CENTAURUS JOURNAL OF THE EUROPEAN SOCIETY FOR THE HISTORY OF SCIENCE

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Entangled Timelines

Crafting Types of Time Through Making Museum Specimens

▼ **SPECIAL ISSUE ARTICLE** in *Collections, Knowledge, and Time*, ed. by Karin Tybjerg & Martin Grünfeld

▼ **ABSTRACT** Focused on the material practices of making insect specimens, I explore how shifting concepts of potential are intricately crafted on the lab bench. Different types of time—from personal histories to imagined futures—are created and entangled as butterflies are made into specimens. Transforming a butterfly into a scientific tool does not merely transform the butterfly, I suggest, but also reciprocally folds back to transform the scientist who makes it. Based on ethnographic fieldwork with scientists in the labs and workrooms at the Smithsonian National Museum of Natural History in Washington, DC and the California Academy of Sciences in San Francisco, California, I follow butterflies and moths (*Lepidopt*era) as they are collected, euthanized, pinned, genetically sampled for rewilding projects, such as reviving a Californian sand dune ecology, and frozen in biobanks for as-yet-unknown future uses. Through a comparative study of practices at these two sites, I examine how a butterfly can contain multiple types of potential: manifesting its inherent potential as it transforms from caterpillar to butterfly, the plasticity of the butterfly body as it is crafted into a scientific specimen, and the potential of that specimen to be used as a site for extracting genomic data. Perceptions of time, salvation, loss, and care emerge as specimens are prepared, sampled, and reimagined as solutions for recreating lost ecologies.

▼ **KEYWORDS** Museums, Collections, Potential, Time, Genomics, Rewilding, Entomology, Anthropology, Natural History

▼ **ISSUE** Volume 65 (2023), issue 2

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Cite this article: Adrian Van Allen, 'Entangled Timelines', *Centaurus*, 65.2 (2023), 291–312 <https://dx.doi.org/10.1484/J.CNT.5.135353>

DOI: 10.1484/J.CNT.5.135353

BREPOLS

Introduction: Engaging the Material Cultures of Museums

Behind the scenes at natural history museums there is a hive of activity in their collections, workrooms, and laboratories. Within these spaces various tools are used by museum staff to transform a living thing into a scientific tool—from the killing jar to steel pins, to specimen labels, to the scalpels and cryotubes used to collect and store genomic samples. These tools highlight the vital role of materials in the current projects of archiving life through biobanking genetic samples and genomic data. In turn, these projects frame an understanding of our current ecological crises, shaping potential futures preserved and understood through frozen materials such as seed banks and blood samples.[1] One method for understanding the construction of different types of time and potential in the museum is through examining the histories, materials, and techniques used to create specimens—analyzing the negotiations between these different aspects as time is folded together in changing practices on the museum's lab bench. This approach emphasizes interspecies and feminist perspectives of material culture, with the obscured labor involved in producing scientific knowledge brought to the fore along with the colonial context of museum collections.[2] As historian Jenny Bangham and STS scholars Xan Chacko and Judith Kaplan point out, there are "layers of invisibility that conceal, eclipse, or anonymize people in scientific research …. Modern science is constituted by a workforce of diverse and specialized roles, only some of which are part of the public face of science."[3] This paper focuses on lab technicians and specimen preparators of two natural history museums, highlighting their labor to craft specimens and construct different types of time and potential in their daily work.

Based on ethnographic fieldwork with scientists in the labs and workrooms at the Smithsonian National Museum of Natural History in Washington, DC and the California Academy of Sciences in San Francisco, California, I follow butterflies and moths *(Lepidoptera)* as they are collected, euthanized, pinned, genetically sampled for rewilding projects, and frozen in biobanks for future uses. In doing so, I emphasize the material practices of making specimens as a method for understanding how shifting concepts of potential are intricately crafted on the lab bench. Through a comparative study of practices at these two sites, I examine the origins and implications of preparing butterfly specimens for natural history collections in the shifting domain of a genomic age.

Each museum has a distinct history that has shaped its contemporary research agenda, collecting expeditions, and specimen preparation practices. Following scientists and their winged specimens through these two museums, I ask two key questions: First, how are insect specimens made and used in the contemporary natural history museum, crafted in response to potential futures of extinction and loss?

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[1] Kowal & Radin (2015); Peres (2016).

[2] On the labor of creating Enlightenment-era scientific instruments, see Shapin (1989). For the invisible labor of contemporary scientific knowledge production, see Harding (2008); Kowal, Radin, & Reardon (2013).

[3] Bangham, Chacko, & Kaplan (2022, p. 2).

Second, how are these specimens then made to embody different types of time as they move across physical and conceptual boundaries, from field to freezer, from lab to collection, from database to scientific publics, and finally into the landscape as part of a regenerated ecology project?

To answer these questions, I explore the narratives of temporality, potential, and care that infuse the process for making and sampling specimens. I examine the construction of a specimen preparator's personal narrative of time through the moths and butterflies they have transformed into specimens—one thumb-width, killing jar, and species at a time. To compare this process of marking the past with one turned towards the future, I follow the emerging process of biobanking butterflies and moths, where preparators negotiate between new methods and traditional techniques. Part of this work involves sampling extinct Xerces blue butterflies (*Glaucopsyche xerces*) to extract ancient DNA, genetic data that has been extracted and isolated from historic specimens. This data is being used to find the closest living relative for a rewilding project in a section of Northern Californian sand dunes. In essence, the scientists are remaking a lost ecology by taking apart insect bodies and making them into new kinds of objects such as genomic samples and their reference specimens.

