

Since the early twentieth century, the chief source of latex has been *Hevea brasiliensis* (Greek 1991), though there are several other tropical and sub-tropical species that yield rubber from their laticifers (latex vessels)—small tubes found in the inner bark. As its botanical name suggests, *H. brasiliensis* is native to tropical regions of South America, especially Amazonia and adjoining areas.

2.1 The Amazon River Basin

During latter half of the nineteenth century, the Amazon River and its major tributaries were inhabited by relatively dense, sedentary populations of indigenous peoples who practised intensive root-crop farming, supplemented by fishing and hunting of aquatic mammals and reptiles. The higher areas away from the rivers and their flood plains were (and still are) inhabited by small, widely dispersed, semi-nomadic tribes of Indians living on hunting animals and on wild fruits, berries and nuts with some small-patch agriculture of low yield. Amazon Rainforest is as much as 100 million years old. Rainforest covers the largest part of the Amazon region, most of the Guyanas, southern and eastern Venezuela, the Atlantic slopes of the Brazilian Highlands and the Pacific coast of Colombia and northern Ecuador (Fig. 2.1). The huge Amazon region is the largest and probably the oldest forest area in the world; it also ascends to the slopes of the Andes until it merges with subtropical and

temperate rainforest. On its southern border it merges with the woodlands of the Brazilian state of Mato Grosso, with galleries of trees extending along the rivers.

The Amazon basin consists of enormous trees, some exceeding a height of 100 m, with an incredible number of species growing side by side in the greatest profusion arranged in different strata. For example, in Manaus (Brazil), 1652 plants belonging to 107 species in 37 different families were found in about 630 m². There are about 2500 species of Amazonian trees (Ducke 1941) and as many as 100 arboreal species have been counted on a single acre of forest with hardly any one of them occurring more than once. Papers of Schultes (1945) and Seibert (1947) further confirm this enormous diversity. The Amazon forest has a strikingly layered structure. The canopy of sun-loving giants, soar to as much as 40 m above the ground and a few, known as emergents, rise beyond such canopies, frequently attaining heights of 70 m. Their straight, whitish trunks are covered with lichens and fungus. A characteristic of these giant trees is the buttresses, or basal enlargements of their trunks, which presumably help stabilize the top-heavy trees during infrequent heavy winds. Further characteristics of these trees are their narrow, downward-pointing 'drip-tip' leaves that easily shed water. Flowers are inconspicuous. Among the canopy species, prominent members include the rubber tree (*H. brasiliensis*), the silk cotton (*Ceiba pentandra*), the Brazil nut (*Bertholletia*



Fig. 2.1 Vegetation map of Brazil

excelsa), the Sapucaia (*Lecythis*) and the Sucupira (*Bowdichia*). Many creatures, including monkeys and sloths, spend their entire lives in this sunlit canopy.

The Amazon River basin is the largest river basin in the world. It is important not only to the seven countries it spreads (Brazil, Peru, Ecuador, Bolivia, Colombia, Venezuela and Guyana), but

to the entire world as it affects the global climate. The name Amazon was given by Spanish explorer Francisco de Orellana in 1541. It slices through the rainforest from the Andes to the Atlantic; it extends beyond the rainforests and reach elevations in the Andes of more than 16,400 ft (5000 msl) at its westernmost watershed (Goulding et al. 2003). The Andes draining into the Amazon span a 2800 mile (4500 km) arc, stretching from Bolivia to Colombia. The Amazon is anywhere between 3903 miles (6259 km) and 4195 miles (6712 km) long. The drainage basin covers an area of over 6,915,000 km² (2,722,000 square miles), or roughly 40% of South America (Schroth et al. 2003). The Amazon basin covers a surface area of 4,100,000 km² (1,583,000 square miles), of which around 3.4 million km² (1.3 million square miles) are presently forested (Schroth et al. 2004). The discharge from Amazon River is about 220,800 m³/s. Or, it drains over 7,381,000 cubic foot of water into the Atlantic Ocean each second. During the monsoons, the width of the Amazon River can reach over 30 miles (50 km). The second longest river in the world (Nile is believed to be the first), the Amazon is by far the largest river in the world, accounting for approximately 20% of the water flowing from the world's rivers into the oceans. It produces about 20% of the Earth's oxygen.

