Chapter 3

Who Is Perturbed by Ecological Perturbations?

Marine Scientists' and Polynesian Fishers' Understandings of a Crown-of-Thorns Starfish Outbreak

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Introduction

Anthropological work focusing on local accounts of climate change has blossomed in recent years (Carey 2010; Crate 2011, Rudiak-Gould 2013a). In regions ranging from the arctic to small tropical islands, research has revealed how local people detect, understand, and interpret the local effects of global climate shifts (Krupnik and Jolly 2002; Mimura et al. 2007). This body of research builds on a long history in anthropology examining indigenous or local ecological knowledge (LEK) (Berkes, Colding, and Folke 2000). Beginning at least in the 1950s with Conklin's path-breaking work in the Philippines (1954), researchers began describing the rich and detailed compendium of knowledge held by indigenous people pertaining to local flora, fauna, and ecology.

LEK studies exploring marine and coastal ecosystems have tended to lag behind terrestrially focused research (Lauer 2017). In fact, the first detailed accounts of marine LEK began in the 1980s, almost thirty years after Conklin's work in the Philippines. It was a natural scientist, R. E. Johannes (1981), not an anthropologist, whose seminal work on Palauan fishers

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brought the first comprehensive documentation of fisher knowledge and inspired a generation of researchers. His study in Micronesia revealed that islanders had greater depth of knowledge about some ecological processes, such as fish spawning aggregations, than did marine scientists. Moreover, on some Pacific islands, local kin groups continue to manage marine resources through long-standing practices, such as temporary closures and cohesive ridgetop-to-reef ecosystem management, and in certain cases have sustained limited island resources for generations (South et al. 1994). These knowledges and practices now serve as a foundation for contemporary marine resource management systems in many parts of Oceania (McMillen et al. 2014; Jupiter et al. 2014).

More recently, local islander knowledge about climate change, especially sea level rise, has captured attention both in the academic community and throughout the wider public (Rudiak-Gould 2013a). Low-lying atolls and the people who inhabit them are suffering the first effects of rising oceans, and studies have documented how island peoples are adapting, migrating, and interpreting these changes (Lazrus 2012). In addition to sea level rise, the degradation of coral reefs, especially in the Pacific region, has garnered much attention. Climate scientists have shown that coral reefs were one of the first ecosystems to begin to respond to climate-induced stresses, such as rising ocean temperatures, and in the coming decades will undergo major shifts (Hughes et al. 2003). While LEK research has detailed how Pacific Islanders can accurately detect the ecological effects of rapid perturbations such as tsunamis, LEK also develops around slower shifts that arise over many decades, such as expanding seagrass meadows (Aswani and Lauer 2014; Lauer and Aswani 2010; Lauer and Matera 2016). Of course, the decline of coral reef ecosystems threatens not only biodiversity but also the life-worlds of the Pacific peoples who depend on them as cultural and economic resources and as a source of cosmological inspiration. As Tongan anthropologist Epeli Hau'ofa eloquently expresses, Pacific peoples have a deep connection with the ocean: "The sea is . . . a major source of our sustenance, and is something we all share in common . . . the ocean is in us" (Hau'ofa 2000).

Although respect for LEK as a viable and accurate knowledge base has increased among the wider scientific community, there continues to be much debate about how to characterize knowledge production in nonscientific contexts and how scientific and nonexpert knowledge should relate (Goldman 2007; Klenk et al. 2017; Jasanoff 2004; Wynne 1996; Agrawal 1995; Bohensky and Maru 2011; Watson-Verran and Turnbull 1995; Goldman, Nadasdy, and Turner 2011). The predominant model has been to assume that science knowledge can serve as a neutral arbiter by which to judge the validity of all other accounts (Davis and Ruddle 2010). Most of the local ecological studies about climate change as well as earlier LEK research explicitly or implicitly accepted scientific knowledge as a means of legitimizing nonexpert ecological observations. It was through the validation of LEK by science that many non-anthropologists have become convinced that LEK is not inferior or deficient compared to expert knowledge. This is itself evidence that the relationship between science and indigenous or non-Western knowledge continues to be asymmetric. As postcolonial scholars have made clear, modern technoscientific knowledge has a dubious history not only of validating racist, sexist, and exploitative treatment of marginalized groups within Western society itself and the Global South more generally (Haraway 1991; Said 1979) but also of neglecting and denigrating local specialist knowledge (Hobart 1993). In response, some indigenous peoples have positioned their knowledge politically against official and scientific claims as a means to bolster their authority and autodetermination (Brosius 2006).

These issues become particularly salient when there is *disagreement* between the scientific community and local people about ecological dynamics. In a well-documented case on the island of Tuvalu, islanders attributed increased erosion, saltwater intrusion, and flooding to climate change–induced sea level rise, even though the scientific research community had not determined that sea level rise was responsible (Connell 2003). Scientific knowledge appeared to be ignored by the Tuvaluan government, which attempted to link many of the island's environmental problems with sea level as a means to blame the international community and seek compensation. This strategy of ignoring scientific knowledge for political gain underpins disagreements between experts and nonexperts that are now rampant, such as debates about climate change, vaccinations, GMOs, and pesticide use (Oreskes and Conway 2011). Yet, even when political motives are less salient and science practitioners avoid overt marginalization of nonexpert knowledge, the sociology of science literature highlights the problems of assuming science can serve as the benchmark to judge validity because it, like all knowledge systems, imposes subtle yet critical epistemic commitments and normative concepts (Latour 1999; Jasanoff 2004).

