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This volume of the *Journal* is devoted exclusively to papers presented at the First International Bamboo Conference held at the University of Puerto Rico in Mayagüez. Some 47 participants from 10 countries attended. They are listed on the following two pages.

The first two days of the Conference were spent with the mornings devoted to field trips within the USDA Tropical Agriculture Research Station (TARS) and afternoons devoted to the presentation of papers. The field trips covered the 16 different bamboo species growing at TARS of which 6 were in flower (see the papers by Edelman et al. and Deitzer et al.). The third day was spent on a field trip to areas in the vicinity of Mayagüez where many of the bamboos from TARS have been established.

The organization of the Conference was planned and executed by committees of people from ABS, the University of Puerto Rico, The Smithsonian Institution and the USDA TARS. The committees were headed and directed by Laura Brinkley of the Caribbean Chapter - ABS.

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Thomas R. Soderstrom*: **Bamboo Systematics: Yesterday, Today and Tomorrow**†

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The use of bamboo in Asia certainly must date back to man's earliest times, for wherever man has come into contact with this plant, he has found a use for it. According to Marden (1980), an ancient dictionary of the Chinese called the *Erh Ya* mentions bamboo by the name of "ts'ao," and doubtless many references to tree grasses under other names are to be found in other early accounts. But while the earliest bamboo technology and artistry belong to the Chinese, who have always lived among it, an understanding of bamboo systematics and the earliest scientific classifications belong to the Europeans. According to Ruprecht (1839), the first mention of bamboo in Western literature was made in a letter from Alexander the Great to Aristotle and referred to by Pliny (23-79 A.D.) in his encyclopedic *Natural History* of 37 books.

I have attempted to search out the earliest references to bamboo that played a role in the ultimate establishment of the name in scientific literature. We are first drawn to a learned man known in later times as the "Prince of Physicians," Ibn Sina, or Avicenna, who was born in Bokhara, Persia (now Iran) in 980 A.D. and who became educated in all branches of science known at the time. This was during the flowering of the intellectual Arabic world. Avicenna travelled from court to court in Central Asia looking for a place for his talents and eventually settled down as physician to one of the rulers. His *Canon* of medicine was a "codification" of the whole of ancient and Muslim knowledge and is considered to be one of the highest achievements in Arabic culture. It became the textbook of medicinal study in European universities and as recently as 1650 was still used at Montpellier. In this book, Avicenna refers to a medication known as "Tabaxir," which in Arabic means milk or juice or a liquid which is condensed. In the same book, Avicenna also referred to "Mambu," which later authors took to be a reference to bamboo.

During the sixteenth century, the southwestern flank of India, known as the Malabar coast, was conquered by the Portuguese, who established their colony of Goa. Here lived its most famous early citizen, Garcia da Orta, a physician who tended a garden of native plants, learned everything there was to know about their uses and wrote an important treatise called the *Coloquios dos Simples e Drogas da India*. This book, which appeared in 1563, was the first to be published on Indian plants. In it, Garcia da Orta talks of "tabaxir" and refers to the earlier reference by Avicenna. Garcia da Orta states that the indigenous peoples (of Goa) called this "Saccar Mambu," derived from the words "açucar de mambu," which in turn came from the Portuguese word "açucar" for sugar and "mambu," a local Indian word for cane or the branch of a tree. Da Orta stated that the merchants called this "tabaxir mambu" and that it was exported as a medication from India by the Arabs, Persians and Turks. The illustration he gave of the plant from which

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this tabaxir was derived and the accompanying description must certainly have been some plant other than a bamboo, perhaps sugarcane. Thus while later authors referred to Avicenna's plant as bamboo, I believe this was in error.

We shall leave Avicenna of eleventh-century Persia and Garcia da Orta of sixteenth-century India and travel to the city of Basel, Switzerland, where we find Caspar Bauhin (1560-1624), a physician and botanist at the University of Basel. Bauhin studied at Basel, Padua, Bologne, Montpellier, Tübigen and Paris, taking his doctorate at Basel where he became professor of botany and anatomy. During his extensive travels, he had made botanical collections and formed acquaintances throughout Europe, building up an herbarium of several thousand plants, not only from Europe but from far-away countries as well.

