GLOBAL ENTOMOLOGIES: INSECTS, EMPIRES, AND THE 'SYNTHETIC AGE' IN WORLD HISTORY*

I

In November 1944, Decca Records released an album featuring Ella Fitzgerald and The Ink Spots. The two tracks on the record, 'I'm Making Believe' and 'Into Each Life Some Rain Must Fall', spent seventeen weeks at the top of the *Billboard* charts in the United States and inaugurated a long-term collaboration between the 'First Lady of Song' and the fabled record producer Milt Gabler. A century before this musical milestone, the Ottoman Sultan Abdülmecid I (1839–61) founded the Hereke Imperial Carpet Manufacture to produce elaborate silk rugs for his Dolmabahçe Palace on the Sea of Marmara. These extravagant carpets, among the finest ever woven, featured between 3,000 and 4,000 knots per square inch. Six decades earlier, on 19 October 1781, Brigadier-General Charles O'Hara of His Britannic Majesty's Coldstream Guards donned his distinctive scarlet-coloured officer's coat, strode onto the battlefield at Yorktown, Virginia, and surrendered the sword of Lieutenant-General Charles Cornwallis to Major-General Benjamin Lincoln of the North American Continental Army.[1]

A trio of more incongruous events, spanning three centuries, might seem difficult to imagine, yet these episodes share an astonishing feature. They depended on the tremendous productive

* Thanks to Nina Gordon, Steven Gray, Hannah Greenwald, Ken Kopp, Tricia Lipton, Benjamin Madley, Jerry Melillo, Lalise Melillo, Michael O'Connor, Dawn Peterson, Khary Polk, Elizabeth Pryor and Theodore Waddelow for their input on earlier versions of this article.

[1] Stuart Nicholson, *Ella Fitzgerald: A Biography of the First Lady of Jazz*, new edn (New York, 1995), 81. Emmett Eiland, *Oriental Rugs Today: A Guide to the Best New Carpets from the East*, 2nd edn (Berkeley, 2003), 80; for more on the Hereke Imperial Carpet Manufacture, see Ayţe Fazlýođlu and Oktay Aslanapa, *The Last Loop of the Knot: Ottoman Palace Carpets* (Istanbul, 2006). On the different materials used in dyeing officers' coats and those of lower-ranking soldiers in the British army, see Scott Hughes Myerly, *British Military Spectacle: From the Napoleonic Wars through the Crimea* (Cambridge, Mass., 1996), 68.

Past and Present (2013)
doi:10.1093/pastj/gtt026

capacity of domesticated insects. The brittle shellac of Ella Fitzgerald's 78-rpm record, the gossamer threads woven into the sultan's silk carpets, and the crimson cochineal used to dye the brigadier-general's jacket entered the circuits of global commerce as secretions from the bodies of tiny arthropods. Women and men in places as far flung as north-eastern India, the Ottoman Bosporus and Mexico painstakingly raised the lac bugs (*Kerria lacca*), silkworms (*Bombyx mori*) and cochineal insects (*Dactylopius coccus*) that exuded the raw materials for these products. Although the histories of shellac, silk and cochineal have been considered in fragmented and episodic accounts, they have never been looked at concurrently.[2]

Starting from a constellation of these three commodities, this article documents a series of long-standing productive relationships between humans and insects. Following the metamorphoses of shellac, silk and cochineal from locally produced goods into commodities circulating throughout the capitalist world system, this article offers two conclusions. First, Europeans existed on the *knowledge periphery* of insect commodity production, incredulous that indigenous know-how beyond the boundaries of the Occident could be so central to global commerce.[3] Historians have cogently demonstrated the symbolic and economic strengths that European empires acquired by dominating colonial environments, but we are only just beginning to hear about the failures of such projects.[4]

[2] *Arthropoda* is the most numerous phylum among living organisms and includes insects, arachnids and crustaceans, as well as other invertebrates. All arthropods have exoskeletons, segmented bodies and jointed appendages. Insects possess chitinous exoskeletons, tripartite bodies (head, thorax and abdomen), two antennae, compound eyes and three pairs of jointed legs.

[3] Referring to such culturally generated epistemological gaps, historians Londa Schiebinger and Robert Proctor have coined the term 'agnotology'. See Robert N. Proctor and Londa Schiebinger (eds.), *Agnotology: The Making and Unmaking of Ignorance* (Stanford, 2008).

[4] For examples of the scientific justifications and environmental outcomes of European imperial endeavours from the sixteenth to the twentieth centuries, see Daniela Bleichmar *et al.* (eds.), *Science in the Spanish and Portuguese Empires, 1500–1800* (Stanford, 2009); Harro Maat, *Science Cultivating Practice: A History of Agricultural Science in the Netherlands and its Colonies, 1863–1986* (Dordrecht, 2001); Richard H. Drayton, *Nature's Government: Science, Imperial Britain, and the 'Improvement' of the World* (New Haven, 2000); Richard H. Grove, *Green Imperialism: Colonial Expansion, Tropical Island Edens and the Origins of Environmentalism, 1600–1860* (Cambridge, 1995); Lucile H. Brockway, *Science and Colonial Expansion: The Role of the British Royal Botanic Gardens* (New York, 1979).

Second, the long-term histories of shellac, silk and cochineal offer a counter-narrative to conventional accounts of modernity. During the nineteenth and twentieth centuries, industrial engineers chemically synthesized and aggressively promoted surrogates for all three arthropod secretions — vinyl for shellac, nylon for silk and aniline dyes for cochineal. Yet the recent re-emergence of shellac, silk and cochineal as extensively traded global commodities demonstrates an enduring reliance upon the secretions of domesticated insects. An awareness of the persistence of seemingly pre-modern means of production exposes cracks in the smooth edifice of technological modernity. The durability of such processes destabilizes the high modernist assumption that human beings are inexorably marching towards a 'synthetic planet' on which the artificial will ultimately replace the natural.[5]

Two factors have driven the recent resurgence of the shellac, silk and cochineal trades. The first is the rise of environmental toxicology. From the 1960s onwards, practitioners of this newly constituted scientific discipline began to expose the poisonous and carcinogenic effects of numerous synthetic chemicals released into the environment by design — such as pesticides and food additives — or by accident as industrial by-products. As a result, consumer demand for alternatives has stimulated a resurgence of organically produced ingredients through much of the world. In numerous cases, manufacturers have abandoned synthetic substitutes in favour of natural substances, such as shellac and cochineal.[6]

The second factor is the more recent discovery that, despite enormous strides in polymer synthesis, industrial chemists remain unable to manufacture inexpensive or structurally adequate alternatives to a vast array of naturally produced materials. Silk, like many similar products, has proved too complex to be

[5] I have borrowed the notion of a 'synthetic planet' from Monica J. Casper (ed.), *Synthetic Planet: Chemical Politics and the Hazards of Modern Life* (New York, 2003). Conceptually, I draw upon Bruno Latour's argument that modernity is paradoxical. On the one hand it is a claim that 'nature' and 'society' are pure and distinct realms, yet it simultaneously depends upon hybrids of human and non-human natures that defy these strict separations. See Bruno Latour, *We Have Never Been Modern*, trans. Catherine Porter (Cambridge, Mass., 1993).

[6] For more on public attitudes towards natural versus synthetic chemicals, see Richard Firn, *Nature's Chemicals: The Natural Products That Shaped our World*, revised edn (Oxford, 2010), 127–39.

efficiently engineered and profitably mass-produced. In an era dominated by the promise of 'Better Living through Chemistry', many organisms still operate as inimitable laboratories of metamorphosis. As a result of surging demand for shellac, silk and cochineal, women and men throughout the world continue to rely upon insect secretions as a means of securing their livelihoods in an age of hi-tech globalization.[7]

Global environmental history offers a powerful analytical framework for relating these interspecies associations to larger social and ecological shifts. For millennia, people and ecosystems in geographically distinct regions of the world have interacted in far-reaching ways. The challenge now facing practitioners of global environmental history is to transcend approaches based solely on local or national comparisons and move towards models that emphasize transnational connections. A more complete understanding of processes as diverse as the expansions and contractions of imperial knowledge, the limits of synthetic chemistry, and the shifting aspects of interspecies relations requires such expansions of scope and scale. Although this article pursues *comparisons* among three insect secretions, the emphasis here is primarily on *connections* — and the antagonisms that these encounters generate — among producers and consumers across space and time.[8]

[7] 'Better Living through Chemistry' was the shortened version of DuPont's tagline 'Better Things for Better Living . . . through Chemistry', which the chemical company adopted in 1935. It remained their slogan until 1982. See William L. Bird Jr, *'Better Living': Advertising, Media and the New Vocabulary of Business Leadership, 1935–1955* (Evanston, 1999), 23. In the 1970s, Monsanto employed a similar catchphrase, 'Without chemicals, life itself would be impossible'. See David Noble, 'The Chemistry of Risk: Synthesizing the Corporate Ideology of the 1980s', *Seven Days*, 5 June 1979, 24.

[8] For discussions of the analytical possibilities that emerge from an emphasis on transnational connections, see Edward D. Melillo, 'The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840–1930', *American Historical Review*, cxvii (2012); Micol Seigel, 'Beyond Compare: Comparative Method after the Transnational Turn', *Radical History Review*, xci (Winter 2005); Kenneth Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton, 2000), 3–27. Over the past three decades, scholars have taken a range of approaches to global environmental history. For several recent examples, see Anthony N. Penna, *The Human Footprint: A Global Environmental History* (Oxford, 2009); I. G. Simmons, *Global Environmental History: 10,000 BC to AD 2000* (Edinburgh and Chicago, 2008); Joachim Radkau, *Nature and Power: A Global History of the Environment*, trans. Thomas Dunlap (Cambridge and Washington, DC, 2008); John F. Richards, *The Unending Frontier: An Environmental History of the Early Modern World* (Berkeley, 2003).

Environmental historians are also uniquely positioned to revise our understanding of the roles that organisms have played in our cultural and technological systems. In an inversion of Leo Marx's now-familiar metaphor of 'the machine in the garden', historian Edmund Russell has contended that the history of biotechnology might instead be seen as the 'garden in the machine', or the interplay of evolution and technical change to produce 'biological artifacts shaped by humans to serve human ends'.[9] Yet insects are not merely the relics of anthropogenic manipulations. Beyond botanical and mechanical metaphors lies an appreciation of the ways in which these creatures have altered — and continue to shape — the frameworks of our existence.[10] As this article concludes, insects are as integral to the realities of our earthly survival as they have been to our visions of otherworldly apocalypse.[11]

Millennia of environmental adaptations and cultural accommodations have underwritten human relationships to insects. Throughout history, these intrepid creatures have populated our folk tales, pollinated our flowering plants and plagued our fields. They have served as culinary cornerstones, even as they dined on our architectural foundations. Civilizations have feared them as vectors of disease, revered them as sacred objects, and ceaselessly manipulated them as models for genetic experimentation.[12] Rather than explore productive relations between

[9] Leo Marx, *The Machine in the Garden: Technology and the Pastoral Ideal in America* (New York, 1964); Edmund Russell, 'Introduction: The Garden in the Machine. Toward an Evolutionary History of Technology', in Philip Scranton and Susan R. Schrepfer (eds.), *Industrializing Organisms: Introducing Evolutionary History* (London, 2003), 1.

[10] Donna Haraway's work on the productive possibilities of experiencing the world through interactions with non-human beings has been influential here. See Donna J. Haraway, *When Species Meet* (Minneapolis, 2008).

[11] Scholars have generally framed the Synthetic Age as a phenomenon following the Second World War. For examples, see Sarah A. Vogel, 'From "The Dose Makes the Poison" to "The Timing Makes the Poison": Conceptualizing Risk in the Synthetic Age', *Environmental History*, xiii (2008), 667–73; John Bellamy Foster, 'The Vulnerable Planet', in Leslie King and Deborah McCarthy (eds.), *Environmental Sociology: From Analysis to Action* (Lanham, 2005).

