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Bleached! The Catastrophe Management of Corals

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Managing Coral Catastrophe

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Inheritance is never a given; it is always a task. It remains before us.
---Jacque Derrida, *Specters of Marx* (2012)

1 Introduction

In the last couple decades, tropical corals have emerged as both a sign and a measure of the imminent catastrophic future of life on earth and, as such, have become the focus of intense conservation management. *Bleached!* explores this management of the corals' ecological catastrophe to come. The article links ecological anticipation with Big Data and statistics, affording insights into particular scientific practices of seeing and calculation.

The article starts by describing the unique life of corals and by considering the interrelations between coral bleaching and death. I discuss in particular the predicted mass extinction of coral species in the decades to come and their dramatic decline in real-time, especially in the Great Barrier Reef in summer 2016. Next, I examine the importance of calculability in catastrophe management and the coral scientists' preoccupation with classifying, counting, and seeing in their attempt to comprehensibly monitor corals and anticipate their decline. I explore the United States' federal Coral Reef Watch project, which utilizes sea surface temperatures (SSTs) and other "products," in the language of the project, in order to "see"—and foresee—major bleaching events. Algorithmic models and elaborate temporal analyses are central to this governmental project of "knowing bleaching."

What happens after such bleaching events are foreseen is the topic of my next exploration, which highlights the emergence of yet *more* monitoring as the central coral conservation "action" in the face of the looming catastrophe. I also briefly discuss other actions—specifically, coral restoration projects and their configuration within broader attempts at enhancing coral resilience. I point out that the "resilience" concept is of growing importance in the ecological community at large and in the world of coral management in particular. Since it underlines unpredictability and nonlinearity, resilience seems to fly in the face of any anticipatory action, instead providing a scientific justification for forms of inaction. Finally, *Bleached!* talks about the heated debates among coral scientists about whether to focus present actions on "buying time" for corals, or whether the only way to prevent or limit imminent coral catastrophe is to deal directly with the elephant in the room: the global regulation of climate change.

In this instance at least, scientific knowledge is *not* power. Here the distinction between *anticipatory action* (namely: actions performed so as to alter the course of events and thus the possible future) and *actions which anticipate* (merely improving data sets and producing more accurate algorithms) becomes important. As it turns out, although environmental scientists warn, monitor, and produce predictions, these actions which anticipate do not end up producing much anticipatory regulation at all.

Quite the contrary, the real political story here seems to lie in the ways in which scientists' knowledge is neutralized and prevented from having political effects, such that it does not lead to anticipatory action to restore ecological order. In this case: bleaching does not lead to retrenchment of fossil fuel mining/combustion/licenses to pollute, but rather to more actions that anticipate. As one of the prominent coral scientists I interviewed for this project put it: current conservation efforts are akin to reorganizing the chairs on the Titanic, rather than to changing the ship's deadly course.

Bleached! draws on in-depth interviews and participatory observations with ten or so coral scientists and managers, situated in the United States, Australia, and Israel. These interviews and observations are part of my larger project that interrogates the relationship between coral life and law, for which I have already interviewed 70 prominent coral scientists based as part of an collaborative ethnography methodology. The interviews in this particular segment of the project were conducted through 2015 and are supplemented with reports and news items from this period and beyond. In "Breathing Meditations" (forthcoming, 2017), I further discuss my methodological stance in my coral work, which I refer to as "immersive ethnography."

2 Corals and Bleaching: An Overview

Coral is a generic name for more than 2,500 species of colonial invertebrates, some of whom excrete a calcium carbonate skeleton. Living within the ocean, tropical coral reefs are among the most diverse marine ecosystems on earth (NOAA, n.d.a) and provide shelter to thousands of animal, plant, and other species. Coral scientists warn that at present, corals are facing multiple stresses caused by pollution, overfishing, ocean acidification, and climate change. The scientists contend that corals act as an "early warning system" in that their alarming status represents the poor health of the oceans. If coral reefs disappear, warn the scientists, other marine life will soon follow (Vernon, 2010).

Scientists refer to the reef-building coral as a "holobiont," a holistic entity composed of an animal "host," algal symbionts (*Symbiodinium*), and bacterial microbes. The *Symbiodinium* algae is the primary producer of reefs in that they convert sunlight to biomass. The symbiosis between algae and coral is thus the foundation of the reef food chain or "trophic pyramid." Temperature increases can cause the coral holobiont to lose its pigmented symbionts and turn white, a process referred to as "bleaching" (Figure 1). As a result, the coral often cannot build its skeleton fast enough to stay ahead of erosion and will likely die (Douglas, 2003).

Place Figure 1 here: Half bleached coral, Culebra, Puerto Rico. Photo by author, January 2015.

In *The Reef: A Passionate History* (2014), historian Iain McCalman documents the history of the Great Barrier Reef. He also describes the global history of bleaching, pointing out that in this relatively new phenomenon was first recorded in the global mass bleaching of 1981-2. The next major mass bleaching occurred in 1997-8, killing reefs in more than 50 countries. "On the Great Barrier Reef the bleaching coincided with the warmest sea temperatures ever recorded," he continues, "Catastrophic global warming has arrived" (p. 270). In McCalman's description:

> When corals are exposed to temperatures that are two or three degrees higher than their evolved maximum of eighty-eight degrees Fahrenheit, along with increased levels of sunlight, it's lethal. The powerhouse algae that live in the corals' tissues, providing their color and food through photosynthesis, begin to pump out oxygen at levels toxic to their polyp hosts. The corals must expel their symbiotic life supports or die. Row upon row of stark white skeletons are the result (McCalman 2014, p. 271).

McCalman ends his book on a somber note: "It is a symbiosis which […] has survived for some 240 million years, but which will split should those harsh forces so dictate. If anything can inspire us to prevent this, it's that very partnership itself, between two of the tiniest and most fragile creatures in the sea" (ibid., p. 281).

