

# The Tree Snail Manifesto

by Michael G. Hadfield and Donna J. Haraway

Focused on the lives and deaths of Pacific Island tree snails, the crafting of apparatuses and practices for their study in laboratory and field, and the diverse people engaged in the work, this double-voiced essay by two long-term friends and colleagues joins science, politics, and culture to contribute to multispecies environmental justice and island biopolitical geography. In part 1 Hadfield tracks his own trajectory, beginning with professional life as a “pure scientist,” fascinated by patterns of development of marine animals, and then finding that fascination moving to efforts to stop the extinctions of native Hawaiian land snails, conservation efforts across the Pacific, and ultimately teaching and practicing resistance to political suppression of science and military takeover and destruction of islands around the world. In the idioms of science studies and anthropology, part 2 by Donna Haraway plays cat’s cradle games with Hadfield’s land-and-sea EcologicalEvolutionaryDevelopmental biology and activism. Haraway explores the complexity of practices crucial to life-altering scientific caring in the patchy Anthropocene. Parts 1 and 2 are linked by Satoru Abe’s print *Parting Trees B*, which is a vital hinge for collaborations in the Tree Snail Manifesto.

## Preamble

Writing by one of us reaches into writing by the other to symbiotically shape a manifesto that is simultaneously scientific, political, personal, and cultural. The shared infection is love of the mortal earth and its vulnerable but hardy living beings. The TSM tells of real places, where structurally shaped patchy links along multiple temporal and spatial scales form mosaics typical of the Anthropocene. The TSM explores how conditions of unlivability develop for both humans and for other species, so as to emphasize also practices for nurturing more hopeful patterns of relating (Tsing, Mathews, and Bubandt 2019). The symbiosis linking the authors of the TSM is part of contemporary movement toward multispecies environmental justice, for humans and nonhumans alike, in situated places for particular beings, in times of manifest destruction and injustice. Like most trajectories in life, the cross-hatched lines of thinking in this manifesto were full of surprises biographically and intellectually, reconnecting the writers in a shared project that neither anticipated. Our two-voiced paper might itself be a patch of the holobiosome of Pacific Island tree snails living on a damaged earth.

Through his life and professional trajectory, Michael broadened his scope of inquiry from one field within biology to others,

which required resistance to the wanton disregard of both science and nature underway in many parts of the world. Making string figures with EcologicalEvolutionaryDevelopmentalHistorical biology (EcoEvoDevoHisto), Donna diverged from practicing biology directly into an exploration of what both natural and social scientists do and how it matters. The inner tissues of Donna’s way of doing science studies changed in concert with Michael’s reshaping his biology into what Donna calls biogeopolitical science as the core of his practice.

We hope that readers join a dialogue through reading both sections together, in reciprocating resonances, linked by Satoru Abe’s magnificent print *Parting Trees B* that appears between parts 1 and 2. The almost-but-not-quite mirror images of skeletal trees, blown into beauty in light and dark, yearning together and apart, are stark but also intensely elaborated forms that embody what we are trying to write.

This dialogue reveals our shared belief that we live on a bountiful earth as and among vibrant beings. Living in peace requires protecting and restoring an earth that can be a home for all. The year of the composition of the Tree Snail Manifesto threw dangers at this homeworld like few before it. We have watched willful governmental changes in the United States to undermine rational respect for and use of the careful scientific information available to us concerning climate change and historically situated human actions as the cause of it. We have seen cold plans to put in place physical and legal barriers to the flow of desperate people into our country from around the world. We have watched in dismay the political dismemberment of programs designed to assure adequate health care for all. Amid resurgent racist and misogynist language and policy, we have counted new extinctions and extractions across the earth. This must be reversed, and we are dedicated to this reversal in whatever ways are available to us.

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Together, in just one small story in one place extended in time and space, we explore the complexity of practices crucial to life-altering scientific caring that ties research to colonial and decolonial institutions, population surveys, incubators, predator fences, websites, angry letters, fierce collegueships, and a host of organisms. The Tree Snail Manifesto is an invitation to join us on the slime trails of resistance and rebuilding.

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## The Ecological Evolutionary Development of a Pacific Island Tree Snail (Marine) Biologist: The Tree Snail Manifesto, Part 1

Michael G. Hadfield

I. Trained to Be a Marine Biologist, Focusing on the Development and Reproduction of Marine Invertebrate Animals: From Washington State to Hawai'i, with Major Stops in Between

I became addicted to marine labs in the spring of my junior year at the University of Washington, when, on a field trip to the university's Friday Harbor Marine Laboratories (fig. 1), I si-

multaneously discovered what great and beautiful places marine labs are for work and that you could actually do that kind of work for a living. I have subsequently spent most of my life studying and teaching at marine labs around the world. Within those labs, I focused my interests on the life histories of marine invertebrates—snails, sponges, worms, corals, crabs, etc. However, as will become abundantly clear below, a result of learning a lot about the life histories of marine snails eventually led me to a major involvement with land snails as well.

After earning bachelor's and master's degrees in zoology at the University of Washington, I was awarded a Fulbright fellowship to study for a year at the marine laboratory of Copenhagen University in Denmark, where I could focus, full time, on studying marine larvae. Leaving Denmark, I went to Stanford University to pursue a PhD, spending most of my time at Stanford's Hopkins Marine Station in coastal Pacific Grove, California. By the time I arrived at Stanford, I had carried out research on a variety of different marine invertebrates, including small and interesting animals in the phylum Phoronida for an undergraduate project, a strange sea cucumber for my MS thesis, and the larvae of nudibranch gastropods in Denmark.

Thus, it wasn't strange that I would try several different research projects at the Stanford lab before finally focusing my dissertation studies on the reproductive biology and development of some amazing coastal snails, the Vermetidae. After short, free-living larval lives, these snails cement their shells to a surface, give up coiling, and live in shells that greatly resemble worm tubes (fig. 2, *left*). Anchored to rocks, they cannot crawl around to find food but instead secrete long, sticky




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Figure 1. Friday Harbor Laboratories, University of Washington. A color version of this figure is available online.

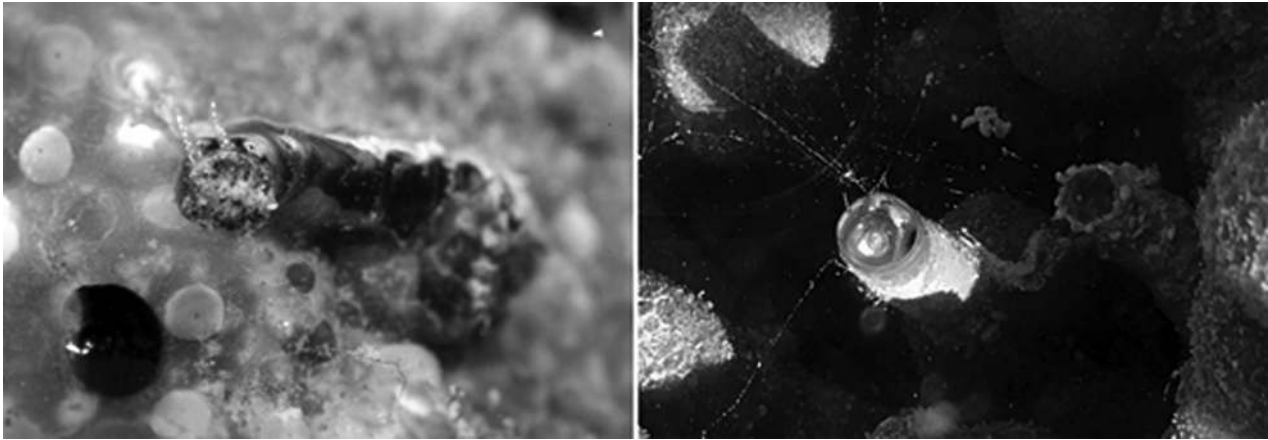


Figure 2. Vermetid snails. *Left*, entire snail in its tube-like shell. *Right*, “face view” of a snail showing its mucous feeding strands. A color version of this figure is available online.

mucous strings from glands just below their mouths, which stream out into the seawater and trap floating detritus (fig. 2, *right*). Periodically, they haul in the threads with a rough, strap-like tongue and swallow them. Being glued to the rocks also requires special adaptations for breeding, and one of my discoveries was that the snails make complex capsules to contain their sperm, spermatophores, which are released into the sea where they disperse and, with good fortune, get stuck on another snail’s feeding mucous strands. When the snail hauls one in, its teeth puncture the spermatophore, causing it to “explode” and literally toss an inner sperm bundle into the water, where it is drawn by respiratory currents into the mantle cavity—a lung-like space along the snail’s back that houses the gill—and then into a special receptacle designed to hold the sperm. Remarkably, these stuck-down snails manage to have internal fertilization even though they cannot get together to mate.

The development of the vermetid snails was also fascinating, beginning with eggs encased in capsules that remain in the mantle cavity until they hatch. Amazing things happen within those capsules. In one vermetid species, all the eggs develop into small larvae that hatch and swim in the ocean for days or weeks before settling to the bottom, attaching and completing metamorphosis. Another species I studied packs around 100 eggs into each capsule, yet only a single small snail emerges! All but one of those eggs serves as “nurse eggs,” to be eaten by the one that develops, and that individual passes right through its larval stage and hatches as a small crawler with a shell a millimeter or so in length. My dissertation described all of this, plus details of sperm formation gained with the electron microscope (and if things weren’t already bizarre enough for these snails, they also make two kinds of sperm, one of which is a giant that has nothing to do with fertilizing eggs!) (Hadfield 1970; Hadfield and Hopper 1980; Hadfield et al. 1972). It was clear to me as I left graduate school that I would spend my life, one way or another, studying the development, and especially metamorphosis, of marine invertebrates. And so I have.

Directly from graduate school, I taught at Pomona College in Claremont, CA, an outstanding undergraduate school with

excellent students. However, during my first year I found that I badly missed time for intensive research, and so with excitement, in 1968 I accepted an offer for a faculty position in the Pacific Biomedical Research Center at the University of Hawai‘i. The center had received National Science Foundation funding to build a new marine laboratory on the coast in an ideal location in Honolulu. The university had hired a noted cell biologist from Dartmouth College, Robert E. Kane, to oversee construction and to direct the new lab, as well as hire a research faculty to staff it. The focus of the lab was to be on employing Hawaiian marine animals as models for basic research in cell and developmental biology. Five of us made up the faculty when we occupied the Kewalo Marine Laboratory, and our research spanned a range from the kind of work I did on reproduction and development, pretty much whole-organism biology, to that of a biophysicist colleague doing fundamental research on the subcellular mechanisms of ciliary beating.

Although 4 years passed before the new lab was ready for use (fig. 3), I had already launched a series of experiments on several Hawaiian marine animals, some in the family of vermetid snails. However, I soon found a very useful nudibranch gastropod, *Phestilla sibogae*, which was to be the focus of many of my lab’s studies on development and metamorphosis for most of the next 30-plus years. These hermaphroditic sea slugs feed on an abundant local coral, mate there, and lay their eggs in jelly-like ribbons attached to the coral skeleton (fig. 4). The eggs develop into swimming larvae in about a week and then must spend at least another 3 days swimming in the ocean until they are developmentally capable of settling to the bottom, attaching, and undergoing a dramatic metamorphosis into small slugs (fig. 5, *left*) (Bonar and Hadfield 1974; Hadfield 1978). In doing so they shed calcified larval shells and, within a few hours, lose the ciliated organ, the velum, that allowed them to swim and feed in the plankton. In less than 20 hours they transform from small swimming herbivorous larvae that feed on single-celled algae into bottom-dwelling carnivorous slugs that eat coral.

