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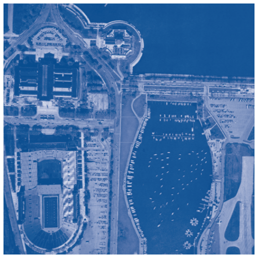

Art Shapiro has spent forty years walking the same ground we walked together, every two weeks stopping to count butterflies and monitor the effects of weather and climate on insect life histories. Through his constant and close observation and study of butterflies, he has become one of the leading researchers of changing climate as well as changing landscape in the United States. Art sees butterflies as colorful fellow travelers and spirit guides, their human impact spanning from folklore to their role in research. Citing drastic declines in butterfly populations from 1968 to the present, Art describes butterflies as "the proverbial canary in the coal mine of climate change." For all forty years, his field studies have been documented on index cards, their hand-written data only recently translated digitally through a National Science Foundation grant, quantifying a mountain of data on more than 150 species and subspecies, one of the largest and most distinctive databases of its kind. He hand-writes weather forecasts too, posting them in the halls of the Evolution and Ecology building where he works. He has forecasted tornados in Sacramento (where they are an extreme rarity) and snow in the Sierra Nevada Mountains in June (when it never snows), signaling his sensitivity to his research on climate, and the climate's sensitivity to human activity.

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ART: The white flowers on the shrub over there are Mexican blue elderberry, which is the host plant of the federally endangered but soon to be de-listed Valley Elderberry Longhorn Beetle. And that's an Acorn Woodpecker there (pointing to the sky). Most years, we have two pairs of bluebirds and a pair of Phainopeplas, but this year none of them have shown up, and I don't know where they are. We do, however, have a nesting pair of Red-shouldered Hawks here who may have eaten them. Up there (pointing to a dead oak tree with many small birds roosting) we have the Acorn Woodpeckers, which are colonial – ten, fifteen, twenty of them gather in one area and they raise their young communally.

MICHAEL: How many mammals and birds are communal?

ART: Communal mammals and birds are fairly uncommon. There has been a lot of behavioral ecology work done on Acorn Woodpeckers. They make holes in dead trees, just the right size, and then stash acorns in them for the winter. So if you get up close there, you'll find the whole tree is riddled with holes and some of them contain acorns they never got around to eating.

We've had twenty-four inches of rain this year, which is probably about five inches above average. Look at the American River (pointing to the river). The San Juan rapids are down there, and I'm frankly surprised there's nobody kayaking or rafting. They are a favorite danger spot.

AMY: We saw a double-wide inflated sofa floating down there a few minutes ago.

ART: This is horehound, an introduced plant; it's an extremely important butterfly nectar source. And it's of course the source of horehound candy.

AMY: This landscape you're describing for us, where are we right now, and how does it relate to your research?

ART: We are at Rossmoor Bar, a regional park in Rancho Cordova on the banks of the American River. Rancho Cordova is one of my permanent field sites, it has been since the mid-1970s, and I've been monitoring it in two-week intervals all of that time. This is a particularly interesting spot because the gravel bars provide a refuge for butterflies. We have an unusually rich and interesting butterfly fauna here, and it gives us a glimpse of what might have been here before Europeans colonized California *(FIG. 1)*.

If you look straight ahead, you see some dome-shaped bluish gray plants. That's the best plant here. That's Wright's Buckwheat, and this is one of only two places in Sacramento County where it occurs. They are always coming up with plans to re-vegetate this and remove that, and I worry about the native plants not being recognized as being important. About an hour ago, I had a meeting with two folks in the American River Natural History Association, and I was relieved that they knew about them. This is another good plant here, the Native Everlasting.

AMY: And when we were walking up here we saw a black butterfly, what kind is that?

ART: That was a Pipevine Swallowtail, which is just about the commonest thing here. We'll probably see its host plant and maybe the caterpillar up there among the oak trees, it feeds on California Pipevine, which is a native plant. The plant is poisonous and the caterpillar takes up the poisons, stores them, and passes them through the whole life cycle so the adults have them too, which means they are not edible to the birds. The adults can live more than a month and they pass the poisons on to their eggs, so the eggs are not palatable either.