Bauhin spent some 40 years in assembling data on all plants known at the time and listing all references under each name. His book, commonly known as the *Pinax*, appeared in 1623. He used the name "Arundo" for reed grasses and devoted several pages to plants in this category. Under the different kinds of "Arundo" from India, his first is "Arundo arbor," i.e., a woody or treelike reed. He stated that the substance derived from this plant was called Tabaxir by Avicenna and the Arabs and that the plant was known as "Mambu" by the Indians. He also listed Garcia da Orta's reference to "Tabaxir" or "Saccar Mambu." Later in his list of references to this plant, Bauhin gives the following (in translation): "Cana Tabaxir and Arundo, which the Indians call Bambus." For the source of information on "Bambus" he cites a reference to part 4 of "India Orient. (*Indiae Orientalis*), cap. 3," a compilation of natural history articles edited by Johann DeBry. In his description of the plants, Bauhin states that they are reeds of very pleasing aspect, are very tall, black, round, thick, and grow spontaneously all over the Malabar coast and especially near Coromandel (the eastern coast of India). He goes on to mention their presence in Pegu (Burma) and in Bantam (Java), and talks of their use in India for making houses and their use by barbarians in Brazil to produce arrows. While Bauhin certainly referred at least in part to bamboo under his "Arundo arbor," he included other elements such as "Tabaxir." While Bauhin had several elements in his "Arundo arbor," it is his use of the word "Bambus" that is important, for it was utilized by Linnaeus in 1753 as the basis of his "*Arundo bambos*," from which the genus name *Bambusa* was later adapted.

We must remember that up until the time of Bauhin, only four thousand or so plants were known, but many names were used for these. Bauhin brought great order out of chaos and gave us our first nomenclatural tag, albeit inexact, for bamboos—"Arundo arbor."

The famous Malabar coast, where Garcia da Orta lived in the 1500's, came under Dutch rule in the following century, and from 1669-1677 the Dutch Commander of Malabar was Hendrik Adriaan van Rheede tot Draakestein. Rheede was born in Amsterdam in 1636 of a distinguished family but was orphaned at four and went abroad at the early age of 14. He entered the service of the Dutch East India company as a soldier and rose to the rank of lieutenant and fought to wrest control of the Malabar coast from the Portuguese, subsequently developing good relations with the King of Cochin. At the time, medicines had to be transported from Holland to the colonies, a costly trip that took many months. Rheede was aware of the great medicinal use made by the natives of the plants of the richly vegetated Malabar Coast and sought to bring knowledge of these plants together in an organized fashion. He employed several Brahmins who knew the plants well to gather information for his *Hortus Malabaricus*, a work that eventually consisted of 12 volumes, the first of which appeared in Amsterdam in 1678. While no specimens were made of the plants illustrated in this book, the plate (number 16) of bamboo, known in the local language of Malayalam as "Illy," is possibly the first published illustration of a bamboo of scientific value. He worked with several scientific collaborators in producing his *Hortus Malabaricus*, among them Jan Commelin, who wrote the remarks on "Illy." Commelin (1626-1692), who was a druggist and a member of the town council of Amsterdam, studied botany in his spare time and helped Rheede on the second and later volumes. He also founded the Amsterdam Botanic Garden and mentioned many of the plants cultivated in that garden.

Even though the illustration in *Hortus Malabaricus* is poor, the name "Illy," which identifies the plant, is used to this day for the common thorny bamboo of southern India. Commelin commented at length upon the bamboo and called it "Arundo arbor," citing Avicenna and Bauhin's *Pinax*. Thus, while various names were again employed, *Hortus Malabaricus* was the first to provide an illustration of the plant in addition to a local name.