In this chapter, we enter into these debates by focusing on local fishers and marine scientists' characterizations of climate change–related coral loss on the island of Moorea, French Polynesia. Moorea is an interesting and illuminating case because there are rich bodies of both scientific and fisher knowledge about the same ecosystem. Fishing is central to Moorea households, and fresh reef fish caught locally are consumed nearly every day. In addition, activities in the ocean and the marine environment are central to Polynesians' cultural identity, everyday life, and way of being.

At the same time, Moorea is one of the world's centers of tropical coral reef research. The island is home to two prominent research centers that have accumulated a wealth of marine science observations in the past half century. The existence of both local and scientific knowledge enables a side-by-side comparison of how different knowledges are produced, received, intermingled, challenged, packaged, as well as entangled with political, economic, spiritual, and social processes.

We focus on an outbreak of crown-of-thorns starfish (*Acanthaster planci*) that, as measured by marine scientists, led to the destruction of 95 percent of the coral on the outer reefs of the island from 2008 to 2010. Crown-of-thorns starfish (COTS) are one of the most studied organisms on tropical coral reefs (Pratchett et al. 2017). These coral-eating organisms are well known across the Indo-Pacific for sudden, massive population booms where huge aggregations rapidly damage large areas of coral. Importantly, COTS outbreaks appear to be exacerbated by climate change–induced ocean acidification and warming (Kamya et al. 2017; Uthicke et al. 2015). During the Moorea outbreak, scientists characterized it as one of the most intense and devastating starfish population booms ever recorded by the coral reef science community (Trapon, Pratchett, and Penin 2011; Adam et al. 2011; Adjeroud et al. 2009). Reports from the marine science community and local NGOs advocated for the removal of starfish (Lagouy 2007; Lison de Loma, Chancerelle, and Lerouvreur 2006: 13). Following these recommendations, the local government supported and financed an eradication campaign on Moorea where starfish were removed and burned on the beaches. Marine science research monitoring the recovery since the outbreak has revealed that coral cover has returned to pre-disturbance levels in many areas (Holbrook et al. 2018), though the species composition has recovered in some reef regions but not others (Adjeroud et al. 2018). Local fishers, for their part, although well aware of the outbreak and of the coral-eating behavior of the crown-of-thorns starfish, did not view the outbreak as a major event warranting action. In what follows, we explore these contrasting standpoints and their broader implications for LEK research. We ask a seemingly basic set of related questions: Who notices changes to Moorea's coral reefs, and how can it be judged if they are noteworthy? Who notices the effects these changes have on coral reef fish? And what should be done if a perturbation and its effects are identified?

Moorea

Moorea (figure 3.1) is a triangular-shaped volcanic island with sharp mountain peaks that jut up abruptly from the coastline. A barrier reef

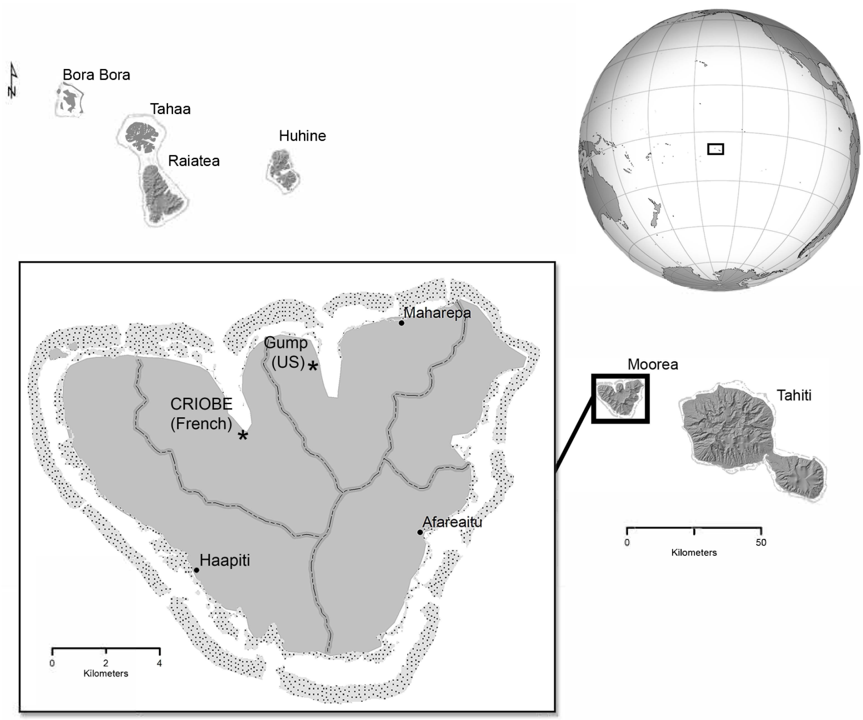

Figure 3.1. Moorea island, main settlements, and its two research centers. © Matthew Lauer.

