of ocean calamities. Scientific or academic skepticism was proposed by logical positivism and logical empiricism as a positive value of scientific progress and has been argued to be a necessary guiding principle for researchers (Merton 1973). Scientists are expected to remain skeptical, questioning, or doubting or to suspend judgment until sufficient evidence and proof is offered to draw conclusions through organized skepticism, involving social arrangements, such as the peer-review

system, for the critical scrutiny of knowledge claims in science (Merton 1973). However, there is a perception that scientific skepticism has been abandoned or relaxed in many areas, which has allowed opinion, beliefs, and tenacious adherence to particular theories to play a major role in holding beliefs based on interpretations unsupported by evidence (Loehle 1987).

In particular, programmatic skepticism in science should motivate efforts to reconsider evidence presented as fact (Merton 1973) in an attempt to scrutinize the correspondence between those “facts” and relevant empirical evidence. Here, we describe, using examples from various marine calamities allegedly resulting from human pressures, how critical scrutiny of key evidence supporting some of the ocean calamities may reveal potential flaws or uncertainties and discuss a set of mechanisms, within or outside the research community, that may introduce biases whereby hypothesized calamities become accepted facts without sufficient empirical testing through data synthesis and, when possible, controlled experiments. The approach described here may also provide a pathway to conduct a much-needed systematic audit of ocean calamities.

Reconsidering ocean calamities

The ocean calamities included in narratives of the deterioration of the oceans include disruptive changes to ocean ecosystems attributable to human pressures that have profound impacts and that are widespread, which are exemplified, for instance, by a tendency for a global decline of vegetated coastal habitats (Duarte et al. 2013) or coral reefs (Pandolfi et al. 2003), growing mortality due to hypoxia (Diaz and

Rosenberg 2008), or the decline in calcifiers due to ocean acidification (Doney et al. 2009).

Ocean calamities may have natural causes, such as the widespread impacts on marine life of the current development of a submarine volcano in the Canary Islands (Fraile-Nuez et al. 2012), to cite an extreme example. Some calamities, such as jellyfish blooms, red tides, or marine heat waves, may also be triggered by both natural or human causes (e.g., Anderson et al. 2012, Condon et al. 2012). However, human pressures may erode the resistance of marine ecosystems to natural pressures and thereby amplify the impacts of those pressures. For instance, overfishing affects the resilience of coral reefs to other stresses (Hughes et al. 2007). Moreover, human pressures are inherently patchy (Halpern et al. 2008), and no one calamity, even climate change, acts homogeneously at global scales. However, the calamities addressed here are those attributable to human pressures and sufficiently widespread that they are relevant beyond those possibly affecting single locations or regions, which are those fueling growing concern on the state of the oceans (e.g., Jackson et al. 2001).

The elements required for a problem in the marine ecosystem to reach the status of anthropogenic calamity include that the problem be a consequence of human activity, including pressures such as exploitation, eutrophication, hypoxia, habitat loss, anthropogenic climate change and ocean acidification, and species relocations; that the problem has grown or spread enough to be considered widespread or global in scope rather than regional or affecting specific locations; and that the problem be sufficiently severe as to hold the potential to disrupt marine social-ecosystems, so that they affect the flow of ecosystem goods and services to society. We acknowledge that there are many other calamities in the marine environment that do not conform to the criteria above, and that may be of interest to scientists or local managers (e.g., alterations of hydrology, loss of ecosystem engineers, increasing aquaculture). However, these are not captured in the list described above, which provides the basis for current societal concern on the health of the oceans.

Therefore, skeptical scrutiny of ocean calamities must involve an analysis to ensure that the following elements be met: their attribution to pressures associated with human drivers, their global or widespread nature, and their disruption of linked social-ecological systems. We illustrate this process of skeptical scrutiny by providing, for each of these components, succinct examples of cases supported by strong, equivocal, or weak evidence. We then discuss the processes that may lead to perpetuating the perception of ocean calamities even in cases in which the evidence may be equivocal or weak.