Place Figure 2 here: Schema of coral bleaching. Public domain, courtesy of NOAA.

The ghostly images of bleaching are the face of mass death in tropical corals. Scientists estimate that by the 2030s, more than 90 percent of the world's reefs will be threatened by local human activities, warming, and acidification, with nearly 60 percent facing high, very high, or critical threat levels (Burke et al., 2011). In October 15, 2015, the United States' National Oceanic and Atmospheric Administration (NOAA) announced the third major global bleaching event in history. From NOAA's website: "a global coral bleaching event is underway. The event is expected to impact approximately 38 percent of the world's coral reefs by the end of this year and kill over 12,000 square kilometers of reefs" (Global Coral Bleaching, 2015). Coral reefs are dying en mass, scientists from across the globe agree (Bellwood et al., 2004; Hoegh-Guldberg, 1999). In her book *Sea Change,* marine biologist and former chief scientist of NOAA Sylvia Earle writes: "The living ocean drives planetary chemistry, governs climate and weather, and otherwise provides the cornerstone of the life-support system for all creatures on our planet…. If the sea is sick, we'll feel it. If it dies, we die. Our future and the state of the oceans are one" (1995, p. xii). Elizabeth Kolbert writes about mass extinction more generally that: "If extinction is a morbid topic, mass extinction is, well, massively so" (Kolbert, 2014, p. 3). Finally, according to Jeremy Walker (2015), mass extinction can be thought of as the end of evolution, an "anti-Genesis." The mass extinction of corals will further result in a mass extinction of all other reef-dependent species. It is estimated that over 25 percent of the world's fish biodiversity, and between nine and 12 percent of the world's total fisheries, are associated with coral reefs (Spalding et al., 2001).

Yet coral bleaching and death are not synonymous. Mark Eakin, director of the Coral Watch Program at NOAA, explains that the bleached coral could potentially recover, although a certain degree and period of bleaching, along with accumulated threats, will likely result in coral death. Mary Alice Coffroth, a coral scientist at the University at Buffalo, clarifies:

> When the tissue is gone—that's death. [But] the end of the symbiotic element doesn't necessarily entail death, although that is likely to be the case if [the bleaching] is complete and prolonged. We sampled [Florida corals] in May [2015] and they hadn't bleached; and then I went back down in the summer [2015] and they had bleached. […] Losing the symbionts is a very bad thing. It's traumatic (interview; see also Figures 3 and 4).

The distinction between bleached and dead has been subject to considerable calculations and has resulted, for example, in two separate categories in NOAA's coral monitoring system: "likely to bleach" and "likely to die."

The distinction between life and death in corals is complicated by an additional factor: the particular morphology of corals. Whereas those coral polyps who are identical in genetic terms are referred to by scientists as "ramets," the term "genets" refers to the clonal entity of similar ramets. So when one polyp dies, its genotype may still be alive elsewhere. Coffroth explains: "when you lose a coral [ramet], you've basically lost the space that the coral inhabited" (ibid.).

Place Figures 3 and 4 here: A pillar coral (*Dendrogyra cylindricus*) before (April 29, 2014) and after (September 17, 2014) bleaching, respectively. Middle Keys, Florida. Photo credit: Cindy Lewis.

3 Governing (Coral) Catastrophe

Many scientists consider corals a measure of planetary health through which they might anticipate the "forth-coming" catastrophe of global warming (and of ocean acidification). "Coral reefs may be warning us to pay closer attention" (Chadwick, 1999, p. 37). In his scholarship about the present anticipation of future catastrophe, Ben Anderson suggests that anticipatory action has been formalized and legitimized in response to a number of major threats to liberal-democratic life (2010, p. 779). The existing threats are depicted as sharing several common characteristics: they are potentially catastrophic—namely, each can irreversibly alter the conditions of life; the source of the disaster is somewhat vague; and the disaster is immanent: without some form of action "a threshold will be crossed and a disastrous future will come about" (ibid., p. 780).

Contra to Ulrich Beck's thesis regarding the "incalculability" of certain modern risks, Anderson argues that a range of practices have been deployed to render the future present (ibid., p. 783). The first practice he discusses, which is also the most relevant to coral conservation, is calculation. In this context, Anderson emphasizes the importance of numbers, "which are then visualized in forms of 'mechanical objectivity' such as tables, charts, and graphs." Next, he highlights the extensive use of catastrophe modeling, for example algorithmic models utilized in the insurance industry to predict and calculate loss by stochastic events (ibid., p. 784).

Such a preoccupation with calculation, numbers, and algorithms is highly evident in coral conservation, where levels of bleaching and rates of morbidity are harnessed into algorithmic models to predict death. This preoccupation also manifests in myriad managerial projects. One important project is the establishment of elaborate systems for monitoring and predicting bleaching events, which I will discuss shortly; another is an elaborate listing system that focuses on classifying species according to their predicted rate of extinction, or "endangerment."

In 2009, the Center for Biological Diversity petitioned NOAA to list as threatened under the Endangered Species Act (ESA) 83 corals species that were already identified as such by the IUCN Red List (Wolf, interview). On September 10, 2014, NOAA published a Final Rule that listed as threatened twenty of the petitioned coral species. The elkhorn and staghorn corals, which were already listed as threatened in 2006, retained their status as such (NOAA, 2015). I have written extensively on the biopolitics of listing species generally (2015; 2016), and about the challenges of listing corals in particular (forthcoming, 2017a), so I will not expand on this topic here. I would, however, like to highlight the preoccupation of coral listers' with calculations.

The regulatory decision to include corals on the threatened or endangered list can have considerable material effects. Tom Moore, marine biologist and director of NOAA's Restoration Center, tells me, for example, that if a coral species is not designated as threatened or endangered, there are currently no laws in place that prohibit killing them (interview). Once they are assigned such a status, however, their "take," which includes any form of change or harassment, is absolutely prohibited. To determine whether or not certain coral species are endangered, scientists are legally required to trace and quantify how many corals exist in the oceans and their rate of decline. Then they must predict whether such corals are likely to become extinct by 2100. If so, they are proclaimed endangered; if they are not currently endangered but are likely to become endangered in the near future, then they are designated as threatened.