rings the island, and ten main reef passes allow open ocean water to circulate through the shallow (less than ten meters deep) lagoons. The island is part of the Society Islands group in French Polynesia and is twenty kilometers west of French Polynesia's most populous and largest island, Tahiti. Moorea's close proximity to an international airport in Papeete on Tahiti across the channel has fueled tourism, and the island is now one of the most visited destinations in French Polynesia. With several large international hotels, numerous family-run guesthouses, and rental houses, tourism dominates the local economy. Attracted by employment in the tourist industry, immigrants from other islands in French Polynesia have swelled the island's population to over seventeen thousand inhabitants that reside in five administrative districts.

Despite centuries of major socioeconomic and cultural change associated with European colonization and the more recent effects of globalization, fishing continues to be a central part of Moorean life (Leenhardt et al. 2016). Over three-quarters of households have a member active in the fishery, and the consumption of fresh reef fish is high, with 67 percent of households reporting that they eat fresh reef fish at least three times per week. Unlike other Pacific island nations, Moorea's local communities are not as dependent on marine resources for food security or income. This is related to French Polynesia's status as a semiautonomous territory of France, where financial support has led to a high standard of living and a social safety net that provides free primary education and healthcare. French Polynesia's dependence on France, of course, brings a neocolonial political climate, but the economic and social safety net has meant that fishing is highly valued for cultural and recreational purposes rather than just for sustenance or economic livelihood. Indeed, eating fresh reef fish is central to the Polynesian sense of identity, and important events such as church gatherings, birthday parties, and *ma'a Tahiti* (large festive meals) invariably involve the consumption of locally caught reef fish.

Moorea also is well known as a center of coral reef scientific research. Moorea's coral reefs are some of the most studied tropical coral reef systems in the world. Two international research centers, one French and the other American, have hosted scientists specializing in coral reef research since the early 1970s, and dozens of scientific papers are published every year. Moorea's scientific community has compiled a detailed series tracking the island's ecosystem change through time. The American research facility (Gump Research Station) is administered by the University of California and is the field base for a National Science Foundation–funded Long Term Ecological Research site (Moorea Coral Reef LTER) that was established in 2004 to study the coral reef ecosystem. The French station, known as the Centre de Recherches Insulaires et Observatoire de l'Environnement (CRIOBE) has a similar Centre National de la Recherche Scientifique–funded monitoring program. The research conducted for this chapter involves the collaboration of social scientists, marine scientists from the Moorea Coral Reef LTER, and local fishers. Our project, titled "Recherche Collaborative Pour la Pêche à Moorea" (Collaborative Research for Moorea's Fishery), is focused on better understanding through collaborative science, the interrelations between fishing practices, livelihood strategies, and shifting dominance of coral and algae on reefs around the island.

Hungry Starfish and Coral Loss

From 2006 to 2007, Moorea's marine science research community began to notice a rapid spike in the abundance of crown-of-thorns starfish (*Acanthaster planci*), an organism that has attracted more attention from the scientific community than any other single species on coral reefs (Lison de

Loma et al. 2006; Lagouy 2007). Found across the tropical Indo-Pacific, this sea star is the world's largest. It can grow up to twenty legs, reach nearly half a meter in diameter, and can weigh up to six kilograms (Pratchett et al. 2014). It is covered with a starburst of thick, venomous, two- to three-centimeter-long thornlike spines, whose toxin can momentarily paralyze a swimmer and cause fits of vomiting. The spines, purportedly resembling the biblical crown of thorns, give the sea star its English common name.

Commonly referred to by the acronym COTS, the starfish has gained a notorious, and infamous, reputation among many marine scientists for its voracious appetite for coral polyps, which it consumes by extruding its stomach out of its body to digest the living tissue of the coral. Moreover, COTS have a propensity to undergo sudden population booms and emerge in large aggregations (Birkeland and Lucas 1990). During outbreaks, the organisms consume huge swaths of coral reef. First reported in Fiji in the 1930s, then in Japan in the 1950s, and later on the Great Barrier Reef in Australia in the 1960s, COTS outbreaks have now caused widespread damage on Indo-Pacific reefs (Zann, Brodie, and Vuki 1990; Brodie et al. 2005).

Despite this apparent increase, there is much debate in the marine science community as to whether COTS outbreaks are the result of recent anthropogenic drivers, such as increased nutrient delivery from land, or if they are a normal population dynamic that has been occurring for many thousands of years. Opinions about COTS outbreaks are so polarized that they have been dubbed a "Starfish War" (Raymond 1986), and only recently, due to the even greater existential threat of climate change, has attention on the starfish waned. Despite these divisions within the marine science community about COTS, some coral reef researchers consider the sea star outbreaks as a menace to coral reefs, and in some areas eradication programs have been established. It has been estimated that nearly seventeen million starfish have been killed or removed from reefs across the Indo-Pacific since the 1970s at the cost of nearly US$40 million (Pratchett et al. 2014). In fact, in 2012 the Australian government committed US$23 million to fund the Great Barrier Reef Marine Park Authority to implement a ten-year control program (Kwai 2018). France's applied research institute IRD (Institut de Recherche pour le Développement) has recently advocated for a citizen-based "lime juice fight" against COTS in New Caledonia and Vanuatu, in which lime juice injections are described as an effective control method (Moutardier et al. 2015; Dumas et al. 2015). Much research continues to investigate more radical techniques of population control, such as injecting the starfish with lethal toxins.