Attribution to human pressures

The attribution of global changes in the ocean ecosystem to anthropogenic drivers is a daunting task, as was discussed in the case of climate change by Parmesan and colleagues (2013). The approaches to attribution include a combination

of long-term parallel time series observations across appropriate spatial scales, *a priori* hypotheses on the ecological changes over time and among locations expected as a consequence of the anthropogenic drivers, and experiments in which such *a priori* hypotheses are tested and in which a mechanistic understanding of the changes is provided.

Strong evidence: The depletion of fish stocks. Perhaps the easiest ocean calamity to attribute to human agency is overfishing, which, by definition, is caused by human exploitation of marine resources such that the rate of reproduction is overtaken by the rate of capture. Human exploitation of marine fisheries has a long history, with effects occurring from the earliest contact (Jackson et al. 2001). In some cases, the decline of a fishery is affected by changing environmental conditions, so effects from exploitation can be confounded with those from natural climate cycles or from climate change, which also has an anthropogenic cause. But in many cases, variance can be appropriately apportioned and the effects of a fishery's decline can be adequately ascribed to human activity. However, other calamities are not so easily ascribed to human activity.

Equivocal evidence: Harmful algal blooms. It is tempting to assume that all harmful algal blooms (HABs) are caused only by human activities, such as changes to the delivery of both the quantity and the ratio of nutrients available to marine systems (Nixon 1995). In particular, excess nitrogen and phosphorus in reference to silica favors the growth and proliferation of nonsiliceous phytoplankton, most often flagellates (Van Dolah 2000). Reduced nutrient inputs have, therefore, proven successful in reducing HABs in some cases (Okaichi 1997, Bodeanu and Ruta 1998). However, the connections between anthropogenic eutrophication and HAB proliferation is more uncertain in some cases (Anderson et al. 2012), such as HAB occurrence in association with upwelling nutrient supplies (Anderson et al. 2008) or nutrient limitation rather than excess (Smayda 2008). Overall, a complex picture remains, with clear cases of some HABs being driven solely by human activities; some being driven by larger-scale forcings; and those that, at this point, cannot be cleanly associated with one cause or another.

Weak evidence: Jellyfish blooms. There has been abundant discussion on the possible drivers of the perceived global increase in jellyfish blooms, one of the calamities of the ocean (Jackson et al. 2001, 2008). The putative drivers include human activities, including global warming, eutrophication, overfishing, and coastal sprawl (Purcell 2012, Duarte et al. 2013). However, the role of these pressures should be considered hypothetical, because there has been no attempt of a rigorous attribution of either global or local jellyfish blooms to any of these anthropogenic drivers (Purcell 2012). Therefore, even if jellyfish populations were increasing globally, this trend cannot be, as yet, attributed to anthropogenic pressures with any confidence.

Evidence for spread to global scale

The putative drivers of ocean calamities, such as increased nutrient inputs, anthropogenic carbon dioxide (CO₂) increases, or overfishing, operate at global scales, and, therefore, problems in the ocean often spread from local cases to global domains. However, demonstrating such spread is constrained by observation bias, because most of the research effort is typically in the northern hemisphere and in developed nations (e.g., Anderson et al. 2012, Condon et al. 2013). Moreover, as the global intensity of marine research has increased, increased effort over time must result in an increased capacity to detect problems, which may be confounded, if it is not corrected for, with the proliferation from local to global scales expected from ocean calamities.

Strong evidence: Invasive species. Although the number of cases of invasive species appears to be increasing exponentially over time, there remain two important sources of bias that have not yet been adequately assessed: (1) The rate of detection has increased over time because of increased research effort, public interest, and improved tools, and some invasions are cryptic and have not yet been discovered (Ruiz et al. 2000). However, evidence that marine invasive species are increasing in number is robust. Seebens and colleagues (2013) modeled the potential for invasion using shipping traffic data and environmental parameters and found a remarkably good fit with field data. Their results provide strong support for a global distribution of marine invasive species and an increasing number of global invasions driven by increased trade over time across the oceans.