[12] Between 396 and 407 million years ago insects evolved on earth. See Michael S. Engel and David A. Grimaldi, 'New Light Shed on the Oldest Insect', *Nature*, 12 Feb. 2004, 627–30. For examples of the various roles insects have played in human society, see Cristopher Hollingsworth, *Poetics of the Hive: The Insect Metaphor in Literature* (Iowa City, 2001); May R. Berenbaum, *Bugs in the System: Insects and their Impact on Human Affairs* (Reading, Mass., 1995); Robert E. Kohler, *Lords of the Fly: Drosophila Genetics and the Experimental Life* (Chicago, 1994); J. L. Cloudsley-Thompson, *Insects and History* (London, 1976).

humans and insects, most historians have — quite understandably — concentrated on the destructive impacts of insects, such as disease transmission, crop damage or structural decay. Indeed, formidable battles against arthropod 'pests' have preoccupied humans for millennia. From pre-modern biblical plagues to contemporary horror films, the spectre of insect invasion has haunted humanity.[13]

The lives of insects offer many paradoxes. These creatures can be microscopically unobtrusive, yet they display devastating power in a swarm; it takes only one swat to destroy them, but they epitomize evolutionary resilience on earth; they are the vectors of devastating diseases such as malaria and dengue fever, yet they carry out some of the world's most crucial services and produce some of its most durable products.[14]

II

SHELLAC

One such commodity, shellac, has been traded for thousands of years. Among the earliest references to shellac is a passage in the ancient Indian Sanskrit epic, the *Mahabharata* (*c.*300–400 CE). In the story, Duryodhana, the leader of one of two feuding royal factions, attempts to murder his cousins, the Pandvas, by trapping them in a flammable house built of shellac (*Lāksagrha*).

[13] Recent examples of this genre include: J. R. McNeill, *Mosquito Empires: Ecology and War in the Greater Caribbean, 1620–1914* (New York, 2010); Gordon Patterson, *The Mosquito Crusades: A History of the American Anti-Mosquito Movement from the Reed Commission to the First Earth Day* (New Brunswick, NJ, 2009); James E. McWilliams, *American Pests: The Losing War on Insects from Colonial Times to DDT* (New York, 2008); Paul S. Sutter, 'Nature's Agents or Agents of Empire? Entomological Workers and Environmental Change during the Construction of the Panama Canal', *Isis*, xcviii (2007); Jeffrey A. Lockwood, *Locust: The Devastating Rise and Mysterious Disappearance of the Insect that Shaped the American Frontier* (New York, 2004); Joshua Blu Buhs, *The Fire Ant Wars: Nature, Science, and Public Policy in Twentieth-Century America* (Chicago, 2004). In movies such as *Tarantula* (1955), *The Fly* (1958), *Killer Bees* (1974), *The Empire of the Ants* (1977), *Swarm* (1978), *Arachnophobia* (1990), *Eight Legged Freaks* (2002), *Black Swarm* (2007) and *The Hive* (2008), Hollywood casts these creatures as 'evil arthropods', which wreak havoc on humankind. For more on this trend, see William M. Tsutsui, 'Looking Straight at *Them*! Understanding the Big Bug Movies of the 1950s', *Environmental History*, xii (2007).

[14] Such ambiguities surface in the periodic appearance of fictional insects and arachnids as sympathetic proto-humans. Examples include Pinocchio's companion Jiminy Cricket, Charlotte the barn spider in E. B. White's *Charlotte's Web* (New York, 1952) and the hookah-puffing caterpillar in Lewis Carroll's *Alice's Adventures in Wonderland* (London, 1865).

The Pandvas foil his plot and escape to safety through a secret passage.[15]

Duryodhana's combustible shellac, or simply *lac*, was a resin secreted by the scale insect *Kerria* (or *Laccifer*) *lacca*. Historically, smallholders in India and other regions across South East Asia have raised lac insects. Indian lac cultivators use three major host trees — kusum (*Scheleichera oleosa*), palas (*Butea monosperma*) and ber (*Zizyphus mauritiana*) — to cultivate two strains of lac insect, known colloquially as 'Kusmi' and 'Rangeeni'. Lac bugs, which grow to the size of apple seeds, colonize the green twigs of these fig and acacia trees, feed on the sap of their host plants, and secrete lac resin as they mature. By scraping the encrusted lac from tree branches during two annual harvests, cultivators collect the valuable product, known as *scraped lac* or *sticklac*. They then crush the sticklac into grains and filter, wash and dry these pellets. At this point, the *seedlac* is ready to be melted, filtered once again, and stretched into sheets that can be sold as shellac. Shellac quality depends upon the variety of lac insect, the species of host tree, the regional climate and the harvester's techniques.[16]

[15] James G. Lochtefeld, *The Illustrated Encyclopedia of Hinduism: A–M* (New York, 2002), 211. Very little has been written on the history of shellac. For a dated but still useful bibliography, see Rajendra Kumar Varshney, *Lac Literature: A Bibliography of Lac Insects & Shellac* (Calcutta, 1970).

[16] J. Mohanta, D. G. Dey and N. Mohanty, 'Performance of Lac Insect, *Kerria lacca Kerr* in Conventional and Non-Conventional Cultivation around Similipal Biosphere Reserve, Odisha, India', *The Bioscan*, vii (2012); K. Buch *et al.*, 'Investigation of Various Shellac Grades: Additional Analysis for Identity', *Drug Development and Industrial Pharmacy*, xxxv (2009); B. Mukhopadhyay and M. S. Muthana (eds.), *A Monograph on Lac* (Ranchi, 1962). Shellac cultivation also occurs in Cambodia, Indonesia, Myanmar, Thailand, Vietnam and China. For example, the Hani ethnic group in Yunnan province has long raised lac insects. See Claude Saint-Pierre and Ou Bingrong, 'Lac Host-Trees and the Balance of Agroecosystems in South Yunnan, China', *Economic Botany*, xlvi (1994). The term 'lac' may derive from the Sanskrit word *Laksha*, which means 'a hundred thousand'. See Col. Henry Yule and A. C. Burnell, *Hobson-Jobson: A Glossary of Colloquial Anglo-Indian Words and Phrases, and of Kindred Terms, Etymological, Historical, Geographical and Discursive*, ed. W. Crooke, new edn (London, 1903), 499–500. Other insect commodities that rely upon domesticated host plants include the maguey worm (*Aegiale hesperiaris*), grown on *Agave tequilana* leaves for the tequila industry. See John E. Staller, 'Ethnohistoric Sources on Foodways, Feasts, and Festivals in Mesoamerica', in John E. Staller and Michael Carrasco (eds.), *Pre-Columbian Foodways: Interdisciplinary Approaches to Food, Culture, and Markets in Ancient Mesoamerica* (New York, 2009), 39–40. Another example is the wasp-induced tree gall used to produce the tannic acids that provided ink during the Elizabethan Age. For more on gall ink, see David N. Carvalho, *Forty Centuries of Ink* (New York, 1904), 97–101.

Throughout Indian history, lac has found its way into Ayurvedic medicine, cosmetics, textile dyes, jewellery and paints, often with official sanction. In 1590, an administrative report prepared for the Mughal Emperor Akbar I specified the necessary proportion of shellac to certain pigments when varnishing the doors of public buildings.[17] During the same decade, Indian shellac achieved widespread notoriety throughout Eurasia, both for its resinous properties and for the deep red hues that its unfiltered pigments could impart. In 1596, the Dutch chronicler of East Indian trade routes, Jan Huyghen van Linschoten, marvelled at 'Desks, Targets, Tables, Cubbordes, Boxes, and a thousand such thinges, that are all covered and wrought with Lac of all colours and fashions; so that it maketh men to wonder at the beautie and brightness of the colour, which is altogether Lac'.[18] Artisans combined shellac with other insect secretions. A seventeenth-century Venetian dyeing manual lists recipes '*A tinger seta con gomma di lacca*' (to dye silk with shellac).[19]

By the 1600s, China, Japan and Venice were importing shellac from the forests of north-eastern India. The French explorer and diamond trader Jean-Baptiste Tavernier visited Assam in 1676, noting two kinds of shellac:

> That formed on trees is of a red colour, with it they dye their calicoes and other stuffs, and when they have extracted the red colour they use the lac to lacquer cabinets and other objects of that kind, and to make Spanish wax. A large quantity of it is exported to China and Japan, to be used in the manufacture of cabinets; it is the best lac in the whole of Asia for these purposes.[20]

During the seventeenth and eighteenth centuries, shellac was among the key commodities shipped from India's eastern coastline to markets on the Arabian Peninsula, and by the nineteenth Assam ranked among the world's leading lac production regions.

[17] For pre-modern uses of lac, see K. N. Dave, *Lac and the Lac-Insect in the Athara-Veda* (Nagpur, 1950); P. C. Sarkar, 'Applications of Lac — Past, Present and Emerging Trends', in K. K. Kumar, R. Ramani and K. K. Sharma (eds.), *Recent Advances in Lac Culture* (Ranchi, 2002). On Akbar's specifications, see A. F. Suter, 'Technical Notes on Lac: A Paper Read by A. F. Suter before the Paint and Varnish Society of London', *Paint, Oil and Drug Review* (Chicago), 21 June 1911, 36.

[18] Jan Huyghen van Linschoten, *The Voyage of John Huygen van Linschoten to the East Indies: From the Old English Translation of 1598. The First Book, Containing his Description of the East*, ed. Arthur Coke Burnell and P. A. Tiele, 2 vols. (Hakluyt Society, 1st ser., lxxi, London, 1885), ii, 90.

[19] Timoteo Rosselli, *De'secreti universali di Don Timoteo Rosselli* (Venice, 1644), 12.

[20] Jean-Baptiste Tavernier, *Travels in India*, trans. V. Ball, 2nd edn, 2 vols. (London, 1925), ii, 221.

Between 1885 and 1899, Assam's average annual lac output was 714,860 kilograms.[21]

Lac was an economic mainstay of poor smallholders throughout India. In 1908, the British colonial official and botanist Sir George Watt noted,

> Lac enters into the agricultural, commercial, artistic, manufacturing, domestic and sacred feelings and enterprises of the people of India to an extent hardly appreciated by the ordinary observer. The existence of the poorer communities, in the agricultural and forest tracts, is made the more tolerable through the income derived from the collection of the crude article.[22]

While lac was a major export commodity, India's domestic craftworkers also employed lac resin as a binding agent, an ornamental element, a varnish and a sealant.[23]

Among European and North American importers, confusion about the origins of shellac abounded. In 1563, the Portuguese doctor Garcia da Orta reported that lac was the product of flying ants.[24] Other sixteenth-century writers frequently confused lac with red-dye woods, known in Burma by the common name 'Lakka'.[25] Shellac even experienced a bewildering multiplicity of introductions into global markets. In his 1813 treatise on dyeing, Edward Bancroft presented lac dye to British readers as though the colonial commodity was a novelty, previously unknown to Europeans.[26] Likewise, as late as 1915, the author of a North American industrial chemistry manual informed readers:

> It has been erroneously stated that lac is the dried exudation of a tree, caused by the sting of the lac insect, and is similar to rosin in its origin. As a matter of fact, it is the secretion of the lac insect, and is a product of the

[21] On the shellac trade between the Andhra coast and the Arabian Peninsula, see Sinnappah Arasaratnam, *Merchants, Companies and Commerce on the Coromandel Coast, 1650–1740* (New York, 1986), 104. For statistics on Assam's lac output, see B. C. Basu, *Note on the Lac Industry of Assam* (Shillong, 1905), 6. During the nineteenth century, the British East India Company exported shellac from India. See K. N. Chaudhuri, 'India's Foreign Trade and the Cessation of the East India Company's Trading Activities, 1828–40', *Economic History Review*, 2nd series, xix (1966), 347.

[22] Sir George Watt, *The Commercial Products of India: Being an Abridgement of 'The Dictionary of the Economic Products of India'* (London, 1908), 1063.

[23] George Watt, 'The Lac Industry of India', *Pharmaceutical Journal* (London), 11 Nov. 1905, 650–2.

[24] Garcia da Orta, *Coloquios dos simples e drogas da India* (1563), ed. Academia Real das Ciencias de Lisboa, 2 vols. (Lisbon, 1895), ii, 40.

[25] Watt, 'Lac Industry of India', 646.

[26] Jo Kirby, Marika Spring and Catherine Higgitt, 'The Technology of Eighteenth- and Nineteenth-Century Red Lake Pigments', *National Gallery Technical Bulletin*, xxviii (2007), 82.

assimilation of the tree sap which the insect feeds upon, just as honey and beeswax are produced by the modification of the nectar of flowers by the bee.[27]

Even the word *lacquer* caused misunderstandings. Nineteenth- and twentieth-century European artisans used the term when referring to shellac, but they also employed it when discussing other varnishing substances, such as the sap of the *Rhus vernicifIua*, a tree endemic to China.[28]

As the immediate predecessor to mouldable plastics, shellac underwrote a vast array of material cultures. In eighteenth-century New England, craftspeople frequently purchased the raw precursor to shellac, Indian seedlac, for use in cabinetry and furniture finishing.[29] During the nineteenth century, shellac served as the main ingredient in photographic cases. In 1837 the Frenchman Louis-Jacques-Mandé Daguerre invented the first commercially successful photographic technique, the daguerreotype process, which used a silvered copper plate to produce a direct positive image in the camera. To protect fragile daguerreotype plates — and the next generations of photographs known as ambrotypes and tintypes — manufacturers fashioned 'union cases' from a mixture of shellac, wood fibres and tinting agents. These artful containers featured elaborate recessed motifs. Shellac boxes became collectables in their own right and gave delicate photographic images the ability to travel.[30]

Shellac's uses expanded in 1896 when the classical music producer Fred Gaisberg discovered the utility of the insect secretion to the recording industry. Phonograph manufacturers soon began pressing their recordings into 10- and 12-inch, 78-rpm discs.