In our conversations with marine scientists working on Moorea, many of them expressed uncertainty about the course of action during outbreaks.

In 2018, for example, a technician from the CRIOBE station shared: "We know very little of the actual effects of human removal of COTS. Actually, removing them may have ecological consequences we are not aware of." During a COTS workshop convened by the Australian government in 2012, dozens of marine scientists—including from CRIOBE and the MCR LTER—agreed that research had failed to ask the important question of what causes a COTS outbreak to collapse (Schaffelke and Anthony 2015). Examples of proactive interventions appear to result in shifting the boom-and-bust dynamics to chronically recurring episodes. In other cases, interventions appear to effectively mitigate severe outbreaks, but only in circumscribed areas to protect a particularly valuable reef tract (e.g., for ecotourism). More broadly, scientists are beginning to focus their efforts to track the ecological effects of COTS interventions.

On Moorea, two COTS outbreaks have been documented by marine scientists, one in 1979 and another in 2009, although outbreaks had been reported on the island as early as 1969 (Trapon et al. 2011; Adam et al. 2011; Adjeroud et al. 2009; Rassweiler et al. 2020). In the more recent and better-monitored 2009 outbreak, underwater surveys revealed a dramatic increase in COTS densities on Moorea's outer reefs in 2007, eventually peaking in 2009 and then abruptly declining in 2010 (Kayal et al. 2012). In just one year, the density of starfish increased tenfold. In addition, a category four cyclone, Oli, battered the island in February of 2010. The combined effects of these disturbances reduced live coral cover from 40 percent to less than 5 percent, a 95 percent reduction.

This dramatic decline was a source of concern for some scientists who, at the time of the outbreak, were cautious about the possibility of recovery (Adjeroud et al. 2009). They advocated for "rapid intervention" (Lison de Loma et al. 2006: 13) in which eradication would be focused in the most infected sites and eventually consider "total eradication" around the island. Culling efforts from a previous outbreak in 1984 to ease the impact of COTS on reefs were noted. In addition, the local branch of an international NGO, Reef Check Polynésie, operating across French Polynesia and founded by a former director of CRIOBE, produced a report arguing how intervention was a necessary course of action (Lagouy 2007). Reef Check Polynésie, which received a 2007 grant from the French and French Polynesian governments, produced a flier outlining different eradication techniques and advocated for harvesting campaigns. We do note, however, that CRIOBE did not take part in or support these campaigns and that some scientists did suggest that recovery could occur without interventions. Despite varied opinion among scientists about the future recovery of corals from the COTS outbreaks, the French Polynesian government's Fisheries Service (presently DRM—Direction des Ressources

Marines—and formerly Service de la Pêche) encouraged COTS eradication during the outbreak. As a result, the local Moorea municipal government, schools, and NGOs organized sea star harvesting campaigns in 2009 during which some community members were paid on a per-kilogram basis to extract COTS from Moorea's reefs. Although some scientists were hesitant to predict recovery, subsequent studies since the 2009 outbreak have documented a rapid regrowth of coral cover (Holbrook et al. 2018; Adjeroud et al. 2018).

Local Knowledge about COTS

As part of an interdisciplinary research project funded by the National Science Foundation, we documented the local communities' perception of and response to the COTS outbreak. With several graduate students working alongside Moorean interpreters, we interviewed over 351 households as well as 15 key informants in 2014 and 2015 in three of Moorea's five administrative districts. Then in 2018–19 we conducted another series of interviews with more key informants on local perceptions of the past and present state of the lagoon and its marine resources (N=59) (refer to Rassweiler et al. 2020 for full details of the methods).

These interviews revealed that Mooreans are well aware of COTS, which they call *taramea*, and their coral destroying habits. Fishers talked about how in the past *taramea* were harvested, dried, ground up, and spread around garden plants as a pesticide, although this practice has disappeared. Generally, fishers were neutral about *taramea* and did not see them has a threat to the long-term health of the coral or reef fish. When asked if they changed their fishing practices because of the 2009 COTS outbreak, less than 25 percent of households stated that they changed their practices, and those that did change their practices were paid to extract COTS during the government-led eradication campaign. Most households did not feel it was necessary to kill *taramea* during the outbreak, and those fishers who did participate in eradication campaigns described the practice of removing *taramea* during outbreaks as a "new thing," and "the old-timers never mentioned anything like this." Many fishers discussed how they were instructed as children to leave the starfish alone and that disturbing the creatures might increase the intensity of an outbreak.

