Reeling in Silk

POSTED IN WINGSPAN (ANA IN-FLIGHT MAGAZINE)

ANA Wingspan
Reeling in Silk
August 2015

Sericulture
养蚕
Things Japanese

REELING IN SILK

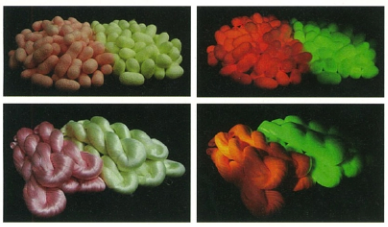
纺丝高科技

Story & Photographs by Lucy Birmingham
文／图 露茜·伯明翰

Think silkworm and you're bound to imagine a creepy crawler. Their tiny suction-cup feet can give you goose bumps when inching across your skin. If healthy, the silkworm grows into a pudgy, eating machine voraciously chomping on mulberry leaves until it's ready to spin a cocoon. It certainly wouldn't win a prize for Most Beautiful Insect.

But this remarkable creature has been a prized possession for an estimated 5,000 years, shaping the trade and economy of ancient civilizations and modern nations across the globe.

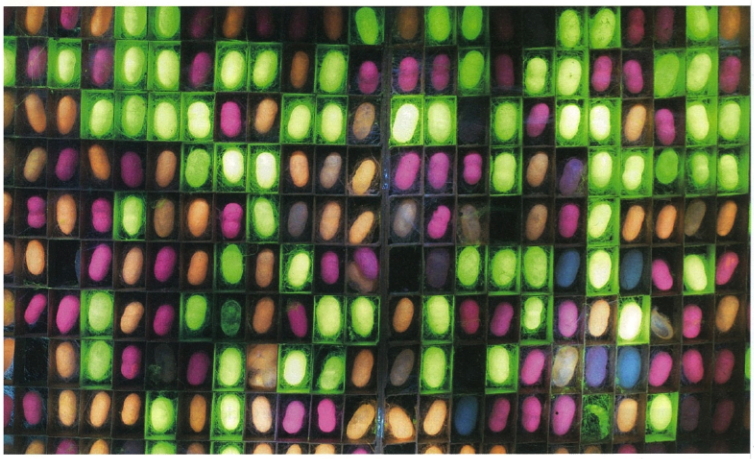
The silkworm and its silk proteins have now emerged as key elements in biotech innovations in pharmaceuticals, cosmetics and other products. The National Institute of Agrobiological Sciences (NIAS) in Tsukuba, near Tokyo, developed the silkworm transgenic (genetically engineered or modified) technology in 2000. Expectations are mounting high. Not only might this revive Japan's declining sericulture (silkworm farming) industry, it could even be the beginning of a 21st-century Silk Road crossing international borders.



Transgenic 3D Printers

"The silkworm is almost like a living 3D printer," says artist/designer and MIT Media Lab assistant professor Hiromi Ozaki, better known as Sputniko! "Silkworms have been bred for thousands of years to produce more silk. Now researchers are developing silkworms with certain DNA to produce a silk 'print up' that can be used to create products such as ultra-strong surgical threads and medicines."

Working with NIAS researchers, Sputniko!, 30, is now taking transgenic technology into the artistic, "design fiction" realm. One of her projects, "The Perfect Love Dress," is woven with silk that virtually transforms a woman "into a modern biotech Aphrodite." "We're



也许，蚕宝宝对你来说是一种让人头皮发麻的小虫，如果爬上身体，它们脚上无数的小吸盘，也能让你起一身鸡皮疙瘩。如果发育正常，蚕宝宝会长得越来越胖，趴在桑叶上就好像一台开足马力的吃饭机器，直到化为蚕蛹。如果要评选昆虫界的美男美女，可没有蚕宝宝的份。

然而据推测，这种令人惊异的生物已经与人们

缝线或药物等产品"。

只有30岁的年轻艺术家尾崎正在与NIAS的学者合作，将转基因技术引入她艺术感强烈的"设计的虚构"系列作品中。其中一个项目"完美爱裙"采用丝绸制成，可以把女性转化为一个真正的"现代生物科技的阿美洛狄特"。"我们用基因工程改造蚕，让它吐出一种含有'爱情荷尔蒙'的丝，可以

