On the Significance of Small Dead Things

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Naturalists have an affinity for the organisms they study; yet, the practice of natural history often includes the killing of animals. This is especially true for small, aquatic invertebrates and insects. I examine this contradictory relationship between naturalists and the organisms they study from historical, scientific, pedagogical, philosophical, and personal perspectives. I also discuss the benefits and costs of the deaths of these organisms as well as alternative approaches for studying these animals. Finally, I advocate for thinking more deeply about their deaths as we explore the natural world.

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"Like most women she wished to exaggerate the significance of small deaths."

-Joyce Carol Oates, *The Gravedigger's Daughter* (2007)

My naturalist tendencies, born in a desert of Joshua trees, asserted themselves more fully when I was twenty years old and studying biology in the tide pools and kelp forests of California's central coast. Defying my poor eyesight, I developed a passion for watching tiny and bizarre invertebrates as they waved their segmented antennae from the crevices of rocky lairs or clung to algae with hooked tarsi, the invertebrate equivalent of hanging on by their toenails. I could put my mask up close to the rock wall and something new would always materialize. On one dive, I watched a decorator crab deftly prod a pink-tipped anemone with its claws until it was positioned just so between its eyes, camouflaging the conspicuous spike that jutted forward from its head. I treasured these creatures, trying not to intrude into their fluid lives.

After navigating my way through a maze of school and life experiences, I am a naturalist still, now with a decidedly ecological bent. I study benthic macroinvertebrates that live within the rocks and rubble of streams or buried in the oozy mud of estuaries. I want to know which creatures are there, and how many, so I can assess the effects of human impact on their communities. Herein lies my dilemma. Most of these animals, including many insect larvae and crustaceans, cannot be identified beyond a basic level, let alone accurately counted, while still alive. What else can I do but collect them with my nets and corers, immerse them in toxic fixatives, and bring them back to the lab for further examination? I also teach entomology, for which collecting insects is a time-honored method of exploring diversity. Yet, with the death of each animal, I cannot help but wonder, must I continue to take the lives of these exquisite creatures in order to study them?

Indeed, the death of organisms is as much a part of natural history as multi-pocketed khaki vests, and the two often go arm-in-arm. Always, these vests contain field essentials: binoculars, reading glasses, field guides, checklists, notebooks, pencils, and (for the truly prepared) toilet paper plus extra plastic bags to leave no trace behind. In addition, the vests of many naturalists house various instruments of death, otherwise known as collecting supplies: fine forceps, ethanol, labels, scissors, and of course the killing jars and vials where small field specimens are destined to meet their demise. Some of the tiny animals are kept in glass vials; others are pinned through their bodies, their wings and legs carefully positioned, and then allowed to dry. Collected organisms, viewed through a microscope's magnifying lenses, allow us to glimpse minute features such as the perfectly-aligned sand grains of a casemaker's dwelling or the jewel-like ocelli crowning the heads of bees and other insects, mingling awe with identification and forming the basis for scientific studies on human impact, habitat recovery, and biodiversity.

Systematic, worldwide collection of biological specimens was promoted by Carl Linnaeus, the 18th century physician-botanist who developed the current binomial (genus-species) system of classification. Linnaeus inspired 17 of his students, known as his

apostles, to participate in several of the great voyages of discovery, including Captain James Cook's first and second circumnavigations of the globe (Hansen et al. 2007). These voyages yielded thousands of botanical and zoological specimens, including many from South Pacific islands previously unknown to the Western world. All manner of small dead things, including insects and marine invertebrates, were well represented among the specimens. The apostles also kept detailed written accounts guided by instructions from Linnaeus, himself a meticulous and poetic writer.

In the 19th century and beyond, expeditions focused on science and natural history were launched, including the voyage of the *Beagle* (1831–1836) that provided Charles Darwin with his experiences of the variability of Earth's organisms that led to his theory of evolution, and the *Challenger* expedition (1872–1876) that explored the ocean's depths. These expeditions profoundly expanded our perception of earth's biodiversity primarily because so many specimens were collected and preserved for later examination.