Because it is easily maintained in the lab from egg until senescent death, *P. sibogae* proved to be an outstanding model

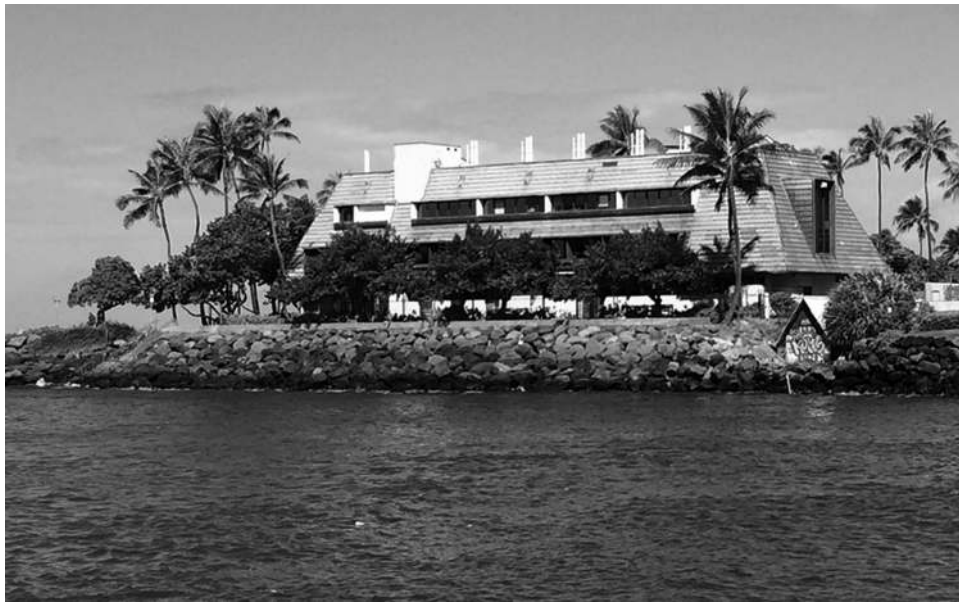


Figure 3. Kewalo Marine Laboratory, University of Hawai'i at Mānoa. A color version of this figure is available online.

organism for studying a wealth of questions pertaining to larval development, metamorphosis, and the hydrodynamically tricky processes faced by a tiny larva (0.2 mm long) that must settle only on the “right” coral to complete its life (Hadfield and Koehl 2004; Hadfield and Pennington 1990). My research team and I have published more than 40 papers dealing with aspects of the development of this nudibranch and have established it as a model for exploring the induction of metamorphosis of marine invertebrate animals by dissolved cues (Hadfield 1977, 1986*b*; Hadfield and Paul 2001; Miller and Hadfield 1990). While we now understand where and how the larva receives the coral cue for settlement, how that cue activates all the processes of metamorphosis and what those processes are, we still have no answer to the question, What is the substance produced by corals that induces all these changes in a sea slug larva? We are still trying.

Since 1990, we have also studied the settlement and metamorphosis of the planktonic larvae of a worldwide marine “fouling species” (animals and plants that create major problems because of their accumulation on the hulls of ships, docks, and pilings and in the pipes that bring seawater to cool coastal electrical plants and factories), a tubeworm named *Hydroides elegans* (figs. 5, right, and 6). These worms live in warmwater bays and harbors around the world, and their larvae settle in response to cues from bacteria resident in biofilms that are ubiquitous on all surfaces submerged in the sea. This research has led my lab into an entirely new and exciting sphere of marine microbiology and animal-microbe interactions. More than 25 papers from my lab group to date focus on experiments with *H. elegans*, its larvae, and their complex interactions with specific marine bacteria (Hadfield 2011). Collectively, studies on development and metamorphosis in my lab have formed the basis for theses and dissertations of 32 graduate students and a host of papers by postdoctoral fellows and myself. This remains a very active research area in my lab, producing exciting discoveries,

mostly on the role of bacteria in inducing larval settlement and metamorphosis (Carpizo-Ituarte and Hadfield 1998; Freckleton et al. 2017; Hadfield et al. 1994, 2014; Huang and Hadfield 2003, 2012; Nedved and Hadfield 2009; Pettengill et al. 2007; Shikuma et al. 2014). Altogether, we have published on eight marine invertebrate phyla, spanning the range from sponges to crustaceans. These studies continue to dominate my professional life.

## II. Entering the Field of Evolution and Extinction: Studies on Hawai'i's Unique and Vanishing Tree Snails

If she or he didn't know it before moving to Hawai'i, any biologist would soon learn about the many amazing evolutionary radiations that produced many unique plants and animals here.



Figure 4. The nudibranch *Phestilla sibogae* on their prey coral *Porites compressa*; two adults and an egg ribbon are above the animal on the left. These slugs are about 2 cm long. A color version of this figure is available online.

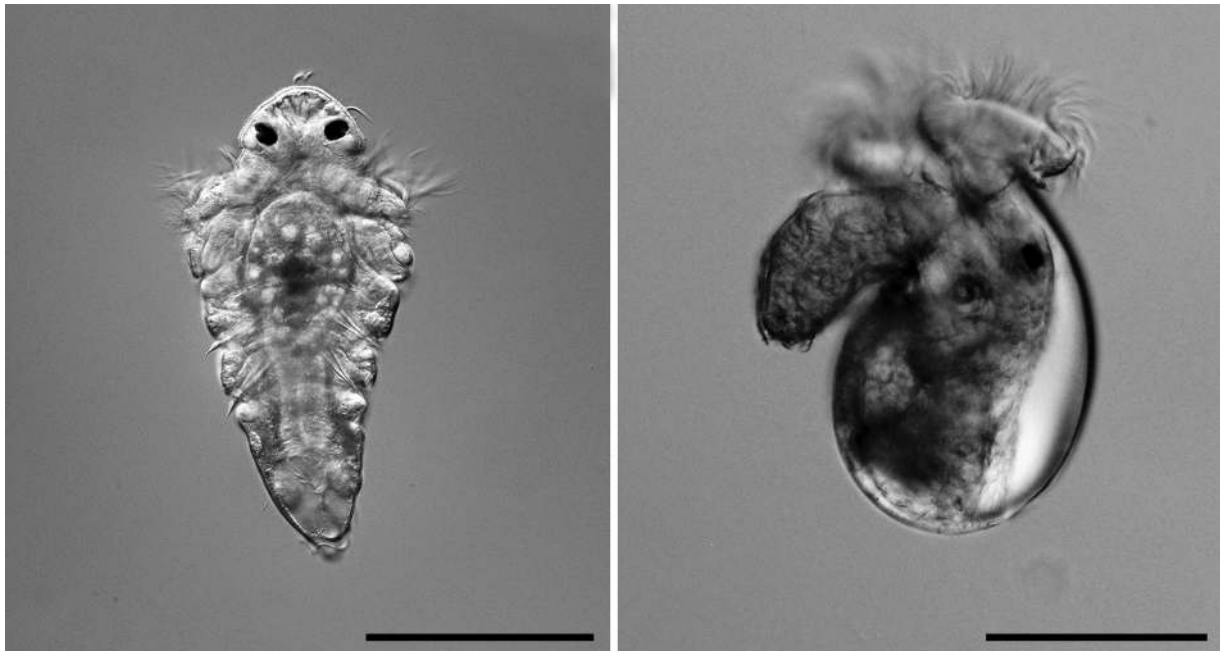


Figure 5. Larvae of, left, *Phestilla sibogae* and, right, *Hydroides elegans*. Scale bar = 0.1 mm. A color version of this figure is available online.

Among them are 11 families of land snails, including many that live exclusively above the ground on bushes and trees. I began observing the Hawaiian tree snails out of curiosity, knowing already that their handsome shells and great diversity had been recognized and publicized since the mid-1800s. John T. Gulick, a Congregationalist missionary and shell collector, had proposed a theory for the evolution of the many species in the tree snail genus *Achatinella* that proved to be correct, although not based on Darwinian evolution by natural selection (Gulick 1905). Forty-one species of *Achatinella* once graced the native bushes and trees of O'ahu, from the seashore to the mountain tops (fig. 7) (Pilsbry and Cooke 1912–1914). Unfortunately, by the time I first saw the snails in 1973, at least two-thirds of them were extinct due to the combined pressures of habitat loss (sandalwood trees harvested for export to China; large hardwood trees cut down for ship masts and spars; understory destroyed by introduced pigs, goats, and cattle; and forests cleared completely for agricultural development), shell collectors (Hawaiian tree snail shells number in the millions in the collections of museums in Hawai'i, Europe, and North America), and finally, introduced predators (three rat species, carnivorous snails from the US Southeast introduced for biological control, and most recently, Jackson's chameleons, escaped from the pet trade). As far as anyone has been able to determine, the large and richly diverse Hawaiian land snail fauna evolved in the absence of predators, so the invasion by many different species and types of snailivores had a devastating impact on the defenseless snails.

Seeking to understand why the remaining snail populations were in such bad shape and wishing to contribute to understanding of the snails beyond knowledge of their shell varia-

tions, we undertook classical mark-recapture studies on snail populations in the field that eventually spread to four of the main Hawaiian Islands. With this approach, an investigator selects a delimited area inhabited by the study species and attempts to benignly mark all of the individuals within it. For us, marking was relatively easy, because the snails' hard shells provided firm surfaces on which to inscribe "names" such as "A5." On each visit to the study quadrat, we timed ourselves to collect all the snails we could find in, say, 1 hour in a particular sector of our field site. We then, one by one, took notes on each snail, such as the color pattern, the direction of its coiling, and whether or not it had a thickened lip around the mouth of the shell, which indicates that the snail has quit growing and has become sexually mature. We measured each shell in two dimensions and assigned it an individual letter-number name, which we wrote on the shell in India ink and coated with a clear, waterproof lacquer. On each subsequent visit—usually spaced at 2-month intervals—we repeated the entire process. For each snail previously seen, we recorded its number and measured it again. We also marked and measured any snails that we had not seen previously.

Over time, the data collected from such studies allowed us to accumulate a large amount of demographic information about the snails, such as the size of the total populations, size at birth and maximum size, growth rate, fecundity, and life span. While it had long been known that the achatinelline snails gave live birth to relatively large babies 4–5 mm long (fig. 7, lower right), the understanding we gained of very slow growth resulting in very late maturity (4–6 years before first offspring), exceedingly low fecundity (4–6 offspring per year),

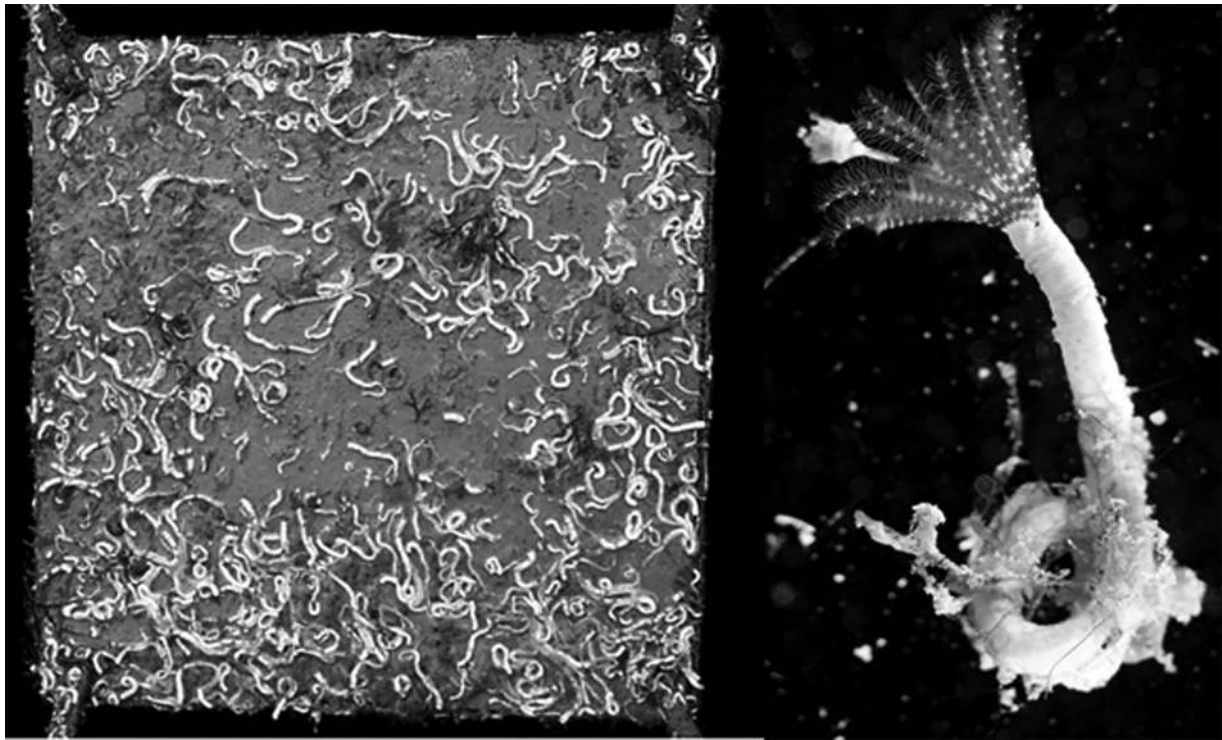


Figure 6. The biofouling tubeworm *Hydroides elegans*. *Left*, PVC plate covered with calcified tubes of *H. elegans* after being submerged in Pearl Harbor for 3–4 weeks. *Right*, single worm with its crown of tentacles and operculum protruding from its tube. The worm tube is about 2 cm long. A color version of this figure is available online.