Thinking through natural history collections, both morphological (a pinned butterfly in a drawer) and molecular (a tissue tube in liquid nitrogen), as transformed *life* raises many questions as well as offering up opportunities for thinking through how, why, and by whom life is being archived and for what *kinds* of imagined futures. As Lucy Suchman suggests, "Objects are not innocent, but fraught with significance for the relations they materialize."[4] For the scope of this paper, I focus on a selected few of these non-innocent objects, following the assemblage, circulation, and boundary crossings of butterfly specimens through the museum and beyond. The specimens' paths from lab bench to pinned specimen to data set underscore the ways that disciplinary histories are being continually re-inscribed, as centuries-old techniques are still used to pin moths and butterflies, while they are also genetically sampled using cutting-edge techniques from biotechnology.[5] Entomology has its own distinct set of disciplinary-specific practices for preserving specimens, methods that preserve and highlight the aspects of the specimen needed for largely taxonomic work.[6] For *Lepidoptera* (moths and butterflies) symmetry is emphasized so that differences can be seen at a glance across a drawer of pinned specimens. In contrast, as those pinned specimens have a leg pulled off and sampled for genomic data, completely new uses for the specimen emerge. The specimens themselves are transformed by the introduction of biotechnology from a single reference point for their species within taxonomy, to an embodiment of multiple potentials—an array of possible future uses

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[4] Suchman (2005, p. 12).

[5] The introduction of genomics into the practices of making museum specimens has a number of consequences: most importantly for this paper, regarding how disciplinary borders between traditional disciplines (such as entomology) and new ones (such as genomics) have different methods, goals, and priorities. For an in-depth discussion of the negotiations in museum genomics, see Van Allen (2018; 2022).

[6] Gibb & Oseto (2006).

for both the specimen and its data. As artist Åsa Sonjasdotter and sociologist of science Tahani Nadim have pointed out, a dead wasp (as a scientific specimen)—and particularly its genomic data—can fly further than the original insect ever did in life.[7]

Crafting Potential

Ideas of time and potential have been examined from various perspectives in the social sciences and history of science. These include histories of collecting wild animals for museums; the recent turn towards instrumentalizing life through cloning animals for agriculture, rewilding projects, and human medical applications; and the "planned hindsight" of making biological collections for future use.[8] The thread of *potentiality* within these perspectives can be seen in a closer examination of the uses of "nature" as both material and metaphor—a perception of living things as being inherently open to modification for as-yet-unknown uses, which in turn provides a driving moral force to preserve them before they go extinct.

In considering the long history of potential as a concept and its instrumentalization in the power and politics of biomedicine, anthropologists and STS scholars Karen-Sue Taussig, Klaus Hoeyer, and Stefan Helmreich define three forms of potential: a hidden force that will manifest itself with or without intervention, an inherent plasticity in something that has the capacity to transform, and also a latent possibility open to human manipulation and direction to propel an object or subject into becoming something else.[9] It is worth emphasizing that physical specimens contain information that cannot be copied.[10] The slippages possible between these forms speak to both the power and ambiguity of the concept of potential itself. A butterfly, as we shall see, can exist across all three forms, manifesting its inherent potential as it emerges from its cocoon transformed from a caterpillar, the plasticity of the butterfly body capable of being crafted into a scientific specimen, and the potential of that specimen to be used in new ways driven by new technology, as a site for extracting genomic data (see Figure 1).

The role of materiality and practice is key in considering these forms of potentiality, particularly the slippages between them—that is, potential as a function of constructed future time. Building on previous work where I examined the materials and practices used by museum scientists to craft specimens and construct futures, I suggest different temporalities are "folded" into the daily practices of preserving specimens, where new technologies are intimately entangled with historical techniques.[11]

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[7] Nadim (2015); Sonjasdotter & Nadim (2015).

[8] On the potential of animals as proxies in biomedical research, see Svendsen & Koch (2013); on the planned hindsight of collecting for the future, see Radin (2015); on museum collections as resources, see Klemun, Loskutova, & Fedotova (2018); Bi et al. (2013).

[9] Taussig, Hoeyer, & Helmreich (2013, p. S4).

[10] Gere & Parry (2006).

[11] Van Allen (2019).

Figure 1. Preserved moth and caterpillar, Smithsonian National Museum of Natural History. Photo by the author (2015).

That is, new modes of making do not merely replace old ones, but instead encapsulate and transform them, integrating them into the daily details of practice. In doing so, scientists incorporate not only new materials and methods into their specimen preparation process, they also incorporate new perceptions of preservation, salvation, and care—all oriented towards charting the unified genomic biodiversity of life and preserving it for uncertain futures.

Through interviews with museum staff and my work alongside them at the lab bench, I encountered multiple concepts of salvation driving their work, where the unending labor of making specimens was motivated by a sense of attempting to forestall (the perhaps inevitable) impending and catastrophic biodiversity loss. With the emergence of biotechnological tools in recent decades, new possibilities have begun to emerge for biobanking wildlife as well as taking viable genomic samples from historic specimens.[12] These new tools of biotechnology were articulated as tools for preserving biodiversity, and potentially recreating degraded ecologies, such as the Xerces Project, which I turn to later in the paper. However, as the scientists pointed out, there is a large gap between the concepts and practices of genomics and conservation, with different ontological frameworks shaping what the data means to different audiences. For now, I turn to the creation and genomic sampling of butterfly specimens at the Smithsonian Institution in Washington, DC.

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[12] For example, see Schäffer, Zachos, & Koblmüller (2017).

Time, Salvation, and Care in Preserving Butterflies

The body of a butterfly can unravel into many different pieces, each capable of embodying different types of time and kinds of potential.[13] In the entomology department of the Smithsonian National Museum of Natural History in Washington, DC, I learned to carefully unfold a butterfly from its paper envelope, anchoring it with a pin through its body. Aligning its legs, antennae, and wings in perfect symmetry, I pinned the wings flat with strips of wax paper stretched across them while they dried (Figure 2). I did all of this with tools that have been essentially unchanged for more than one and a half centuries—the entomology pins, pinning board, and strips of paper to hold the wings in place were exactly the same as an 1830s specimen prep manual, but the laser-printed labels and cryotubes were more recent additions (Figure 3).[14] As I went through the preparation process, I took various genetic samples: sometimes the thorax, abdomen, or a leg; sometimes the entire body with the wings carefully glued onto a sliver of cardstock as a proxy for the absent body; or sometimes I used tweezers to put the entire butterfly into a 2 ml cryovial to freeze in liquid nitrogen. The cryotubes were already adorned with barcode labels, ready to be sent to the museum's biorepository. Our amputated specimens were then left to dry and be sorted into drawers in the collections alongside their preserved kin.