Accounting for parts of the Amazon outside Brazil, the total extent of the Amazon is estimated at 8,235,430 km² (3,179,715 square miles). By comparison, the land area of the USA (including Alaska and Hawaii) is 9,629,091 km² (3,717,811 square miles). Amazonian evergreen forests account for about 10% of the world's terrestrial primary productivity and 10% of the carbon stores in ecosystems (Melillo et al. 1993)—of the order of 1.1×10^{11} t of carbon (Tian et al. 2000). Amazonian forests are estimated to have accumulated 0.62 ± 0.37 t of carbon ha⁻¹ year⁻¹ between 1975 and 1996 (Tian et al. 2000). Fires related to Amazonian deforestation have made Brazil one of the top greenhouse gas producers. Brazil produces about 502 million t of CO₂ a year from fossil fuel consumptions. If one includes land use component, this figure would be much

Table 2.1 Ranking of the world's countries by 2013 per capita fossil fuel CO₂ emission rates. National per capita estimates (CO₂_CAP) are expressed in metric tons of carbon (not CO₂)

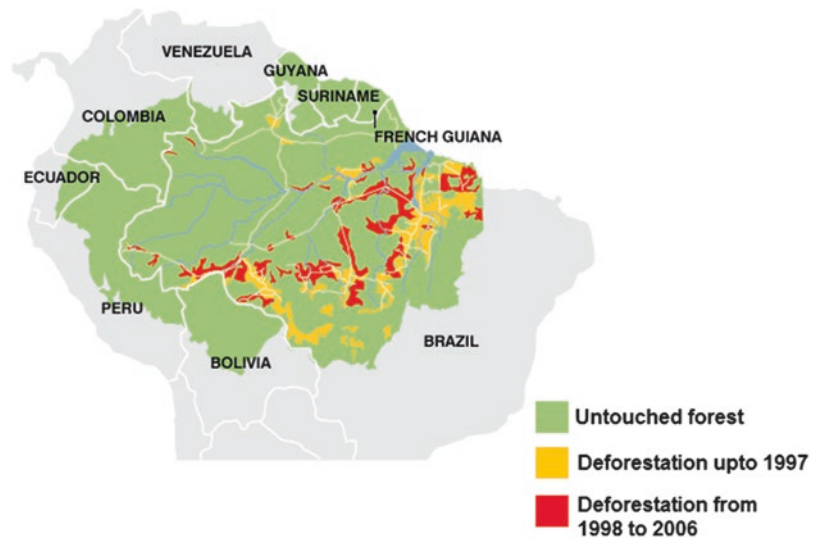
Rank	Nation	CO ₂ _CAP
1	Qatar	11.03
9	United Arab Emirates	5.10
12	Australia	4.43
13	USA	4.40
21	Canada	3.68
23	Russian Federation	3.40
33	Japan	2.67
35	Germany	2.56
37	Singapore	2.55
39	Israel	2.48
40	South Africa	2.41
50	China (Mainland)	2.05
53	UK	1.95
123	Brazil	0.67
133	Indonesia	0.52
143	Vietnam	0.46
147	India	0.43
159	Philippines	0.27
167	Sri Lanka	0.21

Source: Tom Boden and Bob Andres, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory; Gregg Marland, Research Institute for Environment, Energy and Economics, Appalachian State University

higher. CO₂_CAP shall be around 2.2 for Brazil as per World Bank data (see <http://data.world-bank.org/indicator/EN.ATM.CO2E.PC>). Brazil is listed as one of the lowest per capita (ranked 123; 0.67 CO₂_CAP) in CO₂ emissions according to the US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) (Table 2.1). No accurate data on deforestation exists for the Amazon basin as a whole, although annual losses of 8920 square miles to 9420 square miles (more than the size of New Jersey) are frequently cited (Butler 2004) (Fig. 2.2).

Currently, *Hevea* rubber is planted in compact areas as rubber plantations that cover vast tracts of Indonesia, Malaysia, Thailand, India, Vietnam, China, Sri Lanka (erstwhile Ceylon) and Nigeria. Cambodia and Laos are the upcoming rubber producers. How a wild plant of the Amazon jungles was domesticated and trained to be the producer of a pre-eminent industrial raw material is

Fig. 2.2 Deforestation in Brazil



the central saga in the history of the so-called indispensable rubber industry. A crucial episode in that narrative is the transport of *Hevea* seeds from Brazil to England and from there to South and Southeast Asia as described in the 14th edition of *Encyclopedia Britannica* by William Woodruff, professor of economic history and author of *The Rise of the British Rubber Industry During the Nineteenth Century* (1958), and later by many authors (Tan 1987; Simmonds 1989; Clément-Demange et al. 2000; Thomas 2001, 2002; Priyadarshan 2003a, 2007; Priyadarshan and Clément-Demange 2004). A brief account of the history of *Hevea* domestication is given here.