AMY: Your research sites

follow along a line, with one in lower altitude and another in higher altitude relative to this, right? How did you establish these different locations?

ART: When I first came to California, I spent most of the first year scouting out potential sites. I wanted places that had the following set of characteristics: a good butterfly fauna, relatively diverse vegetation, easy access, and a low probability of habitat loss due to development.

AMY: Have those criteria stayed constant? I noticed when we were driving in that this was a really developed area.

ART: When I started coming here, most of the surrounding residential neighborhoods didn't exist. This is in the corridor of the American River parkway, so it is presumably secure from development. Every once in a while, one of the governmental agencies that has a share in the administration proposes something new by putting in tennis courts or boat ramps. But now that the appropriate authorities know about the rare plants in this immediate area, I think that it should be safe. But the river itself is erosive. So if we come back in 500 years, the rapids will have cut away all of that bank and be back there maybe an eighth of a mile.

AMY: Thinking about the *Powers of Ten*, what magnitude of ten do you think you align with?

ART: I have different research programs that do different things. The one that is represented by the place that we are in right now involves nested localities within a regional context. So the individual localities are each contained within a square mile, comprising north-central California from the Bay Area to the great basin. Where would you put me?

AMY: Probably 10^4, maybe 10^5 where you can see the whole region.

ART: Although you can't really see the whole region at once, you must construct a regional picture by putting localities within the region together. GPS helps, but there's no substitute for truthing on the ground.

AMY: If we situate things, thinking of the picnic as the island of knowledge in your field, what would we find if we dig down forty years to the making of *The Powers of Ten*? What's the pursuit of knowledge then as compared to now in your field?

ART: The single biggest advance in my field is evidenced by the book *Evolution and Ecology* by K. D. Bennett, which is, as the title suggests, about the interface of evolution and ecology. This book came out just before the development of what we call phylogeography, which is studying the geographic distribution of genetic variation. This enables us for the first time to do rigorous testing of historical biogeographical hypotheses. So, say there is a butterfly found here and also in Trinidad and Tobago and also in North Wales – we could spin a hypothesis about how it got that weird distribution. But now we know how to use genetic markers to say this population moved from point A to point B at such-and-such times. If we look at a lot of different organisms with similar or related distributions, we can construct a complex scenario for the evolution of the fauna and flora of that region. I took a course in biogeography in 1965 and at that time the professor said to the students, "if you are lucky, the question of whether continental drift is a viable hypothesis will be settled in your lifetime." As it turned out it was settled within five years. Just as that has had tremendous implications for biogeography, the revolution in molecular genetics has enabled us to say much more authoritatively what happened in the past than we could when I was starting out. Back then we could make up stories. Now we can actually test them rigorously!

Amy: And that's due in part to the shift in tools that have been available?

Art: It's partly due to a guy named Kary Mullis, a biochemist who invented something called PCR (polymerase chain reaction), which is a lab technique for taking a really small sample of DNA, like you might get from one insect antenna, and amplifying it, getting it to reduplicate itself until you have a big gob of DNA that's easy to sequence. You can do that with ancient DNA if it isn't too degraded, so you can get DNA from museum specimens collected in the 1800s or even earlier in some cases, or even potentially from insects trapped in amber.

Amy: And what is that doing?

Art: The other book here is relevant to that, *Frozen Earth* by Doug Macdougall. We live in a time of rapid climate change, despite the fact that the extractive industries are being fairly successful at convincing the public that it's all a conspiracy of left-wing scientists, it is happening. It's real. If we want to understand the biological response to climate change, we have ample information to allow us to do that. As the book says, we now have a very detailed record of the climate change in the last two million years, which encompasses the so-called ice age, the Pleistocene, and the so-called recent Holocene, which is really just the current warm interval between ice ages, since we're overdue to start another one. And you can make a good case that the warming we're seeing right now is a run up to the next ice age and is actually facilitating it. If you combine the genetic information with the paleo-climatic information, it enables you to make well-informed predictions about how organisms will react to climate change.