and relatively long lives in the absence of predation (15 years or longer) was startling. No other such snail life history had ever been reported, and we found it repeated for population after population and species after species of Hawaiian tree snails. It also began to reveal why the alien predators were able to decimate entire populations in short periods of time; the snails are vulnerable to predation for up to 5 years before they add even a single offspring to the population. Learning from scratch how to analyze and illustrate the results of demographic studies was no mean task for someone not trained in ecological methods. Still, in 1982 we published the first paper to ever describe the surprising life-history details of the Hawaiian tree snails. Our subsequent papers noted the roles that both life histories and predation by alien species (including humans) were playing in the great extinction rates of the snails (Hadfield 1986a; Hadfield and Miller 1989; Hadfield and Mountain 1980).

Politics delayed Endangered Species designation for the Hawaiian tree snails. As early as 1976–1977, the US Fish and Wildlife Service (USFWS) had begun considering the addition of the *Achatinella* species to the US List of Endangered Species (referred to as the ESA, Endangered Species Act, list). As part of this effort, I began presenting our data, as well as our field observations on disappearing snail populations, to local and federal agencies in support of the listing. The listing proposal was complete and had received favorable recommendation within the USFWS by 1981. However, in January of that year,

Ronald Reagan was inaugurated as president of the United States, and one of his first acts was to suspend any new listings for ESA list.

Interestingly, I had accepted a contract from the Hawai'i State Department of Transportation in late 1981 to survey for tree snails (assuming they would be listed in the immediate future) in a valley through which a major freeway was proposed. Although billed as a route to relieve traffic pressure on existing O'ahu highways, the planned route directly connected two major military installations on the island, and indeed the funds to construct it had been transferred from the US Department of Defense to the Hawai'i Department of Transportation (DoT). As it turned out, my team and I found no living achatinellid snails along the planned freeway route (although shells from extinct populations were there), which we reported to the DoT. Very soon thereafter, the White House allowed the Hawaiian tree snails to be listed, including all 41 species in the genus *Achatinella* (Federal Register 1981, 46:3178–3182). This is the only group of organisms ever listed at the genus rather than the species level, in great part because it was impossible to know which of the 41 species were already extinct.

I had a strong suspicion that, had we found living snails along the planned highway route, because of the contentious politics around many Endangered Species designations, the Hawaiian snails would not have achieved listing until perhaps many years later. An inevitable result of our successful listing efforts was the



Figure 7. Hawaiian tree snails, all species of *Achatinella* from O'ahu, except lower right, which is *Partulina redfieldii* from Moloka'i with its offspring. A color version of this figure is available online.

necessity for us to obtain federal and state permits for all of our future research on the snails. And, sadly, the highway was built (fig. 8) despite great resistance from Native Hawaiians who valued the cultural heritage of North Halawa Valley and many ancient sites located there.

Soon after our first paper on tree snail demography appeared and the snails were ESA listed, I was contacted by state agencies and private groups to request that we conduct field surveys for the presence of the endangered snails along proposed electrical line routes and wind farms, areas subject to intense military practices, and other construction projects that would impact native forests potentially harboring snail populations. In addition, a massive hurricane hit the island of O'ahu in late 1982 and extensively damaged forests in some places, stimulating my students and me to survey those places to determine the wind's impact on the endemic snails. We were also asked to survey areas on the island of Moloka'i recently acquired for management by the Nature Conservancy and on Maui on privately owned lands where snails had been noted. Each site

required more mark-recapture investigations to understand the stability of populations and the absence or presence of snail predators. In several places we initiated studies that lasted 15 years or more, with visits at 2-month intervals (Hadfield and Miller 1989; Hadfield, Miller, and Carwile 1993; Hadfield and Saufler 2009). Not only did these studies inform about urgent conservation issues but they also provided much greater understanding of the biology of the snails and, importantly, their evolutionary history.

For example, our studies of a series of single-tree populations of an achatinellid species, *Partulina redfieldii*, whose shells show great variation in color and banding patterns, scattered across a high-elevation meadow on Moloka'i (fig. 9), enabled us to recognize that the populations were relatively recent, only 15–20 years old, and that the populations in each tree were recognizably different from each other. A study by one of my graduate students revealed that these hermaphroditic snails were capable of self-fertilizing, meaning that each one-tree population could have been founded by a single or very few individuals and

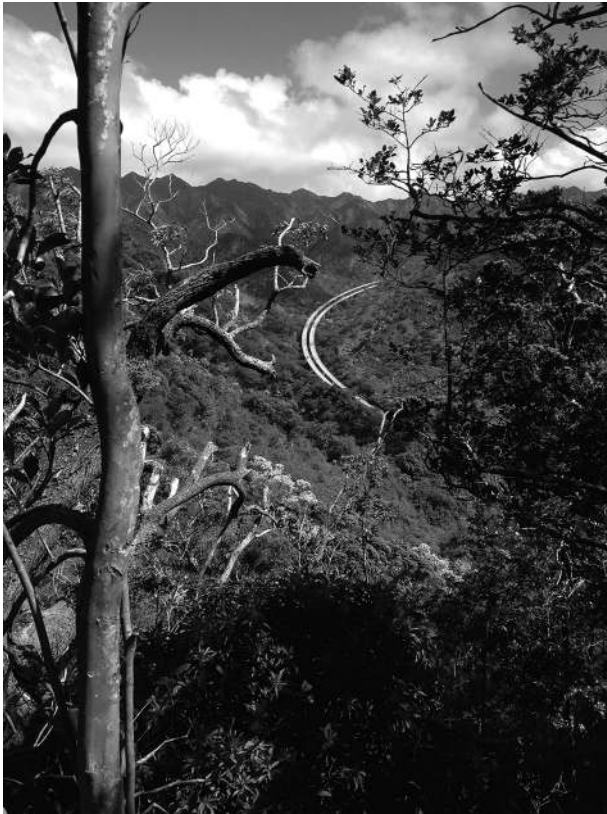


Figure 8. North Halawa Valley, O'ahu, Hawai'i, with the new freeway Highway H3 running through it. A color version of this figure is available online.

explaining why all or most of the snails in each tree had shells of only a single pattern and color randomly “selected” from the forest surrounding the meadow (Kobayashi and Hadfield 1996). These observations supported Gulick’s hypothesis that the large number of snail species found on O’ahu and distinguished only by their shell shapes and colors arose by geographic isolation of local variants of single species over sufficiently long periods of time that the differences became fixed and the variants were no longer capable of interbreeding if the populations eventually spread to a point where they overlapped. That is, typical processes of natural selection appeared not to be part of the speciation process. Recently we learned that we can extract useful DNA from the old shells we collected from the ground during our visits to the Moloka’i meadow in the 1980s and 1990s. With this DNA, we are examining the number of potential ancestors for each tree’s snail population during the years of our studies (1982–1995). That is, we are still learning new things about these snails from shells gathered in the field more than 45 years ago.

Another study we contracted was a survey of Mākua Valley, a beautiful valley on the northwestern coast of O’ahu that had been progressively taken by the army for live-fire training beginning in the 1920s (Kelly and Aleck 1997). Once a home area for many Hawaiians who farmed the valley bottom, the

steep sides and back of the valley had also been home to a wide variety of native plants and animals, including O’ahu tree snails. Conducting the searches was strenuous, in part because we could only get road transportation (in itself almost a 2-hour drive from town) about half-way up the valley and had to hike several more hours to get into the areas where the snails might be. Additionally, because of large amounts of unexploded ordnance known to be present, we were required to undergo training to recognize shells, bombs, and rockets and to understand the dangerous features of each, including more than 90 different types of exploding devices. Some ordnance was pointed out as exceptionally dangerous, for example, fist-sized golden shells shot from cannons mounted on helicopters and typically fired almost horizontally at structures. Because of the incredibly dense cover of “elephant grass” over much of the amphitheater-like back of the valley, we were told, the shells could hit the flattened grass and bounce along like rocks skipped across a lake, and not explode. However, such shells would be armed and ready to explode with any kind of disturbance, even the heat shift that could occur if one of them was shallowly buried under grass where one of us might choose to urinate! Due to these dangers, we were required to be accompanied by Army EOD (Explosive Ordnance Device) specialists, enlisted men who would precede us at every move we wished to make.

Picture trying to search a forest for tree snails where, before each move, you must tell another person, “I want to look at that tree over there,” and have that person walk ahead of you to the tree. It made for very slow going. However, we did see evidence of the danger several times, such as when we spotted an unexploded rocket lying in a dry streambed, with its fuse partly burned, and a 1,000-pound bomb we found high up in a side valley. (We subsequently noted in the local newspaper a warning to nearby residents of the area that the army had found a large bomb left over from WWII practices and would blow it up on a specified day.) And we found the snails, *Achatinella mustelina*, some in trees with bits of exploded rockets in them. Their persistence was made even more precarious because the army’s maneuvers sometimes caused the grasslands to catch fire and the fires to burn up into the native forest. Each year more forest habitat of endangered snails, birds, and plants disappeared, to be replaced by the 8–10-foot-tall stands of invasive elephant grass.

One of the field sites we had established early in 1982 was above the north rim of Mākua Valley, which gave us an opportunity to track the destruction of army practices in the valley from year to year (fig. 10). My alarm at the rate the forest was disappearing led to one of my first “acts of resistance.” I escorted a talented lawyer from the Sierra Club Legal Defense Fund (now Earth Justice) to the valley rim and showed him what was happening. Eventually, the organization filed suit against the US Fish and Wildlife Service to force ESA-Section 7 consultation between the USFWS and the army over violations of the Endangered Species Act and, after a lengthy period of legal arguing, to a now long-standing cessation of live-fire activities in Mākua Valley.





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Figure 9. The Snail Meadow on Moloka'i where we tracked single-tree populations of tree snails for more than 15 years. A color version of this figure is available online.



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Figure 10. Mākua Valley, O'ahu, Hawai'i, where the US Army practiced live-fire training for more than 65 years. Large brown scars running up the ridges are areas where the forest was destroyed by fires started by ordnance explosions. This forest is/was home to endemic snails, birds, and plants. A color version of this figure is available online.

### III. Disappearing Snail Populations in the Field Compel Us to Establish a Laboratory Devoted to Their Captive Propagation and to Construct Fences in the Field to Protect Snails from Predators

Our continuing demographic studies and more published papers brought much greater public notice of Hawaiian snails as Endangered Species and recognition that their safeguarding and recovery deserved federal financial support. We began to have our research funded by the US Fish and Wildlife Service. Grant funds allowed us to continue the field studies on three islands and, importantly, to establish a laboratory focused on rescue and propagation of rapidly declining snail populations. After extensive experimentation on ways to maintain tree snails in the lab through multiple generations, we purchased expensive environmental chambers, roughly the size of large refrigerators, in which temperatures and day-night light cycles could be set to approximate those in the field (fig. 11, right). Nearly all snails ingest their food by scraping it in with a radula, a long strap of tissue bearing rows of teeth that vary depending on each snail's food: large, tearing teeth for carnivores and smaller and more numerous teeth for herbivores. Because the tree snails feed exclusively on molds scraped from the surfaces of leaves in their host trees, we had to solve the problem of food supply by harvesting leafy branches from the native oh'i'a lehua trees (*Metrosideros polymorpha*) upon which the snails are most frequently found in the forest. Gathered at approximately 2-week intervals for the

terraria in which the snails are kept in the environmental chambers, the leaves supplied both food and a more natural substratum. In addition, we isolated a black mold species from oh'i'a leaves and learned to culture it on an agar medium; this is placed in the terraria, along with fresh leaves, at approximately 2-week intervals (Hadfield, Holland, and Olival 2004).