2.2 History of Domestication

History of *Hevea* recapitulates the names of five distinguished men: (i) Clement Markham (of the British India Office); (ii) Joseph Hooker (Director of Kew Botanic Gardens); (iii) Henry Wickham (naturalist); (iv) Henry Ridley (Scientific Director of Singapore Botanic Gardens) and (v) R.M. Cross (Kew gardener), with Kew Botanic Gardens playing the nucleus for rubber procurements and distribution. As per directions of Markham, Wickham (Fig. 2.3) collected 70,000 seeds from the Rio Tapajoz region of the Upper Amazon (Boim district) and transported the col-

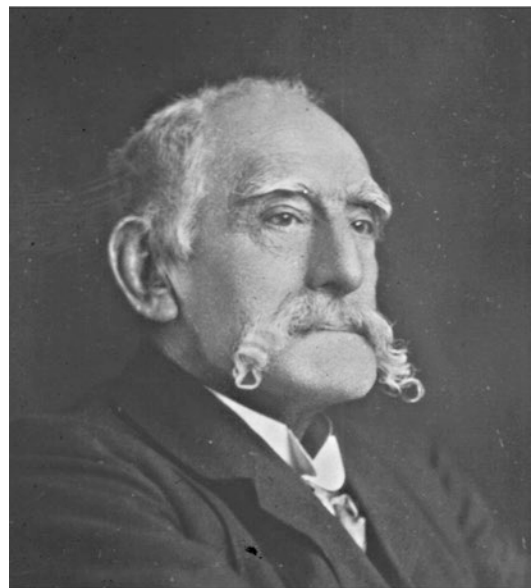


Fig. 2.3 Sir Henry Alexander Wickham (29 May 1846–27 September 1928)

lection to Kew Botanic Gardens during June 1876 (Wycherley 1968; Schultes 1977b; Baulkwill 1989) (Fig. 2.4). Of the 2899 seeds germinated, 1911 were sent to the Botanic Gardens, Ceylon (now Sri Lanka), during 1876, and 90% of them survived at the Henarathgoda botanical garden. During September 1877, 100 *Hevea* plants specified as ‘Cross material’ were

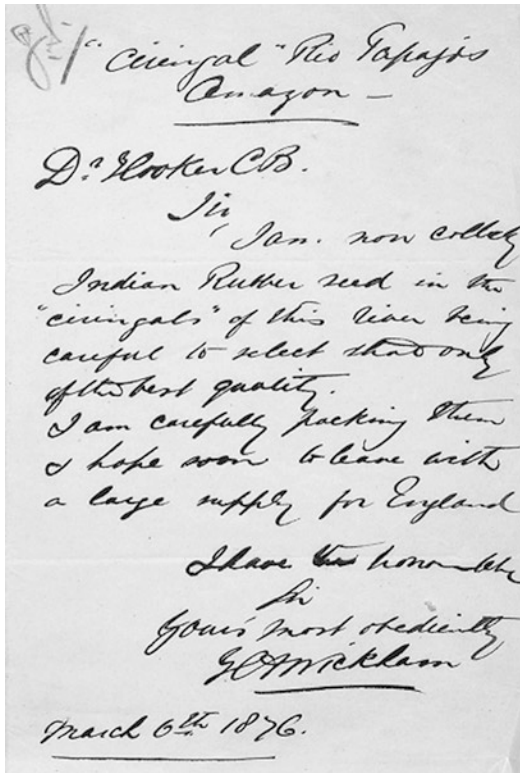


Fig. 2.4 Dispatch notification by Wickham of rubber seeds to from Rio Tapajós region, Upper Amazon to Kew Botanic Gardens, UK (from Kew Botanic Gardens with permission)

also sent to Ceylon. In June 1877, 22 seedlings not specified either as Wickham or Cross were sent from Kew to Singapore, which were distributed in Malaya and formed the prime source of 1000 seedling tappable trees found by Ridley during 1888. An admixture of Cross and Wickham materials might have occurred, as the 22 seedlings were unspecified (Baulkwill 1989). One such parent tree planted during 1877 was available in Malaysia even after 100 years (Schultes 1987). Seedlings from the Wickham collection of Ceylon were also distributed worldwide. Rubber trees covering millions of hectares in Southeast Asia are believed to be derived from very few plants of Wickham's original stock from the banks of the Tapajoz (Imle 1978). After reviewing the history of rubber tree domestication in East Asia, Thomas (2001) drew the conclusion that the modern clones have invariably originated from the 1911 seedlings sent to Ceylon during