4 Counting Coral

Counting the number of individuals, populations, and species is therefore critical for establishing and monitoring endangerment (Youatt, 2008). But counting corals is not an easy task. Indeed, corals pose significant challenges to traditional quantification methods that focus on individuals, populations, and species. Jennifer Moore, Program Manager for Coral Listing and Recovery of NOAA, briefly explains the problem of classifying coral at the level of the species:

> Really, the more we learn about coral taxonomy the more [we] realize it's very fluid, very plastic. There aren't the same hard boundaries between species that we see in other different organisms like vertebrates. It's called "reticulate processes": basically, where species split, come back together, split again, [and] come back together over evolutionary time. With corals, it's just not as clean (interview).

Max Janse of Burgers' Zoo in the Netherlands points to a related, more pragmatic, concern. In his words: "it's really difficult to know [which *Acropora* species it is] because they can change their morphology when growing. Even for good taxonomists, they have trouble knowing exactly what species it is" (interview).

Counting is also challenging because of definitions: how to count individuals when many coral species reproduce asexually and produce colonies of the same genotype (see above)? Margaret Miller, an ecologist at NOAA, explains that at "certain sites, we can go and sample all the colonies at a site, and it's all the same individual. Other reefs and other geographic locations, we can go and sample 50 to 100 colonies and they each represent a different genetic individual. It runs the entire spectrum" (interview). As a result, NOAA has come up with an average estimate of half to determine how many different species exist in an area. Miller explains: "On average, you have to sample two colonies to get an additional genetic individual."

The lack of knowledge about corals is mostly the result of the corals' oceanic existence, which renders them less visible to humans and thus to scientific knowledge regimes, especially in a historical context. Miller highlights to the lack of historical data about corals:

> The ESA requires you to make a determination about endangerment using the best available information. [But] we don't have good historical data; we don't know if there used to be more genetic individuals than there are now. So, in other words, we don't know if there's more clonal reproduction now that there used to be. We don't know any of that. All we have to go on is the few datasets that we have, the historical datasets, that are based on percent cover [and] abundance estimates. They show 90 percent decline maybe, at a couple of sites. So we're forced to use qualitative information to say, "Wow, yeah, it really looks like these species have declined a lot." . . . So we infer (ibid.).

The use of inference in lieu of quantitative data is perceived as a serious problem from the standpoint of traditional science, which likes to present itself as relying on observations rather than inferences. And yet, inference is the norm in the context of the corals' ecological management.

Even when monitored "near-real-time," rather than as part of a historical trajectory, coral monitoring is challenging. Jennifer Moore of NOAA participated in the mandatory biological assessment according to the Endangered Species Act. She describes the overall difficulties of regulating corals:

> Corals are generally very difficult. . . . The types of things people typically consider when they're looking at extinction risk, like generation time and productivity, are hard when you're talking about corals that can live hundreds of years, asexually reproduce but also sexually reproduce, and are dying at alarming rates. Trying to tease all of that out under a law written thinking about wolves and whales is a very challenging task (interview).

"We really diligently went species-by-species and tried to lay out everything we know about those species," she tells me about the coral assessment. "We tried to be consistent between species," she continues. "Our Final Rule document, in Word format, was over 1,000 pages long" (ibid.).

5 Coral Watch

"Coral reef watch NOAA: Satellite monitoring project in real time" is an example of actions performed in the project of anticipating the catastrophic event. This "real time" temporality, as its name implies, is rendered truer than others in that it can be seen at the same time in which the machine sees. Simultaneity is perceived to be a measure of truth and, as such, is more capable of transcending space.

The importance of simultaneity was highlighted recently in the media reports of the dramatic 2016 bleaching at the Great Barrier Reef. Terry Hughes, director of the ARC Center of Excellence for Coral Reef Studies at James Cook University in Townsville, Australia, is part of a team conducting aerial surveys of the reef to assess the extent of the bleaching. He was recorded saying: "I've spent seven days in the air on a light plane and in a helicopter, criss-crossing the whole barrier reef. By the end of Friday (15 April [2016]) when I've done my last flight, we'll have flown over about 900 individual reefs. We've scored every one for the severity of the bleaching" (*Scientific American*, 2016).

Here, sight and calculation occur through the naked, bird's eye view of the scientist, who estimates the degree of bleaching and distinguishes between dead and dying corals. Hughes explains: "Those corals that are lightly bleached will more than likely regain their normal colour in the next few months, and there won't be any significant mortality. . . . At the other end of the spectrum are corals that are snow white—they've been exposed to very high temperatures, and many of those corals will die" (ibid.; see also Figure 5).

Place Figure 5 here: Coral bleaching on the Great Barrier Reef shows up as white and yellow patches visible from aerial surveys. Credit: ARC Centre of Excellence for Coral Reef Studies/Terry Hughes.

Whereas the white coral skeletons of the dying-yet-not-dead category are visible for detection by plain eye from the air, the brownish algae soon smother dead corals, after which the reef's condition can only be determined by close-up inspection (ibid.) or by surface monitoring. Based on the naked-eye aerial assessment, alarming figures were produced that have been contributing to the aura of coral crisis and catastrophe. From the reputable journal *Science*: "mass bleaching has killed 35% of corals on the northern and central sections of the 2300-kilometer-long system. On 24 of the 84 reefs surveyed, 50% of the corals have perished, including specimens that were 50 to 100 years old" (*Science*, 2016).