Future generations of "biotech Aphrodites" may appreciate transgenic silk, seen in natural and fluorescent cocoons and silk fiber (opposite, all four images courtesy of NIAS) and in a colorful fluorescent array of cocoons (image courtesy

富。无论是在古文明时代，还是如今的全球化浪潮下，它都是左右人类社会贸易与经济的重大因素。

如今，蚕宝宝与它的丝蛋白正逐渐成为药物、化妆品及其他领域中生物科技创新的主角之一。筑波——位于东京附近，这里的农业生物资源研究所（NIAS），于2000年开发了蚕转基因（基因加工或改变）技术。人们对这项技术充满期待，不仅希望它能重振日本日益衰落的养蚕业，甚至还希望它能成为21世纪跨越国境的新丝绸之路上的一个引擎点。

基因打印

“蚕宝宝就像一台活的3D打印机”麻省理工大学媒体实验室的艺术家、设计师尾崎博美（很多人都知道她的另一个名字“Sputniko！”）助教说：“人们养蚕宝宝几千年了，不断让它繁殖，吐更多的蚕丝。现在学者们正在开发带有特别DNA的蚕宝宝，让它能吐出“打印丝”，用来打造超强度外科手术

在现实生活领域，尾崎还使用NIAS的学者们在2008年开发的、可以发出荧光的丝。研究组组长濑筒秀树博士说：“我们将源于水母和珊瑚的绿、红、橘色荧光蛋白注入蚕卵”。在紫光灯下端详出自尾崎之手的奇装异服，我们可以看到这异想天开的点子呈现在人们眼前的惊人效果。丝绸还用来制作以传统的“十二单”为蓝本的服饰——这种式样曾是1000年前宫中嫔妃的装束。

“在两三年后，转基因蚕丝就可以进入大量生产，并开始商业销售”，濑筒说：“可惜养蚕业受各种法规的限制比较大”。有关基因工程的科学伦理问题，社会上的讨论正进行得如火如荼。日本已经批准了卡塔赫纳生物安全议定书，保护生物多样性，限制经过基因工程处理过的生物在国际上的流通。濑筒补充道：“我们正在在谨慎推动这项研究，并申请政府许可，目标是造出全世界最好的丝。”

Japan Corporation), but genetically modified organisms may have adverse effects on biological diversity, as noted by the Cartagena Protocol on Biosafety.

未来世代的“生物科技的阿芙洛狄特”，可能会更多地利用转基因蚕丝，比如天然及荧光蚕蛋和丝纤维（标题下方图，4张图片均由农业生物资源研究所提供），或是一组彩色荧光蚕蛋（上图，由日本经济新闻社及株式会社BS日本提供）。不过卡塔赫纳生物安全议定书也指出，经过基因改造的有机体可能会对生物多样性产生负面影响。

Photos by Takashi Kamei (W) of Trancefllora — Amy's Glowing Silk (2015) installation event are courtesy of designer Sputniko! and show her electrifying dresses of genetically engineered silk, a different spin on sericulture compared to Tomioka Silk Mill, circa 1934 (photo courtesy of Tomioka City, Tomioka Silk Mill), or to a local Gunma family's cocoon samples.

genetically engineering silkworms to spin a silk that induces love by adding the 'love hormone' oxytocin," she explains.

In the real life realm, Sputniko! also works with a fluorescent silk created by NIAS researchers in 2008. "Silkworm eggs are injected with green, red, and orange fluorescent protein genes from jellyfish and coral," explains Dr. Hideki Sezutsu, head of the research unit. Under a black light, the freakish results turn to marvel when woven into Sputniko!'s stunning costumes. The silk was also used in a costume designed as a 12-layer kimono originally worn by court ladies a thousand years ago.

"In two or three years, silk spun by transgenic silkworms will be produced on a mass scale and sold commercially," says Sezutsu. "Sericulture, though, is quite restricted due to regulations." The ethics of genetic engineering are hotly debated. Japan has agreed to abide by the Cartagena Protocol on Biosafety, mandated to protect biological diversity and regulate international transfers of genetically engineered organisms. Sezutsu adds, "We're carefully moving forward with research and applying for government permission. We're going to create the finest silk in the world."

