CULTURAL ANTHROPOLOGY

THE AXOLOTL IN GLOBAL CIRCUITS OF KNOWLEDGE PRODUCTION: Producing Multispecies Potentiality

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The southern Mexico City neighborhood of Xochimilco is home to an unusual salamander, the axolotl. Axolotls are a relatively young species: they have lived in central Mexico for fewer than ten thousand years.[1] They have a striking appearance: broad, flat bodies; large heads framed by feathery gills; wide-set eyes; and expressive mouths. In the wild, they hide deep in the aquatic vegetation, remaining still and camouflaged by their mud coloring to avoid being eaten. According to Luis Zambrano (2011, 230), the director of the Laboratorio de Restauración Ecológica (Laboratory of Ecological Restoration) at the Universidad Autónoma de México, the axolotl stays in hiding during the day and "like a good convict, its life is at night."

A charismatic species with deep connections to Mexican history and identity, the axolotl is found in the wild only in the maze of canals winding through Xochimilco. These canals are one of the few remaining traces of the lakes that used to dominate the area; Tenochtitlán, the capital of the Aztec empire that eventually became Mexico City, was famously founded on an island in Lake Texcoco. Yet the aquatic features that characterized the Valley of Mexico in pre-Columbian times have mostly been drained. Today the watery geographic history of the area is most evident in Xochimilco, with its maze of canals separating small,

CULTURAL ANTHROPOLOGY, Vol. 33, Issue 4, pp. 650–679, ISSN 0886-7356, online ISSN 1548-1360. *DOI: 10.14506/ca33.4.09*

Figure 1. A dark or wild-type axolotl. Photo by Stan Shebs, licensed under CC BY-SA, https://commons.wikimedia.org/wiki/File:Ambystoma_mexicanum_1.jpg.

artificial islands that resulted from intensive engineering transforming the land and water of the lake into an immensely productive agricultural site. Farmed since pre-Columbian times, the islands were essential resources for feeding the population of Tenochtitlán and, subsequently, Mexico City. These days, the neighborhood is most widely known as a site for recreation and tourism. The human engineering that transformed the landscape produced new habitats, notably the deep canals that became home to the axolotl.

Unlike other salamanders, including the tiger salamanders from which they evolved, axolotls are neotenic. That is, they do not undergo metamorphosis. Instead, they retain their juvenile characteristics and the morphology of larvae as reproductive adults, remaining aquatic for their entire life span. Stephen J. Gould (1977) speculated on the significance of the axolotl's unusual development in his *Ontogeny and Phylogeny*, hypothesizing that their delayed somatic development (in which they reach sexual maturity before going through the developmental stages typical of a salamander) offered them a selective advantage in the environmental conditions of Xochimilco. Gould (1977, 321) noted that "if they transform, they are forced to trade a favorable pond for harsh ground." Unlike salamander larvae in vernal pools, which dramatically alter their bodies to correspond with a radically changing environment, the axolotl responded to the constancy of the canals of Xochimilco by (forever) delaying transformation into the adult form, becoming sexually mature while still in a larval stage. In other words, its morphology is attuned to the requirements of life in the stable environment that agricultural engineering produced in Xochimilco. In Gould's (1977, 322) formulation, they have "repeatedly abandoned their facultative status for an irreversibly determined, permanent larval life."

While the axolotl is finely adapted to the historic environmental conditions of Xochimilco, the neighborhood has been undergoing rapid change as it urbanizes and as invasive species arrive in the canals (Salles 1992; Peralta Flores 2012). Restoration ecologists, who study damaged or disturbed ecosystems and the efforts to repair them, have paid attention to how these changes have decimated the wild axolotl population, tracking declining populations until a 2014 census found some five hundred to one thousand left in the wild, down from a population of six thousand per square kilometer in 1998 (Vance 2017).

Figure 2. An albino axolotl. Photo by fronx, licensed under CC BY, https://www.flickr.com/photos/fronx/6744367567.

Yet while axolotls are disappearing from Xochimilco, this does not signal their extinction. Instead, they have thrived in the global circuits of biological research, appearing in labs throughout the world as a model organism. Their unusual life cycle does not constitute their only noteworthy biological characteristic; they are also capable of regenerating a remarkable range of body structures at any point in their life cycle. They can regenerate entire limbs and tails, eye and heart tissue, and even their central nervous system. They can also be induced to change sexes. As a result, developmental and regenerative biologists, who study how organisms grow, develop, regenerate, and repair their bodies, prize them as research tools. While axolotls are proliferating, the lab axolotl differs from the axolotl in Xochimilco. To serve as a scientific model, the bodies of axolotls in the lab have undergone transformation, standardization, and commodification. These practices have produced a population with little genetic diversity, setting them at odds with the logic of conservation biology, which seeks to maintain the genetic diversity of species (Friese 2009).

Drawing on fieldwork in Mexico with restoration ecologists working to conserve axolotl habitats, as well as on scientific papers and informal communications among the scientists who use axolotls as model organisms, I examine the fate of the axolotl in and out of Xochimilco. Taking up the lives of both wild and cultivated axolotls, this essay asks what is at stake when a species is eliminated from one anthropogenic environment, the canals of Xochimilco, while being made to live in another, the laboratories of scientists studying developmental and regenerative biology. In contrasting these fields, I show that these different scientific deployments of the axolotl foster divergent imagined futures for human biologies and lives. While for restoration ecologists the axolotl demonstrates the fragility of biological life and the necessity for humans to transform their practices to protect all life forms, regenerative biologists see the axolotl as representing the unlimited potential and flexibility of human life and bodies.