In another recent attempt to "see" corals, scientists will be outfitting a NASA airplane to map the spectra of sunlight reflecting off reefs spread across the Pacific Ocean. This three-year, 15-million-dollar project directed by Coral Reef Airborne Laboratory (CORAL) project "will be the biggest and most detailed study yet of entire reefs, rather than just the small patches that scuba divers can reach. CORAL is part of a growing push to map reefs faster, and in more detail, than ever before. Marine scientists are putting new instruments onto planes, satellites and even drones to gain a broader perspective on how well corals are doing—or not (*Nature News*, 2016). After its surveys in Hawaii, Australia's Great Barrier Reef, the Mariana Islands and Palau, CORAL will have mapped about four percent of the world's reef area, hundreds of times more than previous scuba surveys (ibid.).

In 1989, the Coral Reef Watch (CRW) Program was instituted by the United States government during the first documented global bleaching event in 1989. The missions of CRW is "to use remote sensing and onsite tools for near real-time and long-term monitoring, modeling, and reporting of physical environmental conditions of coral reef ecosystems" (NOAA, n.d.b). CRW uses satellite data to inform marine park managers and scientists when corals may be at risk for bleaching. The reliance on climate monitoring satellites is not incidental. "If fisheries management stood for the relevance of ocean science in the early twentieth century," Stefan Helmreich writes, "climate monitoring plays that role now" (2009, p. 25). "In their barometric readings," Helmreich writes elsewhere, "reefs sound a warning signal from Gaia chastising humans for self-indulgent, shortsighted activities" (2016, p. 56).

In the mid-1990s, with the advent of the internet and other computational tools, then-director of CRW Alan Strong developed "satellite-derived sea surface temperature" (SST) climatologies. According to the NOAA website, climatologies "are charts that show the average conditions (or the 'climate') around the globe for each month of the year" (NOAA, n.d.b). Based on data collected from coral reef scientists in the field, CRW concluded that corals begin to bleach when the temperature of the ocean surface (SST) exceeds the average for the typically warmest month by one degree Celsius. CRW took this data and produced an online experimental chart that displayed where these areas of high SSTs are found in "real-time" across the tropics. This data, referred to as "HotSpot charts" was obtained by satellites and made available over the internet within a couple of hours. Today, CRW automatically generates HotSpot charts twice per week (Figure 6).

Place Figure 6 here: Bleaching Alert Area Product, NOAA Coral Reef Watch. Courtesy of Mark Eakin, NOAA.

NOAA's coral monitoring system is based on "seeing" sea surface temperature. Mark Eakin, who has served as director of CRW since 2005, tells me that:

> The surface is what you're able to see with the satellite. What's going on at depth is important and there are ways to infer that from the data we have, but that's another story and a bit more complicated. Unlike most things we measure from the satellite, for which we are measuring some proxy of [the] calculations we do, sea surface temperature is one of the few direct measurements that we have. It sees the infrared radiation coming off the surface of the earth. *It is seeing.* You're seeing the amount of infrared radiation or heat emanating out from the water (interview; emphasis added).

In other words, bleaching is predicted through temperature changes at the very top ocean layer. In his book *Alien Ocean*, Stefan Helmreich ponders the meaning of sight and vision as those manifest in the ocean. His insights into deep sea oceanography are very much relevant to the context of shallow water tropical reefs as well, as he writes: "Descriptions of the deep as dark and *therefore* mysterious, full of secrets, unknown, draw on a reservoir of meanings that associates sight and light with knowledge; indeed, the word theory derives from the ancient Greek for 'to look on' and 'to contemplate.'" It is no surprise, Helmreich concludes, "that seeing through the opaque ocean has become the governing goal of oceanography, the grail of techniques of remote sensing" (2009, p. 38). Patrick O'Malley reminds us in a different context that uncertainty "requires a certain kind of 'vision'" and refers to this as "governing with foresight" (O'Malley, 2004, p. 5; quoted in Aradau and van Munster 2011, p. 21). Eakin talks precisely about such governance with foresight when he tells me that: "Using sea surface temperature gives us an ability to predict what's going on from one to three weeks in advance." This, he continues, "because of the time lag in the response of the corals to the temperatures" (interview).

Temperature is a good indicator of the coral bleaching to come. The stress is accumulative; it is calculated based on the average temperature in the warmest month of the year, relying on data going back to 1985. "Corals have adapted to the temperature as they normally see during the warm season," Eakin explains. Hence, temperatures above the maximum monthly mean are deemed stressful. This is how the calculation of accumulation works:

> [If] you have one degree of stress that first week and the following week you have another degree stress—you add those two together and it's two [degrees]. If in the third week temperatures rise, say, [by] two degrees above the maximum monthly mean, then in that week you get two-degree weeks of stress and you add that to the previous two and now you're onto four and that's how this accumulates (ibid.).

Scientists translate the accumulative temperature stress directly into coral bleaching rates. Eakin explains that "at four degrees [Celsius] weeks of stress you're likely to have significant bleaching; at eight, you're expected to have a widespread bleaching and significant mortality." Obviously, this prediction is generalized and does not take into account variations in coral species and ecosystems, resilience, or other distinguishing factors between particular reefs. Eakin explains that the system is currently not equipped to deal with such detail, and is explicitly aimed at "coarse" predictions on a global scale.

