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From medicine to butterflies and back again

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My research focuses on the current impacts of climate change on wildlife, from field-based work on butterflies to synthetic analyses of global impacts on a broad range of species across terrestrial and marine biomes. I work actively with governmental agencies and NGOs to help develop conservation assessment and planning tools aimed at preserving biodiversity in the face of climate change.

My professional development is rare for an American in that I received both my undergraduate (B.S.) degree and my Ph.D. from the same university - the University of Texas at Austin. I did branch out by moving on to a Post-doctoral fellowship at the National Center for Ecological Analysis and Synthesis, based at the University of California at Santa Barbara, but ended up back to my Texas roots as Professor in Integrative Biology at the University of Texas at Austin (USA). I have recently shifted my primary base to the UK, and hold the National Aquarium Chair in the Public Understanding of Oceans and Human Health in the Marine Institute, Plymouth University (UK).

Childhood Experiences Shape the Adult

I have had a fascination with the natural world since my earliest memories. I believe much of that can be attributed to my mother, who herself had a Masters in Geology and a Minor in Botany. Since the time I could walk, she took me with her as she explored the wild meadows, forests and beaches of east Texas. By the time I was 12, I knew how to tell basalt from granite from shale, the pileated woodpecker from the red-headed woodpecker, swamp chestnut from American chestnut, and had seen every species of insectivorous plant native to the Big Thicket.

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But early in my life, nature was my hobby, not something I thought of as a career. For that, my love has always been medicine. Human physiology fascinated me, and I knew I wanted to be a medical researcher by the time I was 15. I diligently pursued this love right up until my penultimate year of my Bachelors degree in Zoology. It was vertebrate physiology lab that altered my life for ever after. I went in the first class, saw a room of cages full of the sweetest little white rats, looked over the lab protocol, walked out and never looked back. It wasn't performing surgery on the rat the bothered me (I'd sewn up many a torn cat), nor watching the heart beat, it was puncturing the lung and timing its death that I objected to. A death with no purpose.

Reinvention as a Field Biologist

In looking for alternate careers and a senior Honors project, I latched onto behavior - my very favorite non-medical class. I quickly ran through a series of field projects on honey-bee foraging, belted kingfisher nest vocalizations and chimp social behavior—all interesting in their own ways, but none led to an independent project. My final attempt was drastic—spend an entire summer at a remote montane field site, living in tents, cooking on a Coleman stove, and working with a team of graduate students led by the Professor, Michael Singer. This was yet another system: the Edith's checkerspot butterfly, *Euphydryas editha,* and its interactions with its many host plants. My initiation into this system was on Schneider's Ranch at 6000 feet on the east side of the Sierra Nevada mountains, near Carson City, Nevada. In just two weeks of, admittedly, intensive work, I had all the data I needed for my Honor's project, and it eventually led to a single authored paper in a respectable journal (*Journal of Insect Behavior*).

I was hooked—on the butterflies, on living in the rough right alongside my butterflies, and on the merger of ecology, evolution and behavior that was possible through working on this field system that, as a grad student on the project (now a Fellow of the Royal Society) said, "drips data." I continued with this system for my graduate research, developing projects that continued my initial theme of studying foraging behavior of adult females searching for individual plants upon which to lay their precious egg clutches. The females only live for 1–2 wk in the wild and usually lay only one clutch per day, so every clutch is important. Thus it's no surprise that each female is very choosy, in her flight behavior as well as in her "post-alighting" behaviors, testing each host plant for whether it holds the desired set of characteristics (both chemical and physical). Her choices are largely genetically determined, which allowed me to study the evolution of her "preferences" for different plants across different populations.

Onto a New Phase in the World of Climate Change

In 1991, as I was doing my final write up for my Ph.D., another graduate student in my cohort (Monica Swartz) waved an announcement from NASA at me, saying "you should apply for this—it's a bunch of money and your system is perfect for it." It was a call for proposals to study climate change from the Mission to Planet Earth program at NASA. Here I was, working on what had been known to be an extremely climate-sensitive butterfly since

Paul Ehrlich first began his population ecology studies at Stanford in the 1950s, and climate scientists were still arguing whether or not an anthropogenic warming signal could be detected in the climate data. My first thought was, "Well, if climate warming is really happening, this little butterfly will surely be feeling it." I considered it possible that such a 'biological indicator' might even be more sensitive than what humans can detect by analyzing meteorological station data. The only hitch was that I had to remain a graduate student to accept the funding, which my committee thankfully saw the wisdom of my doing.

The next few years was field biologist's heaven—spending three to six months each year camping out, traveling from Baja, Mexico up through California and Oregon into Canada, then down the Rocky Mountains through Montana, ending up at the western-most populations in Colorado. By the end, I had my Ph.D. in hand (on the behavioral ecology of *Euphydryas editha* and its host plants) and a single-authored paper in *Nature* documenting a range shift in a wild species. Edith's checkerspot had shifted its range northward ~100 km and upward ~100 m, the same magnitude you would predict if it were following the isotherm shift associated with an observed 0.7 °C warming trend in the western USA. This single paper (Parmesan *Nature* 1996), transformed me overnight from an insect-plant biologist to a climate change biologist.