[27] A. C. Langmuir, 'Shellac', in Allen Rogers (ed.), *Industrial Chemistry: A Manual for the Student and Manufacturer*, 2nd edn (New York, 1915), 696.

[28] Marianne Webb, *Lacquer Technology and Conservation: A Comprehensive Guide to the Technology and Conservation of Both Asian and European Lacquer* (Woburn, Mass., 2000), xvii. Plant taxonomists also refer to the Chinese lacquer tree as *Toxicodendron vernicifluum*.

[29] George Francis Dow, *The Arts and Crafts of New England, 1704–1775: Gleanings from Boston Newspapers Relating to Painting, Engraving, Silversmiths, Pewterers, Clockmakers, Furniture, Pottery, Old Houses, Costume, Trades and Occupations* (Topsfield, 1927), 238.

[30] Brian Coe, *The Birth of Photography: The Story of the Formative Years, 1800–1900* (London, 1976). In the 1850s Samuel Peck secured US patent 11758 for the union case, which he produced in partnership with New York City's Scovill Manufacturing Company. For more on daguerreotype cases, see Clifford Krainik, Michele Krainick and Carl Walvoord, *Union Cases: A Collector's Guide to the Art of America's First Plastics* (Grantsburg, 1988).

Shellac was the binding agent in a composite, which also included crushed limestone, lubricants and abrasives. Shellac records were resistant to wear, but featured coarse grooves that created a crackling surface noise like bacon sizzling in a frying pan. Record production drove demand. In 1920 alone, the United States imported more than $23 million worth of shellac from South East Asia.[31]

Because of their physical properties, shellac records exhibited an unusual degree of embedded obsolescence. Cosimo Matassa, founder of the prolific J&M Recording Studio in New Orleans, recalled that in the 1940s 'a hit record would get worn out each week on the jukebox, because shellac supplies were scarce and record formulations were poor . . . [A record] got played 100/110 times and it was worn out. So a hit record kept on selling and selling'.[32] For music companies, this was quite a windfall, but during the Second World War, shellac supplies contracted drastically. Japan's invasions of Malaya, Thailand, Indochina and Burma disrupted global supplies of the valuable product. The United States War Production Board began rationing shellac in April 1942 because the substance was a key finishing material in boat and aircraft production.[33]

These shortages propelled a transatlantic wartime recycling movement. In a 1943 campaign entitled 'New Records Depend on You!' a consortium of recording companies encouraged owners of unwanted 78s to turn in their shellac discs for reprocessing. Representatives of Decca Records, Columbia and Parlophone announced in Britain's *Gramophone* magazine:

> Owing to war conditions the Government has found it necessary to conserve supplies of shellac and other materials essential for manufacturing

[31] Andre Millard, *America On Record: A History of Recorded Sound*, 2nd edn (New York, 2005), 202; Timothy Day, *A Century of Recorded Music: Listening to Musical History* (New Haven, 2000), 19. By 1900, shellac records had replaced earlier wax cylinders and vulcanized rubber discs as the medium of choice for music playback. See Metro Voloshin, 'The Preservation and Storage of Historical 78 rpm Recorded Discs', *Music Reference Services Quarterly*, viii (2002), 39; Michael Chanan, *Repeated Takes: A Short History of Recording and its Effects on Music* (London, 1995), 29. The statistic comes from Chamber of Commerce of the United States of America, *Our World Trade in 1920: Value and Volume of Principal Exports and Imports between United States and Chief Foreign Markets* (Washington, DC, 1921), 19.

[32] Cosimo Matassa, quoted in John Broven, *Rhythm and Blues in New Orleans*, revised edn (Gretna, La., 1978), 106.

[33] John Bush Jones, *The Songs That Fought the War: Popular Music and the Home Front, 1939–1945* (Lebanon, NH, 2006), 7.

> records by the most stringent restrictions as to the use of these materials. At the same time the Government has recognised the value of the gramophone record in supporting morale, and the great help that it gives to the war effort. We have spared no effort to maintain supplies over the last three years, and this, we are sure, is well recognised by record users. The further maintenance of adequate record supplies will depend upon the goodwill and readiness of the public to return old and unwanted records, because only by this means will manufacture continue.[34]

By May 1946, US shellac prices stood at $45 per ton, more than tripling their pre-war average of $14 per ton.[35]

The end of the war marked the dawn of a new era in recording technology and the end of shellac's half-century reign over the record industry. In 1948, Columbia Records introduced the 'Vinylite' 45-rpm, 7-inch extended play ('EP'). Shortly thereafter, RCA Victor followed suit with the 33⅓-rpm, 12-inch long-playing ('LP') vinyl. New records, created by synthesizing a copolymer of vinyl chloride and vinyl acetate, were harder and finer than those made of shellac, allowing manufacturers to press more grooves into the disc. Shellac 78s contained around 85 grooves per inch, while the newer EPs and LPs averaged between 224 and 260 grooves per inch. This innovation transformed the listening experience by extending playing time, reducing background noise and enhancing record durability. The 'hi-fidelity' era had begun.

Even so, the seventy-year commercial existence of the shellac disc had been a period of unprecedented longevity for a musical technology. From their advent in the 1890s to their ultimate demise in 1962, when EMI Music withdrew its last remaining 78s from its catalogues, shellac records filled the collections of music listeners worldwide. The music technologies that have followed — vinyl records, reel-to-reel audio, eight-track recordings,

[34] *Gramophone* (Feb. 1943), 16. In the early 1940s, the 'Big Three' record companies — RCA Victor, Columbia and Decca — manufactured most of the records made in the USA. See Timothy Dowd, 'From 78s to MP3s: The Embedded Impact of Technology in the Market for Prerecorded Music', in Joseph Lampel *et al.* (eds.), *The Business of Culture: Strategic Perspectives on Entertainment and Media* (Mahwah, NJ, 2006), 208.

[35] Kurtz Myers, 'Current Report on the Record Industry', *Notes*, 2nd ser., iii (1946), 413. For examples of corporate-led recycling campaigns during wartime, see Kenneth D. Durr, 'The "New Industrial Philosophy": U.S. Corporate Recycling in World War II', *Progress in Industrial Ecology*, 20 Dec. 2006.

cassette tapes, compact discs, DATs and MP3s — have tended to have much shorter commercial lives.[36]

III

SILK

Like the detailed accounts of shellac's early uses, extensive descriptions of pre-modern silk production have circulated for millennia. According to Confucius (*c.*551–479 BCE), in 2640 BCE, Emperor Huangdi's wife Leizu was preparing tea when a silkworm cocoon tumbled into her cup from an overhanging mulberry tree. The thread that she fished out stretched the length of her garden. Regardless of this charming anecdote's veracity, by the Shang Dynasty (*c.*1600–1040 BCE), sophisticated silk production (sericulture) was yielding elegant textiles.[37]

Sericulture continues to involve many of the same techniques featured in its early history. These include planting mulberry trees, feeding mulberry leaves to silkworms, collecting silkworm cocoons, and then extracting the silk by 'reeling' the cocoons in hot water to remove the sericin gum that binds their strands. Producers then 'throw' the silk to strengthen it, often intertwining two filaments to thicken the final thread for weaving. The Confucian idiom 'men plough, women weave' (*nangeng nüzhi*) conveyed the gendered division of labour that governed the final stages of silk production.[38]

[36] C. A. Schicke, *Revolution in Sound: A Biography of the Recording Industry* (Boston, 1974), 120; A. J. Millard, *America on Record: A History of Recorded Sound*, 2nd edn (Cambridge, 2005), 204; Charles L. Granata, 'The Battle for the Vinyl Frontier', in Spencer Drate (ed.), *45 RPM: A Visual History of the Seven-Inch Record* (Princeton, 2002), 8.

[37] For more on this story, see Dieter Kuhn, 'Tracing a Chinese Legend: In Search of the Identity of the "First Sericulturalist"', *T'oung Pao*, 2nd ser., lxx (1984). On Shang Dynasty silk textiles, see E. J. W. Barber, *Prehistoric Textiles: The Development of Cloth in the Neolithic and Bronze Ages with Special Reference to the Aegean* (Princeton, 1991), 31. The wild progenitor of *Bombyx mori* is *Bombyx mandarina*. See K. P. Arunkumar, Muralidhar Metta and J. Nagaraju, 'Molecular Phylogeny of Silkmoths Reveals the Origin of Domesticated Silkmoth, *Bombyx mori* from Chinese *Bombyx mandarina* and Paternal Inheritance of *Antheraea proylei* Mitochondrial DNA', *Molecular Phylogenetics and Evolution*, xl (2006), 419–27.

[38] On this canonical division of labour in imperial China, see Grace S. Fong, 'Female Hands: Embroidery as a Knowledge Field in Women's Everyday Life in Late Imperial and Early Republican China', *Late Imperial China*, xxv (2004), 6; Li Bozhong, 'Cong "fufu bingzuo" dao "nangeng nüzhi"' [From 'Husband and

(cont. on p. 14)

As practised in medieval China, silkworm cultivation represented one of the world's oldest models of intensive ecosystem management. Developed by Guangdong's peasants during the Ming Dynasty (1368–1644), the 'mulberry embankment and fish pond' system (*cang ji yu tang*) used *Bombyx mori* excrement and leaves from mulberry trees as food for pond-raised carp. In return, fish waste and decomposing organic matter from these aquaculture systems provided rich fertilizer for the mulberry groves. Throughout southern China's Pearl River delta, this scheme produced a sustainable nutrient cycling loop, offered rural families a source of dietary protein, and provided cultivators with a marketable commodity.[39]

Even with such eco-cultural innovations, raising silkworms was difficult. *Bombyx mori* has long been a complete domesticate, unable to survive on its own in the wild, making the care of these creatures a tremendous commitment. The production of their food also took dedication. As the historian Lillian M. Li noted, 'Mulberry trees required a great investment of time as well as land. The sericultural manuals pointed out that if one got discouraged before the six or seven years necessary for a tree to mature had elapsed, all the previous effort could be wasted'.[40] At various times, however, the Chinese state subsidized rural sericulture. In the early 1900s, the reform-minded Governor General Xiliang established sericulture agencies

(n. 38 cont.)
Wife Working Side by Side in the Fields' to 'Men Plough, Women Weave'], *Zhongguo Jingjishi yanjiu* [Research on Chinese Economic History], xi (1996).

[39] Robert B. Marks, *Tigers, Rice, Silk, and Silt: Environment and Economy in Late Imperial South China* (Cambridge, 1997), 119. Alvin So argues that as much as a quarter of China's total silk exports before 1840 came from Guandong. See Alvin Y. So, *The South China Silk District: Local Historical Transformation and World-System Theory* (Albany, 1986), 81 n. 2. China's other major silk-producing region was the Yangzi River delta. For a comparison of silk production in these two regions during 1750, see Pomeranz, *Great Divergence*, 327–38.

[40] Lillian M. Li, *China's Silk Trade: Traditional Industry in the Modern World, 1842–1937* (Cambridge, Mass., 1981), 142. Important works on silk production in nineteenth- and twentieth-century China include: Liu Yonglian, *Jindai Guangdong duiwai sichou maoyi yanjiu* [Study on the Foreign Trade of Silk in Modern Guangdong] (Beijing, 2006); Wang Xiang, *Jindai zhongguo chuantong sichouye zhuanxing yanjiu* [Study on the Transformation of the Traditional Silk Industry in Modern China] (Tianjin, 2005); Lynda S. Bell, *One Industry, Two Chinas: Silk Filatures and Peasant-Family Production in Wuxi County, 1865–1937* (Stanford, 1999).