While the butterfly found its way into the collections, the genitalia, eggs, or other parts of reproductive organs could be removed under a microscope using hair-thin forceps. Mounted on a microscope slide or gold-plated and imaged in a scanning electron microscope (SEM), they could be used to compare the same diagnostic characteristics between species. The remains of the abdomen could be stored in a cryotube for DNA barcoding or for future use, to be slowly whittled away as new technologies and new conservation agendas shape the use of the biorepository's contents. Other parts of the butterfly tissues, such as leg, went to the museum's genomics lab to be frozen and ground into powder, DNA extracted, and consumed, becoming datasets uploaded to public genetic databases. Many of the moths and butterflies I encountered in the collections were mounted in the late 19th century and were considered increasingly "useful"—perhaps in ways their makers never expected or could have imagined, as various curators articulated new and ever-emerging genomic uses for old collections.[15] The potential of the specimen came into focus at these moments, where the specimen conceptually multiplied in the language used by the scientists from one individual into many possible specimens, each in a different stage of unraveling into a genetic sample, genomic data, or a solution to as-yet-unasked research questions. As these historic collections become increasingly valuable, it is important to note that their new potential is being "unlocked" not simply due to

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[13] Author's fieldwork notes in the specimen preparation lab, Department of Entomology, Smithsonian NMNH (2015, Feb. 5).

[14] Ingpen (1839). For further reading on historic insect-preservation materials and methods, see also T. Brown (1870); Riley (1892).

[15] For further discussion of historic preservation techniques and the expanding uses of collections, see Bi et al. (2013).

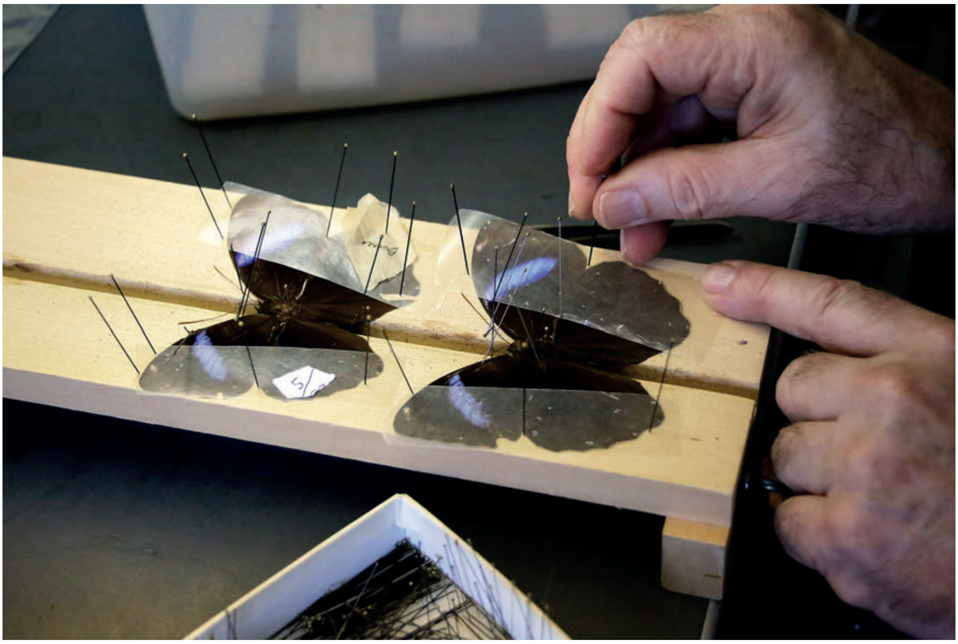

Figure 2. Pinning butterflies, Smithsonian National Museum of Natural History. Photo by the author (2015).

the increasing computational capacity for assembling genomic data. It is also due to the increasing sense among museum scientists of their moral obligation to preserve the natural world, and even to regenerate it through rewilding projects. A sense of salvation infused the ethos of the museum work rooms I encountered, where the meticulous and tedious work of making specimens was driven by a sense of warding off impending ruin and loss.

Sitting at the workbench in the Smithsonian's entomology department, I talked with the specimen preparators as we pinned butterflies, asking them about the details of collecting and preserving, and how they have seen practices change over time. Looking across a drawer of pinned butterflies and moths on the table next to us, they can tell me who prepared a particular specimen just from gauging the amount of space left at the top of the pin—the differently sized fingers of each preparator marking not just their specimens, but their own life histories, measured in thumb-widths on entomology pins. "The rule of thumb, as it were," one preparator tells me with a smile, "is to use your own thumb and forefinger to gauge the amount of space to leave at the top of the anchor pin so the specimen can be picked up without touching it directly … to preserve it for as long as possible" (Figure 4).[16] Different preparators, different fingers, different spaces left at the top of pins. I think about the millions of insects pinned in the collections, and the different fingers that have grasped the top of