Equivocal evidence: Harmful algal blooms and hypoxia. Numerous studies have concluded that the global geographic extent and frequency of HABs have increased (e.g., Van Dolah 2000), which is reflected in maps showing an increase in occurrence over time (figure 1a). Importantly, these same studies highlighted that two causes of this increase might be the increased sampling effort (Van Dolah 2000) and increased detection with new analytical techniques (Anderson et al. 2012). Likewise, the number of coastal ecosystems affected by hypoxia has been reported to have increased exponentially since the 1960s (Diaz and Rosenberg 2008, Vaquer-Sunyer and Duarte 2008). However, the primary evidence from these reports is the cumulative increase of hypoxic zones reported in the literature (figure 1b; also see, e.g., figure S1 in Diaz and Rosenberg 2008, figure 1 in Vaquer-Sunyer and Duarte 2008). Unlike the HAB studies described above, the use of the increase over time in areas reported to be hypoxic to argue for a global spread of hypoxia did not provide evidence for the degree to which the reported increase may reflect both an increase in frequency of occurrence and an increased monitoring effort. Importantly, we do not deny that the geographic extent of coastal ocean hypoxia might be expanding. Rather, the primary data used in these studies are not sufficient to evaluate the magnitude of the expansion, because no effort was made to separate the

increase in prevalence from the increased detection associated with increasing research effort.

Weak evidence: Global jellyfish blooms. The assertion that jellyfish blooms are increasing globally is often found in lists describing anthropogenic ocean calamities (Jackson 2001, 2008). However, no attempts at testing or quantifying the global nature of the increase in jellyfish blooms were attempted until 2012, so the perception of a global rise was driven by extrapolating from only a few cases (Condon et al. 2012). Since then, two analyses have been performed—one an analysis based on a compilation of scientific and media reports and perceptions of scientific experts and fishers (Bortz et al. 2012) and the other a more formal analysis based on a compilation of long-term records of changes in jellyfish abundance (Condon et al. 2013). Both sets of researchers concluded that jellyfish abundance had risen significantly in about 28% (Bortz et al. 2013) to 30% (Condon et al. 2013) of the regions examined, but the quantitative analysis of Condon and colleagues (2013) revealed that these increases were modest and that jellyfish populations undergo large, worldwide oscillations with an approximate 20-year periodicity, which included a rising phase during the 1990s that contributed to the perception of a global increase in jellyfish abundance (figure 1c). Therefore, evidence for a global rise in jellyfish blooms is weak at best, and, therefore, this syndrome should be either removed from the list of anthropogenic calamities that affects the ocean or, at the very least, put on hold until current caveats are dissipated.

Evidence of severe disruption to marine social-ecological systems

Concern over the deterioration of the oceans stems from the dependence of society on healthy oceans, which implies that ocean calamities are associated with severe impacts on society.

Strong evidence: The depletion of fish stocks. Overfishing can proceed undetected when we are unaware of the magnitude of the prior loss, a phenomenon known as the *shifting baseline syndrome* (Pauly 1995). However, all too often, the consequences of overfishing are obvious and insidious. The overexploitation of herbivores in many places in the Caribbean Sea resulted not only in fisheries collapse but also in a phase shift in the benthos from coral-dominated to seaweed-dominated ecosystems after the last remaining herbivore, *Diadema antillarum*, suffered a more than 90% reduction due to a pathogen in 1982–1983 (Hughes 1994). In the United States and Canada, centuries of intense fishing have resulted in the loss of most apex predators in the Gulf of Maine, leaving a highly simplified food chain in the form of a monoculture of the American lobster (*Homarus americanus*; Steneck et al. 2011). Any dramatic decline in this fishery would have enormous social and economic consequences for the communities that rely on this fishery, which is over 80% of the value of Maine's fish and seafood landings.