At the time that Commelin was preparing the comments on the bamboo for the text, he had the drawing of the bamboo from the Malabar coast, which included flowering branches. He also received some specimens that had recently been collected in Ceylon by Paul Hermann, a Dutch botanist who had been to that island between 1670 and 1677. If plants of the Malabar Coast and Ceylon flowered at the same time, Hermann and Rheede must have seen them between 1674 and April of 1675. At the top of page 25 in *Hortus Malabaricus*, Commelin comments that this plant flowers every 60 years and dies, the first reference to my knowledge of a flowering cycle in bamboos.

Hermann's return to Holland came just before the birth in 1681 of George Clifford, who became a wealthy banker and proprietor of a large estate in central Holland called "de Hartecamp." The young Swedish physician and botanist, Carolus Linnaeus, went to Holland in 1735, where he spent the next few years. Part of this time was at de Hartecamp, where he was hired as Clifford's personal physician with duties to catalog the plants on the estate, acquire new ones and publish manuscripts on these. In 1737 appeared the results of Linnaeus' efforts in the form of the now-famous book, *Hortus Cliffortianus*. Linnaeus listed here an "Arundo arbor," so we know at least that Clifford had a bamboo in cultivation at his estate at the time.

While Linnaeus was working for Clifford, the Dutch botanist, Adriaan van Royen, prepared an account of the plants cultivated in the botanic garden at Leiden, the *Flora Leydensis Prodromus* of 1740. In this listing, van Royen also included an "Arundo arbor." It is interesting to note that Bauhin in his *Pinax* of 1623 had cited a fragment of a plant from this botanic garden under his "Arundo arbor," so whatever the bamboo in cultivation in Holland in 1740, it had probably been there at least since the first part of the seventeenth century.

These earlier publications of Linnaeus were leading up to the work for which he is most known, the *Species Plantarum* of 1753, on page 81 of which he used the binomial, *Arundo bambos*. Linnaeus did not give a description but cited previous works and authorities whose concepts were unclear: Caspar Bauhin's *Pinax* (page 18), his own *Hortus Cliffortianus* (page 25) and *Flora Zeylanica* (page 47), and the *Flora Leydensis Prodromus* of Royen (cited as "Roy. lugdb.," page 67). "Tabaxir & Mombu [sic] Arbor" of the *Historia Plantarum Universalis* by Jean Bauhin and Johann Heinrich Cherler, volume 1, page 222, were also listed. Linnaeus also cited "Ily" [sic] from Rheede's *Hortus Malabaricus*, volume 1, page 25, table 16. Certainly the "species" of Linnaeus included all bamboos up to his time and while the circumscription was confusing it is important to note that all formal botanical nomenclature commences with this publication of 1753. In other words, *Arundo bambos* of Linnaeus, 1753, is the first validly published name of a bamboo in scientific literature.

The next bamboo to be described is *Arundo gigantea*, the "large cane" of southern United States, which appeared in Walter's *Flora Caroliniana* of 1788. By this time, the binomial system of nomenclature of Linnaeus was becoming widely adopted, and as more and more plants were described, it became apparent that many species represented distinct genera. And so it became clear that the myriad species included under *Arundo* represented in fact a number of distinct genera. In 1789, two botanists, Retzius and Schreber, decided that what had been called *Arundo bambos* represented a distinct genus from *Arundo*. Retzius called it *Bambos*, employing the specific name as the new genus name as was the custom, while Schreber did the same thing but used the Latin form, *Bambusa*. This latter name has since been the accepted form. The herbarium sheet from which Retzius, a professor at the Swedish University in Lund, made his description consisted of two elements, a thorny bamboo and a non-thorny one. He had received earlier imperfect specimens from travelers and supplemented this material with good flowering material sent by Koenig. In making *Arundo bambos* a genus, Retzius chose "*arundinacea*" as the specific name and described the species on the basis of the two different bamboos which he had mounted on one sheet. The sheet with these two elements is to this day in the Lund Herbarium. Although we cannot be sure from the Lund sheet which material came from Koenig, we may conjecture that it is the non-thorny one. A specimen of Koenig's bamboo, probably a duplicate of the Lund material, is at the British Museum and is a non-thorny bamboo, which we now know as *Bambusa vulgaris*.