In 2005, CRW added a new "product" to HotSpot: "Satellite Bleaching Alert" or SBA. Based on the HotSpot levels, CRW has been issuing four levels of alerts for reef sites, progressing from lower to higher levels of certainty: Bleaching Watch, Bleaching Warning, Bleaching Alert Level 1, and Bleaching Alert Level 2 (NOAA, n.d.c). An automatic e-mail alert is sent to subscribers each time the alert status changes. The SBA is freely available to the public. Since subscribing to this Alert in November 2015, I have been receiving weekly e-mail notifications about the state of bleaching in my sites of choice, which I have randomly picked from NOAA's 227 sites around the globe (Coral Reef Watch, 2015a). The e-mails also list the following definitions of alert levels, as follows:

> --No Stress: No thermal stress (HotSpot <= 0)
> --Watch: Low-level thermal stress (0 < HotSpot < 1)
> --Warning: Thermal stress is accumulating (HotSpot >= 1 and 0 < DHW < 4)
> --Alert Level 1: Bleaching expected (HotSpot >= 1 and 4 <= DHW < 8)
> --Alert Level 2: Significant bleaching expected (HotSpot >= 1 and DHW >= 8)

The Coral Reef Watch "operational product suite," in the language of the website, presently includes HotSpots, Degree Heating Weeks (DHWs), Tropical Ocean Coral Bleaching Indices, and Satellite Bleaching Alerts (SBAs) (NOAA, n.d.d). Eakin explains:

> The HotSpot only tells you what's happening today, or actually yesterday. It doesn't tell you what's been accumulating over time. [For this purpose,] you have the Degree Heating Weeks. The Bleaching Alert Area is a simplified single graphic that combines information from both Degree Heating Week and the HotSpot charts. It's been simplified to make it easier for managers to work with. Rather than having detailed scale, it breaks it down to alert areas and levels [to signify] how critical the situation is for the corals (interview).

Released in 2014, a new satellite "product" offers higher spatial (5 km) and temporal (daily) resolutions that presently includes sea surface temperature (SST), SST Anomaly, Coral Bleaching HotSpot, Degree Heating Week, and a 7-Day Maximum Bleaching Alert Area (Coral Reef Watch, 2015b). Eakin describes the benefits of this new technology:

> The early satellites [do] polar orbiting, they go from pole to pole while the earth is turning underneath. They cover every spot around the world twice a day. . . . The only way you can get accurate products [under this system] is to take a whole bunch of individual satellite pixels and put them together and calculate a larger area of the earth. […] [Recently,] we were able to drive resolution down [from 50] to 5 km. We're still using the data from the polar orbiting satellites which give you other advantages you don't to get from the geostationary. The combination of those two types of satellites and the repeated observations every day allows us to have observations at a 5 km resolution and each 5 km pixel has anywhere from 10 to 50 times more data per day from previous satellite at a larger resolution (interview; see also Figure 7).

The geostationary satellites provide repeat SST measurements as often as every 15 minutes. Complementing this, each polar-orbiting satellite provides global coverage, including coverage for the region missed by the geostationary satellites, by making near-polar orbits roughly 14 times within a 24-hour period. According to CRW scientists, "The combination of the six satellites provides the 5-km geo-polar blended night-only SST analysis with as many as 50 SST observations each night over the same location. These are then combined into a single SST analysis, for each pixel, each night" (Liu et al., 2014, p. 11585). "Instead of getting one image," Eakin continues, "you're getting multiple images a day. You can stack a whole bunch of data—all [the] data that comes in from the satellite" (interview).

The array of multimedia imaging and numbers is mind blowing, "a torrent of sense data that feels like a direct feed from what Kant once called the *mathematical sublime*, that domain of difficult-to-get-your-head-around measures and magnitudes" (Helmreich, 2009, p. 41). The upper level of the ocean, its surface, is used to penetrate into its depth, to bring the inaccessible into scientific vision. This recalls Chandra Mukerji's work on deep sea research, where she observes that utilizing scientific techniques through the manipulation of equipment "gives scientists a way to assert their culture, and not become overwhelmed by the scale of the ocean" (1990, p. 153).

Figure 7 here: 5-kms screen shot, November 2015. Reprinted with permission. Courtesy of Mark Eakin, NOAA.

Although the process of seeing sea surface temperature seems unmediated and direct, multiple algorithms and computer processes are in fact deployed to translate this information into relevant data and legible maps. HotSpot and DHW measurements, for example, are generated via the two algorithm presented below.

$$HS = \begin{cases} SST_{daily} - MMM, & SST_{daily} > MMM \\ 0, & SST_{daily} \leq MMM. \end{cases}$$

$$DHW = \frac{1}{7}\sum_{i=1}^{84}\left(HS_i, if\, HS_i \geq 1^{\circ}C\right)$$

Eakin emphasizes along these lines that "computers actually do the work" (interview). Such an abstract and globalized "algorithmic culture" (Striphas, 2015) is central to the operation of climatology models. The algorithm—a set of mathematical procedures whose purpose is to explore some truth or tendency about the world—encodes information in a way that reveals, but is "equally if not more likely to conceal" (ibid., p. 405). There is something "impenetrable about algorithms. . . [T]hey are deliberately obfuscated, and they work with information on a scale that is hard to comprehend" (Gillespie, 2014, p. 192). In this sense, algorithms "black-box" new forms of knowledge/power, rendering them obscure while at the same time spelling them out (for more on the work of algorithms, see Braverman forthcoming, 2017b).

More generally, computational technologies automate and exacerbate the knowledge about the forth-coming global warming catastrophe, focusing not on the local but on the regional and global scales. Such technologies operate based on an assumption of two worlds: "first, the world of appearances and, secondly, the 'hidden' world where clues can be gleaned and processed" (Aradau and van Munster, 2011, p. 125). The idea: to render the unknown known, the invisible visible, and the unexpected manageable.

6 Managing Time

More than anything else, catastrophe is time-dependent: its defining nature lies in the overturning moment or, in climate change terms, in the "tipping" point (Lenton, 2011). Ulrich Beck notes the changing relationship to time in a society defined by catastrophic risks. "The concept of risk reverses the relationship of past, present and future," he writes. "Its place as the cause of present-day experience and action is taken by the future, that is to say, something non-existent, constructed and fictitious" (Beck, 2005, p. 214). In their *Politics of Catastrophe* (2011), Claudia Aradau and Rens van Munster argue that the temporality of catastrophe governance breaks from Foucault's biopolitics in that it does not focus on linear statistical calculations. "[T]he 'biopolitics of catastrophe' would imply a radical reconsideration of temporality, a temporality that cannot be directly subsumed to the repetitive and the serial of statistical probability," they write (ibid., p. 10).