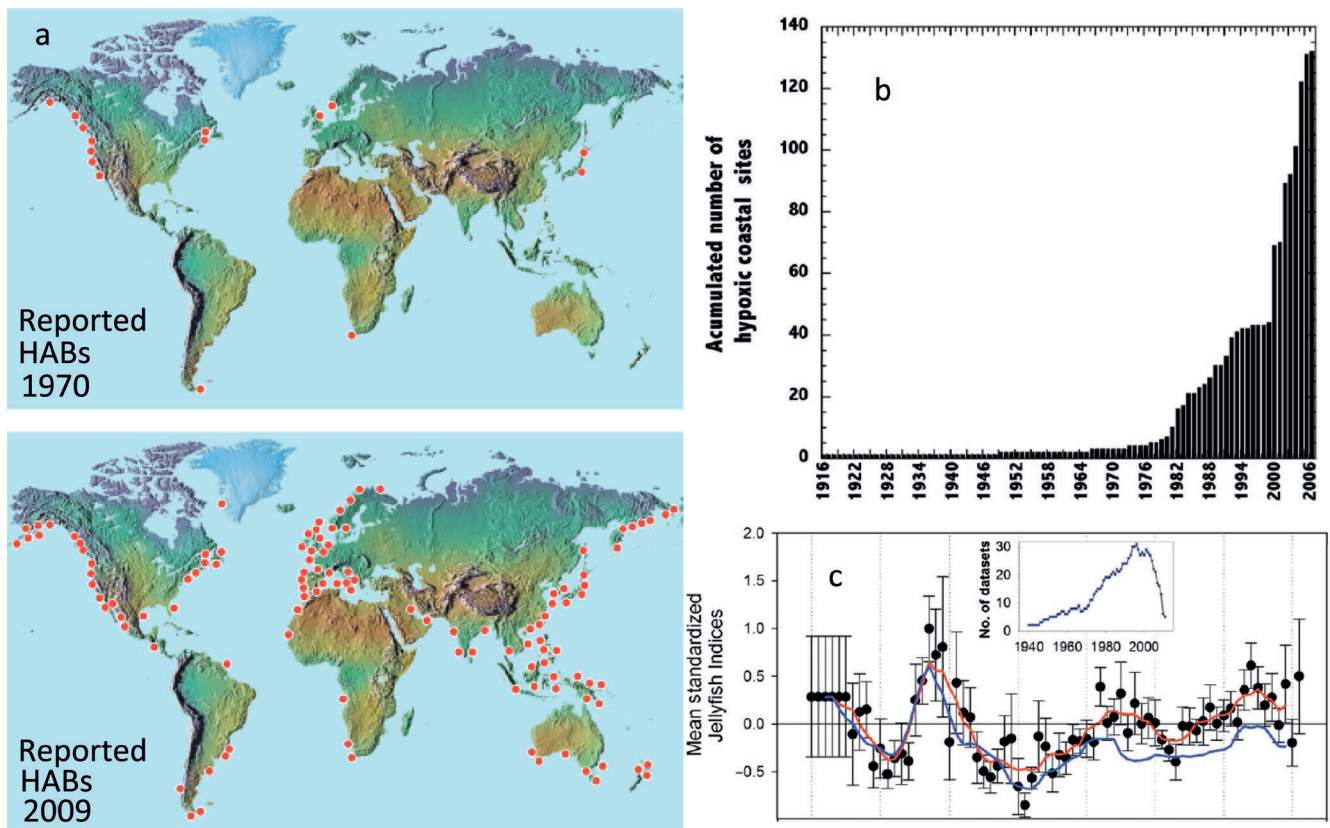


Figure 1. (a) Maps of reported harmful algal blooms (HABs) over time used to argue for a global spread of HABs. Source: Reprinted with permission from Anderson and colleagues (2012). (b) The trend over time of the number of coastal sites reported to experience severe hypoxia used to argue for a global increase in the occurrence of hypoxia. Source: Reprinted with permission from Vaquer-Sunyer and Duarte (2008). (c) The time course of the average standardized jellyfish index, which summarizes the changes in abundance across locations in the ocean for which long-term records are available. Source: Reprinted with permission from Condon and colleagues (2013). Abbreviation: no., number.

But in many cases, human exploitation has already resulted in a severe loss of marine resources, which has resulted in a reduction in food security, undernourishment, and poverty traps (Cinner 2011).