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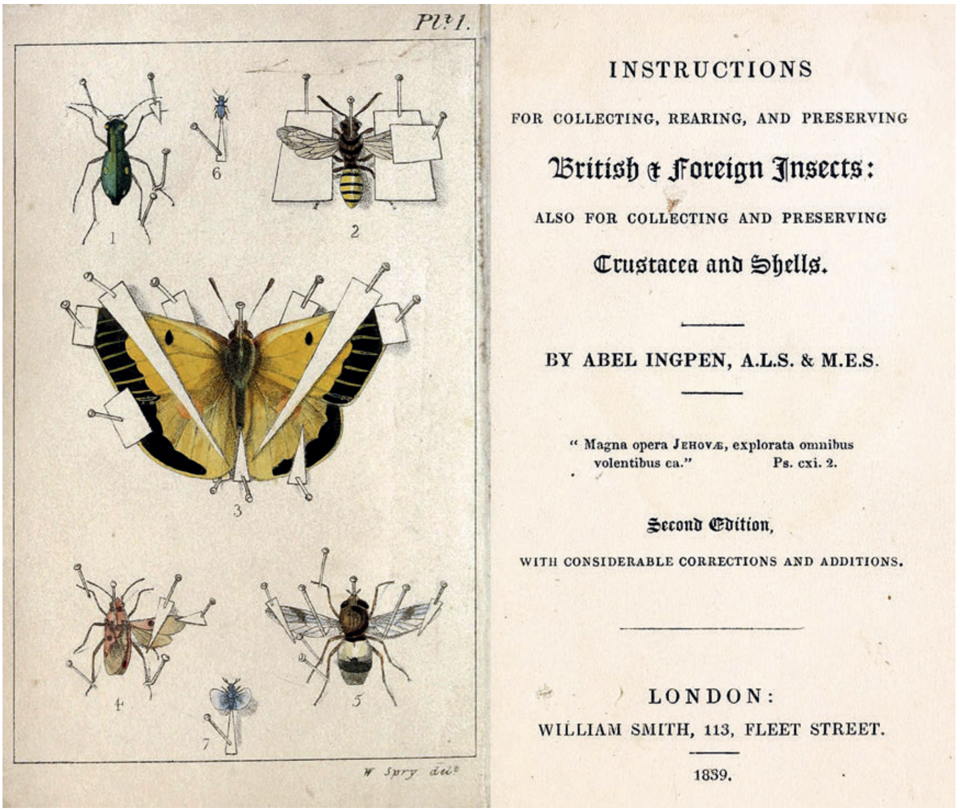
[16] Collections manager, Smithsonian NMNH (2015, Feb. 6), interview with the author.



INSTRUCTIONS
FOR COLLECTING, REARING, AND PRESERVING
British & Foreign Insects:
ALSO FOR COLLECTING AND PRESERVING
Crustacea and Shells.

BY ABEL INGPEN, A.L.S. & M.E.S.

“ Magna opera Jehovæ, explorata omnibus
volentibus ea.” Ps. cxi. 2.

Second Edition,
WITH CONSIDERABLE CORRECTIONS AND ADDITIONS.

LONDON:
WILLIAM SMITH, 113, FLEET STREET.
1839.

Figure 3. Abel Ingpen's (1839) insect preparation manual. Frontispiece shows the same butterfly pinning technique I learned at the Smithsonian in 2015. From *Instructions for collecting, rearing, and preserving British and foreign insects* (title page), by A. Ingpen (1839), London, UK: William Smith.

each pin over several hundred years—an alternative view of this archive of life, one of the measurements of the people who have made and used the collections, measured out in thumb-widths.

While looking through drawers of pinned butterflies with a collection manager at the Smithsonian's department of *Lepidoptera* (butterflies and moths), we come across a drawer of butterflies he had pinned in the early 1970s—row after row of small, bright-yellow wings aligned in perfect symmetry, neatly aligned above labels that marked them as coming from Panama. He plucked one from the drawer and peered at the label, telling me it was a Citrus Swallowtail (*Papilio demodocushe*) and that he could:

> recall the stream where I was when I caught this butterfly 30 years ago, the way the light was … who I was at the time … in a way I can track my whole life through them [the collections]—you know, where I was, what species I was collecting at the time, what I knew then and what I know now … It's my own history in these cabinets.

Timelines of different kinds run through the collections, each with a different conception of—and orientation to—their type of time. The collection manager's reflection of himself through the specimens also speaks to their future potential. He described how each specimen he created was carefully created to fix a moment in time, to make the delicate ephemera of a butterfly durable for centuries if possible: “You never know what it might be used for … so you save everything you can.”[17] What is saved, I suggest, is not only the biological matter of the butterfly specimen, but also the hopes and fears of the preparator, their moments of projecting into the future for what a particular specimen may be used for, and for what the role of preserving specimens for that imagined future may be.

From this perspective, each specimen's history can be seen as a collection of moments, important events as it is collected, prepared, accessioned, and sampled. These moments are markers not just in the afterlife of the specimen that begins after death, but forming a constellation of specimens, clustered points in a preparator's personal timeline as well, triangulated through accumulated specimens and accumulated knowledge. Formerly living things are made into different assemblages that combine biological materials (wings, exoskeletons, antennae), concepts of nature (species, evolution, trees of life), skilled labor (forceps, pins, mounting boards), and regimes of value (“banking” precious biodiversity, global collecting networks). These assembled specimens circulate within the museum and beyond to other museums, institutions, and research sites, accumulating and negotiating these concepts of nature, value, time, and care as they move between domains and different modes of becoming. It is in these moments where scientist and specimen become entangled, in the mesh of biological matter, skilled labor, concepts of nature, and imagined futures where potentiality is negotiated and formed.

Some part of this “becoming,” I want to suggest, is that of the preparator in a process of change as they map their own evolving knowledge and understanding of self through the taxonomic and technical knowledge gained from crafting specimens. In other words, transforming a butterfly into a scientific tool does not just transform the butterfly, it also reciprocally folds back to transform the scientist who makes it. Specimen and maker are bound together in this construction process, co-producing their parallel timelines—the life history of a specimen, and the personal timeline of a specimen preparator. As Taussig, Hoeyer, and Helmreich suggest, “The constant reiteration of potential thus interacts with utopian and dystopian visions of the future of humanness framed as much in terms of limiting as realizing potentials.”[18] In this context, the potential of the specimen is intimately defined by the visions and goals of the specimen preparator—their specific individual, institutional, and cultural understanding of potential, both its capacity and limits—where the imagined future use of the specimen defines what parts of a specimen are saved or discarded, deemed to be precious or to be biowaste. Each of these pieces of the specimen then carry their own timeline, and their own set of possibilities or endings.

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[17] Collections manager, Smithsonian NMNH (2015, Feb. 6), interview with the author.

[18] Taussig, Hoeyer, & Helmreich (2013, p. S4).

Figure 4. A thumb-width measured at the top of a pinned butterfly, Smithsonian National Museum of Natural History. Photo by the author (2016).