Local fishers who were involved in the culling activities described how an elderly woman was upset with the eradication efforts and publicly requested that they leave the *taramea* alone. Although there is no published information about the number of COTS removed from Moorea's reefs, community members recalled that COTS were piled on the beach, dried in the sun, and then burned. However, the idea that harvesting COTS is a necessary and effective course of action during outbreaks continues to pervade some local NGOs and fishing associations, who continue to seek both advice from the scientific community and grants to lead harvesting campaigns for future expected outbreaks.

To most fishers, though, *taramea* outbreaks are nonthreatening events, because it is well known that they occur every few decades on Moorea. They discussed how two sea snail species, *pu* (giant triton—*Charonia tritonis*) and *pu tara* or *pu pae ho'e* (giant spider conch—*Lambis truncata*), are predators of the COTS. They further cited traditional chants that describe starfish outbreaks and portray how swarms creep up from the outer reef ledges into shallower waters. Some fishers, as well as the head of the environmental department of the local municipality, talked about possible positive outcomes of *taramea* and explained their role in the ecosystem wherein they clean the reef of disease "like an antibiotic" or have a regenerative, reinvigorating effect. Indeed, marine scientists have also established that non-outbreak levels of COTS predation increase coral diversity because the starfish feed on the fastest-growing corals, such as plate and staghorn corals, enabling slower-growing species to become established (Great Barrier Reef Marine Park Authority 2017).

Everywhere across the Pacific, islanders have in-depth knowledge of COTS. Fishers interviewed in New Ireland, Solomon Islands, and Samoa all discussed a pattern of past outbreaks and were, in general, unconcerned about current COTS population booms. Another indication of Pacific Islanders' long-term relationship with COTS is evidenced by specific names assigned to the organism in many Pacific Island languages, such as *alamea* (Samoa), *rrusech* (Palau), and *bula* (Fiji) (Birkeland 1981).

COTS Effect on Fish Abundance

Our marine science colleagues documented not only shifts in coral cover after the COTS outbreak but also changes in the coral reef fish assemblage. Rapid and widespread coral loss, whether caused by COTS, coral bleaching, or strong storms, is generally assumed to shift coral reef fish species composition and overall fish biomass (Holbrook et al. 2018). An LTER-led analysis of 271,000 fish observed during an underwater census from 2009 to 2010 quantified the absolute and relative abundance of fish during the 2009–10 period. The biomass of the important food fish *Naso* (*ume* in Tahitian) fell from twenty-one to four kilograms per hectare, while the biomass of parrotfish from the family *Scarus*, another popular food fish known as *pa'ati* or *pahoro*, increased at roughly the same magnitude as *Naso* declined.

Our research team compared the marine science surveys of fishable biomass and species composition with the reef fish catch. To do this, we carried out an extensive roadside fish seller survey in 2014–15. Most reef fish on Moorea are sold along the island's coastal perimeter road. Makeshift metal racks are constructed, and fish are hung in *tui*, strings of freshly caught fish held together by passing a piece of twisted tree-bark string through the fish's stomach and mouth (figure 3.2).

To estimate the reef fish catch, our Tahitian collaborator drove the perimeter road every Sunday morning and interviewed every fish seller she encountered. In addition to a brief survey, she photographed the sellers' *tui*, making sure to place a scale bar near the hanging strings of fish, a technique that allowed us to record eighteen thousand fish. We then analyzed the photographs to identify the fish to the lowest taxonomic level possible (mostly to species) and measured the length of each fish in the photograph by comparison with the scale bar using established photo measurement techniques. Our surveys conducted in 2014 and 2015 were augmented by similar catch surveys conducted by French researchers from CRIOBE in 2007, 2008, and 2012. These combined datasets enabled us to analyze the

Figure 3.2. Strings of fish (*tui*) sold by roadside. © Terava Atger.

composition of the catch before, during, and after the environmental disturbances from the COTS outbreak and Cyclone Oli.

Our analysis showed that, overall, the roadside catch data mirrored the trends revealed through the underwater surveys (for a full description of the analysis see Rassweiler et al. 2020). *Naso* spp., for example, decreased from over a third of the catch prior to the disturbances to less than 10 percent after. In contrast, parrotfish increased from 56 to 66 percent. In fact, there was a rather tight correlation between biomass of the taxa measured during the underwater surveys and those documented in our roadside catch surveys.

However, when we asked fishers about their catch, the fish they ate, and the fish they purchased or sold, few reported any change. Just 1.5 percent of households stated that they changed the kinds of fish they ate, bought, or sold after the COTS outbreak, and just 13 percent indicated that they changed where, what, or how they fished. Of those that did change their behavior, some avoided the *taramea*-infested areas, others switched to new fishing grounds, while others participated in the municipal government's efforts to remove COTS from the reef.

Starfish Glut or Bloom?