Equivocal evidence: Invasive species. Introduced (nonnative) species have been documented to have both negligible to severe impacts on marine ecosystems. In a review of the global impacts of nonnative species, Molnar and colleagues (2008) concluded that approximately half of marine nonnative species have relatively low levels of impacts on ecosystems. This is not to say that some species did not have or will not have large impacts on ecosystems (e.g., the oyster *Crassostrea gigas*, which was introduced to Europe for aquaculture), or economies (e.g., Asian clams in the nuclear power industry) or that control measures that reduce the likelihood of nonnative species' arrival (e.g., ballast water controls) should not be vigorously pursued. Rather, although the evidence of impacts is local, there is, as yet, no clear evidence of a widespread or global disruption from nonnative species to marine social systems. In nonmarine ecosystems,

the impact of nonnative species can also be equivocal, with severe ecological and economic impacts for some species (e.g., avian malaria, zebra mussels) but few impacts for others. The equivocality of the evidence may partly rise because views of whether nonnative species are good or bad depends on one's perspective (Davis et al. 2011), many impacts may not yet be detected (Simerloff et al. 2011), and there are multiple pathways for invasive species to influence ecosystem processes (Ehrenfeld 2010). Finally, the impacts of invasive species on marine ecosystems may differ in fundamental ways from those in terrestrial ecosystems (Ehrenfeld 2010). These differences may account for the lack of evidence of a widespread or global-scale disruption of ecosystem goods and services by invasive species, because marine communities may be better adapted to cope with high species turnover than are those in terrestrial systems. This suggestion needs to be tested.

Weak evidence: The decline of calcifiers due to ocean acidification. Ocean acidification by anthropogenic increases in CO_2 , the decline in seawater pH, and the availability of the

carbonate ion associated with the dissolution of excess CO₂ emitted into the atmosphere through human activities have emerged as powerful ocean calamities argued to compromise the future of calcifying organisms (Orr et al. 2005, Doney et al. 2009). The concerns are particularly important for calcifying organisms' building aragonite-based carbonate minerals, which reach undersaturation at higher pH levels in seawater. In particular, those in polar regions, which are currently closest to reaching undersaturation (Orr et al. 2005), are believed to be at greatest risk.

The realized decline in pH attributable to ocean acidification is about 0.1 unit, compared with the 0.3 to 0.4 units expected by the end of this century, when experimental assessments indicate that ocean acidification is likely to reach levels sufficient to significantly affect marine calcifiers (Doney et al. 2009). Moreover, there are significant uncertainties in the severity of the decline of marine calcifiers due to ocean acidification even at the end of the century, as ocean-acidification experiments are considered to provide worst-case scenarios, because a range of mechanisms, including adaptation, evolution, facilitative interactions in the ecosystem (Hendriks et al. 2010), and physiological mechanisms to up-regulate pH (McCulloch et al. 2012) may buffer the impacts and cause differential responses among species (Pandolfi et al. 2011).

However, there have been a few claims for already realized impacts of ocean acidification on calcifiers, such as a decline in the number of oysters on the West Coast of North America (Barton et al. 2012) and in Chesapeake Bay (Waldbusser et al. 2011). However, the link between these declines and ocean acidification through anthropogenic CO₂ is unclear. Corrosive waters affecting oysters in hatcheries along the Oregon coast were associated with upwelling (Barton et al. 2012), not anthropogenic CO₂. The decline in pH affecting oysters in Chesapeake Bay (Waldbusser et al. 2011) was not attributable to anthropogenic CO₂ but was likely attributable to excess respiration associated with eutrophication. Therefore, there is, as yet, no robust evidence for realized severe disruptions of marine socioecological links from ocean acidification to anthropogenic CO₂, and there are significant uncertainties regarding the level of pH change that would prompt such impacts.

Perpetuating the perception of calamities

The discussion above provides examples of how assessing the calamities in terms of the three criteria that they must meet may reveal that some of the calamities typically included in lists of the problems of the ocean may not be substantiated, and, whereas some, such as the depletion of fish stocks, are strongly supported by evidence, the evidence for some others may be equivocal or weak, which suggests that a formal auditing of ocean calamities is necessary.