Recent work by anthropologists has considered more-than-human engagements and entanglements, tracing the connections between human and nonhuman life forms (Haraway 2008; Kirksey and Helmreich 2010; Ogden, Hall, and Tanita 2013). Scholars have considered the place of the nonhuman in science and conservation (Hayden 2003; Lowe 2006; Birke 2012; Friese and Clarke 2012; Sharp 2013; Hartigan 2017), and the (sometimes violent) forms of care administered to animals and other nonhumans (Chrulew 2011; van Dooren 2014; Lowe and Münster 2016; Bocci 2017). Much of this work engages with the question of life in the Anthropocene, the moment in which human activities have begun reshaping geological processes, creating global environmental crises, and troubling the nature–culture boundaries produced by modernity (Latour 1993). Yet even before the Anthropocene, the axolotl and its home in Xochimilco were made by humans: pre-Columbian agricultural practices and the deep, permanent pools of water they produced made axolotl biologies possible. In the present day, different ways of making the human are emerging from the intersection of axolotls and scientific research. I analyze how scientists (and others) tend to axolotls, and argue that different ways of knowing axolotls suggest different possibilities for human biology and practices. These possibilities differ quite markedly depending on whether humans enact care for the axolotl in the wild or in the laboratory. Restoration ecologists studying the axolotls' imperiled ecosystem call for a return to historic agricultural and consumption practices that shaped Xochimilco. Regenerative biologists, on the other hand, find in the axolotls' malleable bodies models for remaking human bodies and reversing the processes of injury or aging. Producing knowledge about axolotls is speculative, generating new possibilities for humans and ecosystems.

Karen-Sue Taussig, Klaus Hoeyer, and Stefan Helmreich (2013, S5) call for an anthropology of potentiality, proposing three meanings of the term: "a hidden force determined to manifest itself," "the capacity to transmute into something completely different," and "latent possibility imagined as open to choice," available to be worked on and molded in different directions. Each meaning carries with it a different set of implications, calls to action, and politics. In other words, "though presented as insights into 'nature,' they work as vehicles for politics" (Taussig, Hoeyer, and Helmreich 2013, S5). In the distinct contexts of Xochimilco and the laboratory, people interpret the axolotl as embodying significantly different forms of biological potentiality. These interpretations have consequences not only for the axolotl but also for human social and biological life. Examining the divergent meanings scientists draw from the study of the axolotl underscores the contingency of these claims. In the wild, the axolotl is a fragile sentinel species, that is, an organism that provides people with advance warning of environmental hazards by virtue of its greater susceptibility to them. It is seen as in need of protection and as an indicator of the fragility of the ecosystem more broadly. Conservationists interpret its failure to thrive as a message to human populations to reform and reconsider how they live in relation to the environment. In the lab, the axolotl is no longer something that needs protection; rather, as a result of its biological capacity to heal and regenerate, it is interpreted as a being that models the potential power of human biology.

FLEXIBILITY AND ITS LIMITS

Scientists studying developmental and regenerative biology are exploring new possibilities for the plasticity of human bodies (Steinhoff 2016). They suggest that humans may have hidden capabilities for regeneration, capabilities that they propose to unlock through research. These new powers include improved healing, the replacement of damaged tissues, the regeneration of limbs and organs, and even the reversal of aging. Scientists have supported these claims through research with model organisms and by making cross-species comparisons, in particular between the human and the axolotl (Bryant, Endo, and Gardiner 2002; Farkas et al. 2016). As Sarah Franklin (2007, 33) has argued, in a postgenomic age scientists are reimagining the limits of biology, envisioning biological systems as "plastic, flexible, and partible." For regenerative biologists, the axolotl embodies this flexibility. In translating their findings from the axolotl to humans, regenerative biologists reimagine relationships across species lines, suggesting an underlying sameness or kinship between humans and salamanders. Drawing equivalences between salamander and human biology, they propose new possibilities for the flexibility of the human and the ways in which injury, aging, sex, and reproduction might be transformed.[2]

The perception of the animal from the point of view of the lab makes for a dangerously limited one; expanding our view to the axolotl in the wild suggests alternative messages or readings of the axolotl, ones that emphasize the limits of biological flexibility and the different kinds of potentiality that inflexible, conditional biology might enable. With the axolotl populations in Xochimilco threatened, restoration ecologists have taken the salamander up as a sentinel species, its life marking the health and vulnerabilities of the environment. As its population diminished, conservationists used the decline of the axolotl to raise awareness about the threats to Xochimilco. They hope that the axolotl as sentinel has the potential to inspire people to change their behavior to protect the ecosystem in which it lives. Conservationists developing an axolotl refuge in Xochimilco interpret its failure to thrive as a message to human populations to reform and reconsider how they live in relation to the environment. Protecting the axolotl requires rethinking human lives and practices, as well as drawing on the axolotl's charisma and vulnerability to inspire these changes.

Scientists in both regenerative biology and restoration ecology respond to an uncertain future by caring for the axolotl, with the hope that this care will produce future benefits for both salamanders and humans. But who and what benefits from such care varies significantly. As Carrie Friese (2013, S129) has noted, "care is a potentializing practice and, in turn, a site of politics." This essay demonstrates how, through scientists' tending and labor, axolotls come to represent different forms of potential, producing different insights into life. As Aryn Martin, Natasha Myers, and Ana Viseu (2015, 627) have pointed out in their analysis of care in technoscience, "care is a selective mode of attention: it circumscribes and cherishes some things, lives, or phenomena as its objects." By examining this mode of attention and the politics of care in two spaces, I draw attention to the contingency of technoscience, and to the very different worlds and forms of human life constructed by these practices of care and entanglement with nonhuman others like axolotls. Bringing these two fields together highlights how, as María Puig de la Bellacasa (2017, 7) has argued, "caring implicates different relationalities, issues, and practices in different settings." Furthermore, care, even when it involves affection and fondness, is not necessarily benevolent (Chrulew 2011; van Dooren 2014; Bocci 2017). Humans may care for nonhumans without caring about their futures. The axolotl is taken care of, but care is not always *for* the axolotl.