Within a few months of publication I was invited to give a talk at a White House Seminar Series on environmental issues, and a few months after that, invited to be a Lead Author for the Intergovernmental Panel on Climate Change Third Assessment Report (IPCC Third AR). This was a stressful, challenging, thrilling time. The climate scientists were a close, organized, focused community, while the population ecologists were the new kids on the block. There were very few of us working on the impacts of climate change on wild species - the field was wide open. Exciting yes, but also carrying a great weight of responsibility to develop the field in a way that gave the best answers scientifically possible for the key questions government leaders were asking. The IPCC motto of "policy relevant, but not policy prescriptive" is one which I cherish as helping keep me scientifically on-track while working on a media-hot and politically divisive topic, and one which I follow to this day in all my research.

I digress with a message for any graduate students and early career researchers who might be reading this. My first climate change project with Edith's checkerspot was incredibly risky—I might have put in the same 4.5 y of work censusing butterfly populations and not been able to conclude anything about climate change impacts. But the potential pay-off made the attempt well worth it, and in the end I got a much simpler result than I could have imagined, skyrocketing my career onto a new and wonderful path. But taking this risk was possible only because I had my Ph.D. effectively in hand - delaying getting it by a few years did no real harm, and success would (and did) catapult my research program. The take-home moral: take risks, but only if you have a back-up plan.

Policy Impacts Science

Working within the IPCC process brought a new dimension into the way I think about research questions and approaches. Its findings are heavily used in developing international agreements to reduce greenhouse gas emissions, and there was (and is) an added pressure to achieve the highest scientific rigor possible for our ecological assessment of the observed impacts of anthropogenic climate change on wildlife. It quickly became clear that what was immediately needed were new methodologies in the detection of biological responses and correct attribution of those responses to climate change vs. other possible anthropogenic or intrinsic factors. Long-term field data provide, of necessity, only a correlational relationship with anthropogenic drivers (including climate change). Likewise, standard meta-analysis methodologies came from the medical world, and were designed for analyzing data from controlled experiments. My early work sought to identify and set standards for conducting field studies of climate change impacts and interpreting long-term historical biological data. I developed methodologies designed to minimize the influence of confounding factors and to minimize the effects of publication bias, as well as developing approaches for combining disparate, messy data sets from field studies originally designed to address diverse questions, but not targeted to look for climate change impacts.

Ironically, what I'm most proud of from this period has been least recognized. In the process of developing a consensus statement for the Summary for Policy Makers for the IPCC Third AR on observed impacts of climate change on wildlife, I began discussing the problems of deriving conclusions from correlational data with Gary Yohe, fellow IPCC author and economist. These discussions led to an official collaboration in which we further developed and applied meta-analyses appropriate to address this question as well as assessing the potential influences of known and unknown confounding factors (i.e. non-climate drivers, such as land use change, nitrogen loading, or habitat fragmentation) on observed changes in species' distributions. This study was published in *Nature* in 2003, and won an ISI award for being a highly-cited "Hot New Paper."

While the results of our meta-analyses, showing globally consistent poleward range shifts of wild species as well as advancement of spring events, are still widely cited more than a decade later, the analyses which we felt were most compelling have largely been ignored. We took a leaf from the climate scientists who had found patterns of change in observed climate trends that they could uniquely ascribe to warming being driven by greenhouse gases rather than by increased solar input. These included nighttime warming more than daytime, and winter warming more than summer. Gary and I thought hard about what types of "fingerprints" might exist in the biological data. We did successfully identify equivalent biological signatures of responses uniquely attributable to climate change impacts, distinguishable from impacts due to other anthropogenic drivers known to affect wild species.

One of these fingerprints was from long-term studies (>70 y), that encompass periods of climate cooling as well as

Figure 1. This is at a high elevation site in the French Alps—Col du Granon (col = mountain pass). It's at the upper elevational limits for several butterfly species that I work with. This site is right above one of the favorite Tour du France routes (along the Col du Lautaret). During field work, we frequently see Tour du France hopefuls huffing and puffing up these very steep passes.

warming. If the distributions of species are truly driven by climate trends, then we should see wild species responding to decadal temperature trends. And indeed, in Europe, we found birds, butterflies, intertidal invertebrates and marine fish shifting polewards during the (natural) warming of the 1930s and 1940s, southward during the cooling of the 1950s and 1960s, and then northwards again from the start of greenhouse-gas driven warming from 1970s to present day. This and other fingerprints we identified were what convinced many of the non-biologists in IPCC to support a strong statement for the Third AR (published in 2001) that anthropogenic climate change had already impacted wild species.