Over a period of 25 years we accumulated lab populations of 16 achatinelline snail species from five islands. The lab populations were started with small numbers of field-collected snails, usually between four and ten. Despite the great similarities of habitats, host trees, and life-history characteristics across the achatinellid species, their survival and reproduction in the laboratory chambers was very uneven. Some thrived from the start and quickly enlarged their numbers by births. Other populations grew very slowly or not at all. Among the latter were species such as Maui's *Newcombia cumingi*, which never increased in the lab, dying one by one until the lab population was gone. By contrast, the lab population of *Achatinella lila*, which I started from seven snails brought from the field in 1997, grew to 620 by 2009. However, in successive years, with the tree snail lab under a new manager, numbers in all captive snail populations plunged, and by 2014 only 177 *A. lila* remained in the lab. In the field, this species is teetering on the brink of extinction, with the source population now extirpated. With increased state and federal oversight of the lab operations, some of the remaining captive snail populations began to recover, so much so that by summer 2016 there were 272 *A. lila* in



Figure 11. Preserving snails in field and lab. *Left*, a predator-excluding fence built around  $\sim 120$  m<sup>2</sup> of native forest with tree snails. Under the short roof are a two-wire electric fence (note small solar panel in tree to keep the battery charged) and a trough containing rough salt, both for repelling predatory snails and rats. *Right*, an environmental chamber in the laboratory where snails are maintained in small terraria with leaves from native trees. The chambers control both day length and temperatures to simulate the field environment, and small hoses bring water for spraying the terraria four times per day. A color version of this figure is available online.

the lab. More recently, we have focused studies on the long-term impacts of captive propagation of the Hawaiian tree snails (Price and Hadfield 2014; Price et al. 2015).

From very early in our tree snail studies I was aware of others deeply concerned with the high rates of extinction of endemic island snails. Snails of the family Partulidae are known to occur mostly as single-island endemics across the tropical Pacific Ocean, from the Society Islands in the east to the Northern Mariana Islands in the west. Excellent studies had focused on these snails as examples of evolutionary radiation. British and American scientists carrying out those studies had also noted rapid decline of the tree snails on many islands in French Polynesia and set up captive breeding programs in England. In 1994, I first met people at the Invertebrate Conservation Center established by the Zoological Society of London. We began a lively exchange of information that eventually included details of the design and construction of barriers erected on Moorea Island to protect snails reintroduced from the London captive populations in an attempt to repopulate the island, whose endemic snails were thought to be extinct. I visited that predator-exclusion fence in 1998 and observed both its attributes and shortcomings. Although it succeeded in protecting the snails from London while the enclosure was frequently monitored to make certain no branches or ferns had breached its walls, such care was lost after a year or so, predators got in, and the tree snails vanished.

From my firsthand familiarity with the Moorean enclosure, I worked with Hawai'i Department of Forestry and Wildlife personnel to design and build such an enclosure around a threatened snail population within one of the state's natural area reserves. This predator-proof fence—designed to exclude both rats and the alien predatory snail—was made of corrugated roofing material buried in the ground at its base and 4 feet high (fig. 11, *left*). At the top, an outward-sloping roof protected two snail-exclusion devices from rainfall: a salt-filled trough and a two-wire electric fence above the troughs. The electric barrier was fed by a 12-volt battery kept charged by a small solar photovoltaic panel. Three lines of barbwire installed on top of the fence were there to discourage human hikers from entering the enclosure. We got in and out with an A-shaped folding ladder that we kept locked outside the enclosure. Inside the fence, we maintained rat-bait boxes filled with poison bait. It worked! The first enclosure surrounded a snail population we had monitored with mark-recapture studies beginning in 1982 and had watched it grow from about 100 snails to more than 300 by 1986, when predators moved in and devoured 75% of the snails (Hadfield, Miller, and Carwile 1993). By 1998, when the enclosure was completed, fewer than 20 snails remained. The fence has continued to protect the enclosed snails, with a current population of 40–50, while snails can no longer be found in the trees outside.

Most recently, my last PhD student, David Sischo, and his Snail Extinction Prevention Program (SEPP) crew in the State Department of Land and Natural Resources, have constructed a predator enclosure on the summit in the north Ko'olau Moun-

tains, monitored it for a year to make certain there were no predatory snails or rats still inside, and declared it ready for native snail introduction from the lab. This fence was built close to the site where the progenitors of the lab population of *A. lila* were collected, although the species had subsequently become extinct in the area. In July 2016 we carried 50 lab snails—now at least fifth-generation descendants of the original seven snails brought to the lab—to the enclosure and placed them one-by-one onto the good native vegetation there. It was a satisfying culmination of a process I had started 19 years earlier. The postscript is that Dave and his crew are continuing to monitor the snails released into the summit enclosure and have found that the snails are doing very well and are producing babies. Importantly, it has taught us all that snails propagated in the lab for many years and generations can be successfully reintroduced to field habitats. That's no small result; it is a germ of hope.

From the mid-1990s, more of my graduate students and postdoctoral fellows took on research focused on the conservation biology of tree snails, and I spent more time in the field with the students and writing grant proposals to support the research. These studies of the snails in both the field and the lab provided important new information on the biology of the Hawaiian tree snails and much greater understanding of the impacts of long-term inbreeding in the lab populations (Price and Hadfield 2014; Price et al. 2015; Sischo et al. 2016). Some of these studies reassured us that the snail lab conditions were sufficient to support growth and fecundity rates comparable to those in the field. David Sischo and his group have also established a new state-of-the-art facility for the captive snail populations, including what remained of all those we had started in the 1990s, and the snails are thriving there.

#### IV. Genetic Studies Begin: Are Predator-Reduced Populations So Small That Inbreeding Has Been Added as a Destructive Force?

In the late 1990s we took advantage of the gene-amplification technology called PCR (polymerase chain reaction) to examine DNA sequences to understand genetics of tree snail populations. We developed methods to benignly sample tissues from the snails by trying various approaches with common garden snails. When confident we could safely get useful tissue samples, we applied for permission to sample the endangered tree snails, a necessity under terms of my Endangered Species study permit. We allowed a snail to crawl on a sterile surface and, when it was fully extended, took a minute snippet of tissue from the trailing tip of the snail's foot with a sterile blade. We transferred the tissue to a small vial of 95% ethanol, took it back to the lab, and extracted DNA from it.

Subsequently both postdoctoral fellows and graduate students have used the method to do molecular-genetic studies on tree snails to explore the degree of genetic separation of small-field populations (Thacker and Hadfield 2000). The results were surprising in many ways; for example, populations of *Achatinella*

*mustelina* separated by only a few kilometers showed sequence divergences indicative of no gene flow between them for at least 10,000 years (Holland and Hadfield 2002). Such gaps are the result of the snails' very sedentary habits—one of our studies revealed that most of the snails will move only a few meters in their lifetimes (Hall and Hadfield 2009)—and the steep topography of the O'ahu mountains.

Two doctoral students combined field mark-recapture investigations with genetic-sequence analyses to better understand the genetics of small, isolated field populations and dispersal in these mostly sedentary snails (Erickson and Hadfield 2014; Hall and Hadfield 2009; Hall et al. 2010). Two postdoctoral fellows greatly expanded our understanding of the evolutionary biology of the achatinelline snails, their genetic population structures, and the genetic and demographic causes of decline in some of the laboratory populations (Holland and Hadfield 2002, 2004). A recent postdoctoral associate, Melissa Price, is carrying out pioneering genetic analyses to predict where the snails may persist despite the ravages of climate change on native mountain forests. Based on her data, "assisted colonization" trials are underway, moving highly threatened snails from current locations to higher, wetter forests in the Wai'anae Mountains of O'ahu. The combined efforts of many people and agencies, including the US Fish and Wildlife Service, the Hawai'i Department of Land and Natural Resources, and the O'ahu Army Natural Resources Program, as well as the people in my lab at the University of Hawai'i, have vastly increased

our understanding of the population biology, genetics, evolutionary history, and conservation needs of Hawai'i's tree snails.

## V. Expanding Land Snail Conservation Efforts across the Pacific

Publications from my group brought attention to both the plight of the snails and our efforts to learn enough about them to actually do something to slow or even prevent the extinctions that we were observing in the field. In 2006, I was contacted by Kath Walker, a biologist with the New Zealand (Aotearoa) Department of Conservation (DoC) and asked for advice about how to conserve endemic snails in that country. Aotearoa is home to a very different group of magnificent land snails, the *Powelliphanta* species, that feed on earthworms and grow shells 7–10 cm across (fig. 12, *inset*). Like the Hawaiian snails, the *Powelliphanta*s are being devoured by alien mammalian predators, including rats, stoats, and opossums, none native to Aotearoa. To make the situation much worse, vast areas of unique habitat for the snails are being removed by massive and growing open-pit coal mines on the South Island. Subsequently, I was asked to come to New Zealand to see the small bit of remaining habitat for one species, *Powelliphanta augusta*, just before it was removed by the coal miners, and help the DoC biologists develop a plan for conserving at least some of the snails.

It was a shocking experience. From Nelson, at the northern end of South Island, I was driven to Westport on the west



Figure 12. The huge open-pit coal mine on the Stockton Plateau, South Island, New Zealand, sole habitat for the endemic land snail *Powelliphanta augusta* (*inset*). A color version of this figure is available online.

coast, where we began to ascend a beautifully forested mountainside. Just at the top, the entire scene changed, and I found myself gazing into a giant black valley 10 miles or more across and crisscrossed by roads traversed by truly gigantic trucks filled with extracted coal. Ironically, the local name for this area really is Happy Valley (fig. 12). We drove to the top of a nearby peak, Mount Augustus, where the mine was quickly expanding. There, I was able to see both the last of the snail's native habitat and a few remaining snails in it. That entire area would be gone in less than a year. We discussed both translocation of snails in the field—an iffy procedure because closely related snails occupied most nearby habitat, and moving *P. augusta* to those sites could easily result in hybridization and a loss of the endemic diversity—and how to develop a captive propagation facility such as we had done in Hawai'i.

From those discussions, the DoC biologists built a very good captive facility for the snails and, aided by enforced assistance from the coal mining company, combed the last habitat of *P. augusta* to remove the remaining snails. To their surprise, they ended up with a massive job, because more than 6,000 snails were brought to the facility. In this lab, the snails are kept in plastic containers half-filled with sphagnum and fed earthworms of several species, all propagated on-site in large compost bins. The DoC scientists have been successful in maintaining these snails, although a major equipment failure in one chamber caused it to freeze a huge number of the snails. Sufficient snails were in other chambers to keep the species going (Morris 2010). According to colleagues in New Zealand, reintroductions have begun.

In 2011 I served as the external examiner for a doctoral dissertation by Fabrice Brescia at Massey University in Aotearoa, based on research on snails endemic to the islands of New Caledonia. From this excellent dissertation, I learned of yet another group of snails that exist only on a few Pacific Islands groups and are facing extinction ([http://mro.massey.ac.nz/bitstream/handle/10179/3219/02\\_whole.pdf?sequence=1&isAllowed=y](http://mro.massey.ac.nz/bitstream/handle/10179/3219/02_whole.pdf?sequence=1&isAllowed=y)). In addition to the habitat loss and rat predation common to all of the islands, these large snails also face a sudden and unsustainable harvest by the large tourist hotels of Noumea, where they are served as “escargot.” The indigenous Kuniés people of New Caledonia have long eaten the snails without overharvesting them (Brescia et al. 2008). As on other islands, introduced predators, loss of habitat, and human actions (bombing valleys, digging giant coal mines, and food harvesting) may soon cause the extinction of another unique radiation of life.