MATERIAL AND SYMBOLIC AXOLOTLS

Axolotls were significant figures in Aztec life and culture. In marketplaces, raw and roasted salamanders constituted an important protein source for the population of Tenochtitlán (Tate 2010). Their name derives from a Nahuatl word variously translated as "water toy or game," "aquatic monster," "water twin," or "water dog." Many of these translations reference the linguistic and mythic connections between the axolotl and the Aztec deity Xolotl, the canine twin of Quetzalcóatl, and the god of twins and monsters.[3] Axolotls appeared in Bernardino de Sahagún's sixteenth-century text on indigenous life in central Mexico, *Historia general de las cosas de la Nueva España*, in which he reported, "there are little creatures in the water called axolotls that have feet and hands like lizards, and the tail and body of an eel; they have wide mouths and whiskers on their neck. They are very good to eat; they are the food of gentlemen" (Bartra 2011, 38). Their unusual appearance and life cycle drew the attention of other European travelers, and their global circulation dates back at least to Alexander von Humboldt's journeys through Latin America. Humboldt obtained two axolotls, which he passed on to Georges Cuvier, who regarded them as an object of some curiosity (von Humboldt 1966; Bartra 2011).[4]

They also appear in more contemporary literature and social theory as figures of Latin American identity. Julio Cortázar's 1956 short story "Axolotl" depicts a

Figure 3. Xolotl, as depicted in the sixteenth-century Codex Telleranio-Remensis.

nameless, unattached man in Paris who fixates on an axolotl in an aquarium (a descendant of Cuvier's pair?), eventually metamorphosing into one himself. In Cortázar's (1967, 7) rendering, the axolotls constitute an unknown and unknowable Aztec presence in Paris, silent, immobile figures with "Aztec faces, without expression but of an implacable cruelty."[5] Unknown and unknowable, that is, to everyone except the narrator, who comprehends their "secret will, to abolish space and time with an indifferent immobility" (Cortázar 1967, 5–6). They speak to him of a different way of life and way of seeing, utterly incommensurable with the human.[6] The relationship between the man and the axolotls can be interpreted as the return of a denied or repressed connection with a pre-Columbian world, one in which non-European life is cast as inherently inhuman and incomprehensible.[7]

REGENERATIVE BIOLOGY AND LIFE WITHOUT CONDITIONS

As a lab subject, the axolotl has both a storied history of more than a hundred years of use and a bright future as a model for studies of regenerative biology, an exemplar of the flexibility and fluidity of biology (Voss, Epperlein, and Tanaka 2009; Reiß, Olsson, Hoßfeld 2015). Regenerative biologists celebrate axolotls for their endlessly malleable bodies and ability to rebound from the trauma inflicted on them in the course of research. The scientists marvel at their capacity to heal wounds, regenerate, and even produce additional accessory limbs. The kinds of separation between individuals that mark many other species is absent from the axolotl. One can graft tissues from one individual to another at any life stage. The biologists Martin Kragl and Elly Tanaka (2009, 1) describe this as "a remarkable property of axolotls," noting that, "amazingly, there seems to be no rejection of tissue grafts from individual to individual." Likewise, the axolotl suggests surprising possibilities for reproductive flexibility, as ovaries can be made to undergo reversal to testes through the strategically timed transplantation of gonadal tissue, or when female and male axolotls are surgically joined together (a technique known as parabiosis; Humphrey 1945).[8] Pieces of an ovary can be transplanted from one animal to many recipients, where they become functional (Humphrey 1976).

Scientists working in regenerative biology often read the axolotl as representing what life could and should be—ultimately flexible and able to respond to any kind of change by transforming its body to fit new circumstances. This flexibility has been taken up in representations of the axolotl in U.S. popular culture, for example in a 1970s ad for Travelers Insurance Company, where an image of an axolotl appeared with the caption "The adjustable axolotl." The advertisement lauded the axolotl as a being that "isn't, technically, a finished product of any ordinary life cycle. He's simply the aquatic larva of the North American salamander, *Ambystoma tigrinum*. And he has an ability to adjust himself to changes in his living conditions which might well cause a lot of us humans to turn grass-green with envy." The ad goes on to claim that in periods of drought or food shortages, the axolotl can transform from an aquatic creature to a land-dwelling salamander. This is not true—it does not normally undergo metamorphosis—but the ad agency has found the axolotl too compelling a symbol to be hindered by facts. The ad goes on to compare men and axolotls (with unfavorable results for men): "Like the axolotl, man is often confronted with events which threaten to make a major change in his living conditions. But, unlike the axolotl, he can't transform himself physically to meet them." As in the lab, the axolotl here appears to be the epitome of the flexible body that Emily Martin (1994) describes as the ideal body of late-stage capitalism. The work of scientists in regenerative biology intends to make axolotl capacities accessible to humans.

CARE OF THE AMPHIBIAN

The flexibility and potentialities of the axolotl become evident only through the labor that scientists devote to axolotls as laboratory animals, work that has both enabled knowledge production and reshaped axolotl life. This work has been thoroughly documented in both formal publications and in a newsletter circulated among the scientific community engaged in raising axolotls. Published by the Axolotl Colony at Indiana University, Bloomington, the newsletter is informal and chatty, a place in which scientists share not only citations for recent publications, preliminary data, and tips on axolotl care but also art, doggerel, and other ephemera related to axolotls.[9] The newsletter, a space in which scientists have worked out problems related to the care of the axolotl, provides a window into the lives of scientists and their interactions with the animal. It is full of the kinds of understandings and interactions with animals suppressed or erased in typical scientific publications. It is a place where knowledge seen as not properly scientific can nonetheless be shared among a community of practitioners, as they represent the axolotl in terms of what Michael Lynch (1988, 267) called the naturalistic animal, "the animal of common sense, the animal as it is viewed and acted upon in the world of everyday life." It is what keepers of axolotls tell themselves and each other about these animals. Read together with the official reports contained in publications, these archives give a picture of both the practices of care and the models of biology that animate life in the lab.

Since Humboldt sent Cuvier a pair of axolotls, scientists have been acquiring axolotls from Xochimilco. Once extricated from the canals, axolotls moved from lab colony to colony, in circuits documented in genealogies connecting axolotl and scientist families, as in this recounting of how the first animals arrived at the Axolotl Colony in Indiana: "Axolotls were passed on from Mexico to European dealers, to Dr. H. Gloor of Zurich, to Dr. H. Caspari of Cold Spring Harbor, to Dr. J. Holtfreter of University of Rochester to Dr. De Lanney of Wabash College, and finally to Dr. R. Humphrey of Indiana University" (Tassava and Stover 1978, 17). Once they arrived at the Axolotl Colony, the animals were used for studies in embryology and developmental genetics (Humphrey 1976). Lineages of axolotls soon picked up the names of scientists who bought them in markets in Mexico or bred them, although almost always these names were of European or American scientists. For example, Dr. Rafael Palacios, a young Mexican scientist from the Mexican National Institute for Medical and Biological Sciences, came to Indiana to observe the procedures used in rearing axolotls. In return for six white axolotls, he sent Dr. Robert Tompkins at Indiana six young dark animals. The resulting strain of dark animals was promptly named the "Tompkins strain" (Humphrey 1976).