Johan Gerhard Koenig (1728-1789) was a missionary-surgeon, born in the Duchy of Courland (between Poland and Russia), who went to Uppsala to learn medicine. When he was middle-aged, he joined the Tranquebar Mission as a surgeon and naturalist and studied the flora of the Madras Coast. He sent specimens to Retzius between 1768 and 1778 before leaving for Siam and the Malay Peninsula.

In 1790, another well-known bamboo was described, this one by João de Loureiro (1717-1791), a Portuguese missionary and naturalist who worked in Moçambique, Goa and Cochinchina (now South Vietnam). The bamboo was called *Arundo multiplex* (later recognized as a species of *Bambusa*), a common hedge bamboo of the region. Many botanists have felt that the short description given by Loureiro was insufficient to know which species the author had in mind, especially since the author made no herbarium specimen for future reference. Most botanists and horticulturists have therefore taken up a later name, *Bambusa glaucescens*. In my opinion, however, there is enough information in the original description to leave no doubt as to the bamboo Loureiro was describing. For one, he gave the common name as "Cay hóp," and there are only three bamboos from the region with "hóp" in the name: Loureiro's bamboo and two named later by Munro as *Bambusa tuldoides* and *Bambusa flexuosa*. The latter is thorny and not used in hedges so can be ruled out, and the former has culms larger than one inch in diameter as described by Loureiro for his species. This leaves only the one hedge bamboo. A further point, overlooked by other authorities as far as I know, is that Loureiro describes the flower as having three stigmas that are sessile on the ovary. This is indeed true of "*multiplex*" but not of *B. tuldoides* in which there is a style that precedes the three stigmas. It is clear that Loureiro was describing the common hedge bamboo known since as *Bambusa* *multiplex* or *B. glausecens*. Since *B. multiplex* is the earlier name, and the identification is not in doubt, it must be used.

While we cannot review the description of each new species, it is interesting to see what these early entities were. In 1791 *Nastus borbonicus* was described by Gmelin from the island of Réunion, and in 1803 Michaux elevated *Arundo gigantea* to the genus *Arundinaria*. So at this time, we have the three earliest described genera of bamboos: *Bambusa*, *Arundinaria* and *Nastus*.

Our most common bamboo, *Bambusa vulgaris*, was cultivated in Europe by the early 1800's, and how long before that I do not know. J.C. Wendland, a horticulturist at Hannover, Germany, was working on a book, *Sertum Hannoveranum*, with his colleague, Professor Heinrich Adolph Schrader of Göttingen. When Wendland's bamboo came into flower in Hannover he sent a specimen to Schrader. Schrader suggested "*vulgaris*" as a good name for this species new to science, which in fact Wendland used when he described it. That the name was suggested by Schrader and the actual description written by Wendland is reflected in the formal taxonomic name of this most common bamboo: *Bambusa vulgaris* Schrader ex Wendland.

In the early 1800's, the East India Company was flourishing, and headquarters of the enterprise had been established at Calcutta. Across the Hoogly river was the Company's Garden, of which Dr. William Roxburgh was the director. In 1814 appeared his listing of the plants in cultivation at the Garden under the title of *Hortus Bengalensis*. In the list were seven bamboos, all of which are to this day important cultivated bamboos. I have added the current names in brackets: *Bambusa arundinacea* [*bambos*], *B. tulda*, *B. balcooa*, *B.* [*Dendrocalamus*] *stricta*, *B. nana* [actually *multiplex* or a different species?], *B. spinosa* [*bambos*] and *B.* [*Melocanna*] *baccifera*.