However, once hypothetical problems have risen to the status of calamities in the literature, they seem to become self-perpetuating. Indeed, the marine research community seems much better endowed with the capacity to add new

calamities to the list than they are to remove them following critical scrutiny. As an example, the newest calamity extends the problem of the expansion of coastal hypoxia to a concept of global ocean deoxygenation (Keeling et al. 2010). The possible explanation that the list of calamities only experiences growth because all calamities are real is inconsistent with the examples provided above that some of them may not withstand close scrutiny. The alternative explanation is that there are flaws in the processes in place to sanction scientific evidence, such as organized skepticism, that need to be addressed to help weed out robust from weak cases for ocean calamities.

We argue that there are mechanisms, embedded both within the social dynamics of the research process and external to the research community, that tend to perpetuate the perception of the occurrence of ocean calamities, even in cases in which the evidence for these is equivocal or weak. The suite of mechanisms internal to the scientific processes that may operate to perpetuate the perception of the occurrence of ocean calamities includes components of the research process, such as observation and falsification bias; components in the publication process, such as publication bias; and components in the use of the literature, such as citation bias and miscitation; as well as other biases, such as confirmatory research and theory tenacity.

Many apparent trends in nature are based on a significant relationship between the frequency of a variable or event and a spatial or temporal gradient. Observation bias occurs when an apparent trend in frequency of an event or variable is correlated with sampling intensity (e.g., the number of observations). When the potential existence of a calamity is first recognized, the tendency is for an increasing number of observers to verify its existence or to map its geographical spread or increase over time. This increase in sampling intensity needs to be factored into any evaluation of spatial and temporal trends in calamity occurrence data. If it is not, observer bias can inflate our understanding of the true magnitude of an increase or a decrease in the parameter of interest. For example, on the basis of a survey of the scientific literature, Oliver and colleagues (2009) identified four global coral bleaching events (1983, 1987, 1998, and 2005) when the bleaching frequency and intensity dramatically affected a substantial number of countries. However, the number of bleaching records has apparently increased during the past three decades, which has confounded efforts to separate changes in bleaching frequency from changes in reporting (Oliver et al. 2009). Therefore, despite the strong mechanistic or physiological basis for a role of warming in coral bleaching and coral growth, a robust demonstration of a direct causal link between global warming and global coral bleaching over decadal time scales has not yet been produced.

Perceived calamities may also be perpetuated through miscitations and citation biases. The accuracy of citation practices is of fundamental importance for knowledge to be passed on free of distortion. However, citation practices may be prone to considerable errors of accuracy and bias

(Harzing 2002, Todd et al. 2010). Miscitations and citation errors have also been identified as a vehicle for the propagation of error, misconceptions, and unsupported beliefs (Harzing 2002). Citation errors include invalid or unsupported citations; ambiguous citations that take a particular interpretation of evidence presented elsewhere; and empty citations, which refers to citations of secondary sources that did not, themselves, provide evidence in support of the assertion made (Todd et al. 2010). In particular, Todd and colleagues (2010) reported high rates of miscitation in the marine biology literature, with only 75.8% of citations clearly supporting the assertions made. This assessment refers to miscitations of past research, but citation biases can also derive from selective citations. Selective citations are described by authors' tendencies to report the evidence that corresponds with their preconceived ideas while discarding contradictory results. Unfortunately, we are not aware of any study in which selective citation has been systematically examined in marine ecology or biology. Publication bias may also play a role, because papers in which negative results are reported, in the context of failing to provide support for the existence of accepted calamities, may be more difficult to publish than positive results, which confirm the existence of the calamities. Although publication bias has been assessed regularly in the medical sciences, the awareness of publication bias in ecological studies is relatively recent, generally in association with its possible impacts on the outcome of meta-analyses (Rosenberg and Rothstein 2013).

The rise of ocean calamities has generated a worldview in which a host of ecological syndromes resulting from human-driven pressures is leading to the collapse of the ocean. The addition of new problems, such as new invasive species, ocean acidification and deoxygenation, or the perils from plastic pollution, to the litany validates and strengthens this worldview, forming a more compelling case for action to reduce human pressures. Although reducing human pressures on the marine environment is a positive outcome, this may provide a motivation to inadvertently—or, in worst cases, deliberately—fall into the *white hat bias*, defined as “bias leading to distortion of information in the service of what may be perceived to be righteous ends” (Cope and Allison 2009, p. 84). Clearly, no righteous end justifies the perpetuation of scientific bias.