Amy: So where do butterflies fit into this?

Art: Butterflies are very good animals to study because they're just the right size to do a lot of stuff. They are big enough that you can treat them as individuals – you track them in the field and mark them and see how long they live and where they go. And, they're small enough that you can mass-culture them in the lab. I mean there are advantages to studying elephants, and there are advantages to studying fruit flies, and butterflies are somewhere in between.

Michael: The butterfly is probably one of the most beautiful creatures too.

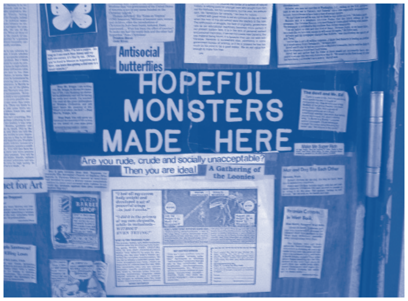
Art: They're charismatic.

Amy: Was your attraction to studying butterflies the beauty?

Art: Who knows? I was eleven when I decided I was going to study butterflies. In junior high, I read the book *Evolution: The Modern Synthesis* by Julian Huxley, which made me a convinced Darwinian. Then I went to college and my advisor was a distinguished ecologist, Robert Macarthur, and I discovered that I could put ecology and evolution together, work on butterflies, and make a career of it.

Amy: What is the function of a butterfly?

Art: There are no functions in nature. There may be a creator and the creator may have intentions, but I don't claim to know what they are. We know the functions of organisms in the sense of what they do, for example in nutrient and energy transfer in ecosystems, but we don't know why butterflies exist. That's not a meaningful question in science because it's totally unanswerable at any level. What's the most fundamental question in philosophy? I believe it was Heidegger who asked, "Why is there



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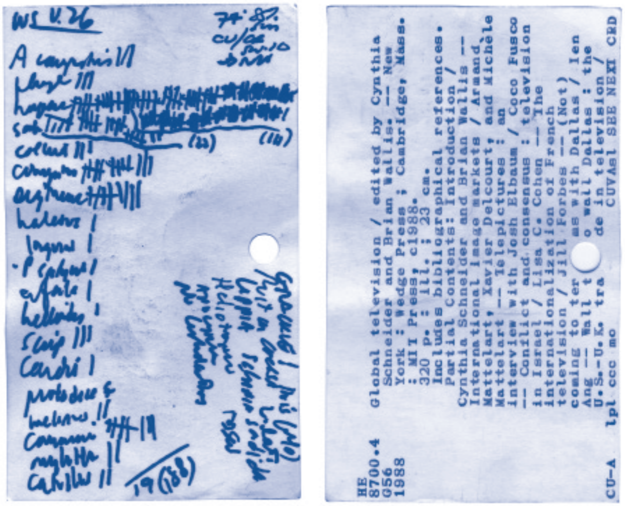

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something rather than nothing?" It's the same question, really.

(FIG. 2) The late Bob Schuster, curator of the UC Davis insect collection and kind of a wild character, used to print up bumper stickers. I had him make a batch for me, including "Ban the Sphragis" (a sphragis is a vaginal plug secreted by certain male butterflies that prevents the female from mating again), "Everything you know is wrong," "Hopeful monsters made here" (alludes to a term coined by the geneticist Richard Goldschmidt as shorthand for a useful mutation), "The number of rational hypotheses that can explain a given phenomenon is infinite." I gave them away, but kept a set in the lab, some of which you saw. I'm sure nobody who saw one on the road would know what "Ban the sphragis" or "Hopeful monsters made here" meant!

AMY: And then someone would ask, "What is nothing?"

ART: Nothing is the intellectual content of most of what you see in popular media. Unfortunately.