(*can sang ju*) throughout Sichuan province, providing farmers with mulberry trees, land and sericulture training.[41]

Such commitments of state resources demonstrated silk's unparalleled standing as Asia's most lucrative commodity. The Romans first encountered the shimmering insect secretion when Marcus Licinius Crassus and his seven Roman legions suffered a devastating defeat by the Parthians at the battle of Carrhae (Harran in south-eastern Turkey) in 53 BCE. Roman troops were petrified when Parthian standard-bearers unfurled gleaming scarlet-coloured silk banners, embroidered with golden threads. This spectacle accompanied the Romans' introduction to the Persian compound bow, commemorated in Plutarch's harrowing account of the 'Parthian shot', with which agile mounted archers pinned the terrified legionnaires to their shields.[42]

Despite this traumatic first encounter, ancient Romans became obsessed with silk. However, while Roman expenditures on Chinese silk were astronomical, their knowledge of sericulture remained rudimentary. In his first-century CE encyclopaedia, *Natural History*, Pliny the Elder wrote of

> the Seres [Chinese], so famous for the wool that is found in their forests. After steeping it in water they comb off a white down that adheres to the leaves . . . So manifold is the labour employed, and so distant are the regions which are thus ransacked to supply a dress through which our ladies may in public display their charms.[43]

A few centuries later, the Byzantine scholar Procopius recounted how in 552 the Emperor Justinian convinced Nestorian monks to smuggle silkworm 'eggs to Byzantium, and in the manner described caused them to be transformed into worms, which they fed on the leaves of the mulberry; and thus they made

[41] He Yimin, 'Sichuan Province Reforms under Governor-General Xiliang, 1903–1907', in *China, 1895–1912: State-Sponsored Reforms and China's Late-Qing Revolution. Selected Essays from Zhongguo jindai shi [Modern Chinese History, 1840–1919]*, trans. and ed. Douglas Robertson Reynolds (Armonk, 1995), 143.

[42] L. Boulnois, *The Silk Road*, trans. D. Chamberlain (New York, 1966), 10; Peter Hopkirk, *Foreign Devils on the Silk Road: The Search for the Lost Cities and Treasures of Central Asia* (London, 1980), 20. Perhaps the account of the silk banners is apocryphal. No mention of it is made in either Plutarch's *Life of Crassus* or Cassius Dio's *Roman History*. See Plutarch, *Lives*, iii, *Pericles and Fabius Maximus, Nicius and Crassus*, trans. Bernadotte Perrin (London, New York and Cambridge, Mass., 1916); Cassius Dio Cocceianaus, *Roman History*, XL, trans. Earnest Cary and Herbert B. Foster, 9 vols. (London, New York and Cambridge, Mass., 1914–27), iii, 437–47.

[43] Pliny (the Elder), *The Natural History*, VI. 20, trans. John Bostock and Henry Thomas Riley, 2 vols. (London, New York and Cambridge, Mass., 1890), ii, 36–7. See also Shelagh Vainker, *Chinese Silk: A Cultural History* (London, 2004), 6.

possible from that time forth the production of silk in the land of the Romans'.[44]

The illicit transfer of silkworms to the West did not disrupt the cultural and material exchanges that connected disparate civilizations across Eurasia's vast latitudinal axis. Chinese silk attained such unparalleled quality that Europeans could do little but search for commodities to trade for the lustrous fabric. In 1877, the German geologist Baron Ferdinand von Richthofen coined the term *die Seidenstraße*, or 'Silk Road', to name the most enduring commercial network in world history. This multiplicity of trade routes, which extended more than 8,000 kilometres from Xi'an in China to the Mediterranean, flourished from 100 BCE well into the fifteenth century CE. A complex web of camel trails, trading outposts and frontier towns, the Silk Road reached its apex during the thirteenth century CE. The stabilizing conquests of Genghis Khan (1206–27) produced the *Pax Mongolica* in Central Asia, ensuring a relatively uninterrupted flow of commerce between European traders and their Asian counterparts. In 1257, more than a decade before Marco Polo journeyed to Cathay, notarial records from Lucca attested to the arrival of Chinese raw silk in the Italian city states.[45]

Increasing global demand for silk during the late middle ages (1300–1500) and the early modern era (1500–1800), along with high transaction costs and wartime disruptions of commerce, prompted European empires to develop their own sericulture operations.[46] Like their imperial rivals, the British encouraged silk production in their overseas colonies. In 1612, Captain John Smith described the tragedy that befell the first attempt to establish this enterprise on North America's shores:

> By the dwellings of the Savages are some great Mulberry trees; and in some parts of the Countrey, they are found growing naturally in prettie

[44] Procopius, *History of the Wars, Books VII. 36 – VII*, trans. H. B. Dewing (London, New York and Cambridge, Mass., 1928), 229–31.

[45] Richthofen's travels are described in Vadime Elisseeff, 'Approaches Old and New to the Silk Roads', in Vadime Elisseeff (ed.), *Silk Roads: Highways of Culture and Commerce*, new edn (New York, 2000), 1–2. On the *Pax Mongolica*, see Christopher I. Beckwith, *Empires of the Silk Road: A History of Central Eurasia from the Bronze Age to the Present* (Princeton, 2009), 183. For evidence of the arrival of silk in the Italian city states by the mid thirteenth century, see Robert Sabatino Lopez, 'China Silk in Europe in the Yuan Period', *Journal of the American Oriental Society*, lxxii (1952), 73.

[46] Debin Ma, 'The Great Silk Exchange: How the World Was Connected and Developed', in Dennis O. Flynn, Lionel Frost and A. J. H. Latham (eds.), *Pacific Centuries: Pacific and Pacific Rim History since the Sixteenth Century* (London, 1999), 41.

> groves. There was an assay made to make silke, and surely the wormes prospered excellent well, till the master-workman fell sicke: during which time, they were eaten with rats.[47]

Britain's colonial sericulture scheme never fully recovered from this unpleasant episode. Despite patronage from the Stuart monarchs, the Virginia colony lacked the skilled workforce to raise *Bombyx mori*, silkworms took poorly to North America's native red mulberry (*Morus rubra*) trees, and highly profitable tobacco (*Nicotiana tabacum*) cultivation quickly monopolized Tidewater planters' investments.[48]

Failed attempts at colonial sericulture did not confound all aspects of British silk production, however. Religious persecution in continental Europe offered a much-needed stimulus to the fledgling industry. Fortuitously, an influx of French Huguenots after 1685 enhanced Britain's silk-producing prowess. English silk manufacturers at Blackfriars in Canterbury and Spitalfields in London cordially welcomed francophone Protestant refugees who crossed the Channel with their sophisticated weaving skills and cloth manufacturing technologies.[49]

Meanwhile, Europeans were acutely aware of mounting Turkish demand for silk. As Jean-Claude Flachat, the Lyon provost of manufactures, wrote in the 1760s: 'The silk trade is more important than that of the woolens . . . because Turks, like other Levantines, consume twice as much silk cloth as the woolens'.[50] The exquisitely furnished Dolmbahçe Palace, the residence of the Ottoman sultans, was the destination for much of the silk acquired by Turkish elites. A reference work on turn-of-the-century rugs noted, 'Recently, the Sultan of Turkey has started

[47] John Smith, *Travels and Works of Captain John Smith: President of Virginia and Admiral of New England, 1580–1631*, ed. Edward Arber, new edn, 2 vols. (Edinburgh, 1910), i, 56.

[48] For comprehensive treatments of sericulture history in Virginia and colonial North America, see Charles E. Hatch Jr, 'Mulberry Trees and Silkworms: Sericulture in Early Virginia', *Virginia Magazine of History and Biography*, lxv (1957); Nelson Klose, 'Sericulture in the United States', *Agricultural History*, xxxvii (1963). US silk production did not expand markedly until after the Civil War, when British silk entrepreneurs set up shop in towns such as Paterson, New Jersey.

[49] Gerald B. Hertz, 'The English Silk Industry in the Eighteenth Century', *English Historical Review*, xxiv (1909), 710; Warren C. Scoville, 'The Huguenots and the Diffusion of Technology: I', *Journal of Political Economy*, lx (1952), 300.

[50] Jean-Claude Flachat, quoted in Mehmet Genç, 'Ottoman Industry in the Eighteenth Century: General Framework, Characteristics, and Main Trends', in Donald Quataert (ed.), *Manufacturing in the Ottoman Empire and Turkey, 1500–1950* (Albany, 1994), 74.

a factory at Hereké, Asia Minor, where about two hundred Mahometan [Muslim] girls ranging in age from ten years up are employed in weaving the best silk rugs of Turkish make'.[51]

Women have long been primary consumers of silk fabric, as well as its weavers. In sixteenth-century New Spain, a type of silk dress known as the *China poblana* gained widespread popularity. Seamstresses crafted these ornate outfits from Chinese silk shipped eastwards aboard Acapulco-bound Manila galleons. Conversely, the sporadic passage of sumptuary laws limited the consumption of silk. In 1567, Charles IX of France forbade all women but princesses and duchesses to wear silk. The world over, the fortunes of *Bombyx mori* ebbed and flowed with volatile consumer trends. Reflecting upon this connection, a French manufacturing official from Grenoble wrote in 1886, 'No industry is more dependent on fashion than that of silk fabrics'.[52]

The Second World War, which had transformed the shellac trade, also dramatically affected silk commerce. Suddenly, silk became more difficult to obtain, and the United States Army and Navy used what limited supplies there were in the manufacture of parachutes. The drive to find substitutes for Asian silk was intertwined with propaganda battles on the home front. In a 1938 pageant at Washington, DC's Wardman Park Theatre, the League of Women Shoppers advertised its ambition to 'reveal the chic a woman can acquire without a thread of Japanese silk'.[53] Likewise, DuPont introduced nylon stockings to

[51] V. Gurdji, *Oriental Rug Weaving*, 2nd edn (New York, 1901), 59–60; E. Attila Aytekin, 'Cultivators, Creditors, and the State: Rural Indebtedness in the Nineteenth Century Ottoman Empire', *Journal of Peasant Studies*, xxxv (2008), 297. The Hereke Imperial Carpet Manufacture depended upon raw silk from the traditional sericulture region of Bursa. See Edward C. Clark, 'The Ottoman Industrial Revolution', *International Journal of Middle East Studies*, v (1974), 68–9. The craft traditions of the Hereke Manufacture were unusually long-lived. See Charlotte A. Jirousek, 'Finding the Cloth for the Clothes: Patterns of Meaning in Traditional Cloth Production and Trade in Anatolia', in Ronald T. Marchese (ed.), *The Fabric of Life: Cultural Transformations in Turkish Society* (Binghamton, 2005), 162.

[52] On the 'Manila Galleon' silk trade, see William Lytle Schurz, *The Manila Galleon* (New York, 1939), 32. Charles IX's sumptuary laws are discussed in Augustin Challamel, *The History of Fashion in France: or, The Dress of Women from the Gallo-Roman to the Present Time*, trans. Frances Cashel Hoey and John Lillie (London, 1882), 98. The quotation is from A. Beauquis, *Histoire économique de la soie* (Grenoble, 1910), 248.

[53] League of Women Shoppers, quoted in Lawrence B. Glickman, '"Make Lisle the Style": The Politics of Fashion in the Japanese Silk Boycott, 1937–1940', *Journal of Social History*, xxxviii (2005), 573.

American consumers during a wave of anti-Japanese publicity. The editors of *DuPont Magazine* even suggested calling 15 May 1940, the date of the nationwide launch of their new product, 'N-Day'.[54]

The DuPont chemist Wallace Carothers first synthesized the polymer nylon on 28 February 1935. A 1940 *Fortune* magazine article hailed the fabric as the harbinger of chemical miracles to come: 'It is an entirely new arrangement of matter under the sun, and the first completely new synthetic fibre made by man'.[55]

IV

COCHINEAL

More than two millennia prior to Carothers's 'chemical miracle', pre-Columbian peoples in the Andes had already revolutionized textile production. The discovery of carmine-infused fabrics from Peru's Paracas culture (700–300 BCE) demonstrates the protracted history of cochineal dyeing. Archaeological evidence suggests that systematic domestication of *Dactylopius coccus*, an insect species indigenous to Central and South America, began with the Mesoamerican Toltec culture (800–1200 CE). The Aztecs, who inherited insect cultivation techniques from their Toltec predecessors, knew cochineal as *nocheztli*, or 'blood of the prickly pear'. One of the few surviving records of Aztec culture, the *Codex Mendoza*, depicts Emperor Moctezuma II accepting sacks of dried cochineal and carmine-dyed cloth as tribute from the subjects he conquered during his reign (1502–20).[56]

Despite widespread misconceptions, the cochineal bug is not a beetle. It is a scale insect of the order *Homoptera*, which has

[54] Pap A. Ndiaye, *Nylon and Bombs: DuPont and the March of Modern America*, trans. Elborg Forster (Baltimore, 2007), 101.