So, what happens to all the dead bodies? The most fortunate specimens make their way to neatly organized collections. Aided by meticulous curators who have put their obsessive propensities to good use, they are properly arranged, labeled, and catalogued in state-of-the-art, temperature-controlled wings of the Smithsonian Institution, Muséum National d'Histoire Naturelle in Paris, the Natural History Museum in London, and other distinguished museums and universities scattered throughout the world. These vast collections, the largest three (named above) housing approximately 30 million specimens of insects each, are treasures for naturalists, systematists, and ecologists, who use them to address fundamental questions in systematics and biodiversity as well as current and crucial issues from public health to climate change. For example, imagine the potential for studying the spread of the West Nile virus and other mosquito-borne diseases by examining the millions of mosquitoes pooled from several major museums (Suarez and Tsutsui 2004).

Individuals who access collections for research often add specimens, extending the value of these collections through time. As naturalist Terry Wheeler remarked at a talk given in Austin, Texas, you can see change through time just by opening up some cabinets and pulling out the drawers (Wheeler 2011). Depending upon the particular specimens available, researchers can determine whether certain species have declined in number or altered their distributions, or even examine whether overall biodiversity has changed. Camille Parmesan and her colleagues (1999) applied this approach to European butterfly collections, providing the first large-scale evidence of northward shifts in populations consistent with climate change.

The continued value of archived specimens depends upon careful initial preservation coupled with long-term maintenance by the dedicated curators. A vast number of invertebrate specimens have been conserved for over a century within museums around the world and are accessible to qualified researchers. Many museums also have created digital archives. For example, the portion of Carl Linnaeus' insect collection that made it into the 21st century has been preserved both physically and with high-resolution photographs by The Linnean Society of London (2014). Anyone connected to the Internet can access the online archives of this collection and zoom in on the minute details of thousands of insects that have been dead for nearly three centuries.

Unfortunately, collected animals often suffer a more ignominious fate. Many of Linnaeus' zoological specimens deteriorated due to neglect, careless handling, and shoddy record keeping after his death (Dance 1967). Another egregious case of curatorial malpractice is associated with the United States South Seas Exploring Expedition of 1838–1842, America's little known voyage of discovery that led to the founding of the Smithsonian Institution. Some of the most delicate marine specimens from the expedition were mistakenly removed from their preservatives by one of the fledgling Smithsonian's curators (or perhaps one of his charges), who then dried and pinned them like insects (Philbrick 2003). The curator was fired and replaced with one of the expedition's naturalists, but the damage was already done.

Similar, but perhaps more understandable, displays of maladroit specimen handling can be observed as my entomology students prepare terrestrial insects for their collections. The insects' spindly legs and antennae often break off their brittle bodies while their bug-eyed heads roll across the table and are hastily plucked from the floor by sharp-eyed students. The students frantically deal with these setbacks with liberal applications of glue and creativity, sometimes reassembling insects with heads on backwards or upside down. Such liberties undermine scientific integrity; imagine a hapless entomologist of the future puzzling over piercing mouthparts that stab upward, and erroneously concluding that these insects ambushed their prey from below.

For those samples that make it unscathed into their collections, the triumph can be short-lived unless the collections are properly maintained. The specimens are subject to attack by dermestid beetles that, apparently

undeterred by the sight of their dead brethren in compromising positions, weave their way through the rows of bodies and devour them one by one, leaving behind pins and piles of dust. In wetter climes, specimens are also attacked by mold. While many students and other amateur collectors may desire to take care of and treasure their collections by properly freezing them or utilizing fumigants (usually rather toxic), most will not have the means or motivation to stave off the eventual decline. So, although the idea of assisting enthusiasts in building their own collections may seem like a way to encourage budding naturalist-scientists, we must weigh this against the ultimate fate of their collections. Are we inadvertently reinforcing a shopping mall mentality, teaching these students that insects are just another commodity to be dutifully acquired, admired, evaluated for a grade—and then forgotten?

What about the collecting experience itself? In my long-term study of the impact of a small town on the stream that runs through it, my students and I remove rocks from the streambed and disturb the underlying gravel and sand to dislodge the invertebrates. Thus exposed, the current sweeps the animals into our awaiting nets. From there, we plunge them into jars of ethanol where they writhe around for a while and then die. We carefully reposition the rocks to make it seem as if nothing has happened. While we do not quite destroy the village to save it—this is more like a targeted drone strike—we certainly ravage a small part of it. My students are often solemn as they watch the insects succumb to the ethanol.