## VI. Going Even Farther West: An Expedition to Pagan Island Begins a New Odyssey of Fieldwork and Activism to Protect a Beautiful and Culturally Significant Place from Destruction

It is unsurprising that when the US Fish and Wildlife Service planned a series of “biological resource surveys” on Pagan

Island in the US Commonwealth of the Northern Mariana Islands, I would be asked to lead a group to survey for endemic tree snails. This group of snails is known to be nearly extinct on Guam, the southernmost Mariana island. Several years earlier, accompanying a graduate student I once advised who lived on Guam, I had seen these snails on Guam and Rota, the nearest island north of Guam. Like the tree snails in Moorea, French Polynesia, these snails are members of the family Partulidae. While most partulid species are single-island endemics, one, *Partula gibba*, was once abundant on seven or eight islands, from Guam in the south to Pagan Island in the north. However, by 2010 the species was already a candidate for Endangered Species status, having suffered depredations from most of the same predators named previously plus a carnivorous flatworm introduced to Guam from New Guinea sometime in the 1970s. *Partula gibba* had experienced drastic reductions in numbers and habitat on Guam and Saipan and was entirely extirpated on Agiguan Island. Although the snail was earlier known to occur on Pagan Island, its current status there was unknown.

By May 2010 I had assembled a group of seven well-experienced colleagues, and we were ready to head for Pagan Island. All were familiar with tree snails, how to recognize them, and how to search for them. We first traveled to Saipan, capital of the US Commonwealth of the Northern Mariana Islands, and from there, after waiting several days, we were lifted by small plane and helicopter 320 km north to Pagan Island, where we camped and searched for snails for 12–14 days.

Pagan Island is dramatically beautiful (fig. 13; see additional photos at [www.savepaganisland.wordpress.com](http://www.savepaganisland.wordpress.com)). The island is made up of three volcanoes, the southern two being inactive. We camped not far from the base of the active Mount Pagan, which smoked continuously during our stay. We first searched the forest we could reach on foot, following the collection maps of Yoshio Kondo, long-time curator of mollusks at the Bishop Museum in Honolulu, who had surveyed the island in 1949. We came up empty-handed at the northern sites where Kondo had located *P. gibba*. However, from our coastal campsite, we were fortunate to get helicopter lifts into the native forest in the large southern caldera, where we finally found the living snails. In addition to the snails, themselves quite beautiful (fig. 13, *inset*), we saw many beautiful birds, every one a native to the island. The butterflies were also diverse and spectacular, as was the great wealth of native plants. We came to appreciate Pagan Island as a very special, very beautiful, and unique spot on earth, and our reports on the tree snails of Pagan Island are the first written about this notable gastropod fauna (Hadfield 2015; Sischo and Hadfield 2017).

It is vital to stress that Pagan Island has a long cultural history. Archaeological studies have revealed that ancestors of the Chamorro people occupied the island as early as 1,000 years ago (Egami and Saito 1973; Russell 1998). I saw remains of their villages in the form of large stone house posts (latte stones) and a boulder with a deep depression from being used as a mortar for grinding nuts, possibly coconut, and other food

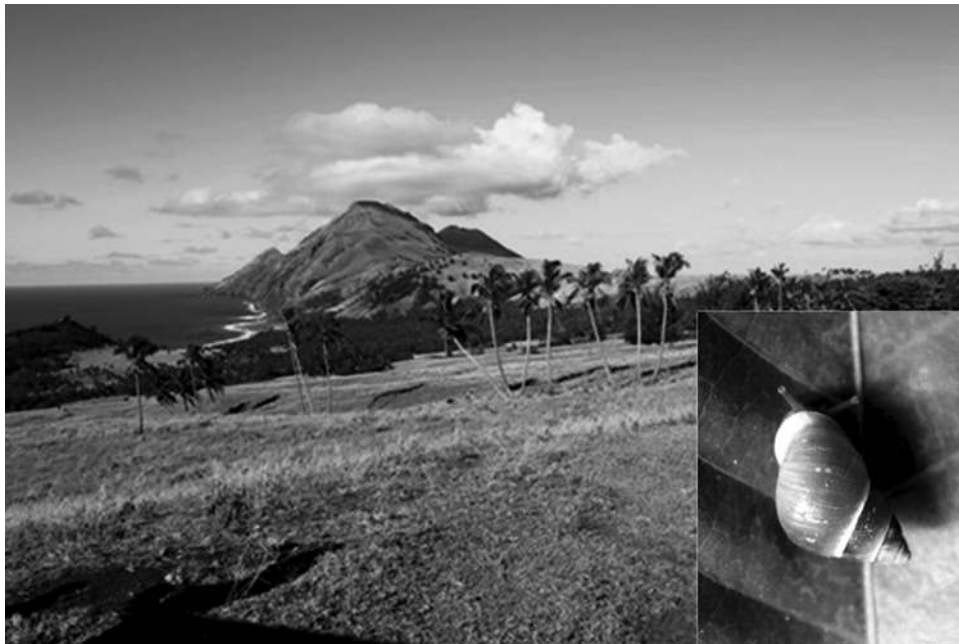


Figure 13. Pagan Island, Commonwealth of the Northern Mariana Islands, view south from the middle of the island. *Inset, Partulina gibba* on Pagan Island, about 1.5 cm long. A color version of this figure is available online.

items. Hundreds of people living on Saipan today trace their ancestry to this island, and many of them were born there. Because of this long human presence, Pagan Island is not “pristine” in any sense of being untouched by human activities. Additionally, it is hard to know how long it has been heavily occupied by pigs and goats, and cattle have been abundant on the island since the 1970s. Large groves of tall coconut palms attest to once-thriving copra production.

Beginning in the 1500s, the people of the Mariana Islands have been assaulted by a series of colonizing nations: the Spanish (1565–899), the Germans (1899–1914), and the Japanese (1914–1945). During World War II, Pagan Island was occupied by as many as 5,000 Japanese military forces who constructed the runway still used today and who drilled into the rocky headlands to make gun emplacements. The fewer than 100 native islanders living on the island were forced to serve this military occupation. The Japanese base was destroyed by US bombing toward the end of the Pacific part of WWII, and the remaining Japanese were removed from the island after the surrender. The Chamorro population was moved to Saipan by the US forces at the same time. Sometime after 1950, families began to return to Pagan Island, and farming and copra production were resumed. In this period, cattle were brought to the island and apparently retained by fences in the area around the base of Mount Pagan where two shallow lakes and springs provided fresh water.

In May 1981 Mount Pagan erupted massively, with heavy ash ejection and a lava flow that overran part of the runway. Ships in the area rushed to rescue the inhabitants, and the island was evacuated without loss of human life. The eruption likely destroyed the fences that had kept the cattle restricted

to areas around Mount Pagan, and they spread out across all easily accessed parts of the island. Today, the forest understory within the huge northern caldera from the middle of which Mount Pagan rises is nearly destroyed by grazing cattle. Large expanses of grassland have the appearance of lawns due to grazing by cattle and goats. However, the southern caldera is still home to almost pristine stands of native forest because the feral cattle cannot reach them, because of either the steepness of the terrain between them and the caldera or the absence of a ready source of fresh water. It was within this southern caldera that we found *P. gibba*, counting a few hundred snails of various colors along five survey routes (Hadfield 2015).

Because of the admiration and respect we had gained for Pagan Island during our stay there, my graduate student, David Sischo, and I were shocked when we learned of a plan being floated in Saipan to use Pagan Island as a “dump” for debris accumulated in Japan following the devastating Fukushima tsunami of 2011. The Japanese government was paying corporations to dispose of this massive amount of debris. At the same time, industrial interests in Japan had learned of the presence of large quantities of volcanic ash on Pagan Island. This ash, known as pozzolan, is a desired component of light and strong cement blocks used in housing and industry. The Japanese group proposed bringing ships filled with tsunami debris to Pagan, dumping the debris, and then filling the same ships with pozzolan, which can be mined simply by shoveling it from the surfaces around the volcano. Dave and I were so dismayed by the thought of turning this wondrous island into a garbage dump and a mine that we went “active” and created the savepaganisland website ([www.savepaganisland.wordpress.com](http://www.savepaganisland.wordpress.com)). On

it, we posted many of our photos from the island, links to news articles on the Japanese plan, and a petition resisting the plan. We set out to inform as many people as we could, urged friends and colleagues from near and far away to sign the petition, and worked to get the petition known on Saipan. Our petition quickly gained several thousand signatures, many from people in Saipan, including influential people in the legislature. The dump-and-mine plan quickly went quiet. We were feeling good.

But the “other shoe dropped” in March 2013, when the US Navy published in the Congressional Record its intention to take all of Pagan Island and much of Tinian Island, immediately south of Saipan, for Marine Corps live-fire training. Dave and I quickly edited our website to be a source for information to save Pagan Island from the US Marines. Then signatures really started rolling in from around the world. I also started writing op-ed pieces for local newspapers and speaking on the importance of Pagan Island at every possible opportunity. Not surprisingly, the navy’s supporters tried to counter our effort, but we found the media in Hawai’i, Saipan, and Guam more than willing to publish rejoinders to letters written by, for example, a Marine Corps officer who wrote, “The Marines always leave a place better than they found it.” To dare a statement like this in the Pacific was absurd, where the people of Hawai’i are terribly familiar with the status of Kaho’olawe Island, bombed and torpedoed by the Navy and Marines for over 60 years and then returned to the Hawaiians mostly posted with Do Not Enter signs because of massive amounts of unexploded ordnance buried beneath the surface. Citizens of the Republic of the Marshall Islands know all too well the histories of their Bikini and Enewetak atolls that were atomic bombed into never-enter lands and their inhabitants exposed to radiation levels so high that they suffer from many types of cancer generations later. In the Marshalls’ largest atoll, Kwajalein, the residents are crowded onto one small islet with polluted waters, inadequate schools, and income available only as workers for the US base on the largest island. Kwajalein lagoon continues to be used by the US Air Force as a target for testing missiles launched from California.

Our website and my newspaper writings caught the attention of people on Saipan, who then contacted me to begin long dialogues and collaborations. For them, I have traveled to Saipan to participate in public education and have written more news pieces. In October 2014 I spoke there in a forum on the cultural and biological importance of Pagan Island and another in Honolulu titled “Bombs in Paradise.” I have also been interviewed on the threats to Pagan Island by local and international media, for example, Radio Sputnik in Moscow, Radio Australia in Sydney, and Talk Nation Radio in the United States. Other groups picked up on our website and circulated petitions of their own, for example, the Sierra Club, RootsAction.org, and Care2.org. Together, these petitions garnered tens of thousands of signatures. All but one of these groups were willing to send us their lists of signatories, which we concatenated with our own to create a huge list, which we included in comments on the Draft Environmental Impact

Statement that the Navy released in April 2015. It has been heartening to see the strong resistance to the military takeover and destruction of Pagan Island, and it has been an exceptional and gratifying pleasure to meet and work with these individuals.

Civil Beat, a Honolulu-based online news service, reported on March 9, 2017, that the Navy received 27,000 comments on the Draft EIS and that it will not release its Revised Draft EIS until late 2018 and deliver its final decision until about 2020. I remain hopeful that the people of the Northern Mariana Islands will prevail in their resistance to US military plans to take and destroy more of their ancestral lands, islands that are also home to an amazing endemic biodiversity.