[55] Matthew E. Hermes, *Enough for One Lifetime: Wallace Carothers, Inventor of Nylon* (Washington, DC, 1996), p. xiv.

[56] Luis C. Rodríguez and Hermann M. Niemeyer, 'Cochineal Production: A Reviving Precolumbian Industry', *Athena Review*, ii, 4 (2001), 76. On the term *nocheztli*, see Eulalio Ferrer, *Los lenguajes del color*, new edn (1999; Mexico City, 2007), 58. Fo. 42[v] of the sixteenth-century *Codex Mendoza* lists tribute items from around the Aztec confederacy, including sacks of cochineal. See Frances F. Berdan and Patricia Rieff Anawalt (eds.), *The Essential Codex Mendoza* (Berkeley, 1997), 90–1. *Dactylopius coccus* was one of only five Aztec domesticates, the others being the turkey (*Meleagris gallopavo*), the Muscovy duck (*Cairina moschata*), the dog (*Canis lupus familiaris*) and the honeybee (*Apis nearctica*). For more on this, see Joseph R. Conlin, *The American Past: A Survey of American History*, i, *To 1877*, 9th edn (Boston, 2009), 16–17.

piercing-sucking mouthparts and is related to aphids and cicadas. The bug's coveted red pigment comes from the carminic acid (anthraquinone) secreted into the intracellular vesicles of the wingless female. Nopal cacti serve as the host plants for these insects, and thus cochineal production occurs in nopalries. The females attach themselves to the pads, or cladodes, of the cacti and use their hollow proboscises to extract moisture and nutrients from the plants. In the process, they exude strands of cottony wax to protect their bodies and egg masses from predators and the elements. Writing in 1653, the Jesuit Bernabé Cobo described the full-grown female cochineal insect as of 'la grandeza de un garbanzo ó frísol' (the size of a chickpea or kidney bean).[57]

In Mexico, two pre-Columbian domesticated nopal cacti, the 'Nopal de San Gabriel' (*Opuntia tomentosa* var. *hernandezii*) and the 'Nopal de Castilla' (*Opuntia ficus-indica*), hosted cochineal cultivation. This process yielded the desired *grana fina*, or fine cochineal, as the Spanish called the domesticated insect's secretion. Like sericulture, the practice of raising cochineal bugs demanded devotion to both insects and host plants. The female cochineal bug is virtually defenceless because of her flightlessness so cultivators spent many hours each day warding off predators, which included wild cochineal (*cochinilla silvestre*), the telero worm (*Laetillia coccidivora*), chickens, turkeys, lizards, woodpeckers, mice and rats.[58]

In preparation for cochineal production, nopal cacti required between two and three years of maturation. Cultivators then built tube-like nests of cornhusks or palm leaves, each housing several dozen pregnant female bugs. Men and women would affix these containers to the nopal cladodes. Once the insects had hatched and matured for four or five months, producers would harvest the bugs and drown, steam or sun-dry them. These processes

[57] Thomas Eisner *et al.*, 'Red Cochineal Dye (Carminic Acid): Its Role in Nature', *Science*, 30 May 1980, 1039; Bernabé Cobo, *Historia del Nuevo Mundo* (1653), ed. Marcos Jiménez de la Espada, 4 vols. (Seville, 1890–5), i, 445.

[58] Eric Chávez Santiago and Hector Manuel Meneses Lozano, 'Red Gold: Raising Cochineal in Oaxaca', *Textile Society of America Symposium Proceedings (Paper 39)* (Lincoln, Nebr., 2010), 2; R. A. Donkin, *Spanish Red: An Ethnogeographical Study of Cochineal and the Opuntia Cactus* (Philadelphia, 1977), 15. There are two types of cochineal dye. The first is made by crushing the dried bodies of the female insects, which yields a final product of about 17 to 24 per cent carmine dye per unit volume. The second is the product of various controlled extractions using acidic, aqueous and alcoholic solutions to produce a purer carminic acid.

reduced an insect's volume by two-thirds. The sheer number of bugs gathered was enormous: 70,000 female cochineal insects yielded 500 grams of pigment. After collection and desiccation, the dried bugs (*grana seca*) would be ground with a stone rolling pin (*metate*) and packed into leather bags (*zurrones*) for transportation. The Spanish did little to disturb elaborate indigenous cultivation techniques, preferring instead to extract enormous profit from cochineal exports.[59]

At every turn, Spaniards saw money to be made from this lucrative trade. Writing about the city of Tlaxcala (in the east-central region of modern Mexico) in the early 1600s, the Carmelite monk Antonio Vázquez de Espinosa noted:

> It takes in quantities of fine cochineal, as do other cities and villages in its jurisdiction; and if the Indians paid tithes on it, as the bishop proposes and has taken legal steps to authorize, the diocese will have an annual income equal to that of the archdiocese of Toledo.[60]

Taxation proved tricky, however. Few Spaniards understood the labour-intensive process of cochineal cultivation, and economies of scale rarely improved output. Thus, small operations — often funded with credit from large landowners — prevailed. Indigenous farmers frequently interspersed *Opuntia* cacti and cochineal bugs among corn, bean and squash plants, much as silk producers and lac cultivators coupled cultivation of insects and host plants with food crops. According to the viceroy of New Spain, some 25,000 to 30,000 residents of the southern state of Oaxaca produced cochineal during the mid 1790s.[61]

Hernán Cortés sent samples of cochineal to the Emperor Charles V after the conquest of the Aztec empire (1519–21).

[59] For more on cochineal cultivation, see Jeremy Baskes, *Indians, Merchants, and Markets: A Reinterpretation of the Repartimiento and Spanish–Indian Economic Relations in Colonial Oaxaca, 1750–1821* (Stanford, 2000), 129–30; Babro Dahlgren de Jordán, 'El nocheztli o la grana de cochinilla mexicana', in Manuel Maldonaldo-Koerdell (ed.), *Homenaje a Pablo Martínez del Río en el vigésimoquinto aniversario de la primera edición de Los orígenes americanos* (Mexico City, 1961). For the number of insects needed for each 500-gram bag, see Alison Downham and Paul Collins, 'Colouring our Foods in the Last and Next Millennium', *International Journal of Food Science & Technology*, xxxv (2000), 12. On the Spanish reluctance to interfere with indigenous cultivation techniques, see Kenneth Pomeranz and Steven Topik, *The World That Trade Created: Society, Culture, and the World Economy, 1400 to the Present*, 2nd edn (Armonk, 2006), 115.

[60] Antonio Vázquez de Espinosa, quoted in Donkin, *Spanish Red*, 26.

[61] Jeremy Baskes, 'Colonial Institutions and Cross-Cultural Trade: *Repartimiento* Credit and Indigenous Production of Cochineal in Eighteenth-Century Oaxaca, Mexico', *Journal of Economic History*, lxv (2005), 192.

Within a few decades, the rich scarlet dye had made a vivid impression across Eurasia. In the sixteenth-century *Florentine Codex*, the Franciscan missionary Bernardino de Sahagún wrote, 'This *grana* is known in this land and beyond her shores, and there are great testaments to it; it has reached China and the Ottoman Empire . . .'.[62] Latin American cochineal soon travelled to the so-called Far East as a result of the 'Columbian Exchange', the widespread transfer of flora, fauna and microorganisms between the Americas and Eurasia that followed Columbus's 1492 arrival in Hispaniola (modern Haiti and the Dominican Republic). In recent decades, environmental historians Alfred Crosby and Charles C. Mann have contended that the exploits of the Genoese navigator 'reknit the seams of Pangaea'. Their commentary on this fateful event was anticipated in the eighteenth century by Voltaire's Pangloss, who quipped, 'if Columbus had not in an island of America caught this disease [syphilis], which contaminates the source of life . . . we should have neither chocolate nor cochineal'.[63]

Long before Columbus and his crew acquired syphilis, chocolate and cochineal in the Americas, red had been the colour of Europe's kings, emperors and cardinals. Its profound associations with virility, sacrifice and prestige made it among the most desirable hues in the palettes of artists and textile manufacturers. Prior to the arrival of cochineal, European dye makers derived red substances from cinnabar (mercury sulphide), lichens and madder plants. The Mediterranean sea snail (*Hexaplex trunculus*) and a pair of insects — Polish cochineal (*Porphyrophora polonica*) and kermes (*Kermes vermilio*) — also provided scarlet pigments. However, cochineal proved itself far

[62] Bernardino de Sahagún, *Historia general de las cosas de Nueva España*, 5 vols. (Mexico City, 1938), iii, 287. The *Historia general* [General History of the Things of New Spain], also known as the *Florentine Codex*, is the most complete work on indigenous colourants in New Spain. Fray Bernardino de Sahagún produced the *Historia general* in Mexico City, from 1575–80. The other useful source for sixteenth-century Mexican dyestuffs is the *Badianus Manuscript*, also referred to as the *Libellus de medicinalibus Indorum herbis* or the *Codex Barberini*. Two Aztec scribes compiled this work in 1552 at the Colegio de Santa Cruz, Mexico City.

[63] The concept of the 'Columbian Exchange' originates with Alfred W. Crosby Jr, *The Columbian Exchange: Biological and Cultural Consequences of 1492* (Westport, Conn., 1972). Charles C. Mann elaborates upon Crosby's concept of re-knitting the seams of Pangaea in his *1493: Uncovering the New World Columbus Created* (New York, 2011), 6. For the quotation, see Voltaire, *Oeuvres complètes de Voltaire,* 52 vols. (Paris, 1877–85), viii, 379.

superior to all of these in terms of its vibrancy and fastness. Within a half-century after its arrival in Europe during the 1520s, Mexican cochineal had completely replaced Polish cochineal and kermes as the most widely used red dye. In 1599, the respected Mexico City resident Gonzalo Gómez de Cervantes noted that Castilians were as eager for shipments of *grana fina* as they were for cargoes of gold and silver.[64]

As with shellac and silk, the origins and production processes of cochineal eluded imperial consumers. Throughout the sixteenth and seventeenth centuries, European writers disputed whether the coveted carmine dye derived from insects, worms, berries or plant seeds. In part, the confusion stemmed from the common Spanish name for the dye-source, *grana*, which literally translates as 'grain'. In 1555, the English observer Robert Tomson declared, 'The Cochinilla is not a worme, or a flye, as some say it is, but a berrie that groweth upon certaine bushes in the wilde fielde, which is gathered in the time of the yeere, when it is ripe'. For more than two and a half centuries, Spain banned the export of live insects, ensuring its monopoly on the cochineal trade and creating an air of mystery around the dye's manufacture.[65]

Spain's colonial rivals went to extraordinary lengths to break the Iberian stranglehold on carmine dye. In 1777, the royal

[64] For a summary of the long-standing associations between red and prestige, see Amy Butler Greenfield, *A Perfect Red: Empire, Espionage, and the Quest for the Color of Desire* (New York, 2005), 1–2. On the variety of other substances used in Europe's red dyes, see William F. Leggett, *Ancient and Medieval Dyes* (New York, 1944), 69–82; Donkin, *Spanish Red*, 7. For more on cochineal's rise to prominence among European dyestuffs, see Judith H. Hofenk-De Graaff, 'The Chemistry of Red Dyestuffs in Medieval and Early Modern Europe', in N. B. Harte and K. G. Ponting (eds.), *Cloth and Clothing in Medieval Europe: Essays in Memory of Professor E. M. Carus-Wilson* (London, 1983), 75; Raymond L. Lee, 'American Cochineal in European Commerce, 1526–1625', *Journal of Modern History*, xxiii (1951), 206. On cochineal's elite position in the hierarchy of Spanish exports from the Americas, see Gonzalo Gómez de Cervantes, *Vida económica y social de Nueva España al finalizar el siglo XVI* (1599), ed. Alberto María Carreño (Mexico City, 1944), 163–4; D. A. Brading, *Miners and Merchants in Bourbon Mexico, 1763–1810* (Cambridge, 1971), 96.

[65] Frank Cowan, *Curious Facts in the History of Insects, Including Spiders and Scorpions: A Complete Collection of the Legends, Superstitions, Beliefs, and Ominous Signs Connected with Insects; Together with their Uses in Medicine, Art, and as Food; and a Summary of their Remarkable Injuries and Appearances* (Philadelphia, 1865), 261; Richard Hakluyt, *The Principal Navigations, Voyages, Traffiques & Discoveries of the English Nation*, 12 vols. (New York, 1903), ix, 358; Donkin, *Spanish Red*, 3. For more on persistent confusions about where to locate cochineal in the taxonomic order, see T. D. A. Cockerell, 'Notes on the Cochineal Insect', *American Naturalist*, xxvii (1893).