My research program continues to be framed around the need for understanding how wild species are responding to rapid anthropogenic climate change. Projections for global warming over the coming century increasingly indicate we're moving into a true climate regime shift which will bring global temperatures to a level not seen for 1–3 million years (3–6 °C above pre-industrial). Understanding of species' thermal biology and relationships between current climate and ecosystem functioning provide some insight into projected biological impacts. Therefore, one thread of my lab's research is to study existing variation in thermal adaptation to latitudinal and altitudinal temperature gradients. My positive experiences with both field and lab work with *E. editha* led me to continue to work with this and closely-related species in the genera *Euphydryas* and *Melitaea,* known popularly as "checkerspots" (in North America) or "fritillaries" (in Europe, **Figs. 1 and 2**).

However, the novelty of expected climate shifts makes unanticipated responses and "surprises" very likely. Thus, attempts to preserve biodiversity and ecosystem functioning in coming decades require new, creative conservation approaches and development of novel adaptation tools. An additional complexity stems from the joint, and often synergistic, interplay between climate change and other anthropogenic forces. Teasing apart the impacts of anthropogenic climate change from those of other stressors and projecting the combined impacts into the future requires continued development of rigorous research methodologies for quantifying current biological impacts and for developing biological projections into the future.

As well as impacting my long-term research aims, IPCC also changed how I

Figure 2. This shows a low elevation phenotype (right) and high elevation phenotype (left) of *Mellitaea cinxia*. At low elevations, all of the adults are bright orange. At high elevations, most individuals are darker, though there is considerable color variation. Studies on other butterfly species have shown that increased wing melanism improves the individual's ability to achieve higher body temperatures. Internal body temperatures vary among populations and species, but are in the range of 30 °C to 40 °C in flight. Average daytime ambient temperatures in Montpellier during the month-long flight season are much closer to this than are daytime temperatures at high elevation, which are often <15 °C even on sunny days. Butterflies do fly on these cool days at high elevation, indicating they are successfully raising their body temperatures by up to 25 °C above ambient.

think about incorporating collaborations into addressing these questions. My early IPCC experiences clarified that tackling global environmental problems required research that spanned disciplines from the first step, and I've continued a strong multi-disciplinary theme in my research programs. This appears clearly in the identities of my co-authors, ranging from economists to climate scientists to environmental lawyers and experts in decision making theory. My biological co-authors have spanned the spectrum as well, from ecosystem ecologists to molecular geneticists to disease modelers.

Science Impacts Policy

This body of research (my own studies as well as others), documenting the global extent and pervasiveness of the effects of anthropogenic climate change across diverse groups of plants and animals has helped support policy arguments for the reduction of greenhouse gas emissions. In particular, IPCC conclusions feed directly into international negotiations by the Conference of the Parties (COP), United Nations Framework Convention on Climate Change. I presented at COP15 in Copenhagen as an official Observer. It was an amazing experience, with some 80 000 people descending on Copenhagen (less than half were 'official' delegates). What particularly affected me was the predominance of young activists—their enthusiasm and energy gave me hope that global policies could be changed. While many have called COP15 a failure, I consider the Copenhagen Accord a milestone in calling out a 2 °C warming as a threshold for "dangerous" climate change. Agreeing on the problem is always the first step.

Coming Full Circle: From Ecology to Human Disease

I've retained a love of medicine and taken opportunities when they arose to merge this love with my primary research themes. This began when I was invited to co-organize a SCOPE Assessment (Scientific Committee on the Problems of the Environment), that led to my being a co-Editor of the book *Biodiversity, Global Change and Human Health: from Ecosystem Services to Spread of Disease*. Here, we sought to assess the scientific strength of links between various anthropogenic activities driving local losses of many native species, changes in communities as exotic species move in and, in turn, how such degradation of these natural ecosystems might be impacting human health and well-being. This was an exciting process, working with yet another multi-disciplinary team, this time including physicians, psychologists, and social scientists, as well as ecologists.

After a decade of thinking and writing about how anthropogenic climate change may be affecting human disease via changes in abundances and distributions of wild animal vectors and reservoirs, I was thrilled when Stavana Strutz came to me wanting to do a Ph.D. on exactly this topic. Stavana is currently researching the extent to which climate change may have driven a recent apparent northward expansion of human leishmaniasis in Texas, via possible shifts in distributions of the disease's vectors (sandflies) and reservoirs (native wood rats). It's clear now why such research is rare. Data on the distributions of these species in the wild are woefully inadequate, data on human incidence of leichmaniasis is at too crude a resolution for robust modeling, and data on disease incidence in non-humans is practically non-existent. True to my earlier advice, I've given Stavana my full support to pursue this risky research—if she's successful, the societal implications are immediate and profound. But, yes, we do have a back-up plan!

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.