Potential here is conceived as a revisiting of the past, tracing a path back to an object and re-envisioning how it may be revisited in the future. This can be seen as a historic specimen becomes relevant as its closest genetic kin go extinct, or a new technology suddenly rendering a whole category of specimens as new, untapped resources for mining data. This imagined future potential of a scientific process or object is not a new one, as historians Annette Mülberger and Jaume Navarro point out in their discussion of the role of promise in the production of scientific knowledge: "expectations circulate and have deep consequences on our perception of the present."[19] As I witnessed at the Smithsonian lab bench, butterfly specimens were pinned with meticulous attention to detail, and great care was taken to craft an object that would last for centuries, while a leg was also carefully pulled off to sample for DNA. Expectations for the future were woven into both acts, with preservation and destruction both enacted in the name of futures both near and far—the specimen (partially) preserved for future taxonomic work and (partially) destroyed for genomic work.

Multiple versions of future utility are built into each specimen, framed by the hopes, expectations, and fears of the preparator. These promises for the future in the biomaterials of the specimen can be seen in another group of pinned butterflies, the

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[19] Mülberger & Navarro (2017, p. 168).

extinct Xerces blue (*Glaucopsyche xerces*). We now move to the Northern California coast, and to the reconstruction of an imagined future landscape as it is brought into being through the bodies of extinct butterflies.

Sampling Butterflies and Resurrecting Ecologies

The Xerces blue butterfly (*Glaucopsyche xerces*) is a small, unassuming member of the gossamer-winged butterfly family, *Lycaenidae*, measuring on average 1 inch (2.5 cm) from wingtip to wingtip (see Figure 5). This small butterfly originally thrived in a small area of sand dunes along the San Francisco coast, including the Presidio, a now-decommissioned military base, laying eggs and feeding on the native deerweed plants (*Acmisphon glaber*).[20] On September 26, 1875, Hans Behr, curator of entomology at the California Academy of Sciences, wrote to his fellow entomologist Herman Strecker that "L. Xerces … is now extinct as regards the neighborhood of S. Francisco. The locality where it used to be found is converted into building lots and between German chickens and Irish hogs no insect can exist beside louse and flea."[21] By the 1930s, the butterfly was restricted to vacant lots. By the early 1940s, these native butterflies were extinct, the first butterfly known to go extinct in North America as a result of human actions such as habitat loss from expanding urbanization. Unfortunately, it was merely another species in a long history of extinctions from human expansion.[22]

With the emergence of biotechnological tools in recent decades, new possibilities began to emerge for reintroducing a closely related species that would allow a version of the unique sand dune ecology to be recreated. "While the Xerces itself is gone, [we can] introduce the closest relative with appropriate ecological requirements in lieu of the extinct taxon," according to one of the conservation biologists on the project.[23] A site had been identified with a sufficient number of deerweed plants on a patch of dunes, with available nectar sources, and with documented ants that have the potential to tend the larvae of the introduced butterfly. In his work on recreating historic landscapes, Robert Pyle terms this approach "resurrection ecology": rebuilding lost landscapes with proxy species instead of recreating extinct species.[24]

Currently, a team of entomologists and geneticists at the California Academy of Sciences (CAS) are collaborating with Presidio staff and various government and NGO organizations to find a suitable species candidate to rebuild the Xerces's lost landscape among the coastal sand dunes, with target dates for butterfly releases in

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[20] Weiss & Swenerton (2018, p. 1).

[21] F. M. Brown (1968, p. 59).

[22] Recently extinct butterfly species include the *Urania sloanus* (Jamaica, ca. 1894–1908); the *Libythea cinyras* (Mauritius, 1866); the Mbashe River buff, *Deloneura immaculata* (South Africa, date unknown); the Morant's blue, *Lepidochrysops hypopolia* (South Africa, 1879); and the Xerces blue, *Glaucopsyche xerces* (United States, 1941) discussed in this paper. A further 10 sub-species of butterflies are also believed to be extinct: IUCN Red List (2022).

[23] Weiss & Swenerton (2018, p. 2).

[24] Pyle (2000, p. 12).

Figure 5. A Xerces blue butterfly (*Glaucopsyche xerces*) collected in San Francisco in 1935, California Academy of Sciences. Photo by the author (2020).

2024 and 2025. One of these NGOs is Revive and Restore, a non-profit organization that has been at the forefront of promoting de-extinctioning and rewilding projects in recent years. One such project is their Wild Genomes project that seeks to "accelerate the adoption of genomic sequencing and tissue biobanking for applied wildlife conservation," with funding provided to field scientists, wildlife managers, and local citizens who are working to "protect biodiversity and their local bioeconomy."[25] Revive and Restore staff contacted the Academy several years ago to see if the Xerces blue, now an iconic species among conservation biology, would be a good candidate for de-extinctioning.[26] In response, the scientists at the Academy suggested a version of Pyle's "resurrection ecology" approach to mapping the Xerces genome at the Academy, as a method for finding a suitable living species to reintroduce into the Presidio. As one Academy scientist said,

> We don't need a new butterfly, we want to answer questions with genomics, such as what is the closest Xerces relative? … And what parts of the Xerces's genome

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[25] Revive & Restore (2022).

[26] The Xerces Society for Invertebrate Conservation was founded in 1971 by Robert Pyle, creator of the concept of "resurrection ecology." See Pyle (2000).

Figure 6. Xerces blue butterfly collections, California Academy of Sciences. Photo by the author (2020).

> allowed it to thrive in the cold and damp of these sand dunes? …This is how we'll find a proxy species.[27]

However, as the scientists were quick to point out, there is a large gap between the concepts and practices of genomics and conservation: “You can generate a lot of data, but then you have to decide how to interpret it—what it means, and if it means something different to different people.”[28]

Working with the Academy's collections—the largest collection of Xerces in the world—a team within the museum are working together to gather genomic data on related species, and to find out just how related they are (see Figure 6). The underlying logic of this endeavor is that genetic similarity will equate to ecological niche-filling, an approach to conservation that recreates landscapes not as they were (or were imagined to be), but instead as populated with proxy species, reconfigured to fit an ever-changing set of economic, political, and biological circumstances.