Yet it seems to me that NOAA's coral management is configured precisely along the older models of repetitive, linear, and statistical calculations of time. Accordingly, NOAA's calculations take place according to not one but *four* differentiated future temporalities, presented in all their linear glory: near-real-time, the current season, past related climate patterns, and long-term climate models for predicting decades and centuries into the future. Eakin explains:

> [We use] satellites to see what is actually happening right now. We also use seasonal climate models using the same algorithms we developed for satellite observations. Using seasonal climate models we can look to see what is the likelihood of bleaching several months into the future. […] The third looking at the events going on now is simply looking out what's going on in terms of the climate systems. […] The fourth [temporal scale] would be to use the long-term climate models, the models used for the intergovernmental panel on climate change, the models that look decades [up] to centuries into the future. Again, using the same sort of approach we use for the seasonal predictive models, we look at the likely bleaching the frequency of return of bleaching events and things like that, [but this time] decades in the future to give us an idea of what the future may hold based on what we understand in terms of changes in temperature that are driven by changes in heat trapping gases in the atmosphere (interview).

The ultimate goal of the four-scaled temporal modalities is to forecast coral bleaching events—namely, to render the catastrophe known and expected. In the words of Aradau and van Munster: "The objective, then, is to make the unknown known and show that what may seem unexpected in reality is an expectable outcome of causal processes" (2011, p. 113). NOAA's website explains the aims behind such knowing: "coral reef managers must be aware that a bleaching event is taking place, so they can act to protect corals from the long-term effects of bleaching. Herein lies the power of NOAA's Coral Reef Watch Program" (NOAA, n.d.b). Whether or not such a move from awareness into action indeed takes place in the context of coral management is the topic I would like to turn to next.

7 Regulating Bleaching?

Clearly, an immense effort goes into predicting bleaching levels and events. Yet once an alert level is detected, a response is not necessarily mandated or regulated. Eakin explains:

> Every country has its own laws and resource management regulations [and] will be making [its] own decisions. […] A number of countries and local jurisdictions have bleaching management and response plans. Every US coral reef jurisdiction, whether it's a state or territory, has a Bleaching Response Plan that gets triggered when an event [happens] (interview).

The Great Barrier Reef Marine Park Authority's (GBRMPA) Bleaching Response Plan is an early and comprehensive example of such programs. The GBRMPA plan includes procedures for prediction, ecological assessment, and communication of mass bleaching impacts. These procedures consist of routine, responsive, and strategic tasks. According to "A Reef Manager's Guide to Coral Bleaching," routine tasks "include the monitoring of environmental conditions and frequently updating assessments of bleaching risk." Responsive tasks include "rapid assessment of ecological impacts and increased communication activities, and "when bleaching thresholds are exceeded at multiple sites, a structured aerial survey is undertaken to determine the spatial extent and severity of bleaching in the region" (Marshall and Shuttenberg, 2006; see also Figure 7).

Place Figure 8 here: GBRMPA's 2015 Reef Health and Impact Survey (RHIS) form is used to quantify the extent and severity of impacts on the Great Barrier Reef. Courtesy of David Wachenfeld, GBRMPA.

In Hawaii, which in 2016 has seen heightened bleaching levels for the second summer in a row, the majority of the effort “at this point is to go out and make observations to see how severe it is, how it relates to the predictions, and looking at the severity in different areas hoping to find some areas where the corals are protected by local currents or more resilient to the warming and impacts of bleaching events” (Eakin, interview).

While the response plans I have read include an “action” section, most of the actions are in fact restricted to monitoring and observation. In other words: scientists conduct comprehensive monitoring in order to predict bleaching events; yet once bleaching events are underway, most of the actions performed consist of yet additional detailed monitoring. Wildlife managers work with the corals’ “knowns” as well as with their “known unknowns” (Aradau and van Munster, 2011, p. 6-7) to render their catastrophic future calculable and manageable. Once such scientific knowledge is produced, it paves way to the production of yet more knowledge, underlining how knowledge can in fact serve as a detriment to political power, or even yet: a busy noise that distracts from the real workings of power.

Eakin qualifies that: “One of the other things that can be done, and has been done in some areas, is [the] reduction of local stressors to reduce multiple stresses to coral reefs to help them to survive. You can help an organism survive one stress by reducing the other stresses at the same time to give them more of a fighting chance” (ibid.). Additionally, Eakin tells me about a variety of experiments performed over the years to provide a technoscientific “fix” for the situation, including pumping cool water or shading the corals as well as inserting aerosol into the atmosphere (see also Rau, 2012).

Eakin admits, however, that much more could, and should, be mandated and regulated by the state and that funneling more resources in this direction is crucial. In his words:

> [P]utting out something to cool coral reefs on a large scale would be as silly as putting a net over an entire hillside to keep a landslide from happening. But we do that, don’t we? Why can we put tens of millions of dollars down into protecting a roadway we built in the first place and can easily rebuild, but we don’t have the resources to protect a natural resource that we have no way to rebuild? It’s a matter of the tragedy of the commons, and the unwillingness to put that level of emphasis on the natural system. The general feeling [is] that if something breaks in nature, it’ll just fix itself (ibid.).

The biggest regulatory effort, Eakin concludes, should be “to reverse the warming we’re seeing now.” Nonetheless, in Australia the government of coral catastrophe seems to be about ensuring that nothing gets in the way of coal and gas expansion, namely: that reef death does not behoove the government to leave those resources in the ground. The catastrophe to be governed is thus reconfigured as the potential loss of mining export income, fossil fuel profits, and tourism revenue, rather than coral loss. Terry Hughes was recorded telling *Nature* along these lines:

> The main issue is obviously reducing greenhouse-gas emissions. Here in Australia, that’s very controversial, because our government is trying to prolong the export of coal. The Commonwealth Government of Australia has recently issued a lease for a new coal mine in Queensland. It will export its coal across the Great Barrier Reef, so shipping and dredging will all increase if this coal mine proceeds. Obviously, the last thing the Great Barrier Reef needs is more coal mines (*Nature*, 2016).