Life Cycles

The domesticated silkworm is the caterpillar of the *Bombyx mori* moth. Like most insects it goes through four stages of development: egg, larva (caterpillar), pupa (inside cocoon) and adult (imago or moth). After hatching from an egg, the larva grows so quickly it molts four times until it reaches a weight about 10,000 times its newborn size and is ready to spin silk.

During this one-month process the worms must be constantly fed fresh mulberry leaves. Nowadays farmers are opting for a combination of leaves and healthy artificial mix.

This stage is followed by the cocoon-spinning process, which takes about three days. Silkworms spin by first anchoring their silk to a frame. They then draw the silk through spinnerets located near their mouths by moving their heads round and round, in a figure-eight pattern. The cocoon is actually a single silk thread (filament) about one kilometer long. Cocoons used for silk reeling (filature) are treated with boiling water to kill the pupas and loosen the threads.

Hatching the Silk Industry

Silk is said to have originated in China around the 15th century B.C.E. Silkworms in

养蚕到死

家养的蚕宝宝是蚕蛾的幼虫，就像大部分昆虫一样，蚕的一生要经过 4 个阶段的变化：卵、幼虫、蛹及成虫。从卵孵化出的幼虫生长迅速，经过 4 次蜕皮，体重长到出生时的 1 万倍，它就要准备吐丝了。

在一个月的成长过程中，蚕要吃大量的新鲜桑叶。如今蚕农们大多选择桑叶和健康增进剂混合的食饵。

在这个阶段完成以后，蚕宝宝开始吐丝造茧，这个过程持续三天。蚕宝宝首先在一个支架上吐丝，然后把头摆动起来，画出一个 8 字形，通过嘴边的吐丝器吐丝。蚕茧其实是一条连续的线头（细丝），约有一公里长。缫丝使用的蚕茧要先用热水煮过让蛹死亡，然后再把蚕丝抽出来。

丝绸产业

据说丝的起源大约在公元前 15 世纪的中国。在日本，最早在古代的神话中就提到蚕，而蚕业养蚕与缫丝大概于公元 1-2 世纪就开始了。蚕丝的生产工艺受严格保护，这使得中国在蚕丝贸易上长期占垄断地位。不过不可避免的是，当世人越来越钟爱这种珍贵的产品，丝绸的秘密也随之在全球不断播散。

让我们把时钟拨快，进入 19 世纪中叶的日本。在经过 200 多年的闭关锁国以后，横滨港终于在 1859 年对外开放，开始通商。在那时，生丝是一种重要的出口产品，制丝行业也就成为国家的支柱产业之一。1868 年，欧洲制丝业经历了一场前所未有的蚕孢子虫病的打击，而这对于日本政府是一个利好消息。新政府渴望得到外汇，于是采用西方的机器大生产方式，来满足市场对生丝的巨大需求。

日本政府聘请制丝专家、法国人保罗·布鲁纳（1840–1908），来建造日本第一家现代制丝工厂。布鲁纳在距离东京大约 100 公里的群马县富冈市的山区选址，该地区因为附近利根川的润泽，有大片茂密的桑树林。过去这里每到 6、7 月的雨季都有洪水，这使得营养丰富的淤泥能每年堆积，与中国的自然环境十分相似，极适宜桑树生长。当时，养蚕业都是家庭作坊式的，传统上从事养蚕的人都是农村妇女。

布鲁纳选择法国进口的缫丝机，把厂房设计成西日结合的建筑风格。厂中一项划时代的技术是用高悬的瓶台式房顶来换气，这个设计由住在富冈附近的蚕农田岛弥平在 1860 年代发明。在 1872 年富冈制丝厂竣工以后，这所国有工厂就被誉为日本近代工业的摇篮。