To recap, marine scientists documented what they characterized as the most devastating and intense COTS outbreak ever recorded on Moorea's reefs. There were mixed views, however, about its significance to coral reef health, with some arguing that the outbreak posed a threat while others refrained from describing its impact as undermining reef health (Kayal et al. 2012). Yet, the French Polynesian press took a decidedly negative stance toward COTS. One local newspaper declared "Les coraux de Tahiti menacés par une étoile de mer" [Tahitian corals threatened by a starfish]. Indeed, major international media outlets have a long history of demonizing COTS. For example, during the first reports of COTS outbreaks on the Great Barrier Reef of Australia in the 1960s, *Time* magazine bluntly described the starfish as a "Plague at Sea" (Time 1969), while outbreaks in Micronesia led to this 1969 *New York Times* headline: "Scientists Say Coral-Eating Starfish Peril Pacific Islands" (Trumbull 1969). More recently, another *New York Times* headline declared, "Voracious Starfish Is Destroying the Great Barrier Reef" (Kwai 2018). These sentiments have led to a long-standing and widespread strategy to mitigate the effects of COTS outbreaks by destroying the organisms through eradication campaigns, a practice that was carried out on Moorea.

However, islanders' perceptions of the COTS outbreak and the decline of Moorea's coral contrasted with some in the marine science community and differed sharply with the government-led program to eradicate the sea stars. Moorea fishers, although well aware of the loss in coral and the coral-eating habits of COTS, did not find the change particularly important and did little to alter their behavior after the outbreak. Climate change–related shifts, such as sea temperature rise, were never mentioned as a possible cause of the outbreak. Moreover, changes in relative fish abundance documented both in the roadside catch surveys and during underwater diver surveys of the reef did not register as noteworthy among Moorea fishers. Few fishers noted a change in the fish they caught or ate. Similarly, a recent coral-bleaching event in Moorea (mid-2019), which has raised a great deal of concern among the local scientific community and local NGOs, does not seem to worry fishers. Coral bleaching, where thermal stress causes coral polyps to expel their symbiotic algae, turn white, and die, is one of the key climate change–induced disturbances affecting coral reefs worldwide. In contrast to the alarm coral bleaching has caused among coral reef scientists, a sixty-five-year-old Moorean fisher interviewed in 2019 mentioned that the ongoing bleaching event would help renew and strengthen the island's coral reefs.

Thus, we are presented with contrasting understandings of what constitutes a perturbation or change on Moorea's coral reefs. These differing standpoints of change in marine ecosystems may be due to the longer time horizon of the Polynesian fishers' knowledge base. While extensive time-series data have been collected in Moorea over the past forty years by both research stations, the temporal depth of scientific research is significantly shorter than the experience of fishers who draw on their own lifespan and the intergenerational transmitted knowledge of their parents and grandparents. The knowledge of fishers, as with all indigenous knowledge, develops and is sustained through a mixture of intergenerational transmitted knowledge, experience, regular interaction with the underwater environment, and the reception of other kinds of scientific and nonscientific knowledge. Fishers were able to evaluate the 2009 COTS outbreak in relation to others in their memory or the memory of previous fishers. This awareness of previous COTS outbreaks and their associated ecological outcomes could be the basis upon which fishers interpreted the 2009 population boom as a normal cyclical pattern rather than a unique and threatening change. The same may be said about the ongoing coral bleaching event: fishers noticed its particular intensity and geographical extent but do not find it alarming as they have witnessed past disturbances caused by bleaching and past recoveries of the reefs. However, intergenerational knowledge may not provide accurate guides to action involving current and future ecological changes associated with rising ocean temperatures and ocean acidification. These climate change–induced changes are unique to our Anthropocene epoch and may produce effects that lie outside the experience horizon of Polynesians' fifteen hundred years of accumulated place-based knowledge. Indeed, Western scientists face the same uncertainties and are not necessarily more prepared than fishers are to predict novel changes that have no historic analog.

We tentatively forward the notion that fishers and local community members may be more preoccupied by gradual and slow-paced changes than rapid, intense ecological changes. Indeed, rapid disturbances (such as COTS outbreaks, cyclones, or bleaching events), while erratic and unpredictable, are nonetheless expected and perceived to appear cyclically. When asking fishers what their main preoccupations are concerning their marine environment, the slow process of sedimentation is often mentioned. One reason may be the linearity of such changes that are perceived as irreversible.

Even more surprising is that the shifts we documented in both the roadside catch and the underwater reef surveys were unremarkable to fishers. The *Naso* species in particular dropped in both the reef counts and our counts of fish sold on the roadside. *Naso* spp. are a highly prized food fish on Moorea and widely sought after, yet fishers noted little change in their catch or in their diets. It could be that the shifts observed in the reef and roadside surveys represent large changes for each taxon but add up to relatively modest change when the suite of common food fishes are considered as a group. In our household surveys, fishers consistently reported *pa'ati* (*Scarus/Chlorurus* spp., terminal phase), *pahoro (Scarus/Chlorurus* spp., initial phase), *i'ihi* (*Myripristis* spp.), *tarao* (*Epinephelus* spp.), *pa'aihere* (*Caranx* spp.), and *ume* (*Naso* spp.) as the most common fish that they ate and caught. Because the decline in *Ume* was mostly offset by an increase in *pahoro* and *pa'ati*, the suite of fish remains consistent. As with the COTS outbreaks, shifts in the relative abundance of food fish may register as normal fluctuations within the local knowledge of fishers. If one of these fish were to completely disappear from the reef, it is possible that this would constitute a radical break from a "normal" catch.