French botanist Nicolas-Joseph Thiéry de Menonville (1739–80) slipped into a Mexican nopalry and absconded with hundreds of cochineal bugs, smuggling them in shipping crates from the port of Veracruz to the colony of Saint-Domingue (later known as Haiti). The insects did not survive beyond Thiéry de Menonville's death of 'malignant fever' in 1780, but his brazen act of biopiracy proved that cochineal cultivation had a future outside Spanish America.[66]

British attempts at colonial cultivation were even less successful than those of the French. Vying for financial rewards promised by the East India Company, Britons established nopalries in South Africa, India and Australia. In all cases, the projects failed, and in Australia the introduced *Opuntia* varieties became devastating invasive species.[67] As a result of its scarcity, cochineal's value soared. Among British military ranks, a hierarchy of lac and cochineal insect secretions prevailed. A popular story from the mid 1800s highlights this distinction: 'The red coats of the British soldiers, meaning common soldiers, are all coloured with the inferior sorts of lac-dye. As for the officers, whose cloth is a good deal more brilliant, they are painted up with cochineal from Mexico'.[68] Once again, multiple insect commodities met in the realm of imperial spectacle.

In the wake of Latin America's wars of independence, the Spanish found it worthwhile to establish cochineal operations

[66] Nicolas Joseph Thiéry de Menonville, *Traité de la culture du nopal, et de l'éducation de la cochenille dans les colonies françaises de l'Amérique, précédé d'un voyage à Guaxaca*, 2 vols. (Paris, 1787). For brief accounts of Thiéry de Menonville's exploits, see María Justina Saraba Viejo, *La grana y el añil: técnicas tintóreas en México y América Central* (Seville, 1994), 35–6; Ángeles Saraiba Russell, 'En busqueda de la grana cochinilla: Thiery de Menonville en Oaxaca, 1777', *Acervos: Boletín de los archivos y bibliotecas de Oaxaca*, v (2001); Londa L. Schiebinger, *Plants and Empire: Colonial Bioprospecting in the Atlantic World* (Cambridge, Mass., 2004), 39–44.

[67] For more on British attempts at cochineal cultivation, see C. K. Chávez-Moreno, A. Tecante and A. Casas, 'The *Opuntia* (Cactaceae) and *Dactylopius* (Hemiptera: Dactylopiidae) in Mexico: A Historical Perspective of Use, Interaction and Distribution', *Biodiversity & Conservation*, xviii (2009), 3347; Francis Hamilton, *A Journey from Madras through the Countries of Mysore, Canara, and Malabar: Performed under the Orders of the Most Noble the Marquis Wellesley, Governor General of India . . . in the Dominions of the Rajah of Mysore, and the Countries Acquired by the Honourable East India Company*, 3 vols. (London, 1807), iii, 399–400.

[68] For the story, see 'Good Lac', *Anglo-American Magazine*, iii (1853), 297. Concurrently, Emily Dickinson was beginning her prolific writing career. Several of her poems featured cochineal, including 'A Route of Evanescence', in which she describes a hummingbird as 'A rush of cochineal'. See Emily Dickinson, *The Collected Poems of Emily Dickinson*, ed. Rachel Wetzsteon (New York, 2003), 91.

closer to home. In 1888, the English traveller Charles Edwardes highlighted one such venture on the Canary Islands:

> The insect was not introduced into Tenerife until 1825; and for a time it could not be encouraged to propagate successfully. A priest was the discoverer of the right method of nurture, and to him it is due that from 1845 to 1866 an annual crop of from two to six million pounds of cochineal was produced.[69]

This transatlantic transfer of cochineal production coincided with a revolution in chemistry. In 1858, William Henry Perkin, an assistant to the German chemist August Wilhelm von Hofmann, invented a synthetic purple pigment, known as mauve. The compound, produced from coal tar, was the first aniline dye. Matías Romero, Mexico's first ambassador to the United States, captured the *Zeitgeist* of the Synthetic Age when he wrote in 1898: 'But recent discoveries in chemistry have supplied other substances for dyeing which are very cheap, especially aniline, and the price of cochineal has fallen considerably, so that now it is hardly raised at all'.[70] This trend continued until the late twentieth century.

V

THE SYNTHETIC AGE

To scientists in the early 1800s, the controlled synthesis of natural products seemed unimaginable. In 1810, John Wilkes's authoritative *Encyclopaedia Londinensis* had affirmed the 'vital force' present only in living organisms: 'The substances which constitute the texture of vegetables differ from mineral substances in this, that they are of a more complex order of composition, and, though all are extremely susceptible of decomposition or analysis

[69] Charles Edwardes, *Rides and Studies in the Canary Islands* (London, 1888), 50. Other sources place the introduction of cochineal from Mexico to the Canary Islands via Cadiz at 1820. See, for example, Nicolás González Lemus, 'La explotación de la cochinilla en las Canarias del siglo XIX', *Arquipélago — História*, 2nd ser., v (2001), 178.

[70] Anthony S. Travis, 'Anilines: Historical Background', in Zvi Rappoport (ed.), *The Chemistry of Anilines* (Chichester, 2007), 2; Matías Romero, *Geographical and Statistical Notes on Mexico* (New York, 1898), 53. For more on the rise of aniline dye production and the corresponding decline in Mexico's cochineal exports, see Atlátida Coll-Hurtado, 'Oaxaca: geografía histórica de la Grana Cochinilla', *Investigaciones Geográficas Boletín (Universidad Nacional Autónoma de México)*, xxxvi (1998), 81.

not one is an object of synthesis'.[71] Less than two decades after Wilkes' definitive statement, Friedrich Wöhler synthesized urea, the nitrogen-containing substance in mammal urine. As the young German researcher wrote to his Swedish mentor Jakob Berzelius in 1828: 'I must tell you that I can prepare urea without requiring a kidney of an animal, either a man or dog'.[72] With the production of a simple molecule, Wöhler shattered the time-honoured distinction between organic compounds and inorganic substances. The 'Synthetic Age' had begun.

In the following century, this fascination with synthetic materials ranged far beyond the confines of the laboratory. In 1923, the prophet of high modernist architecture, Le Corbusier (Charles-Édouard Jeanneret), announced, 'The prime consequences of the industrial evolution in "building" show themselves in this first stage; the replacing of natural materials by artificial ones, of heterogeneous and doubtful materials by homogeneous and artificial ones (tried and proved in the laboratory) and by products of fixed composition'.[73] Le Corbusier's hard-edged functionalism favoured synthetic materials, which replaced the craftworker with the engineer and facilitated an unprecedented standardization of design principles.[74]

The 1950s marked the apex of synthetic hubris. In 1952, the journal *Science* published an article by the organic chemist Roger Adams called 'Man's Synthetic Future'. Adams, who headed the University of Illinois Chemistry Department for nearly thirty years, predicted the imminent demise of such products as wool, cotton, silk and leather, forecasting their replacement with chemically synthesized compounds. As he put it, 'In the future citizens will more effectively farm the land and the seas; obtain necessary minerals from the oceans; clothe themselves from coal and

[71] John Wilkes and J. Adlard (eds.), *Encyclopaedia Londinensis: or, Universal Dictionary of Arts, Sciences, and Literature*, 24 vols. (London, 1810–29), iv, 167 (emphasis added).

[72] Friedrich Wöhler, quoted in Bernard Jaffe, *Crucibles: The Story of Chemistry from Ancient Alchemy to Nuclear Fission*, 4th rev. edn (New York, 1976), 131. These results appeared in Fr. Wöhler, 'Ueber künstliche Bildung des Harnstoffs', *Annalen der Physik und Chemie*, lxxxviii (1828).

[73] Le Corbusier, *Towards a New Architecture*, trans. Frederick Etchells (1927; New York, 1986), 232.

[74] For an example of early predictions that synthetics would replace natural compounds in the postwar period, see D. H. Killeffer, 'Promise and Problems of Peace: Chemical Industry's Postwar Role', *Industrial & Engineering Chemistry*, xxxv (1943), 1139–45.

oil. . .'.[75] Such transformations would come courtesy of modern chemistry. In the provocatively titled book, *The Road to Abundance* (1953), chemist Jacob Rosin and writer Max Eastman claimed, 'The time has come when the chemical industry can and will, slowly but surely, take over from agriculture the task of food production'.[76] A few years later, a special report prepared for the United States Senate Foreign Relations Committee concurred, stating, 'Synthetics may in the reasonably near future make the production of coffee, cocoa, cotton, sugar, wool and some other farm commodities unnecessary'.[77]

This faith in boundless industrial capacity to supplant the natural with the artificial extended to every corner of society. In 1957, the chemical company Monsanto collaborated with the Massachusetts Institute of Technology to create the 'House of the Future', a prefabricated cruciform dwelling constructed entirely of synthetic components (see Plate). Twenty million visitors toured the 119-square-metre plastic and fibreglass home in Disneyland's 'Tomorrowland' exhibition, which proudly proclaimed, 'it could be said that hardly a natural material occurs in its original state anywhere in your new home!'[78] Disney and Monsanto — inventors of chimerical and chemical futures — joined forces on this quasi-magical fusion of symbolic and literal elements. As the literary theorist Roland Barthes framed this collision of myth and matter: 'Despite having names of Greek shepherds (Polystyrene, Polyvinyl, Polyethelene), plastic . . . is in essence the stuff of alchemy'.[79] Although 'Tomorrowland' promised park visitors a window into 'how the typical American family of four will live in ten years from now', the display could

[75] Roger Adams, 'Man's Synthetic Future', *Science*, 15 Feb. 1952. Bill McKibben describes Adams as 'a glib Dacron worshipper'. See McKibben, *The End of Nature* (1989; New York, 2006), 70.

[76] Jacob Rosin and Max Eastman, *The Road to Abundance* (New York, 1953), 7. By the 1950s, Eastman had abandoned his early support for socialism and radical causes. He became a staunch anti-Communist and joined the classical liberal Mont Pelerin Society, founded by Friedrich von Hayek and Ludwig von Mises.

[77] Carroll Kilpatrick, 'Economic Problems in Synthetics Cited: One in Series of Reports', *Washington Post*, 20 Sept. 1959, B12.

[78] 'The Future Imagined', *Wilson Quarterly*, xxx (Winter 2006), 53; Steve Mannheim, *Walt Disney and the Quest for Community* (Aldershot, 2002), 52–4; Bernard Cooper, 'The House of the Future', *Grand Street*, viii, 3 (Spring 1989), 76.

[79] Roland Barthes, *Mythologies*, selected and trans. Annette Lavers (New York, 1972), 97. On French ambivalence towards plastic and other synthetics, see Douglas Smith, '"Le Temps du plastique": The Critique of Synthetic Materials in 1950s France', *Modern & Contemporary France*, xv (2007).

not keep up with the relentless pace of ultramodern design trends. Disney dismantled the exhibit in 1967, but enthusiasm for synthetics continued. That same year, Mike Nichols's film *The Graduate* served up one of Hollywood's most enduring one-liners when the Los Angeles businessman Mr McGuire offered unsolicited career advice to the lethargic young Benjamin, played by Dustin Hoffman: 'I just want to say one word to you . . . Plastics!'[80]

VI

THE SOCIAL PROBLEM OF TOXICITY

At the very moment synthetic futurism was captivating park visitors and filmgoers, toxicology was rapidly maturing as an applied science.[81] An array of environmental disasters and public health crises stemming from chemicals created by human activity stimulated the field's development. Such influential events included London's 1952 'Great Smog' of airborne pollutants, the discovery in 1956 of widespread methylmercury poisonings in the population living near the Chisso Corporation's chemical factory in Minamata, Japan, and the health crisis of the late 1950s and early 1960s during which women in 46 countries who had used the anti-emetic drug thalidomide gave birth to 10,000 physically deformed children.[82] As Julius M. Coon, chairing a 1960 conference on 'Problems in Toxicology', announced to a distinguished

[80] The quotation from the display is cited in Eric Avila, 'Popular Culture in the Age of White Flight: Film Noir, Disneyland, and the Cold War (Sub)Urban Imaginary', *Journal of Urban History*, xxxi (2004–5), 16. For a popular history of plastics, see Stephen Fenichell, *Plastic: The Making of a Synthetic Century* (New York, 1996). In 1907, the Belgian chemist Leo Hendrik Baekeland (1863–1944) mixed phenol and formaldehyde under high heat and pressure to yield a pliable resin. This substance, known as Bakelite, was the world's first synthetic plastic. See 'New Chemical Substance: Baekelite Is Said to Have the Properties of Amber, Carbon, and Celluloid', *New York Times*, 6 Feb. 1909.