Once an axolotl has arrived in Indiana, it (or members of its lineage) might go anywhere in the United States. Started by the biologist Rufus Humphrey, the Axolotl Colony was instrumental in proliferating axolotl bodies throughout laboratories nationwide. Supported by the National Science Foundation and the U.S. Department of Public Health, the colony provided axolotls to scientists at no charge beyond shipping expenses. Demonstrating the docility of the axolotl and how easy they are to ship from place to place, Humphrey described transporting five larvae he was given in Pennsylvania in the summer of 1935. Tucked into thermos jugs, he took them on a sightseeing road trip, noting later that "the axolotl passengers may be the only ones of their species to have had the distinction of visiting Fort Ticonderoga and ascending to the summit of Mount Washington" (Humphrey 1976, 3). The ease of shipping axolotls and their amenability to even circuitous or lengthy trips greatly facilitated their spread in laboratory ecologies, if not in the wild. Axolotls could easily be moved from the canals of Xochimilco, compatible not only with the agricultural infrastructure but also with other human-designed environs, whether thermoses or labs, their biological requirements converging with preexisting arrangements.

MAKING A NEW AXOLOTL

Scientists sought out the axolotl as an ideal lab resident. While the wild axolotl hides in canals, camouflaged in mud, the axolotl of the lab proves remarkably tractable. Once in the laboratory, it was remade as a model organism, a process that transformed axolotl life cycles, bodies, and genetics. While other salamanders breed only after periods of hibernation and metamorphosis and require diverse habitats, the axolotl, adapted to the ubiquitous pools of water in Xochimilco, is easily bred in the lab. Its eggs can be obtained with ease, and it produces great quantities of large embryos at each spawning: between 500 and 1,500 eggs, four times a year in the wild (Voss, Epperlein, and Tanaka 2009; Zambrano 2011). While, in the wild, spawning occurs only at particular times of the year, axolotls raised in windowless laboratories and exposed to light in regulated twelve-hour periods will never acquire a seasonal rhythm and can be induced to spawn at any time (Løvtrup 1981). In addition, selection pressure has resulted in the survival of larvae adapted to life in glass bowls (Tassava and Stover 1978).

Scientists extensively characterized the genetics of the axolotls in the lab, developing transgenesis tools and intentionally breeding axolotls for particular characteristics. They produced mutants with differences in pigmentation patterns, size, morphology (such as animals with short toes or arrested limb development), and organ development (including axolotls without eyes or with abnormal cardiac function) (Malacinski 1978; Briggs 1982).[10] They carefully orchestrated the breeding of axolotls "for the purpose of having available a ready supply of genetically uniform experimental material" (Malacinski 1977, 22) to be used in studies of developmental genetics. Standardizing the axolotl and its genetics became particularly critical as developmental biology turned increasingly toward descriptions done at the molecular level in the 1950s (Ankeny and Leonelli 2011; on the importance of standardizing amphibian model organisms, see also Nace 1978). Standardizing animals helped guard against the individual animal body as a source of variation and ensured that each animal had predictable characteristics.[11] In this sense, axolotls have proven themselves to be highly adaptable to the human-engineered environment of the lab. Axolotl adaptability has made the animals abundant, expanding far beyond their initial habitat to labs around the globe. As a lab tool, the transformed and standardized axolotl had the potential to produce

Figure 4. Axolotls in the Laboratorio de Restauración Ecológica. Photo by Emily Wanderer.

generalizable knowledge about biology and to stand in for human bodies, at least at the cellular level.

Even as axolotls are seen as easier to raise and more adaptable to the lab than other amphibian life forms, they are still delicate and fragile, requiring precise care and attention. Axolotls in laboratories have been trained to eat meat (generally minced liver or heart) and have become accustomed to being fed by hand, a time-consuming tendency that scientists found difficult to break (Forbes and Forbes 1980; Lampiaho 1980; Lawrence and Montoya 1980; Montoya 1982). Tending to axolotls thus entails preparing special foods, feeding them by hand, and noting and attending to their moods so that they might go on to produce good data. The biologist Rudolf Brun (1980, 21) wrote about the challenges of axolotl care, observing: "Probably many of us keeping *Ambystoma mexicanum* in the lab have gone through the difficult times when they seemed to prefer to sicken or even die rather than cooperate in providing research material. My lab is no exception to this sinister axolotl rule."

This tongue-in-cheek comment suggests the necessity of enlisting the collaboration of axolotls to produce data; an unhappy axolotl will prove useless to the scientist. Brun (1980, 21) goes on to say that he

> followed the rationale of preventing disease by keeping the animals in good spirits (if they have any). How can this feasibly be accomplished? As anyone knows, good eating is an essential part of happiness. As indicated in several "pet store books" dealing with the care of salamanders, fresh, live earth

8. Finally, your animal may respond to a different type of food. Try any of the following gourmet axolotl delicacies:

Straight Liver:	Our basic "No Frills" dish. A favorite with the younger set. Pureed to perfect consistency. Goes down like buttered silk.
Sliced Liver:	The "Filet Mignon" of salamander cuisine. Carefully prepared in delicately tasty strips. A real palate pleaser.
Daphnia:	The perfect appetizer. Bite-sized morsels lovingly raised in our own special ponds.
Axolotl Larvae:	A really sweet bunch of kids. For the mature axolotl with a taste for the exotic. More than a mouthful's wasted!
Vickie's Special Mix:	The newest addition to our menu. A "Vegetarian Delight" blending tofu, fresh alfalfa sprouts, and a host of garden goodies solidified in gelatin for today's discriminating axolotl. Write for recipe!

Figure 5. Suggested menu for axolotls. Reprinted from an article by Nathan Montoya in the Winter 1982 issue of the Axolotl Newsletter, courtesy of the Ambystoma Genetic Stock Center.

worms seemed to be the correct diet. Although the liver-trained axolotls were initially frightened by the twisting and turning worms in their glass bowl, they learned quickly how to deal with the new food.