The perpetuation of ocean calamities in cases of equivocal or weak support suggests that scientific studies of marine calamities typically provide confirmatory evidence for their occurrence. But this may also be prone to bias, which is termed *confirmatory bias* in the psychological literature (Klayman and Ha 1987) for a number of reasons. Confirmatory bias describes our tendency to test cases that have the best chance of confirming our beliefs and also to test cases that are expected (or known) to have the property of interest (e.g., in this case, the presence of a calamity) rather than those that are known to lack that property (Klayman and Ha 1987). Confirmatory bias may be particularly strong when academic competition is strong

(Fanelli 2010). In a study of research papers across all disciplines in the United States, the papers were more likely to support a tested hypothesis if their corresponding authors were working in states that, according to National Science Foundation data, produced more academic papers per capita, which suggests that competitive academic environments increase not only scientists' productivity but also their bias (Fanelli 2010).

Theory tenacity, or the commitment to basic assumptions even in the face of contradictory evidence, can also impede progress in assessing the basis for ocean calamities. Loehle (1987, p. 405) observed that “theory tenacity tends to make opposing camps dig their trenches deeper.” In addition, long delays in publishing can also result in some early ideas' becoming law just by virtue of their longevity, particularly if the researcher is prominent (Loehle 1987). Both confirmatory bias and theory tenacity can be positive forces, keeping ideas alive when only partial support for a hypothesis exists, but confirmatory bias and theory tenacity can be particularly important in slowing progress toward a rigorous assessment of ocean calamities (Loehle 1987).

A lack of sufficient data to robustly test ocean calamities arguably plays a significant role in their perpetuation. For instance, the perception that jellyfish blooms were increasing globally emerged prior to the availability of sufficient data to attempt to falsify this hypothesis (Condon et al. 2011) and played an important role in allowing this perception to be carried on until efforts were made to test the hypothesis with robust data (Condon et al. 2013). In contrast, the widespread and sustained efforts to assess the status of fish stocks have allowed overfishing to be consolidated as a robust, well-documented calamity.

All of these sources of bias within the scientific community act to essentially reverse the burden of proof, such that it becomes incumbent on the scientific community to disprove the originally unsubstantiated calamity, because further work on the nature of the calamity is already based on the assumption that it is truly manifest of the worldview that the ocean is in a state of near collapse. Indeed, Dunlap and Van Liere (2008) discussed the emergence of a worldview that they termed the *new environmental paradigm*, which has gained momentum among academics and scholars focused on the insults to the environment associated with sustained growth in human appropriation of resources. Society is, therefore, eager to consume news that confirms this worldview, providing an incentive for the media to report on ocean calamities, often with overly exaggerated headlines (table 1). In turn, the appetite of the media for particular headlines can influence the contents of top scientific journals. For instance, following a series of high-profile publications on overfishing and the collapse of the oceans, Hilborn (2006) became alarmed at the existence of what he termed a *faith-based fisheries movement* based on a faith-based acceptance of ideas and a search for data that support these ideas, rather than critical and skeptical analysis of the evidence. Hilborn (2006, p. 554) asserted that “the two journals

with the highest profile, *Science* and *Nature*, clearly publish articles on fisheries not for their scientific merit, but for their publicity value... and their potential newsworthiness." This issue continues to resonate in the scientific community, as, in a recent commentary in *The Guardian*, Nobel Laureate Randy Schekman (2013) asserted that the incentives offered by top journals—namely, *Science*, *Nature*, and *Cell*—can act to distort science. Schekman stated, "The prevailing structures of personal reputation and career advancement mean the biggest rewards often follow the flashiest work, not the best." Alternatively, it may be that the perception by the scientific community that top journals select for articles containing newsworthy messages drives a selective submission of articles on ocean calamities and collapse, which results in high academic rewards for authors of these type of papers in these journals.