1876. Also, Charles Farris could transport some seedlings to Kolkata in India (erstwhile Calcutta) during 1873 (Fig. 2.5). Hence, the contention that the modern clones were derived from '22 seedlings' is debatable. Moreover, if the modern clones were derived from 1911 seedlings, then the argument that they originated from a 'narrow genetic base', as believed even now, needs to be reviewed (Thomas 2002). A chronology of events is given in Table 2.2.

The first introduction of rubber to India was during 1873 from Ceylon (now Sri Lanka) when 28 *Hevea* plants were planted in the Nilambur Valley of Kerala state in South India (Haridasan and Nair 1980). During the period 1880–1882, plantations on an experimental scale were raised in different parts of South India and the Andaman islands. *Hevea* was first introduced to Vietnam in 1897 by the French, but was rejuvenated only after 1975 because of the long-lasting war (Priyadarshan 2003a).

Developments in domestication of rubber after 1880 commenced in Singapore Botanic Gardens, one of the world's finest in terms of both its aesthetic appeal and the quality of its botanical collection. Approximately 3000 species of tropical and subtropical plants and a herbarium of about 500,000 preserved specimens are the hallmark of this garden. Under the direction of Henry Nicholas Ridley (Fig. 2.6), who took over as Director of Singapore Botanic Gardens in 1888, the garden became a centre for research on *H. brasiliensis*. Ridley developed an improved method of tapping rubber trees that resulted in a better yield of latex. His innovation revolutionized the region's economy. His persistence resulted in the first rubber estate in 1896 using his seeds and thereon the rubber industry grew into one of the economic mainstays of the Malay states. It is also known that 100 plants went to Sri Lanka in the summer of 1877 and a further 50 to India. In all, by the end of 1877, Kew had distributed over 3000 seedlings; vastly more than their primary stock, so there must have been considerable propagation from cuttings. Sri Lanka then forwarded 22 seedlings from that delivery of 100 to Singapore. All of these survived and Henry Ridley, Director of the Singapore Botanic