Yet, the behavior of naturalists in the wild as they hunt their quarry is more often lively than somber. My invertebrate zoology professor, Dr. Donald Abbott, walked with a slight limp, a permanent remnant of a bout with polio that nearly killed him, but he was indefatigable on collecting trips in the rocky intertidal. He leapt agilely among boulders and over deep pools, overturning rocks and gleefully picking off tiny invertebrates that would have remained hidden from a less skilled hunter. It seemed that his thick black glasses gave him x-ray vision, as he knew exactly where to find the richest caches of his prey. I was part of the boiling wake of students behind him hauling buckets packed with wriggling, slimy creatures. We slipped on algae and scrambled to keep up with him, like bear cubs sliding on water-slickened river rocks as they mimicked the movements of their mother hunting for salmon. And like the cubs, we became ever more competent, jubilantly shouting to each other as we found our own treasures to add to the buckets. Perhaps an affinity for the hunt is essential to being a good naturalist, a way of cutting a hole in the fence that separates us from the wild animals we hope to understand.

Acknowledging that I may be partly motivated by the joy of the pursuit prompts me to think more honestly about how I view other animals. I reject the belief of many people who see the living world as subservient to human needs and desires, yet my own relationship with nature is complicated and often contradictory. I need to eat to survive; I willingly play my role as an omnivore in the food web and truly enjoy a juicy, well-seasoned steak with nary a thought of Bessie's big, brown eyes, but I buy my beef only from local ranchers committed to humanely raising grass-fed cows. Similarly, I devour Dungeness crabs with reckless abandon, greedily cracking the exoskeleton of their legs with my teeth to extract every morsel of tasty flesh, but limit myself to locally caught, sustainable seafood, pulling out my handy Monterey Bay Aquarium Seafood Watch guide (2014) from my wallet at markets and restaurants as needed. I smack mosquitoes dead when they attempt to suck my blood, unwilling to be a hapless host to the parasites they carry, but I gently trap spiders I find in my home and release them to the outdoors. Like most naturalists, I love animals but also kill them in pursuit of scientific knowledge. Is this out of need or desire?

In fact, there is much we cannot learn from the dead. This way of studying the diversity of life illuminates the diversity but not the lives of the collected animals. It is no accident that much of what we know about animal behavior and life history strategies has been learned from birds. Birds are more easily observed and identified than many other animals; we can watch them establish territories via song and flight, engage in courting rituals that often feature exaggerated movements and bright plumages, and raise young in nests often visible with the naked (or binoculared) eye. Earth's smaller inhabitants are also amenable to field observations and experimentation in the wild, although this requires more effort and ingenious methodology. Indeed, the seminal work in animal behavior conducted by Konrad Lorenz, Niko Tinbergen, and Karl von Frisch, for which they shared the Nobel Prize for Physiology and Medicine in 1973, was heavily based on field studies of insects as well as birds and fish.

I have always admired Tinbergen's research on the homing and hunting behavior of digger wasps, which he sometimes studied by observations alone, and sometimes by cleverly (but only temporarily) manipulating their environment in order to test his hypotheses. Evident in his writings is the incredible time commitment required for this approach. In *Curious Naturalists*, Tinbergen (1969) writes about his quest to observe the bee-capture behavior of these wasps. "I

began by spending a couple of days sitting at the north-west edge of the heath and was actually lucky enough to observe the full hunting behavior a few times," Tinbergen notes. He later reveals, "It had taken us five summers to build up this picture of the life of bee-killers." The focus, patience, and above all, time, necessary for this level of detailed observation stands in stark contrast to the high-paced acquisition of data expected in modern science and contemporary life in general.

I sometimes wonder if I tend to efficiently collect and kill invertebrates, rather than spend more time in the field studying living animals, because it seems the expedient thing to do. Weeks after such collecting adventures, with indentations circling my eyes from leaning on the microscope oculars for too long, I realize that I have grossly underestimated the time and patience needed to identify and count all the tiny invertebrates. Despite my best efforts, boxes of yet-to-be examined specimens and ice cube trays of partially sorted samples accumulate on my laboratory floors and shelves like cats and newspapers in a hoarder's home. Thus, I find myself more carefully considering the merits of field observation.