## VII. Training Pacific Islands Students and Faculty to Join Environmental Efforts in Their Home Islands

Focusing on the rich human Pacific Island community, I backtrack to 1999, when the US National Science Foundation (NSF) announced a grants program titled Undergraduate Mentoring in Environmental Biology (UMEB). The grants supported research experiences for undergraduates both during intense summer internships and in year-round programs. We successfully applied for a 5-year UMEB grant to focus on training the under-represented minority students from Hawai’i and the eligible Pacific Islands. The latter include the “US flag” territories, Hawai’i, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands, plus three independent Pacific Island countries that hold compacts of free association with the United States: the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Palau. Our program started small, with funds for only about five students per year, but grew steadily, as I was able to renew the grant and transition it to a new program when UMEB changed into URM, Undergraduate Research Mentoring in the Biological Science, with a broader scope, and to augment it with funds from an NSF Centers for Ocean Science Education (COSEE) subgrant (fig. 14).

Over 16 years, we supported more than 120 students with summer internships, including about 40 who continued in a year-round program for the academic year. A major effort in a weekly colloquium with the year-round students aimed to prepare the students for graduate school entry and completion. Most of these students earned baccalaureate degrees, at least three now hold PhD degrees, and several more have MS degrees in the life sciences. Nearly all the interns have returned to their home islands where many hold positions in schools, colleges, government agencies, and NGOs, where they contribute to the training of their people and environmental and resource management.

A major gain for me from these internship programs was building a network of colleagues at the community colleges and 4-year campuses across the Pacific. In addition to the student programs, we secured funding for faculty training programs during four summers, and focused on topics such



Figure 14. Pacific Island interns in a National Science Foundation–supported internship program at the University of Hawai‘i at Mānoa. A color version of this figure is available online.

as genetics for conservation goals, microbes in the sea, and genetic connectivity across the Pacific Ocean.

In 2017 I successfully applied for a grant from NSF’s REU (Research Experiences for Undergraduates) program aimed at increasing training and participation of underrepresented minority people in STEM. We began our program, titled REU—Environmental Biology for Pacific Islanders, with 12 island interns at the University of Hawai‘i in the summer of 2017. Throughout the 18 years I have been associated with undergraduate internship programs, my goal has been to produce a cohort of young island people who take on the identity of scientists and who recognize the huge threats that climate change, overfishing, and pollution, etc., pose for the islands, make their fellow islanders aware of these realities, and work toward mitigations and solutions.

In addition to these internship programs, in 2005 I began to teach a senior seminar for students at the University of Hawai‘i titled Science and Politics. I was stimulated to create this successful course by the assaults on so many aspects of science that came about during the presidency of George W. Bush: stem cell research, evolution, reproductive rights, and climate change, etc. It was amazing, but gratifying, to watch an excellent group of undergraduates become aware that elected officials too often are working not from a standpoint informed by science but instead from a reductive economic and frequently white Protestant Christian standpoint. The students got angry; I hope they stay that way.

#### VIII. Meanwhile, Still in the Marine Lab, We Begin to Understand How Bacteria Make Larvae Settle and Metamorphose

Our lab studies on the settlement of invertebrate larvae have led us deeply into analyses of marine surface microbial communities. From these complex communities composed of thousands of bacterial species, we have isolated single bacterial species that induce settlement in our tubeworm larvae and have examined them to determine what they make that induces settlement. We are employing the latest tools of molecular biology and genomics. To our surprise, we are finding this is not a project to simply identify chemical compounds found on bacteria or in their secretions but, rather, to examine complex structures that result from the actions of many genes. In one case, the structures, dubbed “tailocins,” are genetically derived from tails of certain bacterial viruses and used by them to infect bacterial cells with their genetic material (Shikuma et al. 2014). Other stimulating bacteria lack these structures and instead release spherical “outer membrane vesicles” (OMVs) that cause the larvae to settle and metamorphose (Freckelton et al. 2017). Utilizing an array of the latest techniques of biotechnology, our focus now is on understanding how, at the larval side, this stimulation takes place.

We have also initiated studies on the complexity of biofilms from different marine environments using the developing tools of metagenomics and their bioinformatics analyses. We



are focusing on the relative abundance of known inductive bacterial strains and finding them consistently in the “rare” category. This has led us to explore the possibility that more abundant biofilm-bacterial species may play a role. We are studying these species to determine if they are inductive for settlement of worms, snails, sponges, corals, and many other types of marine invertebrate animals.

It is exciting to be at the forefront of a developing field, although convincing the world at just this time that a marine surface microbiome is as important as that of the human gut is a daunting challenge (McFall-Ngai et al. 2013). In a time of global climate crisis, when all the characteristics of the sea are changing, what could be more fundamental than understanding the basis by which all marine communities are established and maintained through larval recruitment, from mud flats and mangrove swamps, to coral reefs and the bottom of the sea?

## IX. Postscript

Our work continues in the lab, the field, and the protest lines. In all three patches our work tries to draw together beautiful, fascinating, valuable-in-their-own-right animals and habitats in very special places on Earth—the Pacific Islands—and the best ambitions of people, including indigenous islanders, students, and scientists both native and western. Global warming is about to accelerate due to the antienvironmental, profossil fuel policies of the new administration in Washington, DC. Funding for basic research is being cut, meaning the competition for remaining funds will become even worse; pity young scientists trying to earn tenure at American universities in coming decades. At our end, we will continue to carefully monitor the navy’s plans for the Northern Mariana Islands and lend our expertise and protests wherever they appear useful. Whether we will be funded to carry through on the exciting discoveries recently made in our labs on the roles of biofilm bacteria in determining the content and survival of marine communities for more than a few more years is in question. Nonetheless, as curious and determined as ever, we will train new Pacific Islands interns and raise our voices when and where we can.

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Figure 15. *Parting Trees B*, 2010, by Satoru Abe (from M. Hadfield's collection, reprinted with the artist's permission). A recurring theme of internationally recognized sculptor and painter Satoru Abe's work is the tree form, with which he expresses many things. We found this etched print to beautifully express our shared vision of life, science, engagement, and so much more. A color version of this figure is available online.

## Following the Slime Trails of a Pacific Island Tree Snail (Marine) Biologist: The Tree Snail Manifesto, Part 2

Donna Haraway

### I. Introduction by an Ectoparasite on the Trail of a Pacific Island Tree Snail Biologist

Michael Hadfield and I have been symbionts for 45 years, beginning in a run-down wooden World War II barracks hut on Coconut Island in Hawai'i, then housing for University of Hawai'i marine biology researchers, where we lived in a kind of collective family or nest of friends in 1972–1973 (fig. 16). We moved into a commune with our oddkin in a big white house in Mānoa Valley on O'ahu the next year. These kin-making practices shaped us both. Human nonbiogenetic kin making was afoot, but many other beings settled and developed on the eager surfaces of our minds and bodies then as well. Our Tree Snail Manifesto (TSM) is a tale of those unexpected and life-changing multispecies EcoEvoDevo (ecological evolutionary developmental) events in complex natural-social holobiomes. Remember, “holo-” does not mean complete and entire, finished and whole; it means good enough to hold things together relationally, meaningfully, and dynamically at heterogeneous scales of time, place, and matter. That is what the “patchy Anthropocene” requires.

I prefer the term “holoent” to “holobiome” because the living are always entangled with the nonliving, in furling and unfurling natural-social “things,” or, to be Greekish, “ents.” In “holoents,” human beings become with each other and other



Figure 16. Snail slime trails. Max Pixel, Creative Commons Zero, CC0 Public Domain, free for commercial use. <http://maxpixel.freegreatpicture.com/Slimy-Snail-Shiny-Slime-Trail-Mucus-Carpet-474286> (accessed October 9, 2018). A color version of this figure is available online.

beings without the killing category separations of nature, on one side, and culture or society, on the other. Nature is relentlessly historical, and history is relentlessly earthly, mundane, full of entangled critters. In the TSM I trust my readers to understand holobiomes in this extended, patchy, and capacious sense.

My job is to join the TSM in the register of a science studies scholar who also resides in anthropology and biology. I situate myself as a hungry ectoparasite on Michael's narrative, sending probes into his text to provide nourishment for mine, but giving back some trace nutrients too, so that our manifesto becomes something neither of us could do alone.

Michael's Tree Snail Manifesto begins and ends with falling in love. His are exuberant invertebrate love affairs that decompose and recombine beings, including himself, in ways that perhaps only Papua New Guinea Melanesians could adequately theorize with their dividual (not individual) makings and unmakings of persons through material exchanges—yams, pigs, Land Rovers, cell phones, people to marry, cash, etc.—that, when done properly, make things grow and transform in thick relationality (Strathern 1990). These exchanges are always more than human. This is a structured, patchy relationality of a kind familiar to those who have recently transformed the biological sciences with their empirical-cognitive proposal of holobiomes. No bipedal hominid of the modernist individual persuasion stuck outside holobiomes could begin to understand Michael's rapturous fascination with weird California coastal snails. They shaped his youth and changed his life, as first loves do. These mollusks belong to the heterodox family of the Vermetidae (worm snails), which, lodged in habitats accessible from Stanford's Hopkins Marine Station, taught him everything he needed to know for his PhD thesis.

And such things he came to know! Even the name of these mollusks, appealing to worms categorized in wholly other taxa, suggests their virtuosity with form and development. By the time he had his PhD, Michael was committed to beings that did things like throw out long, sticky, mucous strings that trap their food, as well as trap the sperm packets tossed out by males intent on internally fertilizing distant females without budging from their glued-to-the-rocks positions, on which they had given up typical molluskan shell shapes for more comfortable worm-like tubes. Michael tells us that some of the Vermetidae make egg capsules in which 99 eggs nourish the single egg that will become a new snail, which will look like a worm before it is finished developing. Add to all this the compelling questions about how in the world—actually in the world, not in fantasy or science fiction—vermetid larvae swimming in the open ocean somehow respond to cues telling them to come settle on a distant bit of bare rock, metamorphose entirely, and start casting their mucous lines for food and sex. What is sending those cues? How are they perceived in such unpromising turbulent, dilute conditions? Why do the males make two kinds of sperm, one of which does not seem to have any function in fertilizing eggs? What kinds of laboratory apparatus, including electron microscopes, enabled

Michael's love and knowledge to grow? What cyborgs are afoot here? Where did marine biological stations around the world come from? How DO these mollusks make a living, make babies, make companions both technical and organic, and make their scientists? Michael was caught on the sticky threads of snails that make life-changing and paradigm-changing oddkin. Eventually, they propelled him into ohī'a trees on land to make life-changing commitments to Pacific Island tree snails.

I was a graduate student in the embryology course at the Marine Biological Laboratory in Woods Hole, Massachusetts, in the summer of 1967. The intellectual, emotional, and natural/social experiences with marine critters grounded my own subsequent work in acts of ongoing love and curiosity in ways similar to Michael's story. There is no way to swim naked after dinner in luminescent waves and then retire slightly stoned with one's grad student colleagues to the lab to watch throughout the night the first magical cleavages of an octopus egg, or cheer on the pulsating squid in the tank in their collective mating rituals, without knowing at the core of one's being that the living world is beyond measure beautiful, complex, and vulnerable.

My point is obvious: love and knowledge co-shape biology that matters. Cognitive work is affective and vice versa, or else we are in fatal trouble. Love and knowledge of exuberant diversity shape caring, responsive biologists through attraction and attachment to what is not self (or even like self), but intrinsic to co-becoming in ongoing EcoEvoDevo worlds. Drawn by a kind of "involutionary momentum" (Hustak and Myers 2012) across difference toward beauty and diversity (Darwin 1862; Margulis 1992; Prum 2017), processes evident in affinities and attractions in the chemistry at the threshold of life and ever after, Michael narrates his beginning as an act of pure science. Soon, however, driven by violent simplifications and feral proliferations in rich island worlds, rage is added to love and knowledge in a sympoiesis—making-with—that metamorphoses the story of youthful pure science into an account of open-ended geopolitical scientific practices of caring. Love, knowledge, and rage are the threads in the string figure of the Tree Snail Manifesto.