The arguments above indicate that biases do not arise solely from within the scientific community but that biases within the media can further skew scientific information, because the mass media plays a pivotal role in guiding public opinion on scientific matters. This may be simply because the priorities of good news stories differ from those of science. Newsworthy items favor stories that are completely new, that have a big impact on society, that contradict popular belief, or that are controversial or scandalous (Cribb and Sari 2010). Consequently, null results or incremental contributions to scientific understanding are generally omitted from the media. We contend that this can create a public perception that the environmental situation is irreconcilable.

The loop of external drivers of bias does not end with the media, because, in democratic societies, the public is responsible for electing political representatives. Consequently, public opinion, which is highly influenced by the mass media, is crucial in determining political agendas. Political agendas, in turn, affect funding priorities and decisions. The outcomes of funding competitions strongly affect research agendas, thereby creating potential for a positive feedback loop that reinforces and perpetuates scientific bias.

Best practices in assessing ocean calamities

It can be argued that the litany of anthropogenic ocean calamities discussed here has been raised to the status of a paradigm embraced by a significant fraction of the research, management, and policy communities, as well as the public. Khun (1962) described how paradigms arise and identified some of the mechanisms that are used collectively to defend them, such as publication bias, until cumulative contrary evidence leads to the replacement of the paradigm. Merton (1973) proposed a set of admittedly idealistic norms of science that are mechanisms of informal social control for the academic profession. These include *universalism*, the idea that the validity or value of any scientific statement is independent of the characteristics or qualities of their protagonists; *communalism*, which means that the findings of research must be made public; *disinterestedness*, which means that research should be motivated by the purpose of

advancing knowledge not for gaining recognition, prestige, or financial rewards; and *organized skepticism*, which has already been discussed. Furthermore, Platt (1964) argued for the systematic application of an approach of strong inference, involving the formulation of alternative testable hypotheses and the design and execution of crucial tests with the capacity to either falsify or confirm them, in order to ensure solid progress in science.

The previous discussion of the forces that enter into play to perpetuate the perception of anthropogenic ocean calamities identifies a failure of current processes to fully comply with Merton's (1973) norms of science. In order to progress, challenges to these calamities necessitate a strong inference approach. Foremost, a failure to support organized skepticism, which must be underpinned by a fair but rigorous peer-review system, is largely responsible for the perpetuation of the perception of some of the calamities, in cases in which these may be unsupported by robust inference or observations. Organized skepticism requires that the scientific community concerned with problems in the marine ecosystem undertake a rigorous and systematic audit of ocean calamities, with the aim of assessing their generality, severity, and immediacy. Such an audit of ocean calamities would involve a large contingent of scientists coordinated by a global program set to assess ocean health. This also requires funding to collect sufficient data and that they be made openly available, because only 1% of ecological data are currently available after the publication of the results (Reichman et al. 2011). The analysis illustrated here provides a model of the elements involved in such an exercise. However, disinterest is also compromised by the set of rewards that enter into play for research that identifies or supports calamities, because this is most likely to be published in top journals that seek media impact from their content or to receive public funding.

For some of the ocean calamities, we may be at a very early stage of discovery. However, even for such cases, data reporting should follow robust practices and should avoid common pitfalls, such as a failure to correct for observation effort when reporting the increase in a perceived problem over time (e.g., figure 1). Concerted efforts to develop robust theory, adopting best practices in reporting data, and combatting confirmatory bias and theory tenacity in the literature will aid in understanding the processes that give rise to what are perceived as ocean calamities. Most important, we should remain skeptical and, in exerting organized skepticism, will ensure a depiction of global ocean problems devoid of unsupported claims and statements, which will help organize management and policy options targeting the most pressing problems to limit the deterioration and to provide effective stewardship of the oceans. We conclude that a robust audit of ocean calamities, probing into each of them much deeper than the few examples provided here, is imperative to weeding out the equivocal or unsupported calamities, which will confer hope to society that the oceans may not be entirely in a state of near collapse and which will

provide confidence that the efforts by managers and policy-makers targeting the most pressing issues may still deliver a healthier ocean for the future.

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