在日本政府实业报国的呼吁下，来自日本全国的年轻女工陆续来到富冈制丝厂工作。很多女工来自原先的武士家族，需要赚钱贴补家用——在日本社

会急剧进入现代化之后，武士的津贴也被大幅削减。

有了长时间的技术革新，以及富冈制丝厂的成功，群马县成为了日本养蚕、缫丝和纺织业的中心。

到 1906 年，日本一跃成为世界第一生丝出口国，而由于美国丝袜市场的旺盛需求，这个地位一直保持到 1920 年代。技术革新使 F1 杂交蚕等高生产效率的品种问世，但不可避免地，外国的廉价劳动力和低生产成本也压低了日本产生丝的价格。日本的生丝工业也从繁盛到凋零，开始从出口生丝转向出口先进的缫丝机器。

由龟井隆司（W）拍摄的“Tranceflora—— 艾米的发光丝绸”（2015）系列照片由设计师尾崎博美（Sputniko!）友情提供。她在其中展示了转基因丝绸制作的电子衣裙。与富冈制丝厂（照片摄于 1934 年前后，由富冈市富冈制丝厂提供）及群马县一个养蚕人家的蚕茧标本所体现的那种传统不同，它昭示了一条养蚕业之新路。

养蚕家族

在群马县，高桥家族经营的养蚕业延续了四代人，现在传到了 24 岁的高桥直矢这一代，他在大学毕业后开始在这里做全职工作。高桥家对未来充满信心。不管是转基因技术的进步，还是去年富冈制丝厂被列为联合国教科文组织的世界遗产的消息，都让人们再次对这里的养蚕制丝业产生兴趣。

“在每年 5 月到 10 月的养蚕季节，蚕农终日不得休息。养蚕种桑树非常辛苦，收入还不稳定”，高桥直矢说。“我的朋友大部分都在东京做白领”，直矢的父亲纯一接过话题：“这是附近地区 7 年来第一次有年轻人继承家业。人们都担心本地产业最终会消亡。”

高桥直矢现在成了本地名人，各路媒体都来采

Japan are first mentioned in ancient mythological tales, and commercial sericulture and filature began between the first and second century A.D. Production methods became a tightly guarded secret preserving a Chinese monopoly on the trade. Inevitably, the secrets of silk making spread across the globe as demand for this precious commodity grew.

Fast forward to Japan, mid 1800s. After over 200 years of national isolation, the port of Yokohama was opened to foreign trade in 1859. At the time, raw silk was an important export product, so silk production became one of the country's principle industries. It was a stroke of luck for the government when Europe's silkworm industry suffered a severe blight of pebrine disease in 1868. Desperate for foreign exchange, the new government set out to meet the huge demand for silk abroad with Western-style machinery.

They hired Frenchman Paul Brunat (1840–1908), an expert in silk manufacturing, to build Japan's first modern silk factory. He picked a site about 100 kilometers from

Silk-reeling machines and a revolutionary ventilation technique are still hallmarks of traditional sericulture at Tomioka Silk Mill. The area is renowned for mulberry trees, like the Great Mulberry of Usune known well by Mitsu Ishii today and circa 1934 (photos courtesy of Mitsu Ishii, opposite bottom). Magazine stories on the Takahashi family (photos courtesy of Takahashi family) show the silkworm farmers with mulberry trees and feeding the leaves to silkworms.

Tokyo, in the hills of Gunma Prefecture, in the town of Tomioka. The area is known for healthy mulberry trees, thanks to the nearby Tonegawa River. It once flooded every year during the rainy season in June and July, leaving muddy silt with lots of nutrients, similar to conditions in China, perfect for growing mulberry trees. Sericulture grew as a cottage industry there, labored traditionally by farming women.

Brunat chose silk-reeling machines imported from France and designed the factory buildings with a hybrid of Western and Japanese architecture. One was a revolutionary ventilation technique using a raised turret-like roof developed by silkworm farmer Yahei Tajima in a town near Tomioka in the 1860s. After construction for Tomioka Silk Mill finished in 1872, the state-owned facility was lauded as the cradle of industrial Japan.

Young women from throughout Japan joined the factory force as part of a government campaign to labor for the sake of the nation. Many were from former samurai families that needed the extra income. Samurai had their stipends drastically cut in the sudden transition to modernization.

With a long history of technological innovation, and the success of Tomioka Silk Mill, Gunma Prefecture became the center for Japan's sericulture, silk reeling, and textile manufacturing.