Fig. 2.5 The voyage of rubber to India

Table 2.2 Events in the history of rubber

1.	1735—Rubber samples sent to Europe by Charles-Marie de La Condamine
2.	1763—French (François Fresneau) found caoutchouc could be dissolved in naphtha; suggested use in waterproofing clothing but it became tacky when warm
3.	1770—Joseph Priestly discovered that the material would rub out paper marks, hence the name India rubber, and now simply ‘rubber’
4.	1803—The first rubber factory was established near Paris
5.	1823—Mackintosh manufactures waterproof raincoats by coating fabric with rubber dissolved in naphtha
6.	Early 1820s—Hancock invented the masticator, a machine that shredded rubber scraps, allowing rubber to be recycled after being formed into blocks or rolled into sheets
7.	1824—Hancock suggested plantation growing of rubber
8.	1839—Goodyear and/or Hancock discovered vulcanization; when rubber was heated with sulphur, rubber retained physical properties from 0° to 100 °C. This led to rubber boom
9.	Interest in rubber with vulcanization process led to increased demand and exploitation of wild <i>Hevea</i> trees (<i>Hevea</i> was the native word)
10.	1845—The first patent for a pneumatic tyre was issued to Robert William Thomson in England
11.	1858—The first patent on an integral pencil and eraser was issued in the USA to Joseph Rechendorfer of New York City
12.	1870—Sir Clements Markham of India Office suggested that rubber along with cinchona (source of quinine) be obtained from tropical America and grown in Asia
13.	1872—James Collins reviewed rubber producing plants, published monograph entitled <i>Caoutchouc of Commerce</i>
14.	1873—Seeds from Brazil sent to Kew Botanical Gardens; 12 plants raised and sent to Calcutta, but failed
15.	1875—Second consignment of seed failed to germinate
16.	1876—Makham sends Robert Cross to Para, Brazil, where he obtained 1000 plants of <i>Hevea</i> , but no plants reach the East. At this time H.A. Wickham, an Englishman residing at Manaus (centre of the rubber boom in Brazil), sent 70,000 seeds from Central Amazon basin (he received £10/100 seeds). This provided the basis for the world’s rubber industry. The seeds were sent to Kew. Seeds had short viability but produced 2899 plants. Seedlings were sent to Ceylon and 50 plants to Singapore and a few to Java
17.	1888—In Singapore, there were 9 trees of the original introduction, 21 five-year-old trees and 1000 seedlings. Ceylon had 20,000 seeds
18.	1888 to 1911—H.N. Ridley, scientific director of the Botanical gardens at Singapore demonstrated that <i>Hevea</i> was the superior rubber bearing plant; discovered excision method of extracting latex and devised method for coagulating latex
19.	1888—John Boyd Dunlop, a veterinary surgeon of Belfast, obtained patents on a pneumatic tyre for bicycles
20.	1898—Dunlop rediscovers pneumatic tyres (motor cars invented in 1885). Today, 70% of rubber involves transportation, 6% for footwear, 4% for wire and cable
21.	1898—First planting in Malaysia by a Chinese grower named Tan Chan Yoy. At this time, coffee prices slumped and there was interest in establishing a new industry
22.	1910—Rubber boom; rubber reaches \$3 a pound
23.	1956—Ridley dies at the age of 101
24.	After 1956 till date— <i>Hevea</i> rubber popularized as a cash crop all through east Asia and many countries of Africa. Agencies like ANRPC, IRSG and IRRDB constituted. Development extended to suboptimal climates of various countries

Gardens, was later to remark that it was from these 22 seedlings in the Gardens that more than 75% of the cultivated plants in Malaysia were derived.

The arrival of 22 seedlings in Singapore did not create the Malaysian plantations overnight. *Hevea* seedlings were planted in the Residency

gardens at Kuala Kangsar where they were nurtured by the Resident Hugh Low while investigations of both *Hevea* and indigenous rubber producing plants were carried out by H.J. Murton, the Superintendent of the Singapore Botanic Gardens, and by his successor, N Cantly. In 1885, Cantly claimed that the latter offered

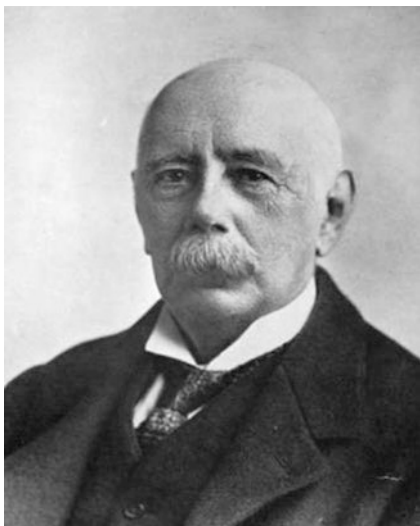


Fig. 2.6 Henry Nicholas Ridley (10 December 1855–24 October 1956)

better commercial potential. Meanwhile, in 1884, Frank Swettenham, later to be the High Commissioner of the Federated Malay States, planted 400 *Hevea* seeds from the Kuala Kangsar trees in Perak. More were planted in Selangor between 1883 and 1885 by T H Hill although these were possibly ornamental rather than commercial plantings.

Henry Ridley suggested that the government should consider large-scale plantings, as there was little private interest in planting crops which would take 5 years or more to start paying their way. He was able to use his additional position as Supervisor of the Straits Forest Department to carry out plantings in both Singapore and around Malacca and to investigate ways of cultivating and tapping the trees for optimum yield. He published his recommendations in 1897 and, following his ideas, Curtis in Penang and Derry in Kuala Kangsar obtained yields of latex from which they were able to calculate that rubber production could be profitable. It was also noted from samples sent to England that there would be a ready market for plantation rubber as it was much cleaner and more consistent in quality than the wild rubbers of either Africa or Amazonia.