Talking with the Xerces Genome project team at the California Academy of Sciences over video, they each described a different part of the process for transforming

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[27] Senior researcher, California Academy of Sciences (2020, Nov. 2), interview with the author.

[28] Curator, California Academy of Sciences (2020, Nov. 2), interview with the author. For further discussion of the gaps between genomic data and its interpretation, see Reardon (2017).

a historic museum specimen into a genome for filtering proxy species in the wild.[29] Each individual articulated a perspective that highlighted a different aspect of the perceived potential embedded in the technology, the museum collections, and the specimen itself. One of the geneticists explained how all the tools she uses are "trickle-down from biopharma," shifting the pace of the natural history museum to match that of the biomedical sciences. As she described it, this intense rate of change in the field means that the quality and quantity of DNA tests are improving rapidly. That means the concentration and quality of the DNA can decrease while still providing enough data to be useful for analysis. "It can even be single stranded DNA," the geneticist told me with visible excitement, "Low DNA doesn't mean we have to discard it … even single cells identified in genetic blood tests, ones originally designed for human pregnancy, they can now be used in identifying cells in our [butterfly] DNA." One of the other geneticists broke in, "It is all about finding the right [genetic] markers … in what you have available, and now that doesn't have to be much." The potential of biotechnological tools was clearly forefronted by these two scientists, for whom increasingly powerful tools will continue to "unlock" more data trapped within the specimen collections, releasing their potential into the future, and perhaps allowing them to be used to rebuild a variety of potential ecological futures.

Offering another perspective, an entomologist had a different take on the concept of potential. He suggested that accessing the genetic data within specimens to rebuild a lost ecology is "our moral obligation." However, it is an obligation that results in partial destruction of a specimen and conflicts with the other moral obligations of museum staff to preserve the specimen collections for (as-yet-unknown) future uses—to save their carefully curated library of life for posterity. This resolves itself in the creation of new and less destructive techniques for taking genetic samples. So, rather than pulling off a butterfly's leg and grinding it to a powder to extract DNA (as I had done at the Smithsonian several years earlier), techniques had been developed to keep the specimen as intact as possible.

A tone of concern crept into an entomologist's voice as he described the process (see Figure 7):

> Instead of destructive sampling we carefully pull a leg … make sure it's at the joint so you do less damage, then soak it in buffer [acid] to expose the DNA, then we process the buffer to get our [DNA] sequences. After all that you can glue the leg back on the specimen … almost as good as new.

To emphasize his point he holds a shallow, white cardboard box up to the camera, showing small, blue butterflies pinned in rows with all their tiny legs, presumably, glued back in place. It is worth noting that this new and far less destructive process has only recently been made possible due to the increasingly powerful computational capacity that allows tiny snippets of genetic data to be reassembled into meaningful genomic sequences. These intimate material links between morphological specimens

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[29] Entomologists and geneticists, California Academy of Sciences (2020, Nov. 2), video conference interview with the author.

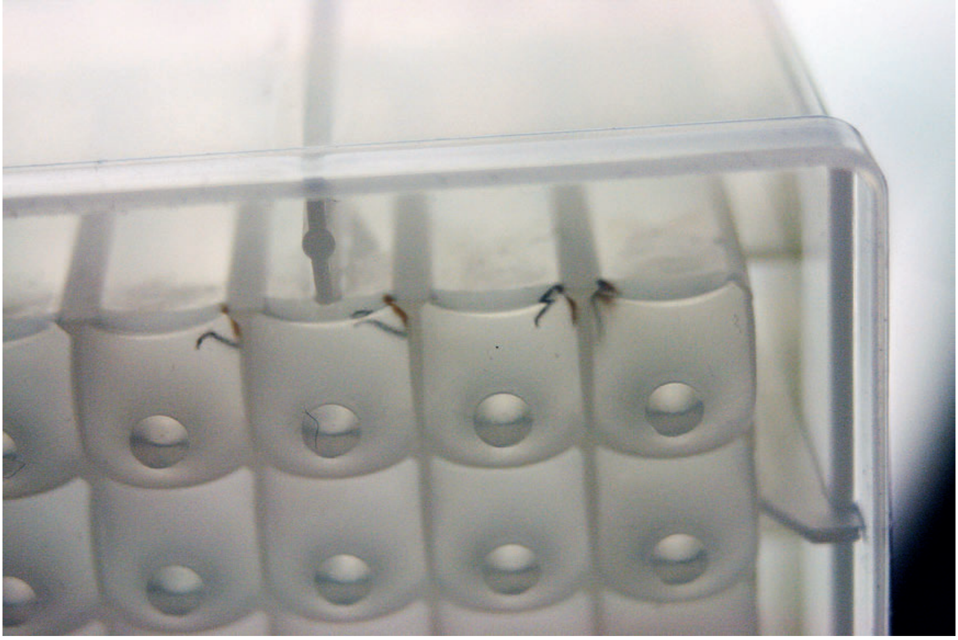

Figure 7. Butterfly legs for extracting DNA, California Academy of Sciences. Photo by the author (2019).

(the butterfly pinned in the box) and molecular ones (the aDNA extract floating in the cryotubes) highlight the tensions between systematic and genetic taxonomy—each with a distinct ontological view of what butterflies and their genomes mean, and in turn, what kinds of relationships they can potentially have with each other.[30]

As techniques evolve to use smaller pieces of DNA, an increasing number of collections previously deemed unusable will suddenly have their potential as a genetic resource re-evaluated.[31] To this point, another entomologist underscored the inherent value of the collections themselves, and the steps being taken to preserve them as far into the future as possible. While the new process involves less damage to collections, the Xerces blue specimens themselves are still considered too valuable to use while they are perfecting the process. Instead, the entomologists are using a proxy species, the closely related Silvery Blue (*Glaucopsyche lygdamus behrii*), to refine the DNA extraction protocol before they begin to pull legs from the precious specimens of the extinct species. In a sense, they are using a proxy from the collections to find a proxy species to rewild.