## II. A Word on Models as Work Objects for GeoevoDevohistotechno Biology

Michael's story also begins with curiosity about signaling between and among organisms that result in dramatic developmental events in the life histories of marine invertebrates. The vermetid larvae must be responding to cues to settle out of the open water onto a solid surface. Where do these cues come from, and what are the implications of answers to that question? One key branch of his subsequent work over more than 30 years focused on a scientifically cooperative nudibranch gastropod, *Phestilla sibogae*, which lives in intimate relationship with local coral. I treasure a T-shirt depicting these collaborative mollusks from Mike's lab. These Pacific

sea slugs were coaxed by the intense labor of Michael and his students to live out their entire hermaphroditic lives as working guests in their laboratory at the Kewalo Marine Laboratory in Honolulu. Michael has made a habit of inviting invertebrates inside his lab in ways that enable them to flourish there, and in the case of at least some of the threatened tree snails, with immense luck and ongoing human caring, flourish again on the outside. The Pacific sea slugs became key working models for establishing the cross-taxal communicative relationality that grounds the biological revolutions of EcoEvoDevo and the extended evolutionary synthesis, which have made obsolete expressions like "organism plus environment." Holobiomes don't work by units plus relations (Gilbert and Epel 2015; Gilbert, Sapp, and Tauber 2013; Gilbert et al. 2010; Laubichler and Maienschein 2007; McFall-Ngai 2017; McFall-Ngai et al. 2013).

Living beings are much more reciprocally each other's "environments"—or each other's "selves"—than the part-whole or units-plus-relations games allow. Co-shaping in unfolding dances of becoming-with each other is the name of the mortal earthly game. Joy and beauty are other names for attraction and attachment, composing and decomposing, merging and repelling. These are the material-semiotic actions from which natural selection must work its magic too.

Sea slug model systems in Mike's lab are among the precious crafted entities that can show EcoEvoDevo in molecular detail. Models are not metaphors; perhaps they are more like built metaphors. They are working objects, enrolling the labor of many sorts of living and nonliving entities, including technologies (Gilbert 2009; Haraway 1976; Star and Griesemer 1989). In deceptively laconic prose, Michael tell us that in more than 40 papers he and his coworkers have established *P. sibogae* as a model, now used by other workers all over the world, for exploring the induction of metamorphosis of marine invertebrates by dissolved cues. Molecules produced by the faraway coral partners tell the larval sea slug it is time to settle down. Here is such a deceptively simple fact, one that took extraordinary equipment, labor, institutions, and unexpectedly cooperative marine mollusks to establish. Happily, this is the kind of fact that can be marshaled to stand in the way of yet more violent simplifications of the living world. Situated histories and technologies are key to these practices of love, knowledge, and action. EcoEvoDevo is in string figural relationality with HistoTechno. These are patchy, cyborg worlds.

Another intensively cultivated branch of Michael's work crafted a second model system establishing the fundamental processes of co-shaping across taxa in holobiomes. Here, animal-bacterial communications between a ship-surface "fouling" tubeworm and several specific kinds of bacteria forming layered biofilms are the subject of attention, in ways the Office of Naval Research and many shipping companies find riveting. By the summer of the Tree Snail Manifesto's composition, eight marine invertebrate phyla from sponges to crustaceans had been shown to engage in necessary developmental communications with bacteria in their life histories. Signaling major changes in the conceptual foundations of biology, Geo-

EcoEvoDevoHistoTechno is full of looping multitaxal cuing and shaping. Call that metamorphosis. My point is simple: protect holobiomes in their temporal and spatial complexity, which takes a great deal of scientific labor, or say goodbye to human and nonhuman biosocial diversity. This is the lesson guiding us through the story of Pacific Island tree snails in damaged worlds.

### III. Situated Histories in the Colonial and Postcolonial Pacific

By the time Michael established his research in the new Kewalo marine lab in Honolulu around 1970, he had already worked at the Friday Harbor labs of the University of Washington, Stanford's Hopkins Marine Station in Pacific Grove, and the marine lab of the University of Copenhagen. Embedded in the history of European colonial exploration and expansion, marine stations in the Pacific are central to the story of biogeography and of developmental, evolutionary, and ecological biology. Darwin's observations on islands in the Pacific are famous, as should also be the exploits of surveying, collecting, classifying, and experimenting throughout the Pacific that are so crucial to processes of destruction and extraction as well as to protection, partial healing, and postcolonial and indigenous conflict and collaboration for flourishing worlds. In distinction from Atlantic-centric "indoor" science, historians have called the natural and built laboratories of the Pacific a vast and consequential invention of "outdoor science."<sup>1</sup>

1. See esp. Browne (1996); Esposito (2015); Jardine, Secord, and Spary (1996); Kohler (2002); Livingstone (2003); and McLeod and Rehbock (1988, 1994). The essays in McLeod and Rehbock (1994) are especially important for examining the invention of the Pacific from the point of view of Atlantic science, the use of the Pacific as a vast collecting ground and laboratory for testing theories, the development of "outdoor science," Pacific testing grounds extended to nuclear times, and the history of Pacific biogeography. See Alison Kay's (1994) "Darwin's biogeography and the oceanic islands of the Central Pacific, 1859–1909," in McLeod and Rehbock (1994). Roland Amundson's (1994) essay on J. T. Gulick confirms Hadfield's remarks on the importance of Gulick's explanations of diversification and speciation in the isolated populations of tree snails, sometimes confined to a single tree. See also Carson (1987) and Rundell (2011). Benson (2015) examines the aesthetic aspect of the Pacific Coast, the unique character of the intertidal zone, and the construction of natural laboratories and built laboratories as characteristic places for biology. See also Hopkins Marine Station (Stanford) history, <https://hopkinsmarinestation.stanford.edu/about/history>; Kewalo Marine Laboratory, <http://www.kewalo.hawaii.edu/index.php/2013-08-02-03-40-51/history-of-kml>; Friday Harbor, [https://en.wikipedia.org/wiki/Friday\\_Harbor\\_Laboratories](https://en.wikipedia.org/wiki/Friday_Harbor_Laboratories) and <http://faculty.washington.edu/cemills/FHLLTimeline.html>; Scripps Institution of Oceanography, <https://scripps.ucsd.edu/>. The Pacific is not the only or the first scene for the establishment of marine biological stations. See esp. *The Naples Zoological Station and the Marine Biological Laboratory: one hundred years of biology* (1985). See also Maienschein (1985) for the history of the Woods Hole Marine Biological Laboratory. Robert Kane, the first director of the Kewalo Marine Lab, was one of my teachers at MBL in 1967. Europe, the east coast of the United States, and

These historians argue that the seas and lands of the Pacific became a collecting ground and laboratory for testing much more than evolutionary theories. The Pacific became key testing grounds for the expansionist, extractivist, and war-saturated Plantationocene and Capitalocene with their simplifications and feral proliferations, extending histories of appropriation and of human and nonhuman genocides and displacements deep into nuclear times (Dibblin 1988; Firth 1987; Kuletz 2001; Teaiwa 2005). Although I don't think either of us thought about it then, Michael and I met each other on Coconut Island in 1971 because of these histories. I was an assistant professor hired to teach "general science" to so-called "non-science majors," the great unwashed of technoscientific knowledge industries. My students were fashion design majors and tourist management majors who were supposed to learn science as the exemplar of objective, rational knowledge, free of the pollutants of religion and politics.

The problem was, this was the middle of the Vietnam War, when the electronic battlefield and its systems-apparatus of Command-Control-Communication-Intelligence became the paradigm for militarist cyborg worlding across domains of science, politics, and culture. This was also the Pacific in which nuclear weapons testing had already blasted Bikini and Enewetak atolls, consigning their human peoples and nonhuman beings to permanent dislocation and dispossession. Then there was the matter of technoscience-fueled monocropping agriculture (sugar and pineapple, soon to be supplanted by their successor crop, namely, endless tourist hotels), which took particularly virulent forms on Pacific islands, including Hawai'i, complete with labor systems for people and plants (and hotels) that define the racist Capitalist Plantationocene. So-called invasive species are the proliferating companions of colonizing Plantationocene and Capitalocene peoples. "Introduced pests" is much too weak a term for the historically situated human beings (not humankind) who turned the Sea of Islands that is Oceania into a theater of war and extraction (Hau'ofu 1993).

Recently arrived from graduate study in Yale University's biology department, with its serious opposition to chemical and biological warfare, and from Science for the People, Civil Rights, Anti-War, Anti-Nuclear, Gay Liberation, and Women's Movement science critiques, I found it impossible to teach general science in the way I was supposed to do. Walking around downtown Honolulu the day I arrived from Yale New Haven in 1970, I was disoriented; somehow the actual layout of the New Haven green was physically replicated in Honolulu. Slowly, I learned that I had indeed landed where my own elite colonial education, paid for by post-World War II federal funding that turned even Irish Catholic girls' brains into national resources, prepared me to go: the islands where the sugar-planting families and Protestant missionaries of New England paved the way for a long history of dispossession in

Japan, among others, figure large in the story of marine stations in the history of biology.

the Pacific. Many of us did everything we could to reeducate ourselves for more emancipatory alliances, politics, and knowledges for partial healing and still possible flourishing on a damaged planet.

I have been instructed by the offspring of a couple hundred giant neotropical cane toads (*Rhinella marina*) that had been introduced into Oah'u in 1932 to control sugar cane pests. Companion species of agribusiness production science in the ongoing Plantationocene, joining the colonial destroyers of endemic species, these toads multiplied exuberantly and ate with abandon. Our home on the Islands, the repurposed barracks on Coconut Island, with its huge and scary, cautionary cane toads sitting sentry by the toilets at night, became a provocation for remaking kin and kind.

I also had begun to learn something else while I was still a graduate student in biology, under the life-changing mentorship of G. Evelyn Hutchinson, a true polymath best known for groundbreaking theoretical ecology and limnology, who fed his students on art, literature, freedom of the imagination, astonishingly diverse critters, love of place, and mathematics (Hutchinson 1978, 1979; Skelly, Post, and Smith 2010). I learned that nature is relentlessly historical, in both human and non-human metamorphoses; and history is relentlessly earthly, diverse, and mortal. I learned that historically situated natures are made but not made up, that engaged relationality is not skeptical relativism, and that human beings and their technologies are not the only actors.

Initially unsettled by the collapse of the categorical division between nature and history, I learned that conventional cells and organisms are—actually are—systems of production and reproduction organized by a hierarchical division of labor, and that they had recently become cyborgs, information systems at every level of their being. I learned that demography, cost-benefit calculations, and life tables are essential to the students of coral reefs, as well as to the analysts of life insurance companies. I learned that political economies and natural economies are much more closely co-shaped and co-shaping than terms like metaphor will ever allow (Bear et al. 2015; Haraway 1979, 1985, 1989; Kingsland 1994; Moore 2015). The actual material-semiotic entities of biology are historical; that is how they can be shaped into models and engaged in situated projects. Catholicism and Marxism both preadapted me for these kinds of ideas; nonetheless, I found them terrifying. But also, in “Western” naturecultures and elsewhere, critters are partners in knowledge making, not raw materials.

I learned that differently situated human beings and their apparatuses do living beings in their worlds differently, and critters do human people differently, with important consequences crucial to decolonization (de la Cadena 2015a, 2015b; Kohn 2013; Lyons 2014). The difference is not one of rationality versus something else, something “unscientific.” The difference is about how to do the world in sympoietic material-semiotic relationality, where love, knowledge, and rage rekindle possibilities. These things are inconceivable outside the histories I

have sketched above. For decades I have tried to work through the implications of knowing that nature is historical, and that much of that history is crafted by the relations—cognitive and material—of racist, misogynist capitalism and colonialism.

Rooted in such histories, Michael and scientists like him fiercely claim other forces of love, knowledge, and rage nurtured from the beginning in marine laboratories in order to expand them now for the work of holding open space for possible multispecies, including human, flourishing in the face of past and ongoing destruction. Multispecies environmental justice is the goal. Making peace (for snails as well as people) in the Pacific requires a militant practice. Perhaps the most important implication of realizing that nature is historical and vice versa is that revolt is both possible and necessary. The tree snails are not the only ones depending on this fact.