It is perhaps ironic that another Brazilian commodity pushed Malaysia into rubber. Various

government inducements had encouraged planters to create and expand plantations and many of these chose coffee as their main crop. The price of coffee had been high due to production problems in Brazil but, by the mid-1890s, these problems had been overcome while fungal disease was attacking the Malaysian plants. In 1895, Tan Chay Yan planted 43 acres of *Hevea* on his estate at Bukit Lintang in Malacca and the Kindersley planted a further 5 acres in Selangor. These were the first commercial rubber estates in Malaysia and, as the coffee market collapsed, more and more planters turned to rubber. Initially the plantings were interspersed with cash crops such as coffee but by 1898 Stephens, in Perak, was planting dedicated rubber plantations. At about this time Ridley noted that he had received requests for one million seeds in a single day!

Significant development on the propagation of *Hevea* rubber occurred after 1910. The contribution to propagation and breeding of *Hevea* made by P.J.S. Cramer (Bogor, Indonesia) during 1910–1918 is noteworthy. He made a trip to the Amazon and succeeded in getting seeds of *Hevea spruceana* and *Hevea guianensis*. Cramer also conducted experiments on variations observed in 33 seedlings imported from Malaysia in 1883 from which the first clones of the East Indies were derived (Dijkman 1951). Along with van Heltten, a horticulturist, he could standardize vegetative propagation by 1915. The first commercial planting with bud-grafted plants was undertaken during 1918 in Sumatra's east coast. Ct3, Ct9 and Ct38 were the first clones identified by Cramer (Dijkman 1951; Tan et al. 1996). Commercial ventures gradually spread with the introduction of bud grafting; 'generative' and 'vegetative' selection methodologies were simultaneously used that resulted in seedlings and grafted clones (Dijkman 1951). Around 1950, the advantages of grafted clones proved to be overwhelming for yield potential compared to genetically improved seedlings, and the focus shifted to derivation of clones for latex productivity. With all these cultural developments, *H. brasiliensis* soon ousted many other rubber-producing species including *Castilla*, *Manihot glaziovii* (ceara or manicoba rubber tree), *Ficus elastica*,

Landolphia and *Clitandra* vines (African rubber).

Once the *Hevea* tree had been successfully transplanted to Southeast Asia, the development of rubber plantation industry was rapid and considerable quantities of the commodity were in the market by 1910. Factors such as availability of labour and favourable soil and climate contributed to this development. With the growth in world demand increasing, the total area of plantation in the East in 1900 amounted to 5000 acres. In 1910, it was 1 million acres and in 1920, 4 million acres. After the end of World War II in 1945, the total acreage exceeded 9 million, and by the mid-1960s it was 11.5 million. Rubber produced from *Hevea* in Asian countries, ranging from the Philippines to Sri Lanka, accounted for almost 95% of the world's natural rubber supply (Table 2.3) (IRSG 2015). Worldwide, there is almost 15% increase in yield from 2008 to 2012 (IRSG 2015). Currently, the production and consumption of natural rubber is equalized (little more than 12 million metric tons) (Fig. 2.7).

There has been a constant correlation in the prices of oil and natural rubber. World economic recessions also have always experienced a downfall in the prices of natural rubber. An extensive survey of the history and development of natural rubber is beyond the scope of this book. Readers

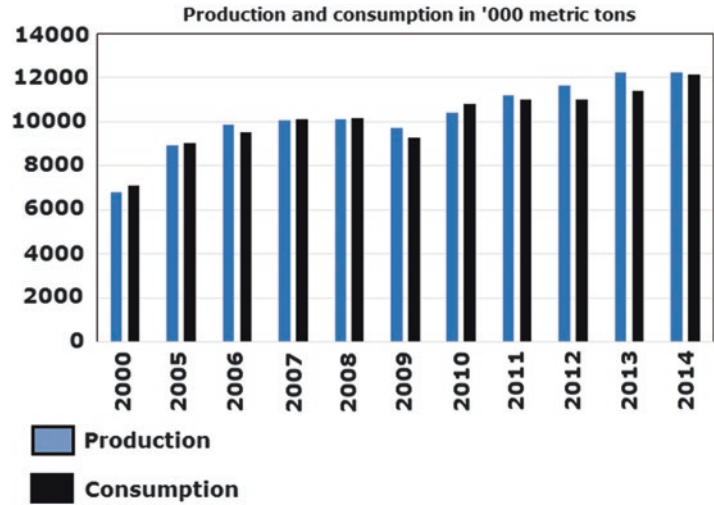
interested in such details may refer to Baukwill (1989) for an extensive account on the history and various bulletins by IRSG for rubber statistics.