Advances in imaging technology may make a shift from collecting small, dead organisms to examining them in their natural state more feasible and less time-consuming. Doctors routinely wind tiny cameras through our gastrointestinal passageways to diagnose and treat disease. Similarly, the use of miniature cameras has become part of the repertoire of biological studies and has led to some brilliant films exposing once hidden behaviors. Sir David Attenborough, British naturalist and broadcaster, and his film crew have allowed us to follow individual ants along the winding corridors of their colonies. We have witnessed them communicate with complex antennal interactions and carefully carry larvae in their fierce jaws. Scientists studying the world's zooplankton now deploy visual plankton recorders to survey the density and diversity of these tiny, drifting animals. Although they cannot yet identify most individuals to the species level, this technology is promising. Imagine what Tinbergen might have done if he had been able to combine his observational acumen with our modern tools.

Recently, Minteer and colleagues (2014) suggested that technological advances, including high-resolution photography, audio recording, and tissue sampling, could replace collection of individuals from rare or rediscovered populations. Unfortunately, identification of most small invertebrates requires careful microscopic examination, and many invertebrates, such as those buried in the estuarine mud, cannot be found unless they are actively sampled (Rocha et al. 2014, Wheeler 2014). Thus, I continue to collect invertebrates from estuaries and streams to study human impact and ecosystem recovery, aware that I might occasionally take rare individuals. Perhaps in the near future, advances in technology similar to the plankton imaging systems now in use will allow me to peer beneath rocks in streams, identifying and counting the insects present without having to remove them from their habitats. Such tools might even allow me to use behavioral characteristics of the animals, rather than merely their abundance and diversity, as indicators of ecosystem health.

Decisions about the relative merits of collecting extend into my role as a teacher. As I consider the growing availability of stunning insect images, the value of field observations, and the often-pitiful fate of student-collected specimens, I ponder shifting the focus of my entomology class to emphasize field observations and photography rather than creation of collections. In such a revised course, students would still have the opportunity to explore insect diversity and minute details of anatomy by examining previously collected specimens along with photos and videos.

Unfortunately, such a change could deprive students of an opportunity for exploring our messy and often contradictory relationship to the natural world. For example, in the process of hunting for insects to include in her collection, one of my students discovered that her yard was eerily devoid of insects, reminiscent of Rachel Carson's *Silent Spring* (Carson 1962). Like Carson, my student connected this lack of fauna to the use of pesticides; by the end of the term, she had stopped applying toxic chemicals to her yard. So, although hundreds of insects died for her collection, her decision to ban pesticides from her home will likely save thousands of insects and other inhabitants of her backyard, perhaps even her own children. Additionally, while the prepared insect specimens of most students fall well short of professional standards for pinning and spreading of wings, some students become remarkably skilled at these techniques. If I continue to guide students in creating their own collections, perhaps one of them will become the curator of centuries-old specimens collected by Linnaeus, Darwin, or other esteemed naturalists who participated in voyages of discovery and natural history.

Will it ever be possible for me to return to where I began, content to watch in wonder and leave the small live things to their own fates? I realize that the small deaths I have caused, and perhaps those caused by all of the naturalists in the world in the past century, are miniscule in scope compared to the deaths caused by habitat destruction that has paved the way for mega-

malls and high-rise hotels. Moreover, as Ed Ricketts and John Steinbeck suggest in the log from their Sea of Cortez expedition, perhaps an animal cannot be fully understood unless it has been studied in multiple ways: dead and preserved, in its natural habitat, and in aquaria (Steinbeck and Ricketts 1941). Nevertheless, what I have learned from small dead things has increased my reverence for them, and has led me to re-examine my own practices as a naturalist, scientist, and teacher.

If, as the founding president of the Natural History Network suggests, the practice of natural history is meant to "encourage our conscious, respectful relationship with the rest of the world and affirm our sense of beauty and wonder" (Fleischner 2011), then it is essential that we weigh the costs and benefits of the deaths of these small, but not insignificant, animals to ecosystems and to ourselves. We must acknowledge the naturalist's paradox of both loving and killing other animals, and think deeply about when and why we kill as we explore the natural world.

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