#### IV. Holding Open Space for Partial Resurgence: The Materialism of Caring

Revolt has many registers; caring requires many materialisms (Puig de la Bellacasa 2017). Apparatuses of caring are a fundamental matter in feminist science studies (Barad 2007). Paradigm earthquakes like those proper to GeoEcoDevo-HistoTechnoPsycho and to entities like holobiomes and holonts indicate some of those registers, materialisms, and apparatuses. They have diverse roots that do not follow the supposed nature-society divide. When I was a graduate student in the biology department at Yale, action against chemical and biological warfare, critique of scientific racism, and working with Science for the People and the Women's Health Movement were normal activities for many of us. Science, politics, and culture did not exist in separate universes, even if we did not quite know how to speak them in the same sentences. Michael's career is full of intense thinking and action tying science and politics together for barely still possible human and nonhuman flourishing on a plundered planet.

The political awakening of Mike's students was an important part of their formation as proper biologists. I have some of his syllabi from his senior seminars that he taught for many years on Science and Politics. The class originated with concern over antiscience, especially antievolution, politics in the G. W. Bush administration, but soon also took up climate change science and politics. The popular undergrad seminars were taught annually until Mike retired in 2015.

Helping write the original statement, developing the website, organizing petition drives, staffing information tables, and arranging forums at national meetings, Mike labored hard in conjunction with activists in the San Francisco Bay Area to launch and sustain the Defend Science initiative (<http://www.defendscience.org/statement.html>). Defend Science was initiated in 2005 in response to a massive wave of attacks on science unleashed during President George W. Bush's administration. These attacks occurred on many fronts and included at their core attacks on the very foundation of science—scientific

method and thinking. Circulating the statement and petition, Mike tapped a global network of scientists, mostly biologists, whom he knew personally. In his own words, Mike and his allies “decided to take the Defend Science effort to the annual meetings of the Society for Integrative and Comparative Biology.” To continue the email communication, “Carolyn [an astute socialist activist and theorist and Mike’s life partner] and I got ourselves very organized, signed up for a booth at the meetings from 2005 until about January 2015. . . . The booth turned out to be VERY popular. We printed out tons of articles on climate, evolution, reproductive rights, . . . and passed them out at the meeting. The booth was continuously crowded with people wanting to talk about all of this stuff. Our e-mail list grew and grew” (personal email, June 9, 2017). In 2007 Mike, Carolyn Hadfield, and marine biologist John Pearse “organized a near revolt within the Society for Integrative and Comparative Biology, when John and I were President (Pearse in 2007) and Past-President (Hadfield in 1996), to support a major statement about the reality of evolution. This was, of course, at the height of G.W. Bush’s totally ignorant anti-science efforts, which pale in current circumstances” (personal email, June 6, 2017). For better and for worse, the election of Obama quieted action for a time, but with the election of Trump and ensuing developments, Defend Science is again a strong part of scientists’ resistance.

Remembering the materialism of Michael’s and my own roots and branches in Science for the People, Defend Science, teaching science and politics in the same courses for graduate and undergraduate students, and other personal radical science histories, I want to assemble the practical things required to cultivate effective scientific caring. The job is to hold open space for possible multispecies futures in the midst of escalating extractions and extinctions (Tsing et al. 2017; van Dooren 2014, 2015). I want to examine more closely the registers of revolt that have to do with things like designing predator fences against hikers, predatory snails, and rats and like mentoring Pacific Island students for decades so they have the tools to repossess scientific knowledge and policy for their own lands, seas, and ecologies. Michael’s paper is full of compelling narratives and details, and so I will call attention to a few that especially touch my heart.

I enumerated things and practices crucial to holding open space for threatened Pacific Island tree snails—all of which constituted a third line of investigation, initially unexpected research and action, sustained over several decades out of urgent love, curiosity, and rage, in addition to an overfull, full-time university teaching and marine research center job. All these things happen in a holoent of researchers, apparatus, organisms, and other things. The weave of collective work is breathtaking and completely normal in Michael’s world.

My abbreviated list: designing incubators in the lab for captive propagation; determining how to feed snails in the lab with the right kinds of molds on the right sorts of leaves; gathering the correct types of leaves every 2 weeks for years; building and testing fences and barriers in the field to hold off

human and nonhuman predators; assessing enclosures and exclosures; capture-mark-and-release work; repeated surveys; organizing and analyzing life-history data; practicing assisted colonization, assisted introductions, and assisted reintroductions; making Endangered Species filings; endless research permit filings; endless grant applications and reports; hiking to out-of-the-way places; flying to distant sites; cultivating international biological collegueships; engaging state and federal apparatuses in advance of highway projects; following bomb squad technicians to avoid stepping on explosives on the way to a tree that might host a snail; studying museum collections of shells; observing habitat-wrecking coal mining operations in Aoteoroa/New Zealand; working with and training graduate students; finding and counting snails in individual trees in remote areas; not finding snails in areas where they previously were and managing the emotional consequences of repeated losses and disappearances; using the latest molecular technologies for genetic relatedness studies to understand tree snail populations and their evolution; learning to snip bits of snail tissue without damaging the animals; witnessing still more snail populations and species come under new as well as old threats (e.g., becoming restaurant escargot or further habitat destruction); and just plain putting one’s whole self in the way of the destroyers. There is more, but one gets the idea about just how materially practical research has to be to make a difference for another. The materiality of caring is richly mundane.

Solidarity for decolonizing the Pacific, this Sea of Islands, and for an emancipatory politics of the living world, human and more-than-human, demands many kinds of practices from differently situated allies. Michael’s work strengthens several decolonial threads, but perhaps the most consequential is his hands-on mentoring of Pacific Island undergraduate students since at least the late 1990s, concretized in the NSF grants for Undergraduate Mentoring in Environmental Biology. He and his colleagues continue that mentoring into subsequent study and jobs. I have been in Michael’s home in Honolulu many times over the years when he stays up nights and works weekends to nudge reluctant NSF administrators to move the bureaucracy to keep the grants coming for these students. Mentoring means intense, sustained, invisible work, like drawing on numerous scientific colleagues to visit or teach, picking up students at the airport and making sure they get continuing emotional as well as other support, hosting students in his home, responding to all sorts of emergencies, comforting students whose families experience a crisis while their young person is off island and far from home for the first time in their lives, encouraging and inspiring students to stay with their study through degrees, and addressing the state of scientific education on the islands for K–12 youngsters. In understated prose, Michael recounts the network of colleagues he has nurtured at community colleges and 4-year campuses across the Pacific. This is a network that holds open the possibility of multispecies, including human, futures on an ill-used earth.

In early June 2016, Michael organized a 2-day NSF-funded workshop at University of Hawai’i at Mānoa to better un-



derstand the reasons Native Hawaiians and Pacific Islanders encounter great difficulty in entering and completing STEM studies. The report to the foundation on the workshop noted that participants were drawn from colleges in Hawai'i, the US-affiliated islands of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands, and the compact-of-free-association Pacific Island countries (Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau). Many of these participants were members of the indigenous peoples of their islands, as well as science teachers in their colleges. The practical details of what the participants discussed are moving for their concern for the students and their explication of structural barriers, including ongoing colonialism across the islands and lack of quality primary and secondary science education. Lack of teacher training, lack of laboratories, geographical distance and lack of transportation from isolated islands where many students live to a high school or community college on a main island, financial obstacles when wages are so low, and more. Among the barriers discussed was the fact that "the Marshallese of Kwajalein Atoll are forced to live on the single islet of Ebeye by the U.S. military that uses the atoll lagoon as a target for missile practice from California, and [the military] is the sole source of income for the islanders. Very few Ebeye high-school students even graduate" (<http://hellomarshallislands.weebly.com/education.html>).

The workshop organized itself to foreground participants' ideas to address the problems concretely. For example, focusing on how skeptical students might come to trust scientific education, a participant from Hawai'i stressed, "Students pursuing environmental science, biology, and ecology see the need for native perspective in resource protection." Indeed. And so the Pacific Island tree snails have led their scientist to ideas, places, and practices that the graduate student enthralled by the vermetid mollusks could not have imagined. The geopolitical scientific practice of care changes lives across species, including across Peoples.

## V. Island Geopolitical Naturalsocial Biology

Pagan Island is the final place in this story for the metamorphosis of an island geopolitical biologist committed to multispecies environmental justice in the Pacific. Tracking the slime trails of vulnerable tree snails, the story moves from pure science to geopolitical naturalsocial biology and sustained scientific activism across many worlds of knowledge and politics. Frank activism was not new to Michael's scientific practice by the time he was asked to lead a biological survey of Pagan Island in 2010. Michael's account of that survey and subsequent developments is for me the most riveting part of his writing for the TSM. Focusing on *Partula gibba* turned out to require attention to the astonishing surviving biodiversity of this special island; the history and ongoing struggles of displaced Chamorro families who claim Pagan Island as their home island; the devastation caused by proliferating escaped cattle after a volcanic eruption; and politically slimy plans involving government officials on

Saipan and Japan to dump "low-level" nuclear debris on Pagan from Fukushima, as well as to mine vast quantities of pozzolan.

I first became aware of the nuclear waste dumping and mining when Michael and his then graduate student David Sisco "went active" in their anger and determination to protect the holobiosomes of Pagan Island. Joined by signers from around the world, many of my friends and colleagues at the University of California, Santa Cruz, signed the [savepaganisland.org](http://savepaganisland.org) petition. The impact of a multifaceted, coordinated publicity campaign was fast and impressive—but not permanent.

Three years later, the US Navy made plans to turn Pagan Island and other nearby areas into a practice free-fire zone. The "pivot to Asia" of the Obama administration was the context for expanded US militarization of the Pacific, which continues beyond Obama. This struggle will be long and hard, and Pagan Island is only one small place on the map of immense forces of international capitalist conflict in the Pacific. But it is a place that matters. What has followed for a marine invertebrate developmental biologist in love with tree snails and their knotted, entangled worlds has been a storm of sustained activism in league with diverse allies who refuse to cede this place, with its human and nonhuman beings, to destruction. Again, Michael's understatement in the TSM: "I remain hopeful that the people of the Northern Mariana Islands will prevail in their resistance to US military plans to take and destroy more of their ancestral lands, islands that are also home to an amazing endemic biodiversity."

Here, both traditional and contemporary knowledges of the sea-loving peoples of Oceania surge to the surface. Modern scientific marine labs are latecomers in crafting fundamental knowledge of the oceans and interrelated human and nonhuman beings of the Sea of Islands. Native Hawaiian and other island peoples' knowledge making and marine practices—in navigation, fishing, human-nonhuman relatedness, aquaculture, and more—were important in the past and remain important now for Hawaiian and other sovereignty movements, for recovery of indigenous ways of living, and also for crucial decolonial alliances for multispecies environmental justice and conservation.<sup>2</sup> The friction of names is important; the colonial, postcolonial, national, and transnational Pacific are not the same kinds of entity as the Sea of Islands. But the contact zones of allies are formed from the intersections, and the healing arts of living on a damaged planet require all the players.

2. See *He Wa'a, He Moku—Mālama Honua: Caring for Our Island Earth*, July 18–20, 2017, <http://hawaii.conference-services.net/programme.asp?conferenceID=4143>; the Hawaiian Environmental Alliance, <http://kahea.org/about>; and Goodyear-Kaopua, Hussey, and Kahunawaika'ala (2014). A crucial text in this context is Hao'ofa (1993). Native Pacific cultural studies is a lively field that is crucial to thinking and acting in the Sea of Islands without the many-headed separations of nature and society. See Diaz (2010). The Mariana Islands and Chamorro struggles entered the Tree Snail Manifesto via Pagan Island.

## Coda

The Pacific Island tree snails and the biologist are oddkin (Clarke and Haraway 2018; Haraway 2016). Not biogenetic kin, but something that must be even stronger in our times. Kin is about sustained relationality, about who and what are accountable to whom and what. If Michael has a snail, a snail has him; that is kinship. Donna has a colleague-friend; a colleague-friend has her; the snails have both, and vice versa. Making oddkin for multispecies environmental justice is part of an emancipatory scientific politics of and for the living world. GeoEcoEvoDevoHistoTechno turns out to be about a holobiome—a holoent—in which the threads of the pattern are relentlessly historical, patchy, natural-social, and entwined in love, knowledge, and rage. This is the geopolitical scientific practice of actually caring.

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