The advice provided by Brun offers just one example of the tips and suggestions traded through the *Axolotl Newsletter*. The kind of individualized care that axolotls require to produce good data in turn produces an affection in the scientists who care for them, one that becomes evident in the descriptions that scientists provide about their axolotls for the newsletter. For example, one described the population of a laboratory in the following terms: "We have white animals, inbred for five generations, hyper-pigmented whites, a few black and—(the most cherished of all our axolotls) two beautiful golden albinos" (Thomas 1978, 13). The language of beauty and cherishing indicates an aesthetic appreciation and fondness for the animals.

FROM AXOLOTL RESEARCH TO HUMAN BIOLOGY

However, care *of* the axolotls did not necessarily translate into care *for* the axolotls. While scientists spoke with affection about these creatures, they often treated the animals violently, removing axolotl limbs or organs, grafting one axolotl to another. In the Axolotl Colony and, subsequently, the Ambystoma Genetic Stock Center (AGSC), axolotls were highly inbred, both for purposes of standardization and to reveal new recessive phenotypes. While initially advantageous for research, the extent of laboratory axolotl standardization has become problematic; according to the AGSC, the lack of diversity indicates "an ominous future for the AGSC population if genetic management strategies are not enacted" (Voss, Woodcock, and Zambrano 2015, 1136), imperiling its future and indicating some of the negative consequences of exposure to laboratory life.

Tending to axolotls is a potentializing practice, but the potential generated is human potential rather than axolotl potential. While regenerative biologists are concerned about the viability of the axolotl and its health in the lab, they study axolotls not because they find the animals interesting for their own sake, but because scientists believe that they contain clues to capabilities and powers available to humans, if only we pursue them.[12] In the work of biologists studying development and regeneration, axolotls come to stand in for the potential embodied in all vertebrates. This argument makes the claim that the processes of cell and organismal development do not radically differ across classes and that the regenerative powers of urodele amphibians could be shared by all vertebrates.

Some developmental biologists argue that amphibians, rather than being exceptional creatures, should "remind us that regeneration is an ancient and fundamental biological process, and challenge our creative and scientific abilities to discover how to unlock the regenerative potential with us" (Bryant, Endo, and Gardiner 2002, 895).[13] This argument holds that failing to properly interpret the axolotl as a model for human bodies and instead viewing it as an alien aberration has hindered research.

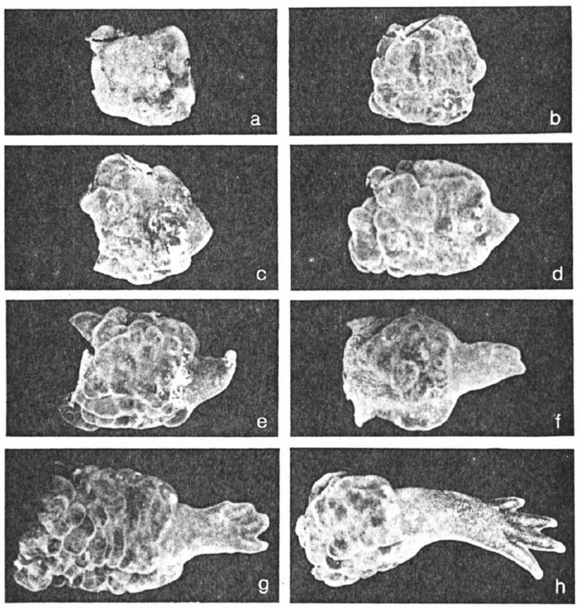

Figure 6. The process of limb regeneration. Reprinted from an article by Bruce M. Carlson in the October 17, 1976 issue of the Axolotl Newsletter, courtesy of the Ambystoma Genetic Stock Center.

Scientists studying the axolotl have demanded a reconsideration of the prevailing view that humans are incapable of regeneration in light of recent discoveries of multipotent cells—cells that can give rise to a variety of cell types—in adult mammalian tissues (Bryant, Endo, and Gardiner 2002). Axolotls and their powers of limb regeneration thus become a source of "strategies for inducing regeneration in mammals" (Bryant, Endo, and Gardiner 2002, 888). Biologists argue that "the remarkable regenerative abilities of salamanders demonstrate what we reasonably can expect in terms of enhancing our regenerative potential"

(McCusker and Gardiner 2011, 566). Scientists studying axolotls claim that the process of limb regeneration in axolotls, on one hand, and mammalian tissue repair, on the other, are based on common cellular and molecular programs, and that the pattern of gene expression in regenerating axolotl limbs resembles that of developing limbs in other vertebrates (Morrison et al. 2006). Beyond possibilities for limb regeneration, the axolotl is seen as suggesting an improved human future, one in which aging as well as trauma can be overcome. While most studies focus on limb regeneration, the developmental biologists Catherine McCusker and David Gardiner (2011, 566) suggest that the study of these regenerative mechanisms might also provide a means "to enhance our intrinsic regenerative abilities in order to slow and even reverse the damage of aging." In their labs, the axolotl serves as a model for remaking human capabilities, one suggesting that the standard developmental narrative presumed to underwrite human life—birth, aging, and death—could perhaps be otherwise. They read the axolotl as evidence that within ourselves we have the capability to produce alternative developmental pathways, ones that do not end in aging or death.

By scaling their focus to conserved genetic sequences, shared cell-signaling pathways, and other similarities at a cellular, molecular, or genetic level, scientists call into question the significance of the apparently vast differences at the level of the organism. They argue that at the scale of the cell, the preconception of fundamental difference between humans and salamanders is misguided and has obscured the possibility that humans might be capable of regeneration. Following in the axolotls' footsteps, rather than a speculative or radical proposal, is what we can reasonably expect.

In the lab, the axolotl can repeatedly generate surplus vitality in the form of additional or replacement body parts. It transforms in response to new conditions, whether adapting itself to life in the glass bowls of the laboratory or to manipulations of its reproductive organs. It is a model of what Sarah Franklin (2007, 10) has called "the age of biological control," in which biology is remade as plastic, flexible, and ideally suited to the market forms of biocapitalism. Through the care and labor of regenerative biologists, the axolotl has become a tool that could potentially unlock new sources of value and surplus vitality within the human body. These potentialities are produced under capitalist logics that would most likely make flexibility, transformation, and rejuvenation unequally distributed, available only to those who could afford them.