MICHAEL: I'm curious about the tools you use to do your research. I've seen you walk around and you write notes on these index cards, very low tech. What happens when that goes back to the lab?

(FIG. 3) Art logging species with pencil on index card: One Pipevine Swallowtail.

ART: It's entered in our computerized database. My data collection is low tech, and the data analysis is cutting-edge computerized statistical method, which isn't as fun until you get the output and it makes sense, which it occasionally does, but not always.

(FIG. 4) Field notes taken on discarded library cards.

AMY: In the movie, they start with this couple picnicking and they zoom out all the way to outer space and back down into molecular space, both places we can't see with the naked eye. Michael and I were interested in staying on the picnic blanket and in the human scale, traversing through ideas instead of space. So how do you humans factor into your research?

ART: Humans have a role in the climate change that's occurring. Defining that is controversial but it certainly exists. It's uncontroversial in that land-use change is human driven, and our analyses suggest that land-use change is a bigger driver of butterfly change than climate is. That is to say, butterfly habitats are being transformed for human use, and what that does is fragment the remaining habitat in such a way that patches become isolated from one another, and it's very difficult for butterflies to find and colonize them. So although the total amount of favorable habitat may not be diminished, its accessibility is greatly reduced, and that means there's a much higher probability of local and even regional extinction as a consequence.

AMY: Has there been a time in your practice where you saw these effects of the human expansion on these species in defense of them, like stopping development?

ART: The biggest impact I've had along those lines involves a beetle, not a butterfly. It's the famous Valley Elderberry Longhorn Beetle, which was very influential in regulating development in the riparian habitat (the interface of land and water) here in the Sacramento Valley for several decades beginning in the mid-1970s. I was one of the people who helped get that beetle listed as a federal endangered species, so the habitat was protected. It's about to be de-listed, because recent surveys have indicated it's more common than we used to think. That beetle was instrumental in helping to save riparian habitat and maintain that continuity, and now it remains to be seen what happens when that protection is removed. As one of my professors at Penn was fond of saying, "No matter how much you plan, you end up being overtaken by events."

AMY: When you were talking about the advances in your field from then to now, you were saying that histories can be reconstructed based on the DNA of these beasts, and that provides an amount of certainty. Do you feel there's any margin of error in that?

ART: There is always a margin of error.

AMY: For me, science is a lot like art, in that there's this idea or an articulation of an idea that needs to be materialized in order to communicate something you're trying to figure out, but that you're not certain of yet.

ART: Well, the fundamental difference between science and art is that science is constrained to take reality into account, whereas art is suggestive and should transcend reality. We can't just tell a story; we have to have it grounded in reality and there's always a margin of error in that. For example, as the species becomes rarer, the probability of seeing it goes down, you get more false negatives. I didn't see the Acmon Blue today, but I had a student in the field at the same time who was specifically looking for Acmon Blues, and she saw three of them in the three hours. Are you familiar with Karl Popper's take on falsifiability as the demarcation line for science?

MICHAEL: I'm not.

ART: Well, the philosopher Karl Popper says that to qualify as science, an idea has to be falsifiable, so at least in concept there has to be something that would cause you to reject it. If you cannot think of anything that would cause you to reject it, then it's metaphysics, it's philosophy of religion, but it's not science. So if I said I believe that there is

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an invisible green hippopotamus sitting twelve feet over there, there is nothing that could falsify that because it's invisible, right? I may have taken LSD when you weren't looking, so that's not a scientific concept. On the other hand, if I say I believe the wind is blowing about five miles per hour from the southwest, that's testable and if it's really blowing forty-three miles per hour from the northeast, it's false. You cannot say that because you didn't see something it wasn't there; you can only say you didn't see it. Absence of evidence is not evidence of absence. So the fact is that because we know many butterfly species are getting rarer, the probability of seeing them goes down, which is to say we register fewer positive records of them, which will in turn enhance the appearance of them going extinct.