Hevea rubber invites sharp criticism from environmentalists. For instance, new millennium saw a boom in rubber prices. This led to rapid and widespread land conversion to monoculture rubber plantations in Southeast Asia, where natural rubber production has increased >50% since 2000. Rubber was planted into increasingly sub-optimal or marginal environments (nearly 72% of plantation area) where one can anticipate reduced yields. Of this, an estimated 57% of the area is susceptible to insufficient water availability, erosion, frost or wind damage. In 2013, typhoons destroyed plantations worth US\$ >250 million in Vietnam alone (Ahrends et al. 2015). Such vagaries in nature can still reduce the potentiality of new areas. Expansion into marginal areas creates potential for loss-loss scenarios: clearing of high-biodiversity value land for economically unsustainable plantations that are poorly adapted to local conditions and alter landscape functions (e.g. hydrology, erosion)—ultimately compromising livelihoods, particularly when rubber prices fall. For example, between 2005 and 2010, >2500 km² of natural tree cover and 610 km² of protected areas were converted to plantations (Ahrends et al. 2015). More than 500,000 ha may have been converted already in the uplands of China, Laos, Thailand, Vietnam, Cambodia and Myanmar (Ziegler et al. 2009). By 2050, the area of land dedicated to rubber and other diversified farming systems could more than double or triple, largely by replacing lands now occupied by evergreen broadleaf trees and swidden-related (a plot of land cleared for farming by burning away vegetation) secondary vegetation. Ziegler et al. (2012) conducted meta-analysis of over 250 studies reporting above- and below-ground carbon estimates for different land use types that indicated great uncertainty in the net total ecosystem carbon changes that can be expected from many transitions, including the replacement of various types of swidden agriculture with oil palm, rubber or some other types of agroforestry systems. These transitions are underway throughout

Table 2.3 Natural rubber production- Asian countries against world (in million metric tons)

Country	2012	2013	% of change
Bangladesh	0.18	0.19	2.6
Cambodia	0.64	0.85	32.1
China	0.8	0.86	7.9
India	0.91	0.7	-13.4
Indonesia	3.0	3.2	7.5
Laos	0.07	0.08	17.6
Malaysia	0.92	0.82	-10.4
Myanmar	0.013	0.14	7.9
Papua New Guinea	0.075	0.075	0.0
Philippines	0.11	0.11	0.0
Sri Lanka	0.15	0.13	-14.2
Thailand	3.8	4.17	10.4
Vietnam	0.8	0.9	8.2
<i>Asia total</i>	<i>10.85</i>	<i>12.15</i>	<i>11.9</i>
<i>World total</i>	<i>11.6</i>	<i>12.22</i>	<i>5.2</i>

Fig. 2.7 Production and consumption of rubber over years



Southeast Asia and are at the heart of REDD+ (Reduce Emissions from Deforestation and forest Degradation) debates. As some transitions may negatively impact other ecosystem services, food security and local livelihoods, the entire carbon and non-carbon benefit stream should also be taken into account before prescribing transitions with ambiguous carbon benefits. A deeper and more systematic analysis of the multiple consequences of these policies is consequently necessary for the design of successful REDD+ policies in MMSEA (Montane Mainland Southeast Asia) and other areas of the developing world (Fox et al. 2014a, b).

Further, Kumagai et al. (2015) conducted eddy flux measurements over 3 years in two plantation sites of north-eastern Thailand and central Cambodia having distinct dry seasons. They used a combination of actual evapotranspi-

ration (ET) flux measurements and an inverted version of a simple 2-layer E_T model for estimating the mean canopy stomatal conductance (g_s). There was less sufficient stomatal regulation at the Thailand site, where there might be little risk of water stress-induced hydraulic failure because of its higher annual rainfall amount. In comparison, at Cambodian site where annual potential water balance (precipitation – potential evaporation: $P - E_{T-POT}$) was negative and there was stricter stomatal regulation, preventing excessive xylem cavitation. This demonstrates *Hevea* behaves differently under water stress conditions (see Chap. 3 for details). High water use by rubber raises concerns about potential effects of continued expansion of tree plantations on water and food security in MMSEA (Giambelluca et al. 2016). However, this issue demands thorough debate by experts.

Biology of Hevea Rubber

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2017, IX, 251 p. 81 illus., 46 illus. in color., Hardcover

ISBN: 978-3-319-54504-2