RESTORATION ECOLOGY AND THE AXOLOTL AS SENTINEL SPECIES

The image of the axolotl as regenerative harbinger becomes ironic once one ventures out of the lab to consider the amphibian in the wild. In 2011, I went to Xochimilco, the axolotl's only native habitat. The present-day canals of Xochimilco are popular destinations for residents of Mexico City and tourists alike. People come for rides in *trajineras*, festive colored boats that can carry up to thirty people and are available for rental by the hour or the day. As the boats make their way slowly through the canals, they are stopped by vendors offering drinks, multicourse meals, or serenades by mariachi bands. The whole area has the atmosphere of a party, and few people seem to take notice of the extremely murky quality of the water below. I went to Xochimilco with Luis Zambrano, the director of the Laboratorio de Restauración Ecológica, who studies aquatic ecosystems and organisms with a focus on the axolotl. Zambrano's work in conservation and restoration has made him well known, and he has a high profile both within Mexico and internationally. Shortly after we arrived in Xochimilco, Zambrano hailed a *trajinera* to take us to the site of one of his research and conservation projects, a refuge for the axolotl. Zambrano scoffed at the tourists, telling me

Figure 7. Trajinera in Xochimilco. Photo by Emily Wanderer.

that we would not be following them. We were going to what he called "the *nice* area. Not the tourist area." Eschewing the more populated canals, we headed toward the area where Zambrano was developing the refuge.[14] While axolotls used to abound in the canals, populations have been declining; starting in 2006 they were listed as critically endangered by the International Union for the Conservation of Nature, and today they are protected under the Convention on International Trade in Endangered Species agreement. Hence, the need for a refuge to protect them.

We arrived at the refuge after a short ride in a skiff. The refuge was one of the lake's artificial islands that had been restored to its historical function as a *chinampa*, an area for labor-intensive agriculture. Like most of the *chinampas* in Xochimilco, it had been abandoned for two decades. *Chinampas* had fallen out of favor as Xochimilco underwent acute change, becoming increasingly urbanized

Figure 8. In the axolotl refuge. Photo by Emily Wanderer.

while agricultural production was marginalized. The growing water needs of Mexico City and the accompanying diversion of water from Xochimilco resulted in declining water quality and food production and harmed the agrarian landscape (Salles 1992). Yet despite these changes, the Laboratory for Ecological Restoration managed to transform this *chinampa* after acquiring the land with a grant from the federal government. It had once again become a thriving garden, demonstrating the continued fertility of the land. Zambrano had hired laborers to work the soil and had purchased the equipment, tools, and seed necessary to make it productive. They grew organic lettuce, broccoli, cabbage, and chamomile to sell in urban markets. To provide a refuge for the axolotl, they tended to and cultivated the canal, planting water hyacinth and other native plants, and they constructed a filter to prevent nonnative fish from entering and to improve the canal's water quality. The improved water quality was also intended to better the quality and healthfulness of the crops grown in the *chinampa*, which were irrigated with canal water.

Zambrano was optimistic about the refuge's promise to provide a haven for axolotls and to protect the ecosystem in Xochimilco more broadly. The refuge began with one experimental canal and one control canal, subsequently expanding to four additional canals (Valiente et al. 2010). As we walked around the refuge, he told me that they had been working on it for the past three years, exclaiming: "And see the changes! From this experience, we know that in three years we can change the land. You need to have a good team. One person can't do anything alone." He went on to describe the refuge as a "synthesis of culture and nature." In this project, he was attempting to resurrect a historical form of agriculture to protect a species that had the status of a national symbol. People are fascinated by the axolotl, and the refuge project received significant attention from journalists within Mexico and from abroad.[15] The affective appeal of organisms, or their charisma, has proven key to motivating conservation projects globally (Lorimer 2015). Zambrano intended to make use of the animals' charisma and significance for Mexicans to call for the protection of not only an entire ecosystem but also the agricultural practices that have historically characterized the area. This project contrasts with other conservation efforts in Xochimilco that have paid little attention to the local community and have often resulted in its dispossession in the name of protecting nature (Narchi and Cristiani 2015). The refuge would offer protection from encroaching urbanization, making it possible for the axolotl to survive in its native environment while maintaining the *chinampa* as a space for agricultural life and labor. To protect axolotls, Zambrano argued, Mexico had to maintain the historic cultural practices that had allowed humans and axolotls to coexist for centuries. The canals in which the axolotl lived could never be conceived of as pure spaces of nature; they are anthropogenic landscapes, tied to human practices, in which axolotl and human lives are produced together.

LIVING WELL WITH AXOLOTLS

As Mette Svendsen (2011, 416) argues in the case of human embryos, articulations of potentiality are "acts deeply embedded in a social context and constitutive of the mobilization of social relations and networks." Articulating the potentiality of the axolotl depended on activating a range of social relations, including interest in particular food products. The success of the *chinampas* depended on the development of a culture within Mexico City that valued food attached to a specific locale. The concept of *terroir*, or the taste of place, conveys the idea that the geophysical attributes of a place, like soil, topography, climate, ecosystem, combine with social and cultural practices of agriculture to produce particular tastes (Paxson 2010; Weiss 2011). Zambrano and the farmers I spoke with at the *chinampa* described the produce as having a unique flavor. "The rosemary has a saltier flavor," one said. "The earth is different," another added, "the *epazote* [wormseed] has its own taste." A third: "Whatever herb we grow here, it has a different flavor." The process of constructing a connection between a particular taste of food, a form of agriculture, and a particular place requires the development of a consumer market, one that is willing to seek out and support local foods and is invested in conservation. The growing prominence of fine-dining restaurants that emphasize the use of local produce suggests the possibility of generating an interest in the *terroir* of Xochimilco.[16] At the moment, the products produced in the axolotl refuge are not explicitly marketed as coming from Xochimilco. Gradually, the team hopes to get people to pay more for plants from Xochimilco because they are more delicious, and because supporting agriculture in Xochimilco means maintaining practices that produce places essential for nonhuman life forms like the axolotl.