Amy: So what is all of this knowledge doing? Where is it getting us, and why are we all running around trying to prove hypotheses?

Art: You never prove a hypothesis; you keep trying to falsify a hypothesis. If you get evidence that supports a hypothesis, that just means it isn't dead yet. The longer it lasts, the more tests it survives, the more confidence you have that it probably is true – but you can't prove it's true.

I teach a course called Principles of Systematics to show the students what it means to classify things. Students typically come into college with the naive belief that there is an order in nature and all we have to do is document it; they don't realize how theory-laden classification is. The students are organized into teams; each team gets an identical set of nuts and bolts and screws and staples, and they generate a classification as if they were organisms. Then we have a symposium, and they put their classifications up side-by-side and proceed to argue about why'd you do one thing, and how another thing doesn't make any sense at all. They are supposed to put aside any knowledge they think they have about what these objects are or what they are used for and treat them as biological organisms, and I deliberately give them some really difficult organisms that give contradictory clues as to who they are related to. I'll show you a couple of objects that cause trouble. What is this?

(FIG. 5) Various hardware used to teach Principles of Systematics.

Amy: It's a hook.

Art: It's a cup hook. But is it more closely related to screws, or screw eyes? Who is it related to? What about this?

Amy: I think it's a nail groove. We used these on our shoes recently.

Art: It's a paneling nail. Most students will classify it as a screw until you point out to them that the so-called threads don't form a continuous spiral; they are rings, like the earthworm. Convergent evolution perhaps -- it's not a screw but it looks like a screw. Or this expanding drywall bolt. It's interpretable as a mutualistic symbiosis -- it's actually two different organisms that are growing together like a fungus and an alga in a lichen. Of course these things don't really have an evolutionary history, there is no phylogeny in hardware. But if we are doing evolutionary-type classification, the assumption is they have evolved, and that means we have to try to discriminate between actual evidence of relationship versus convergence.

AMY: This exercise is exciting to me because it says forget everything you know, or try to look at these in a different way, ridding yourself of all of these assumptions and theories. I feel like that's kind of what we try to do as artists, throwing ourselves into situations we don't understand or don't have a language to even articulate, and through that you possibly see things in a different way.

We assembled an Argentinean meal for you today; the food often speaks as another entry point into research.

ART: A significant part of my research is done in Argentina. I know more of Argentina first hand than I know of my own country. My wife and I worked in Argentina right through the bad times, but I eventually called a halt on Chile when I was invited to be a speaker at a scientific meeting, and there was a particularly atrocious event. A Chilean young man had gone into exile in California for political reasons, and he went back to visit his girlfriend; and they were kidnapped by right-wing goons, doused with gasoline, set on fire, and left to burn to death in a ditch. And that was too much for me, so I wrote a public letter of resignation from the conference. The word liberation is a Communist code word in Latin America, so I didn't dare use it, but I used a substitute. And I said, "I will return to my beloved Chile to celebrate its inevitable unchaining," and sent the letter knowing it would be publicized. Some of my Chilean friends were afraid to communicate with me for two years after that. And then after Pinochet left I was invited again, and I went down and I told that story. I recited from my own letter, and said what a pleasure it is to be back with you to celebrate your inevitable unchaining. I got this huge round of applause, and it turned out the host institution – I hadn't known this – had been heavily impacted itself, as several faculty and students had been murdered.

AMY: Have you ever discovered something in your research that made you afraid of something, of your place in the world?

ART: No, the stuff I work on is not the sort of thing that tends to cause existential crises.

AMY: What does?

ART: Oh, if I discovered a bacterium that had the potential to wipe out the human race, then I would have a crisis. But nothing I do is going to be weaponized. The closest I've come to getting scared in the course of my research was an incident involving an old plane – we had an emergency landing in Panama, which was not a direct result of my research, I just happened to be on that plane. And then the time I accidentally stumbled into an unmarked security zone and found myself surrounded by men in uniform pointing guns at me.