Resolving Disputes over Ocean Calamities

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The debate has reemerged about the prevalence of "ocean calamities" (Duarte et al. 2015a, 2015b, Jacquet et al. 2015)—defined by Duarte and colleagues (2015a) as human-caused "disruptive changes to ocean ecosystems that have profound impacts and that are widespread and global in scope." Two issues form the debate's core: First, how should we interpret circumstantial evidence in data-poor situations? Second, what is the role of the precautionary approach in ocean science and policy? We argue that prior information—even when circumstantial—should not be ignored and that Bayes' theorem guides its incorporation. We agree with Duarte and colleagues (2015b) that precautionary approaches belong firmly in the realm of policy, although they are informed by science. Finally, we suggest abandoning "ocean calamities" as a scientific concept, because it entangles science and policy questions in a way that could introduce sociopolitical biases to scientific questions.

The ocean-calamities debate

Duarte and colleagues (2015a, 2015b) argue that the evidence for many claimed *ocean calamities* (e.g., harmful algal blooms and jellyfish blooms) is equivocal, at best. They also suggest (as others have) that incentives for sensationalism could be injecting bias into science and reporting—violating the principles of objective, evidence-driven analysis. In contrast, Jacquet and colleagues (2015) argue that enough evidence of severe human impacts on marine ecosystems already exists to justify broad concern and sweeping action, even if this evidence is not as strong as we would like it to be. In waiting to satisfy higher standards of proof, we could miss opportunities to prevent irreversible damage. This viewpoint, too, has been expressed before (e.g., Pauly 2013). For a range of issues, there are specific disagreements over the strengths and types of existing evidence, the strengths and directions of sociopolitical biases driven by scientific and journalistic incentives, and how precautionary approaches in addressing ocean calamities should be applied.

What should our priors be?

Potential ocean calamities are one of many contentious issues beset by data limitations. In such situations, our conclusions and preferred policies may hinge largely on our priors—our beliefs based on prior information. The formal apparatus for incorporating priors into scientific inquiry is provided by Bayes' theorem. Indeed, a cardinal rule of Bayesian inference is that we should use relevant prior information when it is available to us.

In that spirit, it should be recognized that having prior beliefs that inform our conclusions—even when based on circumstantial evidence—is perfectly acceptable from a scientific perspective, so long as we repeatedly update these beliefs in accordance with new evidence. The beauty of Bayes' theorem resides in how it achieves this updating procedure. In short, our prior beliefs are weighted against the strength of any new evidence that we have collected. If the new evidence is not very precise or compelling, then our prior conclusion will tend to dominate the final (i.e., posterior) conclusion and vice versa. Therefore, it is important to acknowledge what our priors *are* so that others may better understand the way in which they have shaped our conclusions.

How different participants choose priors may be an unstated point of contention in the ocean-calamities debate. Taking Duarte and colleagues (2015a, 2015b) as a reference point, it would seem that they are implicitly assuming so-called *noninformative priors* in arriving at their relatively sanguine positions on some cases—*noninformative* in the sense that they place minimal restrictions and expectations on their analysis beyond those provided by the (limited) data. There is nothing wrong with this approach in principle, but we believe that it is important to explicitly acknowledge the role of such noninformative priors and carefully consider whether useful information is being omitted by not considering other priors. Absent these caveats and considerations, the suggestion that this approach is uniquely objective is misleading.

Consider harmful algal blooms (HABs), for instance. Documented HAB cases have increased dramatically since the 1970s (see figure 2 in Anderson et al. 2012). However, the incidental magnitude of this increase is unclear because of coincident increases in sampling frequency and improvements in detection equipment (Anderson et al. 2012, Duarte et al. 2015a). Similarly, there is clear evidence of humans causing many cases of HABs (often via nutrient pollution), but there is more uncertainty in other cases because of coincident natural causes, such as productive upwellings. On this basis, Duarte and colleagues (2015a) claim at best "equivocal" evidence for HABs being sufficiently human induced and global in scale to warrant calamity status.

Nonetheless, circumstantial evidence might justify relatively pessimistic priors regarding the increasing rate of HAB incidence, their global extent, and human actions as their primary cause. For example, a prior on HAB incidence could be based on well-documented increasing trends in human nutrient pollution and the relationships between nutrient inputs and algal growth. Similarly, priors in data-poor or newly monitored areas could be based on the known local trends in comparable places where HAB drivers have been established over a longer period of time. Such priors, when combined with the available evidence, might yield high posterior probabilities of HABs being a global-scale, human-caused threat to ocean health.

A precautionary approach versus the presumption of innocence

Some have rightly pointed out that human sociology, psychology, and career incentives can influence how we interpret and report scientific evidence. These discussions have focused largely on the role of incentives to publish flashy, newsworthy results—both categories occupied by numerous ocean calamities.

We suspect that the immediate policy relevance of scientific conclusions about ocean calamities could also sociopolitically affect the scientific assessment process in either direction. Calamities are often discussed in a binary sense (there either is or is not a calamity; e.g., Duarte et al. 2015a), and conservation science typically takes as a given that we should enact policies to remediate any identified ocean calamities (e.g., Jackson et al. 2001). This type of discourse effectively entangles the science question (how severe is the disturbance, and are we causing it?) with the policy question (should we be changing our activities to mitigate the disturbance?).

Courts in Western justice systems provide a useful analogy. They similarly make a binary determination—guilt or innocence—and if a defendant is found guilty, punishment is automatic. For this reason, courts presume defendants' innocence, set high standards of proof, and strictly limit the use of prior circumstantial evidence (see, e.g., US Federal Rules of Evidence, Rule 404b; *www.uscourts.gov/file/rules-evidence*). The rationale is not scientific, per se, but rather aims to prevent type-I errors—wrongly punishing the innocent, which is often considered more injurious than wrongly acquitting the guilty (i.e., type-II errors). However, attempting to frame the determination of guilt in criminal proceedings as a purely objective task would ignore the inherent sociopolitical bias in favor of defendants.

Similarly for ocean calamities, excluding relevant information in forming null or optimistic priors or requiring a high standard of proof before declaring the existence of such calamities could be interpreted as natural inclinations to avoid type I errors. We may intrinsically wish to minimize the risk of unjustly punishing polluters, fishers, and other human groups linked to these problems. However, this would be no more objective than assigning lower standards of proof or applying overly pessimistic priors in identifying calamities because of a precautionary approach to policy.

Of course, appeals to a precautionary policy approach are also common in situations of deep structural uncertainty—situations in which we are ignorant about the very nature of the uncertainty. Bayesian inference must actually be treated with caution in such cases, because it effectively defines away this ignorance by fully characterizing probabilities in terms of subjective beliefs (e.g., see Millner et al. 2013).

There are arguments to be made for approaches to ocean policy that are either precautionary or presume the innocence of certain sectors of society. However, we should be careful to keep these approaches separate from the science. Otherwise, both optimistic and pessimistic biases are possible. If the concept of ocean calamities requires a binary definition that restricts the separability of science and policy questions, the concept should be abandoned in favor of more nuanced approaches to communicating scientific results.

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