In follow-up surveys, we asked fishers about the roadside and reef surveys, and they responded that their concerns focus more on fish behavior than on the abundance of fish on the reef. Fishers frequently commented how *Ume*, in areas where they are heavily fished, learn to be wary of fishers and evade them quickly by swimming to deeper water beyond the range of most free-diving spearfishers. Yet this does not necessarily result in fewer fish caught for skilled spearfishers. As one fisher noted, "A good spearfisher will find and catch the fish he desires." This suggests that Moorean fishers may grasp fish abundance as constituted in the *relationship* between fishers and their preferred targets rather than as an *attribute* of the fishery that is independent of the observer.

Discrepancies between fishers' and marine scientists' understanding of change may also be due to crucial knowledge gaps in tropical coral reef science. The forty-year running debate about the causes of COTS outbreaks is just one example. The same type and intensity of disturbance to a coral reef can vary greatly in the intensity, spatial scale, magnitude, and longevity of its impacts (Wilson et al. 2010). Marine scientists still struggle to predict coral reef decline associated with COTS, as well as thermal stress related coral bleaching. The fact that at least some of Moorea's coral reefs have rapidly returned to their pre-COTS levels of coral cover highlights the level of scientific uncertainty involved when predicting the effects of disturbance (Holbrook et al. 2018; Adjeroud et al. 2018).

Differences in Local Knowledges

The differences in how scientists and fishers understand the COTS outbreak and its noteworthiness raise a number of challenging questions for studies investigating local knowledge of climate change–induced ecological change. Much of the literature highlighting how local or indigenous people detect climate-related change relies, either explicitly or implicitly, on climate science to validate local knowledge claims about changing ecosystems. Crate (2008), for example, working among the Viliui Sakha of northeastern Siberia, discusses in detail how local elders lament the disappearance, due to warming temperatures, of winter, which they describe as a "white bull with blue spots, huge horns, and frosty breath" (Crate 2008: 570). The warming observed by the Sakha is assumed to be an outcome of "unprecedented global climate change" (Crate 2008: 570), yet many climate scientists fiercely deny the possibility that global climate change is locally visible (Rudiak-Gould 2013b). As discussed in detail by Rudiak-Gould (2013b), research such as Crate's accepts climate change science as a means to legitimize local ecological knowledge and emphasize that it is a viable and empirically sound body of knowledge. Moreover, by validating LEK, the voice of marginalized communities tends to gain more traction in decision-making.

This kind of commitment to bolster the legitimacy of LEK has been central to many indigenous knowledge studies and indigenous advocates for decades, but in many cases LEK is positioned not in concert with scientific, expert knowledge but *in opposition* to it (Brokensha, Warren, and Werner 1980; Agrawal 1995; Hobart 1993). A case in point is illustrated by "counter mapping" (Schofield 2016). This popular technique utilizes LEK to develop cartographic and other kinds of spatial data to represent the knowledge and interests of local and indigenous people that are overlooked in official cartographic representations. These techniques have emerged to reverse the long track record of international development schemes and conservation initiatives where expert knowledge tramples local adaptations and practices (Hobart 1993). In this body of research, science and expert knowledge are understood not as neutral forces for good but rather as hegemonic forces, tied with postcolonial power and, in many cases, oppression of the marginalized (Said 1979; Foucault 1990; Haraway 1988).

Indeed, on Moorea there are tensions between fishers and scientists. Like most Pacific Islands, life in French Polynesia has been subjected to countless impositions since the arrival of Europeans, including unequal trade, imposed religion, privatization of land tenure, monolingual French education, and broad cultural oppression (Thompson and Adloff 1971). Although overt colonial oppression has declined somewhat in French Polynesia, Moorean fishers have grown increasingly skeptical of the motives of the scientific community because fishers associate them with the implementation of a top-down and expert-led lagoon management plan that disproportionately restricts fishing activities compared to other kinds of uses, such as tourism and scientific activities (Walker 2001; Hunter et al. 2018). Known as the Plan de Gestion de l'Espace Maritime (PGEM), in 2004 it established eight no-take zones and other restrictions on harvesting marine life around the island. It is widely known on the island that the PGEM restrictions are often ignored by fishers. In fact, marine science evaluations conducted a decade after the establishment of the no-take zones have shown them to be ineffective in substantially increasing the biomass of fish inside of the reserve areas (Thiault et al. 2019).

In response to the PGEM, grassroots movements have emerged on Moorea, as well as on other islands in French Polynesia, that seek to increase local control over marine space. Many of these groups frame their community-led management as a form of a neotraditional management known as *rahui* (Bambridge 2016; Bambridge et al. 2019). One of the key elements of the emerging *rahui* groups who advocate for more community control is to have influence over management decisions in situations like the COTS outbreak. The fact that the French Polynesian government's Fisheries Service and Moorea's municipal government organized the COTS eradication campaign during the 2009 population boom suggests that they followed the lead of at least part of the scientific community about the COTS outbreak and maybe faced pressure from tourist operators, who feared that coral loss would harm tourism, rather than consulting fishers[1] and involving them in the decisions over marine management.