In *The Cage of Melancholy*, Roger Bartra (1992, 7) deploys the axolotl, which he identifies as "that most Mexican amphibian," as a metaphor for Mexican national identity. He translates the Nahuatl word *axolotl* as "game of water," drawing attention to the playful and fluid qualities of the axolotl. Bartra (1992, 7) suggests that there are "certain associations between social and biological phenomena, associations of ideas which traditionally have been at the root of national thought." In his telling, the biology of the axolotl and its mysterious double nature as both larva and salamander, the result of an eternally delayed metamorphosis, becomes a representation of the Mexican national character, highlighting the nation's perpetual delay and immaturity with respect to global trends. The biological properties of the axolotl in this account are signs, "a message that is transmitted to Mexicans in order to instruct them on their condition, their origin, and their future" (Bartra 1992, 8). Taking Bartra's deployment of the axolotl seriously, I ask what the fate of the axolotl tells us today. What is the axolotl's message as it is circulated in scientific labs and taken as object of conservation for the Mexican nation?

The refuge brought together nonhuman life forms and human practices to move past anthropocentric conceptions of a good life toward a more biocentric view, one that considers better living not only for people but also for Mexico's biodiverse life forms. Projects like the axolotl refuge incorporate both human and nonhuman into projects that conjoin the political with the biological, producing new forms of biopolitics (Foucault 1978, 2008). Nonhuman and human lives have long been entangled in Xochimilco and this project, rather than seeking to address one in isolation from the other, brings them together in the same frame. Reports on Zambrano's projects described the conservation of the axolotl as crucial for the ecosystem of Mexico City, ascribing to the retiring salamander tremendous ecological significance. Zambrano explained that "keeping the salamanders would imply that the urban environment had improved, and that Xochimilco had become a strong point for sustainability that would provide the city with water, climate, food, air, and vegetation" (Olivares Alonso 2011). Protecting Xochimilco would represent at least a symbolic commitment within Mexico City to protecting the environment. Zambrano argues that the health of the nation is tied to the preservation of life forms like the axolotl and that this preservation will come through a commitment to maintaining human ways of life tied to Mexican history. The management of nonhuman animal life entails management of human life, labor, production, and even taste. Saving the axolotl thus becomes a project that could reshape human lives in Mexico City.

While the refuge draws on contemporary Western scientific principles and is organized by a well-regarded, mainstream academic scientist, it also exemplifies efforts in Mexico and Latin America more generally to use concepts of *buen vivir/vivir bien* to reconceptualize and challenge Western scientific paradigms. *Buen vivir/vivir bien* has emerged as a social movement in Latin America in recent decades. Translated as "living well," the concept of *buen vivir* draws on values, experiences, and practices from indigenous communities to challenge capitalist practices and conventional Western notions of the good life. The goal of *buen vivir* is to value harmony among individuals living in a community and between peoples and nature, decentering the human in favor of an ecosystemic view of the world (de la Cadena 2010, 2015). *Buen vivir* has been written into the constitutions of Bolivia and Ecuador, where the idea that all life forms ought to be "living well" has been used to critique narratives that represent the global South as underdeveloped and in need of conforming to the developed world. The axolotl refuge (unlike other so-called conservation projects enacted in Xochimilco) refuses standard narratives of development in which nature is subject to domination and exploitation, as well as the modern division between culture and nature itself. The stalled development of the axolotl, and its refusal to metamorphose, might in this light be reinterpreted as resonating with *buen vivir*'s rejection of Western categories of developed and underdeveloped and its calls for alternatives to development that draw on indigenous lifeways and practices. I read the axolotl refuge as an effort to highlight local indigenous and mestizo practices to find a new way forward, to construct a future in which both human and nonhuman life forms are valued and thrive and to imagine an economy based on solidarity, sustainability, wholeness, and diversity.

Despite these efforts to care for the axolotl and to sustain human forms of life, this is ultimately not a story of hope and survival across species lines. The axolotl has radically diminished in Xochimilco, succumbing to invasive species, pollution, and generally degraded water quality and habitat. Neither the corporeal flexibility lauded by regenerative biologists nor the refuge project has protected the axolotl against the continuing transformation of an increasingly malfunctioning ecosystem. The axolotl in the context of Xochimilco represents a very different future than the axolotl of the lab. Rather than exhibiting limitless, unconditional biology, the axolotl in the canals appears inflexible and vulnerable. It is far from a unique case. The story of salamanders and amphibians more broadly in the Anthropocene is one of collapse and disappearance; indeed, amphibians are often taken as indicator species signalling anthropogenic harm. Herpetologists argue that contemporary extinction rates among amphibians indicate that the class is currently undergoing a mass extinction event, one that rivals the one at the end of the Cretaceous period that brought about the extinction of the dinosaurs (Wake and Vredenburg 2008; Kolbert 2015). The extinction events among salamanders and other amphibians carry a broader message as well; these species are often seen as sentinel species, crucial indicators of the broader health of the watershed (Hovingh 1982). Their disappearance tells us about the broader environment, and about the future of other species. Despite the axolotl's poor prospects, the refuge project itself remains an important example of how scientists engaging in efforts to improve life have drawn connections between forms of human life and protecting biodiversity, an example that perhaps should be more broadly applied. Zambrano continues his work on the refuge, attempting to improve at least a small portion of Xochimilco for the axolotl and raising wild axolotls in his lab for potential release (Vance 2017).

CONCLUSION

The axolotl in the canals of Xochimilco and in the biological laboratory suggest different models and practices for living alongside species; in each setting, the axolotl embodies different forms of potential. Both projects break down species boundaries, imagining human and axolotl lives as intertwined. However, the nature of this relationship differs radically depending on the context. In the laboratory the axolotl multiplies. Flexible and fluid, it becomes a model for not only biological processes but for modern life. It is an idealized form of vitality and regeneration, able to adjust and regenerate in the face of any kind of abuse or violence that modernity supplies, and one that humans should strive to emulate. Yet the vitality and regenerative potential of the axolotl exist only within very narrow parameters: in the monitored and controlled spaces of the lab where the animals are tended to with a particular kind of care. In the wild, axolotls are vulnerable to change and can only be sustained by equally precarious human forms of life, certain agricultural practices fast being pushed aside by urban living. Despite being touted as models of flexibility and adjustability, axolotls are here better understood as precarious and fragile, creatures whose survival in a degraded environment requires human commitment and work to preserve their habitat. The axolotl demonstrates how biological care can enable very different imaginings of the future and very different biopolitics for both humans and other creatures.