Japan became the world's number one exporter of raw silk in 1906 and continued through the 1920s to feed high demand in the U.S.A. for silk used in stockings. Innovations continued with development of the highly productive F1 hybrid silkworm. But inevitably, cheaper labor and manufacturing costs abroad undercut Japanese raw silk prices. The nation's raw silk industry went from boom to bust. Instead, Japan began exporting its advanced silk reeling machinery.

Silkworm Farming Family

In Gunma, the Takahashi family has continued their sericulture business for four generations, now with Naoya, 24, joining his parents full-time after graduating from college. The family is upbeat about their future. Advances in transgenic technology and Tomioka Silk Mill's listing as a UNESCO World Heritage site last year are bringing renewed interest in the region's sericulture and silk products.

"Farming silkworms is a 24/7 job between May and October. It's tough, unstable work, growing both silkworms and mulberry trees," says Naoya. "Most of my friends are doing regular office jobs in Tokyo." His father, Junichi, adds, "It's the first time in seven years that someone from the younger generation has continued their family's sericulture

business in this area. Everyone has been very worried that local production would die off."

Naoya is now a local celebrity, attracting wide media attention for his efforts to promote the region's silkworm farming. "It's nice to get praise, but it's not helping with my biggest challenge: finding a wife. I don't know any women who want to work with worms."

The right type of wife is one key to success. "A husband and wife work as partners," says his mother, Michiko. Men do the heavy jobs, while women grow the silkworm eggs and do the time-consuming detailed work tending the silkworms as they grow. "We women are called *kakadenka* in this region, which means 'hard working and strong [enough to manage the entire household].'"

Sacred Stewards

Beyond business, women in Gunma are also the spiritual protectors of the silkworm and mulberry tree. Mitsu Ishii, 78, is the 12th-generation member of a family chosen as caretakers of the 1,500-year-old Great Mulberry of Usune. Legend has it that the tree is imbued with spiritual powers. "Visitors tell me they can feel the tree's power," says Ishii. She began her duties about 60 years ago, after graduating high school. "I go to see the tree every day, to check on its condition and keep track of the many visitors who come to pray there." A major concern is continuing the tradition within her family line. "I'm the last one, since I don't have any children. I don't know what we're going to do."

From ancient, fine silk thread to modern-day, DNA-induced fluorescent varieties, the silkworm remains a celebrated, influential insect in Japan shaping the nation's past and hopefully its future.

访他为推进本地养蚕业所做的努力。“受人赞扬很好，但我最大的挑战是要快点找到个人幸福，这一点别人帮不了我。只可惜我不认识愿意与虫子为伍的女孩子。”

好的贤内助是成功的一半。“丈夫和妻子就是一对拍档”，直矢的母亲道子说。男人做重体力活，女人养蚕籽，负责那些蚕宝宝成长必须的艰辟费时的工作。“很多人用‘母天下’称呼这里的女人，意思就是勤劳刚强，足以当家的意思。”

守护神圣

除了工作以外，群马县的女性还是蚕宝宝和桑树的精神守护者。石井满现年 78 岁，是被选中守护有 1500 历史的“薄根大桑树”的家族第十二代成员。传说中这棵桑树具有神奇的法力。“来访者告诉我他们能感受到它的能量”，石井说。她从 60 年前高中毕业后就肩负起这项神圣的职责。“我每天来看这棵树，观察它的状态如何，注意来祈福的访客的动向。”她最关心的事是如何让这项传统能在她家中传承下去。“我没有孩子，我不知道未来会怎样。”

从古迄今，从优质丝线到经过 DNA 改造的荧光丝，对日本人来说，蚕宝宝永远是家喻户晓、不可或缺的亲密朋友，伴随这个国度走过历史，也指引它走向光明的前程。

缫丝机和具有革命性意义的换气技术依然是富冈制丝厂中传统养蚕业的证明。该地区以桑树闻名，比如“薄根大桑树”和对这棵树了如指掌的石井满。石井满还提供了几张大约是在 1934 年拍摄的老照片（下图）。高桥家族的故事还上了杂志（图片由高桥家提供），照片拍摄的是养蚕农家与桑树丛、和正给蚕宝宝喂桑叶的场景。