Moorea's *rahui* groups recognize that French Polynesian decision-makers base their management decisions, at least in part, on scientific knowledge, and as a result, some groups are now conducting their own quasi-scientific assessments of marine resources. One group, for example, carried out an underwater fish survey to assess areas for overfishing and reported their results in a detailed summary document. This same group, in overt conflict with both the local municipality and CRIOBE research teams, has adopted scientific claims about COTS and is advocating for their removal during outbreaks. However, rather than physically removing COTS, the members proudly claim possession of traditional knowledge that can influence ecological processes to mitigate COTS outbreaks. However, this and other such groups refuse to share this knowledge with scientists. Their strategy to withhold knowledge from the scientific community exemplifies how LEK and Western scientific knowledge may be pitted against one another in contexts of political struggles over management of environmental resources.

That local people such as Moorea's *rahui* organizations are adopting scientific methods and positioning LEK in ways to achieve political aims, however, raises red flags for many scientists who hold the view that science conducted by professionals is the most effective method to produce accurate knowledge (Carr and Heyman 2012). For example, Davis and Ruddle suggest that the most cited LEK literature lacks scientific validation and that this is problematic because of the "need for researchers to be held accountable to their knowledge claims" (Davis and Ruddle 2010: 893) through "systematic evaluation." For these researchers, Western science provides privileged access to phenomena, and, "like it or not, until replaced at some future time, Western science is the dominant paradigm that sets the prevailing standard" (Davis and Ruddle 2010: 881). The commitment is in some ways a reversion back to older pejorative understandings of non-Western knowledge that viewed local understanding as simply "tradition" or "belief" and that LEK only gains legitimacy when it is absorbed by peer-reviewed science.

Yet, much research from the field of science and technology studies has shown how scientific knowledge production, albeit extremely powerful and important, is never fully purified of its specific epistemic assumptions about social relationships, value, and behavior (Latour 1993; Turnbull 2000). Rather than a positionless view from nowhere, what Donna Haraway (1988) calls the "God trick," science, like all knowledge systems, is a situated practice that brings with it its own terms of validation (Lauer and Aswani 2009). More often than not aspects of LEK are disqualified in favor of science, and even when LEK is seen as a possible source of reliable information, bits of it are brought into the work of science only after being properly framed (Klenk et al. 2017).

Knowledge Spaces

That Moorean fishers appear to have been accurate in that the massive loss of coral documented by marine scientists did not constitute a persistent, irreversible change to the ecosystem suggests that peer-reviewed science is not always sufficient. We make note of this not to suggest that Moorea fisher knowledge is necessarily superior to that of the marine scientists but rather to highlight that all knowledge systems may produce useful insights and spur innovation if given the space to do so. Here, following Turnbull (1997) and Turnhout et al. (2012), we suggest that although there are critical differences between knowledges, we should seek ways to enable their coexistence. To open spaces for the coexistence of LEK and science, validity, accuracy, and verification are better conceived as *products of knowledge practices* rather than external criteria (Wynne 1996), and these critical criteria must be subjected to active debate, deliberation, and topics of inquiry rather than harnessed as resources and hidden behind claims that either science or LEK has privileged access to a "real" reality.

A symmetrical approach to knowledges should not be interpreted as a call that all knowledges are justified or that antiscientific thinking should be encouraged. Indeed, extreme relativism is what has led to the current political tactics in the United States, where large portions of the population can be swayed by powerful corporations who accuse scientists of being nothing more than lobbyists for their own interests. Likewise, the hostility toward science expressed by many indigenous rights activists is equally flawed since it relies on the spurious claim that indigenous or local knowledge invariably produces harmonious human/nonhuman relations and a socially just world. To circumvent the expert/nonexpert and LEK/science divides, it is vital to explicitly emphasize that the production of all knowledges is bound up with certain epistemic commitments, value-laden assumptions, and political positions. This approach not only encourages us to begin to critically examine, recognize, and research how knowledge claims are constructed but also serves as a means to rebuild the legitimacy of scientific knowledge while not denigrating nonexpert knowledge. As Sarewitz argues, "The social value of science itself is likely to increase if . . . value disputes have been brought out into the open, their implications for society explored, and suitable goals identified" (Sarewitz 2004: 399).

Moorea, we argue, provides a unique opportunity to implement these kinds of knowledge spaces and experimental partnerships since there is thriving local knowledge *and* a local science community operating and intertwining side by side. Recognizing this and the challenges we face, our research group is developing workshops to enable fishers and marine scientists to interrogate each other's methods, knowledge, and ways of knowing. Rather than just meeting and discussing, fishers and marine scientists will be asked to jointly conduct field-based assessments of fish abundance, examine each other's methods and knowledge claims for determining abundance, and discuss the issues at stake and the aims of generating knowledge along with the epistemic criteria it should be judged by. In this way, our hope is to produce knowledge about Moorea's coral reef system in a more open-ended and less dichotomized manner while also potentially redistributing recognized authority to and spurring action among fishers who have been marginalized from most formal knowledge- and decision-making processes.

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Note

1. We note that some local environmental and *rahui* groups on Moorea are now advocating for COTS removal during outbreaks.

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