[81] For more on the genesis of environmental toxicology, see Frederick Rowe Davis, 'Unraveling the Complexities of Joint Toxicity of Multiple Chemicals at the Tox Lab and the FDA', *Environmental History*, xiii (2008), 674–83.

[82] William Wise, *Killer Smog: The World's Worst Air Pollution Disaster* (Chicago, 1968); W. P. D. Logan, 'Mortality in the London Fog Incident, 1952', *The Lancet*, cclxi (1953); Timothy S. George, *Minamata: Pollution and the Struggle for Democracy in Postwar Japan* (Cambridge, Mass., 2001); Trent Stephens and Rock Brynner, *Dark Remedy: The Impact of Thalidomide and its Revival as a Vital Medicine* (Cambridge, Mass., 2001); R. E. McFayden, 'Thalidomide in America: A Brush with Tragedy', *Clio Medica* (July 1976).

The Monsanto/Massachusetts Institute of Technology 'House of the Future' was a prefabricated cruciform dwelling constructed entirely of synthetic components. On exhibit at Disneyland in Anaheim, California, from 1957 to 1967, it represented the aspirations of the 'Synthetic Age'. Photographed in 1957, photographer unknown. Reproduced courtesy of the United States Library of Congress.

body of scientists assembled in Chicago, 'toxicity is suddenly upon us as a social problem'.[83] Two years later, biologist Rachel Carson's ground-breaking *Silent Spring* offered an eloquent exposé of the detrimental effects of synthetic pesticides on human and environmental health.[84]

Revelations about the darker side of the Synthetic Age continued to accumulate. In the mid 1970s, the disclosure that a playground in Love Canal, New York, was perched atop 21,000 tons of toxic waste and the news in 1984 that thousands were dying from a devastating leak of methyl isocyanate gas at the Union Carbide India pesticide plant in Bhopal offered jarring wake-up

[83] J. M. Coon, 'Opening Remarks', in J. M. Coon and E. A. Maynard, 'Problems in Toxicology', *Federation Proceedings, Federation of American Societies for Experimental Biology*, xix (1960), 19.

[84] Rachel Carson, *Silent Spring* (Boston, 1962).

calls about the dangers of chemical pollution.[85] By the late 1980s, four million synthetic chemicals were in production throughout the USA, and sixty thousand had entered into common use.[86] Revelations about the implications of this state of affairs for human health began to receive widespread attention in North America, Europe and Japan. As the historian Linda Nash points out, 'Debates over chemicals and their regulation are, at root, debates about the relationship between bodies and their environments'.[87]

The ensuing cultural backlash was most apparent with the 1996 publication of *Our Stolen Future* by a group of environmental health specialists. Featuring a foreword by United States Vice President Al Gore, the widely circulated book asserted that synthetic compounds were disrupting human endocrine functions.[88] In the words of the historian Michelle Murphy, this new world order amounted to a 'chemical regime of living', where 'molecular relations extend outside of the organic realm and create interconnections with landscapes, production, and consumption, requiring us to tie the history of technoscience with political economy'. The advent of this era also marked a shift in the timescale of environmental health issues. Products that biodegrade over millennia leave a multi-generational imprint on both ecosystems and the human tissues in which they accumulate.[89]

[85] Firsthand testimonials about these two disasters can be found in Lois Marie Gibbs (as told to Murray Levine), *Love Canal: My Story* (Albany, 1982); T. R. Chouhan, *Bhopal: The Inside Story. Carbide Workers Speak out on the World's Worst Industrial Disaster* (New York, 1994). For detailed assessments of the health consequences of Love Canal and Bhopal, see Dwight T. Janerich *et al.*, 'Cancer Incidence in the Love Canal area', *Science*, 19 June 1981; Pushpa S. Mehta *et al.*, 'Bhopal Tragedy's Health Effects: A Review of Methyl Isocyanate Toxicity', *Journal of the American Medical Association*, 5 Dec. 1990.

[86] Timothy Mitchell, *Rule of Experts: Egypt, Techno-Politics, Modernity* (Berkeley, 2002), 21.

[87] Linda Nash, 'Purity and Danger: Historical Reflections on the Regulation of Environmental Pollutants', *Environmental History*, xiii (2008), 651.

[88] Theo Colborn, Dianne Dumanoski and John Peterson Myers, *Our Stolen Future: Are We Threatening our Fertility, Intelligence, and Survival? A Scientific Detective Story* (New York, 1996).

[89] Michelle Murphy, 'Chemical Regimes of Living', *Environmental History*, xiii (2008), 697. For more on this, see Devra Davis, *The Secret History of the War on Cancer* (New York, 2007); John Wargo, *Our Children's Toxic Legacy: How Science and Law Fail to Protect Us from Pesticides*, 2nd edn (New Haven, 1998).

VII

THE LIMITS OF SUBSTITUTION

On a finite planet, ideologies of limitless growth require corresponding theories of substitution. In an earlier era, colonialism offered a geographical fix for such constraints to capitalist accumulation. By employing 'ghost acreage', imperialist nations relied on spaces beyond their own *terra firma*, such as oceans and foreign lands, to supplement their harvests and augment their resource stocks.[90] Yet, in the cases of domesticated insects, their highly skilled cultivators and their rarified host plants, such dependencies often proved frustrating for those putatively in charge. Enduring misconceptions about the process of shellac production, failed attempts at sericulture in colonial settlements, difficulties in transferring the cochineal bug and its *Opuntia* cactus host to territories outside Latin America, and the resistance of domesticated insect cultivation to economies of scale flustered European imperialists in a variety of ways. Often carried out with striking ignorance of local knowledge, top-down attempts to industrialize nature through radical simplifications of complex ecological processes have produced a litany of embarrassing failures and unmitigated disasters over the centuries.[91]

The promoters of the Synthetic Age promised that the laboratory would provide a post-colonial escape from such confrontations with the 'limits to growth'. However, in a number of cases, the substitution of synthetic products for natural ones has proved intractable from the standpoint of either molecular chemistry or economic efficiency. Substances as varied as blood, rubber and vanilla are remarkably resistant to replacement with

[90] Michigan State University food scientist Georg Borgström first developed the concept of 'ghost acreage'. See Georg Borgström: see his *Hungry Planet: The Modern World at the Edge of Famine* (New York, 1965). William Catton extended Borgström's concept of 'phantom carrying capacity' to include past 'fossil acreage', or 'imports of energy from prehistoric sources'. See William R. Catton Jr, *Overshoot: The Ecological Basis of Revolutionary Change* (Urbana, 1980), 41. For discussions about the contradictions that arise when substituting labour and capital for natural resources, see Robert U. Ayres, 'On the Practical Limits to Substitution', *Ecological Economics*, lxi (2007); Alf Hornborg, *The Power of the Machine: Global Inequalities of Economy, Technology, and Environment* (Walnut Creek, Calif., 2001), 32.

[91] For examples, see James Beattie, *Empire and Environmental Anxiety: Health, Science, Art and Conservation in South Asia and Australasia, 1800–1920* (Basingstoke, 2011); W. Scott Prudham, *Knock on Wood: Nature as Commodity in Douglas Fir Country* (New York, 2005); James C. Scott, *Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven, 1998).

manufactured versions.[92] Silk is similarly inimitable. As the authors of a study in the *Journal of Applied Polymer Science* noted, 'Biological materials often show a combination of properties that cannot be reproduced by artificial means. Silks, produced either by spiders or moth larvae, are a good example when compared with artificial organic fibers'.[93]

In the cases of cochineal and shellac, many of the synthetic substitutes for these insect secretions turned out to be toxic outcomes of the Synthetic Age. In 1950, children in the United States became sick from eating candy and popcorn coloured with the synthetic compounds FD&C Orange No. 1 and FD&C Red No. 32. New York Congressman James J. Delaney subsequently organized hearings into chemical additives in the nation's food supply. The so-called 'Delaney clause', which the US Congress passed in 1958 as an amendment to the Food, Drug, and Cosmetic Act of 1938, stipulated that 'No additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is

[92] The biggest obstacle to synthesizing artificial blood is the fact that oxygen-carrying haemoglobin becomes toxic outside the protective coating of the red blood cell. See Andrea Mozzarelli and Stefano Bettati, *Chemistry and Biochemistry of Oxygen Therapeutics: From Transfusion to Artificial Blood* (Hoboken, 2011), xxiv; Jerry E. Squires, 'Artificial Blood', *Science*, 8 Feb. 2002. Likewise, many of the most significant applications of latex from the Pará rubber tree (*Hevea brasiliensis*), such as the tyres of aircraft and earth-moving vehicles, cannot easily be replaced with synthetic latex because of the sophisticated molecular properties, unprecedented pliability and cheap production costs of natural latex. See Mann, *1493: Uncovering the New World Columbus Created*, 270–1; Mark R. Finlay, *Growing American Rubber: Strategic Plants and the Politics of National Security* (New Brunswick, NJ, 2009). Synthetic and natural vanillas differ in purity, scent and taste. As many as 250 volatile aromatic compounds, along with non-volatile tannins, polyphenols, resins and free amino acids, augment the flavour profiles of natural vanilla (*Vanilla planifolia*). This complex composition contributes to the taste and olfactory characteristics that appeal to many consumers. See Firn, *Nature's Chemicals*, 80; Gary Reineccius, *Flavor Chemistry and Technology*, 2nd edn (Boca Raton, 2006), 250; Rémi Kahane *et al.*, 'Bourbon Vanilla: Natural Flavour with a Future', *Chronica Horticulturae*, xlviii (2008).

[93] J. Pérez-Rigueiro, C. Viney, J. Llorca and M. Elices, 'Silkworm Silk as an Engineering Material', *Journal of Applied Polymer Science*, lxx (1998), 2439. For new applications of silk, see Aldo Leal-Egaña and Thomas Scheibel, 'Silk-Based Materials for Biomedical Applications', *Biotechnology and Applied Biochemistry*, lv (2010). Many insects (caddisworms, black flies, katydids, lacewings, sawflies and fungus gnats) and other arthropods (mites and spiders) produce silk, but few achieve the high tensile strength and lustrous appearance of domesticated silkworm threads. See Zhengzhong Shao and Fritz Vollrath, 'Materials: Surprising Strength of Silkworm Silk', *Nature*, 15 Aug. 2002, 741; Barber, *Prehistoric Textiles*, 31.

found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal'.[94] Naturally produced products, such as shellac and cochineal, provided convenient alternatives to these newly banned substances.

Because of shellac's approval by the United States Food and Drug Administration (FDA) and the European Union, food manufacturers routinely use it as an ingredient stabilizer, a product thickener, a product coating and a packaging adhesive. Candy companies employ it as a confectioner's glaze, while the pharmaceutical industry relies upon shellac as an enteric agent to slow the release of active ingredients in pills and tablets. Likewise, cosmetic producers use shellac — often labelled as 'gum Lac' — in aerosol sprays, lotions, shampoo, nail polish, lipstick, eyeliner and mascara. Embalmers now rely on shellac as a non-toxic substitute for formaldehyde, while dentists routinely use it in fluoride varnishes.[95]

Cochineal is similarly pervasive. From mock crab legs to flavoured waters, berry yogurts to ruby red grapefruit juice, high-end coffee drinks to Campari, carmine extract appears on ingredients labels as carmine, carminic acid, Natural Red 4 or E120. In 1990, the FDA banned Red Dye No. 3, one of the oldest and most widely used synthetic food colourings, following test results linking it to thyroid cancer in rats. The non-toxicity, chemical stability and low price of cochineal made it a desirable replacement for such synthetics. As the website of a Kentucky-based supplier of the insect secretion notes, 'Carminic acid is one of the most light and heat stable of all the natural colorants and is more stable than many synthetic food colors . . . Derivatives from cochineal are increasing in use due to the influence of the

[94] On the 1950 incident, see S. S. Deshpande, *Handbook of Food Toxicology* (New York, 2002), 227. The Delaney clause appears in the United States Statutes: 21 USC 348(c)(3)(A) (199).