In the entomology department of the California Academy of Sciences in San Francisco I walked through seemingly endless rows of white, metal cabinets with a staff

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[30] See Endersby (2018).

[31] For example, see Santos, Ribeiro, Cabral, & Sperança (2018).

member, each of us wearing a mask which slightly muffled our voices as we talked.[32] The COVID-19 pandemic had changed many aspects of museum work, with masks and social distancing slowing progress on various projects. However, several projects were still pushing forward, and we were going to view the Xerces blue in their new habitat—the museum collection drawer—and select one for display in a new exhibit at the Academy. Along the way we discussed the other types of preparations that the collection houses, and I recalled previous (pre-pandemic) visits where we had gone through and seen every variety of object in the entomology collection, each one a physical manifestation of a type of time, as embodied in an insect specimen. Pulling out drawers, I had been shown insects preserved at different points in their developmental cycle—from a fertilized egg to pupae preserved in vials of alcohol, to carefully dried trays of chrysalises, some still attached to carefully trimmed pieces of branches or stalks of plants. Each of these specimens was a moment from a point along the individual's own unique timeline, a representation of a moment in their collective, and species-specific, developmental process from pupae to cocoon to butterfly or moth. However, each was also a part of an entangled timeline, one that marked time for both the specimen as well as the specimen preparator.

These moments were now also enmeshed in the recreation of lost ecologies. As one museum entomologist told me:

> Each of these specimens could be a source for aDNA [ancient DNA] sometime in the future ... [We] can get something out of most of it now, but the reads [lengths of genomic sequence data] will just keep getting longer ... or if they don't we'll be able to assemble them.

The increase in computational capacity means even shorter “reads” of sequence data extracted from sampling a butterfly specimen can be assembled into a useful piece of a genome, so its potential can be captured and made manifest. For example, when genetic sampling tiny species such as microlepidoptera (tiny moths and butterflies), a number of individuals are needed to get enough DNA to produce a viable sample. Tiny butterfly legs simply do not have enough muscle tissue to produce viable data. To solve this issue, many butterflies can be combined to be one genome, or one butterfly can become multiple genomic samples—it all depends on the scale of the specimen and the scope of the scientist's goals.

These re-articulations of butterfly bodies into new kinds of objects mark a shift in how natural history collections are mapping the connections between the parts and pieces of specimens as they are transformed to carry different kinds of meaning and value. Further, all of these carefully crafted specimens—from butterfly legs to DNA extracts—were but a small fraction of the types of insect life preserved in the collections, with each one representing a different form of frozen time and untapped potential.

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[32] Collection manager, California Academy of Sciences (2021, Jan. 12), interview with the author.

Conclusion: Crafting Potential on the Lab Bench

Potential does complex work as a conceptual apparatus, as Taussig, Hoeyer, and Helmreich point out, for "to imagine or talk about potential is to imagine or talk about that which does not (yet and may never) exist."[33] This projecting into unknown futures with the materials of the present can be understood in a long history of specimens shifting in value within the museum, dating back to early histories of museums and their struggles to expand categories of things in an expanding world, as well as in the molecularization of life in a contemporary genomic era.[34] These two threads—museums and biotechnology—converge in the emerging practices of museum genomics. Yet they also converge in the bodies of the specimens themselves, as they are made and remade to fit new articulations of potential in the face of extinction and unthinkable ecological loss.

During my fieldwork at the Smithsonian and the California Academy of Sciences, I interviewed collection managers, specimen preparators, and lab technicians about what they perceived as vital to preserve for the future and what to use now. What I witnessed from engaging with scientists as they mapped genomes and mapped their own histories were a series of entangled timelines—multiple projected futures in which interests, shifting values, potential, and human and non-human subjects were caught up in the idea of salvation. More precisely, it was the idea of caring for these species that came to the fore, and through those acts of care the preservation of a shared ecological future could be achieved.

Following butterflies as they unraveled into increasingly abstracted parts and pieces across the workspaces of the museums—pinned body, pulled legs, genomic data—allowed me to chart how different forms of potential were built into specimens as they were made, unmade for sampling, and reassembled. New modes of making specimens, such as genomic sampling, do not simply replace the old methods, but instead encapsulate and transform them. As scientists incorporate these new processes, they include not only new materials but new ideas about salvation, preservation, and loss. The potential of the specimen is intimately defined by the visions and goals of the scientist—their specific individual, institutional, and cultural understanding of potential—where imagined future utility defines what is saved or discarded. Each of these pieces of the specimen then carries its own timeline, and its own set of possibilities. Further, while the specimen itself is framed by the shifting hopes, expectations, and fears of the preparator, these practices also reciprocally fold back to transform the scientist. Specimen and maker are therefore bound together in the construction process, where they co-produce parallel timelines—the life history of a specimen, and the personal timeline of a specimen preparator.

The project of sampling the Xerces blue butterfly to regenerate the sand dune ecology of the California Presidio is just one example of how the potential of a

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[33] Taussig, Hoeyer, & Helmreich (2013, p. S4).

[34] For further reading on the creation, circulation, and shifting value of early modern museum specimens, see Findlen (1994); Gerritsen & Riello (2015); Daston (2000).

scientific object could shift according to differences in the imagined potential within a specimen. Each scientist involved in the project articulated a different view of the untapped potential of their collection of extinct Xerces blue butterflies, from the need to preserve the precious specimens intact for future uses, to the moral imperative to use them in the present moment to resurrect the degraded ecology from which they originally came. New techniques such as removing the legs, soaking them in a type of acid to extract DNA, and then re-attaching the legs, served as an acceptable method to satisfy everyone's goals. However, this was only possible due to the increasing sensitivity of genomic collecting protocols and the expanding computational capacity to assemble tiny fragments of extracted DNA.