Accordingly, the Australian government lobbied against and censored Unesco's 2016 climate change report, demanding that any mention of the Great Barrier Reef be left out of the report (*The Guardian*, 2016).

And while global warming is admittedly at the heart of the problem, many coral scientists shy away from calling for the relevant regulatory changes in fossil fuel emissions, which they perceive as being a political rather than a scientific topic. Moreover, the International Society for Reef Studies—the umbrella association of coral reef scientists from around the globe—is convening its 13th meeting in Hawaii. While it was not debated explicitly by the organizers and no options for buying carbon footprints was made available on the online conference page, this decision sparked heated debates on the coral listserv and resulted in a few vocal refusals to participate in the event. Notwithstanding, the June 2016 meeting will be held as planned, with thousands of coral scientist delegates who will be flying into the Hawaiian island for this purpose.

8 Buying Time

In the face of the unknown and seemingly unwieldy properties of global climate change and ocean acidification, many coral reef scientists prefer to focus on specific and well-defined conservation actions that "buy time." Margaret Miller of NOAA explains that buying time means "maintaining some minimal population levels, basic levels of reproduction and genotypic diversity within the species, [until] we can hopefully, over time, get a handle on global warming and acidification and disease and these factors that are impairing natural reproduction and causing mass mortality events" (interview).

Coral restoration has been central to such scientific discourses that focus on how to battle the global warming catastrophe to come. Although, admittedly, "coral restoration by itself is not going to change the curve of coral reef decline," Tom Moore of NOAA tells me, he nonetheless holds that:

> [Restoration] gives us a fighting chance when and if we fix those global issues. Some of the folks who work on this from [The Nature Conservancy] created a graph to show the decline of reef over the years and the trajectory of that with no continued action, with continued action, and with restoration and continued action. These various different scenarios modeled out really helped show and illustrate that these are one of the tools that are out there (interview).

Massive underwater gardening projects include restoring devastated reefs using nursery cultivation and transplantation, as well as eliminating pest and invasive species such as the crown-of-thorns starfish in Australia and the red lionfish in the Caribbean. Techniques for restoration include both asexual and sexual reproduction and propagation of corals (Figures 9 and 10, respectively) as well as the more recent, and controversial, management model of "assisted evolution" (van Oppen et al., 2015).

Place Figure 9 here: Coral nurseries in Culebra, Puerto Rico, January 2015. Photo by author.

Place Figure 10 here: SECORE work in Curacao. Courtesy of Dirk Peterson, SECORE.

Along the lines of assisted evolution, SECORE's website introduces the term "super corals," which are "[s]ingle coral individuals [that] may be more resilient to heat stress than others," the website explains. "Can we utilize the capacity for corals to adapt to thermal stress by assisting evolution in corals? Seeding reefs with selectively bred *super corals* that are more thermally tolerant than others may buy us some time" (SECORE, 2015). Geoengineering interventions have also been called for, including shades placed on floating sails (Rau et al., 2012) and solar radiation management (Mumby and others, see Sale, 2015).

9 Coral Resilience

Restoration is often perceived as a way to enhance the reef's resilience. "How these reefs are actively managed plays a big role in how resilient they are to warming ocean temperatures," James Byrne from The Nature Conservancy writes (The Nature Conservancy, 2015). In 2005, The Nature Conservancy launched the Reef Resilience Program, a partnership effort that "builds the capacity of reef managers and practitioners around the world to better address the local impacts on coral reefs from climate change and other stressors." The coral reef module includes resilience monitoring strategy plans (Reef Resilience, 2015). The program's website indicates that: "A monitoring plan will guide the selection of indicators and provide the rationale for setting thresholds and triggers" (ibid.).

The logic underlying these managerial schemes is that "'Catastrophic futures' can be avoided through resilience" (Aradua and van Munster, 2011, p. 46). The active fostering of resilience is not the same as simply reducing vulnerability and risk. Instead, living through a catastrophic event "requires a different type of subject: not the prudential risk-calculating subject but the resilient subject" (ibid.). As part of their discussion about governing insecurity in the context of biorisks and terror, Filippa Lentzos and Nikolas Rose (2009) ask: "What, then, is a logic of resilience?" To which they respond with a broad definition of resilience:

> Initially an act of rebounding, recoiling or springing back: in the nineteenth century the term became applied to the capacity of a property or a structure to regain its initial shape after compression, and then, later, to the mental state of being able to withstand stress or adverse circumstances or to recover quickly from their effects, and, later still, to the capacity of systems, structures or organizations to resist being affected by shock or disaster, and to recover quickly from such events (p. 242).

The logic of resilience, these authors emphasize, extends beyond preparedness. "Perhaps the opposite of a Big Brother State, a logic of resilience would aspire to create a subjective and systematic state to enable each and all to live freely and with confidence in a world of potential risks" (ibid., p. 243). This form of resilience has been applied in discourses of biosecurity and the management of biorisks, especially those emanating from terror.

But in fact the concept of resilience has its origins in ecological discourses, and from there it traveled into contemporary security practices. According to C.S. Holling (1973), who alerted to the importance of ecological resilience already in 1973, resilience stands in opposition to stability and exemplifies a nonlinear way of thinking (p. 140). There is a growing recognition on the part of the scientific community that ecological resistance is an important property of viable ecosystems. In the words of Lance Gunderson:

> Much of the "command and control" resource management that leads to loss of ecological resilience is based upon the presumed predictability of complex ecological systems and driven by the myth that disciplinary science will resolve most uncertainties of management. But there has been a growing sense that traditional scientific approaches are not working, and, indeed, make the problem worse. One reason why rigid scientific and technological approaches fail is because they presume a system near equilibrium and a constancy of relationships. In this case, uncertainties arise not from errors in tools or

> models but from lack of appropriate information for the models. Another reason for failure is that few approaches account for inherent complex relationships among variables that lead to inherent unpredictabilities in ecological systems (Gunderson, 2000, p. 433; references omitted).