[95] The European Union requires shellac to be labelled E904 in ingredients lists. For FDA labelling, see Tracy A. Altman, *FDA and USDA Nutrition Labeling Guide: Decision Diagrams, Checklists, and Regulations* (Lancaster, Pa., 1998), 9.8. For other uses, see Stefanie Stummer *et al.*, 'Application of Shellac for the Development of Probiotic Formulations', *Food Research International*, xliii (2010); Christophe-J. Le Coz *et al.*, 'Allergic Contact Dermatitis from Shellac in Mascara', *Contact Dermatitis*, xlvi (2002), 152; Abdulmonem A. Al-Hayani *et al.*, 'Shellac: A Non-Toxic Preservative for Human Embalming Techniques', *Journal of Animal and Veterinary Advances*, x (2011); B.-T. Hoang-Dao *et al.*, 'Clinical Efficiency of a Natural Resin Flouride Varnish (Shellac F) in Reducing Dentin Hypersensitivity', *Journal of Oral Rehabilitation*, xxvi (2009).

"natural" trend'.[96] While Mexican farmers still supply carmine to the global market, 85 per cent of the world's cochineal now comes from highland Peru, where its production involves over 100,000 families.[97]

Contemporary sericulture shares many features with present-day shellac and cochineal production. The expansion of hi-tech industries has caused many Japanese and Korean citizens to abandon silkworm cultivation, but China, India, Thailand, Vietnam and Brazil have rapidly increased their silk-raising operations in the past few decades. Because sericulture is a home-based activity that responds well to microfinance, it offers unusual opportunities for elevating the economic and social status of rural women. Although silk comprises only 0.2 per cent of the total volume of textiles traded on the world market, its commercial value is several orders of magnitude greater, not only because of its status as a luxury good, but also because many nations produce primarily for internal consumption. For example, Indian silk weavers sell 85 per cent of their product to domestic consumers, much of it ending up in women's saris.[98]

[96] José Schul, 'Carmine', in Gabriel J. Lauro and F. Jack Francis (eds.), *Natural Food Colorants: Science and Technology* (New York, 2000); Ronald E. Wrolstad and Catherine A. Culver, 'Alternatives to Those Artificial FD&C Food Colorants', *Annual Review of Food Science and Technology*, iii (2012); Jane Zhang, 'Is There a Bug in your Juice? New Food Labels Might Say', *Wall Street Journal*, 27 Jan. 2006, B1. In Apr. 2012, Starbucks switched from cochineal to a vegetable-based dye in its strawberry 'Frappuccino' following a consumer outcry over the presence of bugs in beverages. See Karin Klein, 'Starkbucks Is Getting the Bugs Out', *Los Angeles Times*, 23 Apr. 2012. For cases of adverse health reactions to cochineal, see Cindy Skrzycki, 'Allergy Fears Tinge Debate on Bug-Dye Rule', *Washington Post*, 9 May 2006, D1. On the Red Dye No. 3 ban, see Ronald Hamowy, *Government and Public Health in America* (Cheltenham, 2007), 188; Wild Colors From Nature website, <http://www.wildflavors.com/?page=cochineal_carmine> (accessed 30 January 2013).

[97] For Peruvian cochineal production, see Rodríguez and Niemeyer, 'Cochineal Production', 78; Luiz Carlos Rodríguez and Unai Pascual, 'Land Clearance and Social Capital in Mountain Agro-Ecosystems: The Case of Opuntia Scrubland in Ayacucho, Peru', *Ecological Economics*, xlix (2004). The Canary Islands has also reinvigorated its cochineal production. See Desiree Martin, 'Spanish Islands Launch a Cochineal Comeback', *Taipei Times*, 18 Sept. 2011, 11.

[98] Rajat K. Datta and Mahesh Nanavaty, *Global Silk Industry: A Complete Sourcebook* (Boca Raton, 2005), 10–11; G. S. Geetha and R. Indira, 'Silkworm Rearing by Rural Women in Karnataka: A Path to Empowerment', *Indian Journal of Gender Studies*, xviii (2011); Barbara Earth *et al.*, 'Intensification Regimes in Village-Based Silk Production, Northeast Thailand: Boosts (and Challenges) to Women's Authority', in Bernadette P. Resurreccion and Rebecca Elmhirst (eds.), *Gender and Natural Resource Management: Livelihoods, Mobility and Interventions* (London, 2008); G. Sandhya Rani, *Women in Sericulture* (New Delhi, 2006). On Indian silk production,

(cont. on p. 35)

Women have also been central to the revitalization of Indian lac production. Given their systematically disadvantaged position in the labour market and their limited access to capital, poor women in outlying regions often depend upon the collection of non-timber forest products (NTFPs), such as lac. Lac-rearing involves as many as five million people in India, and NTFPs continue to provide up to 75 per cent of rural women across the nation with their primary source of income.[99]

Through much of the developing world, insect cultivation has long been a mainstay of economically marginalized smallholders. In the cases of Ella Fitzgerald's 78-rpm record, Sultan Abdülmecid's silk carpets and Sir Charles O'Hara's red coat, insects and their human cultivators produced aural, tactile and visual globalizations that set in motion far-reaching relationships across continents, oceans and species boundaries. When it came to shellac, silk and cochineal, Europeans inhabited a *knowledge periphery*, mystified by the presence of insect secretions in their midst but dependent upon the local knowledge of highly skilled workers in distant ecosystems.

Shellac, silk and cochineal are no longer the materials that convey music, adorn palace floors or colour elite vestments. Instead, they have re-emerged as ubiquitous elements in transnational networks of food, medicine, cosmetics and fashion. What remains to be seen is whether rural insect cultivators will benefit from these burgeoning international markets or simply become further impoverished by capitalism's polarizing tendencies.

(n. 98 cont.)
see Iyanatul Islam and Moazzem Hossain, *Globalisation and the Asia-Pacific: Contested Perspectives and Diverse Experience* (Cheltenham, 2006), 158.

[99] Over 90 per cent of Indian lac comes from the states of Bihar, Madhya Pradesh, West Bengal, Maharashtra and Orissa. For numbers employed in lac cultivation, see S. P. Bhardwaj and R. K. Pandey, 'Study of Production, Trade and Policy Reform for Lac Cultivation in India', in Jagdish Prasad (ed.), *Encyclopedia of Agricultural Marketing*, 12 vols. (New Delhi, 1999), vi, 229. For women's empowerment, forest conservation incentives and NTFPs, see Madhu Sarin, '"Should I Use my Hands as Fuel?" Gender Conflicts in Joint Forest Management', in Naila Kabeer and Ramya Subrahmanian (eds.), *Institutions, Relations, and Outcomes: A Framework and Case Studies for Gender-Aware Planning* (New Delhi, 1999), 238; V. L. V. Kameswari, 'Communication Network in Forest Management: Privileging Men's Voices over Women's Knowledge', *Gender Technology and Development*, viii (2004), 169; K. Krishan Sharma and K. K. Kumar, 'Lac Insects and their Host-Plants', in G. Tripathi and A. Kumar (eds.), *Potentials of Living Resources* (New Delhi, 2003), 80.

VIII

APOCALYPSE OR METAMORPHOSIS?

Despite the omnipresence of insects in our daily lives, the modern Euro-American attitude towards these creatures generally remains one of revulsion. In his treatise *British Central Africa* (1897), the botanist and colonial administrator Sir Harry Johnston admitted to his 'sweeping hatred of the insect race' and remarked, 'It is surprising to my thinking that our asylums are not mainly filled with entomologists driven to *dementia* by the study of this horrible class'.[100] Thirty-three years later, the popular North American science publication *Modern Mechanix* told readers:

> A world ruled by giant insects, with the last remnants of the human race as slaves is one of the favorite devices of one school of fiction writers. Fantastic? Not at all . . . All past history indicates that when, and if, the present civilization comes to an end, it will die because of an unsolved food problem, and that insects will be a contributing factor, and hence may be the survivors.[101]

Yet, innovative inversions of this scenario are transforming terror into terroir. Long practised by indigenous cultures on nearly every continent, entomophagy — the consumption of insects — is gaining currency among nutrition scientists as a viable route towards global food security.[102] Once again, the entomological knowledge of such practices thrives outside Europe and North America. As a 2010 report from the Food and Agriculture Organization of the United Nations points out:

> The practice of eating insects goes back thousands of years and has been documented in nearly every part of the world. In modern times, however, consumption of insects has declined in many societies and is sometimes ridiculed as old-fashioned and unhealthy. Yet, it would be prudent to carefully consider the value of customary knowledge before discarding it too readily. Scientific analysis confirms, for example, the exceptional

[100] Erich Hoyt and Ted Schultz (eds.), *Insect Lives: Stories of Mystery and Romance from a Hidden World* (Edinburgh, 1999), 52; Harry Johnston, quoted in 'Nyasa-Land', *Nature*, 23 Dec. 1897, 175.

[101] Jay Earle Miller, 'Will Monster Insects Rule the World?', *Modern Mechanix* (Dec. 1930), 68. For more on human–insect antagonisms and the role played by synthetic pesticides in these conflicts, see David Kinkela, *DDT and the American Century: Global Health, Environmental Politics, and the Pesticide That Changed the World* (Chapel Hill, 2011).

[102] R. T. Gahukar, 'Entomophagy and Human Food Security', *International Journal of Tropical Insect Science*, xxxi (2011); Peter Menzel and Faith D'Alusio, *Man Eating Bugs: The Art and Science of Eating Insects* (Berkeley, 1998); Jean-Louis Thémis, *Des insects à croquer: guide de découvertes* (Montreal, 1997).

nutritional benefits of many forest insects, and studies point to the potential to produce insects for food with far fewer negative environmental impacts than for many mainstream foods consumed today.[103]

In less alimentary ways, winged arthropods continue to facilitate human production and environmental reproduction. Entomologists estimate that wild insects contribute at least $57 billion annually to the USA's economy from such 'ecosystems services' as pollination, nutrient cycling and parasite control. At the global level bees are responsible for nearly a third of agricultural output on earth. Insects also serve as key barometers of pervasive problems, including environmental toxicity and climate change.[104]

Such examples confirm that competition and pestilence are not the only possible avenues of interaction between human and arthropod communities. In 1980, the entomologist Charles L. Hogue coined the term 'cultural entomology' to describe the study of insect influences on human culture. Even though Hogue's framework promised a more systematic approach to human–insect interactions, its emphasis on high art, symbolic representations and anecdotally driven 'interpretative history' produced an intriguing, but under-theorized, cabinet of curiosities. A more rigorous methodology for general historical research into global entomologies awaits further development.[105]

As this article has suggested, the histories of shellac, silk and cochineal — coupled with the stories of their cultivators and consumers — have much to tell us about under-studied aspects of globalization, especially the unacknowledged dependencies of

[103] Hiroyuki Konuma, 'Foreword', in Patrick B. Durst (ed.), *Forest Insects as Food: Humans Bite Back. Proceedings of a Workshop on Asia-Pacific Resources and their Potential for Development, 19–21 February 2008, Chiang Mai, Thailand* (Bangkok, 2010), iii.

[104] See, for example, John E. Losey and Mace Vaughan, 'The Economic Value of Ecological Services Provided by Insects', *BioScience*, lvi (2006); Jehan Sorour, 'Ultrastructural Variations in *Lethocerus niloticum* (Insecta: Hemiptera) Caused by Pollution in Lake Mariut, Alexandria, Egypt', *Ecotoxicology and Environmental Safety*, xlviii (2001). For more on the concept of ecosystems services, see Gretchen C. Daily (ed.), *Nature's Services: Societal Dependence on Natural Ecosystems* (Washington, DC, 1997). On bees and global agricultural output, see Renée Johnson, *Honey Bee Colony Collapse Disorder* (Washington, DC, 2010), 1. On insects as ecological barometers, see Dmitry L. Musolin, 'Insects in a Warmer World: Ecological, Physiological and Life-History Responses of True Bugs (Heteroptera) to Climate Change', *Global Change Biology*, xiii (2007).

[105] See Charles L. Hogue, 'Commentaries in Cultural Entomology: 1. Definition of Cultural Entomology', *Entomological News*, xci (1980). Four issues of an online journal known as *Cultural Entomology Digest* appeared between June 1993 and November 1997.

'the West' upon indigenous knowledge from outlying geographical regions and unfamiliar ecosystems. Using both comparative and transnational perspectives, this article demonstrates that the emergence of a synthetic planet has never been as straightforward as its promoters have asserted. Despite claims to the contrary, insects remain omnipresent factors in commonly consumed products and crucial planetary functions. Their existence may also present us with unanticipated opportunities for self-reflection. As the entomologist Jean-Henri Fabre remarked, 'The insect does not aim at so much glory. It confines itself to showing us life in the inexhaustible variety of its manifestations; it helps us to decipher in some small measure the obscurest book of all, the book of ourselves'.[106]

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[106] Jean-Henri Fabre, *The Life and Love of the Insect*, trans. Alexander Teixeira de Mattos (London, 1911), 128.