The different kinds of potential created in these practices included perceiving it as a hidden force that manifests itself (such as a caterpillar becoming a butterfly), the inherent plasticity of an object that can transform (a butterfly body transformed into a specimen), and yet also the latent possibility of an object being manipulated into something else (that specimen also becoming a site for genomic sampling). Potential here can also be understood as a function of *constructing futures*. To expand on this idea, it is important to understand the perceived potential of living things (both within the museum and beyond) as being inherently open to modification, embodying an inherent plasticity for human manipulation and transformation. The construction of specimens also constructs specific kinds of imagined future potential: what is imagined to be useful and valuable by the scientist preparing the specimen sets up specific expectations for future use, while also limiting other uses and other futures. It is these small acts on the lab bench that collectively create an array of specific potential futures where genomic data can be extracted and used to recreate an ecological landscape with Xerces blue butterfly proxies populating the sand dunes of Northern California, for example. If only part of a specimen is saved (or replaced with parts from another individual, to the dismay of insect collectors in the early 19th century), such as the legs removed from the butterfly, then genomic sampling becomes problematic without a viable snippet of muscle tissue.[35] The thorax, or abdomen, of the butterfly was used in previous genetic sampling, but the data, as one collections manager told me, “ended up all muddied with gut bacteria mingling with the butterfly DNA … not helpful when you're reconstructing a single genome.”[36] The details of practice are therefore vitally important to attend to, as they construct not only a specimen but also the trajectory of that specimen, its DNA samples, and its genomic data into multiple potential futures of salvation or loss.

As one Smithsonian scientist told me as we walked through the collections, looking at specimens he had sampled for ancient DNA: “We're essentially asking the same questions as [Charles] Darwin did, just asking them with new tools.”[37] The same questions asked by Darwin about the relationships between diverging forms of life are, according to at least one scientist, still being asked in the contemporary

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[35] Ingpen (1839, p. 80).

[36] Collection manager, California Academy of Sciences (2021, Jan. 12), interview with the author.

[37] Curator, Smithsonian NMNH (2016, Mar. 13), interview with the author.

museum, but now the answers are being sought with new biotechnological tools. How have these tools in turn shaped the frame of reference for the perceived value of collections as they expand into the molecular? In other words, are the Darwinian questions now being asked in purely molecular terms? It is only from the perspective that genomes are fundamentally *what we are* that makes sense of the project of capturing dwindling biodiversity's genomes, mapping their differences, and using the data to rebuild specific versions of lost ecologies. Practices of archiving life in natural history museums have always broken down individual creatures into pieces and parts, such as a skin and a skeleton, an insect and its genitalia.[38] However, the move towards molecular specimens shifts these practices into new types of abstraction and disembodiment, transforming individuals into tangled webs of data and matter.

The anthropologist Cori Hayden argues that social processes cannot be explained solely by identifying the interests of individuals involved.[39] In other words, it is not enough to assume that collectors are motivated by their interest in preserving nature as a resource. Instead, a more comprehensive approach combining various individuals, materials, and values provides insight into these processes. Bioprospected plant life, in her assessment, is defined not by what it *is* but by what it *does*, such as providing a basis for developing new pharmaceuticals. I would add it is also what a specimen can be *imagined to do* in a specific vision of the future. For example, the Xerces blue will not be resurrected, yet its essential functions within the ecosystem will be, such as pollinating, eating, and being eaten. The way to determine what the appropriate proxy species is for these tasks is based on what a similar species can functionally do within that ecosystem.

The assembly of the biomaterials of specimens; the interests of collectors, curators, preparators, and policymakers; and the values created and perceived, all shift according to new contexts, as the plasticity of the specimen is utilized to make an ecology anew. As Taussig, Hoeyer, and Helmreich point out in their discussion of the inherent power dynamics invoked in discussions of potential, "each articulation reflects its own moral and political order and promise."[40] It is these different articulations of potential that highlight the changing use of specimens—figuratively, as butterfly bodies are re-thought as archives of lost pasts, on the one hand; but also literally, as butterfly legs are bent and articulated into specific shapes to form a symmetrical specimen for posterity.

Each butterfly also articulates a specific moment in time for the preparator, and for the disciplines of taxonomy, museum genomics, and recreated ecologies—what has been prioritized in crafting these small, delicate subjects on the lab bench articulates a variety of hopes and fears for the future. As new ecological crises and new technologies emerge, they are bound together by the work in museum labs to create potential within the specimens they make and unmake. These different articulations of potential are what highlight the changing use of specimens, as butterfly bodies

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[38] For details on historic insect specimen preparation methods, see Ingpen (1839); T. Brown (1870); Riley (1892).

[39] Hayden (2003, pp. 10–12).

[40] Taussig, Hoeyer, & Helmreich (2013, p. S5).

are made into new kinds of objects. These new objects, in turn, mark a shift in how natural history museums are mapping connections between the unraveling biological pieces of specimens as they are transformed to carry different kinds of meaning and value.

Engaging with scientists as they mapped butterfly genomes and mapped their own histories, I have traced the entangled timelines these practices created—multiple projected futures in which different interests, shifting values, potentiality, and human and non-human subjects were caught up in the idea of preservation for a shared ecological future. This perspective allows the analytical focus to shift from an oversimplified assessment of the traits of a particular project or discipline—such as the view that museums have removed and concentrated valuable objects from other parts of the world for centuries simply to understand and preserve the natural world.[41] Instead, I suggest our attention shift to the assemblage of materials, potentiality, and types of time that are bound up with scientists and their specimens as they are created and used. Analyzing these assemblages refocuses the analytical frame from individual subjects or objects, out to the work they do for those who use them.

Funding Statement

Funding was generously provided by an Abe Fellowship from the Social Science Research Council and a Smithsonian Institution Postdoctoral Fellowship. This paper is part of ongoing research and collaborations with staff at the Smithsonian Institution and the California Academy of Sciences—I owe much to their generosity. I would also like to thank Karin Tybjerg and Martin Grünfeld for inviting me to take part in the lively and productive *Collections, Knowledge, and Time* workshop at the Medical Museion in Copenhagen, 2019.

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[41] See MacGregor (2018) for a historical perspective on natural history collecting across a range of disciples; for an overview of "understanding and preserving" the natural world through specimen collections, see MacGregor (2018, pp. 1–39).

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