By now the number of genera and species of bamboos was increasing at a rapid pace, and in the first really good natural system of classification of grasses, Kunth recognized bamboos as one of his ten natural groups of genera. In his paper, published when the young German of twenty-seven was working in Paris, Kunth referred to the group as "Gramina Bambusacea." This excellent botanist was followed by another of equal stature, the great Nees von Esenbeck (1776-1858), who was a naturalist, physician and professor of botany at universities in Erlangen, Bonn and Breslau. In 1835, he published a book on the bamboos of Brazil (*Bambuseae Brasilienses*), in which he included *Streptochaeta* as one of the bamboo groups and was thus the first to recognize a relationship between woody and herbaceous species. Nees divided the bamboos into three groups: a, Bambuseae (with *Bambusa*); b, Arundinariae (with *Arundinaria*); and c, *Streptochaeta* (by itself and not in a tribe). In his treatment of Bambuseae, he recognized 2 subgenera, *Bambusa* and *Guadua*.

By 1839, Ruprecht, working in St. Petersburg (now Leningrad), published his *Bambuseas Monographic* and included 67 taxa, representing the first worldwide treatment of bamboos. Franz Joseph Ruprecht (1814-1870), who had been born in Freiburg, Germany, spent 31 years in St. Petersburg and for part of the time was director of the Botanical Museum there. He had studied under the great agrostologist, Trinius, and completed his bamboo monograph when he was only twenty-five!

The next monograph of bamboos to appear was that of Colonel William Munro. Since this world monograph of 1868, there has been none other, and it remains a classic, to this day one of the most useful original references on bamboos. Munro was born in 1818, and at the age of 16 joined the English army, eventually rising to the rank of general in the 39th Regiment. He saw much active service in India and was severely wounded in the Battle of Maharajpore. In the various places where he was stationed, among them India, Canada and the West Indies he established gardens for the recreation and comfort of his soldiers. His beautifully written introduction is a must for all to read. In it he speaks of Ruprecht who had described nine genera and 67 species, of which he had seen 55 in flower. Munro states that he has reduced the number of species to 50 and has in his monograph described upwards of 170 species in 20 genera, "showing how largely our knowledge of this family has increased in the last twenty-five years." Munro's system was based on the foundation that Nees had laid down earlier but expanded to include many new taxa. All of the groups and subgroups that Munro recognized have remained in systems to this day, even though we may use other names or place them at other ranks. Munro, like Nees before him, had a keen perception of natural relationships, and the two must be counted among the best in bamboo systematics.

At about the time Munro was preparing his monograph, a young German, Wilhelm Sulpiz Kurz, born in 1833 in Munich and a pupil of the famous Martius, was curator of the herbarium in Calcutta but left for Indonesia where he learned all he could of bamboos. His long paper on "Bamboo and its Use," which appeared in 1876, is full of original information. He was the first to make observations on the special nature of the proliferating bamboo spikelet, the type later to be studied in more detail by McClure (1934), who called it "pseudospikelet." Kurz's plan to write an account of the bamboos of India ended with his premature death at Penang (Malaysia) in December of 1877. His notes and specimens, however, were later used by Gamble in his treatment.

I think it is interesting here to note that in 1887 Adrien Franchet, a botanist at the Muséum National d'Histoire Naturelle in Paris, wrote a small paper in which he described new genera of bamboos from French Congo: *Atractocarpa*, *Guaduella*, *Microcalamus* and *Puelia*. He referred to these as miniature bamboos and is, to my knowledge, the first botanist to recognize herbaceous bamboos since Nees, who had included the American genus, *Streptochaeta*. Franchet, it may be recalled, described some interesting woody bamboos as well—the curious *Glaziophyton* from Brazil, which he named in honor of the French landscaper and botanist in Rio de Janeiro, M. Glaziou (1889), and *Fargesia*, which he named for the French missionary in Sichuan province of China, Abbé Farges (1893). (We now know that *Microcalamus* is not a bamboo and that *Atractocarpa* is congeneric with *Puelia*, but apart from that, all of his other genera are recognized to this day.)