ABSTRACT

The axolotl is a noteworthy species of salamander, one both biologically remarkable and culturally significant. Native to the canals of Xochimilco, a neighborhood in Mexico City, the charismatic species has deep connections to Mexican history and identity, as well as serving as an important model organism for scientists studying regenerative biology. Drawing on fieldwork in Mexico with restoration ecologists engaged in conserving axolotl habitats, as well as on scientific papers and informal communications among scientists who use axolotls as model organisms, I examine the fate of the axolotl in and out of Xochimilco. Taking up the lives of both wild and *cultivated axolotls, this essay asks what is at stake when a species is eliminated from one anthropogenic environment, the canals of Xochimilco, while being made to live in another, the laboratories of scientists studying developmental and regenerative biology. In the lab, axolotls are interpreted as plastic and flexible, potential models for reconfiguring human capabilities, injury, and aging. In the wild, the axolotl is a fragile sentinel species in need of protection that serves as an indicator of the fragility of the ecosystem more broadly. Conservationists interpret its failure to thrive as a message to human populations to reform and reconsider how they live in relation to the environment. This essay demonstrates how, through scientists' care, axolotls come to represent different forms of potential and produce different insights into human life, enabling distinct imaginings of the future.* [potentiality; care; restoration ecology; regenerative biology; multispecies ethnography; Mexico]

NOTES

Acknowledgments I am very grateful to Luis Zambrano for showing me his work in Xochimilco. Many colleagues read and commented on drafts of this article; I would like to especially thank Mary Brazelton, Laura Brown, Heath Cabot, Stefan Helmreich, Amy Johnson, Gabriella Lukacs, Lisa Messeri, Tomas Matza, Joy Rankin, and David Singerman for their thoughtful engagement. I presented versions of this research at the University of California, Santa Barbara Latin American and Iberian Studies Program, at the University of Pennsylvania Program in Environmental Humanities, and at the University of Cambridge Centre for Research in the Arts, Social Sciences, and Humanities; the responses I received from these audiences helped shape and improve the essay. Thanks also to the *Cultural Anthropology* editorial collective; Cymene Howe's editing was particularly valuable. This research was supported by the Wenner-Gren Foundation and the National Science Foundation.

1. Compare the axolotl with the jaguar, another iconic Mexican animal, which evolved between 2 and 4 million years ago (Johnson et al. 2006).
2. Scientists compare axolotl and human cellular and molecular programs and genomes, trying to establish what biological differences enable axolotls to regenerate while humans cannot and what similarities exist between the two species' biological processes. Mammals do have some capacity to regenerate; for humans, this ability is most evident in newborns, who can regenerate amputated fingertips (Hutchins and Kusumi 2016). Work by regenerative biologists seeks to draw on animal models to find ways to extend and enhance this capacity. Scientists study genetic programs, the processes of cell signaling, proliferation, and dedifferentiation, immune responses, and other elements of regeneration in their search for commonalities between model species and humans. The axolotl has an extremely large genome (its thirty-two-gigabase pair is about ten times the length of the human genome). Due to its large size, it has only recently been sequenced (Nowoshilow et al. 2018). Researchers hope that studies of the axolotl genome will allow them to better understand which genes related to regeneration have been conserved across species and how their regulation differs in mammals and salamanders (Koshiba et al. 1998; Farkas et al. 2016; Hutchins and Kusumi 2016).
3. Afraid of death, rather than being offered up as a sacrifice, Xolotl transformed first into a maize sprout, then a maguey or agave plant, and finally hid as an axolotl in Lake Xochimilco, a mythical transformation that ties these three life forms and food sources together (Read and Gonzalez 2000).
4. Of course, Mexico City was also an important space for knowledge making at this time, not simply a source of raw materials for European consumption; see Achim 2007 on the circulation and debates about lizards as remedies in the late 1700s.

5. What was, for Zambrano, a survival strategy—immobility during the day—becomes an indication of axolotl alienness, foreignness, and disconnection from the human.
6. Axolotl ways of knowing and being may be incommensurable with the human, but, as this essay argues, axolotl ways of being may have important consequences for human practices.
7. For a more detailed analysis and other interpretations of the story, see Levinson 1994.
8. See Fausto-Sterling 2000 for an analysis of the history of models of male and female development in animals and humans and their implications.
9. The Axolotl Colony has been a major center of axolotl breeding and research. It moved in 2005 from Indiana University to the University of Kentucky's Department of Biology, where it was renamed the Ambystoma Genetic Stock Center (AGSC). In 2016, the AGSC resurrected the newsletter, which had ceased publication in 2003.
10. The laboratory population of axolotls is highly inbred (Voss, Woodcock, and Zambrano 2015). Most appear to be descendants of a shipment of thirty-three animals to Paris in 1864 (Malacinski 1978; Reiß, Olsson, and Hoßfeld 2015). According to George Malacinski (1978, 196), an early director of the Axolotl Colony, they are notable even within populations of laboratory animals for their degree of inbreeding: "Among vertebrates, the axolotl may indeed have achieved one of the higher extents of selective, closed colony breeding yet achieved for a laboratory maintained experimental animal."
11. For more on the standardization of animal bodies for scientific research, see Kohler 1994, Creager 2001, and Rader 2004.
12. This recalls Rachel Ankeny's (2007) point about how modeling work assumes that findings can be generalized across species.
13. These claims are eye-catching and remarkable for scientific, peer-reviewed articles, borrowing the capitalist language of sales and salesmanship to promote the science of regenerative biology.
14. For an account from Zambrano's lab on the development of the refuge, see Valiente et al. 2010.
15. For examples of media coverage of the refuges, see Walker 2009, *Universal* 2011, Varela Huerta 2011, and Castello y Tickell 2012.
16. Take Pujol, Enrique Olvera's restaurant in the neighborhood of Polanco, which frequently appears on lists of the world's best restaurants and emphasizes local ingredients.

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