Whereas the traditional forms of resilience, often referred to as "engineering resilience," are defined by resilience ecologists as the return time to a single, global equilibrium, in ecological systems theory resilience is often defined as "the amount of disturbance that a system can absorb without changing stability domains" (ibid., p. 435). This alternative "is integrative and holistic, searching for simple structures and relationships that explain much of nature's complexity" (ibid., p. 433). Such an alternative underpins what is typically referred to as an adaptive approach in management, which assumes that "surprises are inevitable, that knowledge will always be incomplete, and that human interaction with ecosystems will always be evolving" (ibid.). A system's adaptive capacity is described as its robustness to changes in resilience. Ecological thinking has been steadily moving toward accommodating unexpected and unknown futures (Aradau and van Munster, 2011, p. 48), reorienting once distinct policy arenas "toward a horizon of critical future events that (we are told) we cannot predict or prevent, but merely adapt to by 'building resilience'" (Walker and Cooper, 2011, p. 144). The resilience strategy thus becomes part of a scientific discourse that rationalizes the avoidance of political action, effectively enabling such avoidance through the scientific language of adaptive management.

10 Epilogue: Chairs and Titanic

Bleached! has explored the management of the future catastrophe of coral reefs and their anticipated mass extinction. I have detailed the project of "watching" coral, executed by scientists, and by NOAA in particular, so as to predict and alert for their bleaching. I have shown how rather than resulting in policy mobilizations and political change, high-level bleaching alerts typically result in yet more scientific watching, more scientific monitoring. In this sense, then, scientific knowledge production serves to divert, detach, and neutralize the political responsibility for the catastrophic ecological future and the obligation to act in the face of such responsibility. Put differently: the cacophonic and compulsive scientific monitoring and reporting seems to dim rather than highlight the necessity for anticipatory action on a political scale. Instead, resilience is deployed as a deconstructive strategy that assumes that preparedness and prediction are impossible, so why bother taking action?

Accordingly, Australian coral scientist Ove Hoegh-Guldberg warns that we are "beyond conservation as we used to know it: we're now in the game of trying to garden and manage this moving vista." After many years of focusing his energy to initiate local actions to save particular coral reefs from bleaching, Hoegh-Guldberg has recently reached the conclusion that "a lot of what we're doing in terms of conservation actions is futile until we stabilize the climate again."

> I've been very involved in projects where we've grown coral back onto reefs in the Philippines and so on using some very clever techniques, [for example] creating rope nurseries where you can grow corals in large numbers and you can put them back on the reef. But, of course, if you haven't solved the problem, which is warmer seas or deteriorating water quality, you're just putting the communities there and they're there for about a year and [then] they die. So you need to solve that problem (ibid.).

"There's an interesting psychology here," Hoegh-Guldberg reflects in our interview. "This is the psychology of the reef gardener who wants to keep gardening even though he knows that the gardening is futile." Finally, in a statement that has elicited much criticism among his fellow coral scientists, Hoegh-Guldberg argues that "we're wasting a lot of money doing this sort of [management]. I'm not saying that we shouldn't be trying and refining the techniques. But until we deal with the climate issue, this is futile. *This is rearranging the chairs on the Titanic to get a better view*" (ibid.; emphasis added). Quite a few coral scientists have told me in our interviews that Hoegh-Guldberg's catastrophe perspective is not only exaggerated but is also not helpful for a successful campaign of coral conservation.

Yet again, from Hoegh-Guldberg's perspective current coral management is largely a practice in psychological avoidance: a preoccupation with gardening while all the while the earth below is shattering. Such coral management is, in this view, the very opposite of anticipatory action; it is an attempt to depoliticize the contemporary ecological crisis through a preoccupation with calculations and temporary solutions. The only way to deal with coral catastrophe head-on, Hoegh-Guldberg argues, is to regulate what has been largely viewed as the unregulated, to control what is seemingly beyond control, or at least beyond the control of scientists: climate change.

Despite its grimness, I would like to end this article with Hoegh-Guldberg perspective on the coral, and our, catastrophic future to come. In his words:

> If we don't arrest ourselves, we're going to destroy ourselves, a bit like an alcoholic planet. We're going to do all the worse things to ourselves and we'll have only ourselves to blame for it. But we won't quite die, we'll be a shadow of ourselves of course (ibid.).

We ourselves will become like the ghostly bleached corals: dying yet not dead.

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List of Interviews

Mary Alice Coffroth, Professor, Department of Geology & Graduate Program in Evolution, Ecology and Behavior, University at Buffalo, The State University of New York. Interview by author. Buffalo, New York. 2015, November 16.

Mark Eakin, Coordinator, NOAA Coral Reef Watch. Interview by author. Telephone, 2015, November 16.

Max Janse, Ocean Curator, Burger's Zoo, The Netherlands. Interview by author. Skype, 2015, October 30.

Ove Hoegh-Guldberg. Director of the Global Change Institute and Professor of Marine Science, The University of Queensland, Brisbane, Australia. Interview by author. Skype, 2015, February 25.

Margaret W. Miller, Ecologist, NOAA/NMFS, Southeast Fisheries Science Center. Interview by author. Telephone, 2015, September 16.

Jennifer Moore, Coral Coordinator, NOAA. Interview by author. Telephone, 2015, September 30.
Tom Moore, Coral Restoration Program Manager, NOAA Restoration Center. Interview by author. Telephone, 2015, October 2 & 7.
Madeleine van Oppen, AIMS Senior Principal Research Scientist, Australia. Interview by author. Skype, 2015, October 15.
Shaye Wolf, Center for Biological Diversity. Interview by author. Skype, 2015, November 4.

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