Little research has been done on the bamboos of Africa since the time of Franchet, but the same cannot be said of India and Burma, and here the town of Dehra Dun in northern India plays a big role. Sir Dietrich Brandis, who like Beethoven before him, was born in Bonn, was called upon by the British to help them in matters of forestry, in which the Germans had much more experience. Brandis was in Burma between 1856 and 1862 where he was the superintendent of Forests in Pegu, which is the large area of forest in the southern part of that country. In 1878, he founded the forestry school at Dehra Dun, which to this day remains a strong force in forestry in Asia. While Brandis did not work principally on bamboos, he published a remarkable paper in 1907 on the structure of bamboo leaves and noted the great similarity in features of the leaf anatomy and epidermis of different bamboos. Interestingly, he also looked at leaves of *Olyra*, *Diandrolyra*, *Leptaspis* and *Pharus* and remarked on the similarity of these leaves to those of the bamboos. The anatomical figures that accompany this paper are superior.

James Sykes Gamble, who had been born in London in 1847, had his practical training at the École National des Eaux et Forêts at Nancy, France, and then went to India in 1871, where he spent many years in the Indian Forest Service. In 1890, he was appointed Director of the Imperial Forest School at Dehra Dun where he remained until 1899. He wrote several important works on the forests of India and Burma, among them a monograph on the bamboos of British India, which appeared in 1896 in the *Annals of the Royal Botanic Garden, Calcutta.* Gamble's first-hand knowledge of bamboos can be felt throughout his excellent work, accompanied by illustrations made in India from fresh material. This treatise covers 15 genera and 115 species and contains 119 plates, certainly the most exhaustive work to its time. The publication was prepared at the herbarium of the Royal Botanic Gardens, Kew, which had earlier been consulted by Munro and contained at the time the best bamboo herbarium in the world.

By the beginning of this century, the study of bamboos had progressed rapidly with major emphasis on those of India. No further world monographs of bamboos have appeared in this century except for that of E.-G. Camus of the same museum where Franchet had worked. His book, *Les Bambusées —Monographie, Biologie, Culture, Principaux Usages*, appears to be most useful since it is a compilation of all previous works, but it was poorly done and cannot be relied upon.

During the early years in this century, a young American from Ohio, Floyd Alonzo McClure, went to Lingnan University in Canton, China to teach biology. There he became interested in economic plants, particularly bamboos, which he saw all about him. So intrigued by these plants was he that he worked on the morphology of the spikelet and published a paper on the pseudospikelet as found in *Schizostachyum* (1934). In later years he returned to the United States and worked at the Smithsonian Institution where his plans were to revise all of the bamboo genera for *Die Natürlichen Pflanzenfamilien*. By the time of his death in 1971, he had mostly completed the manuscript for just the New World bamboos.

I must introduce McClure in this discussion for two facts: one, in 1946, he chose the 1678 illustration of Rheede as the type species of the genus *Bambusa*. The correct name for this bamboo is thus *Bambusa bambos*, which combination had first been made by Voss in 1896. This name takes precedence over *Bambusa arundinacea*, which has most generally been used for the thorny bamboo of India. Two, in 1961 McClure published a description of the subfamily Bambusoideae, which was thorough and detailed but included only the woody members.

In this same year, 1961, Professor Lorenzo R. Parodi, an eminent agrostologist from Argentina, defined the subfamily Bambusoideae as it applied to representatives from his country. In the subfamily he included all of the woody bamboos under the tribe Bambuseae, but placed the herbaceous members in three tribes—Olyreae, Phareae and Streptochaeteae.

During my discussions with McClure toward the end of the 1960's and just before his death in 1971, we talked of the herbaceous grasses that so resemble the woody bamboos, and he agreed that all should be treated in the same subfamily. McClure (in McClure and Smith, 1967:3) mentioned how Parodi had brought into sharper focus the "long-recognized bambusoid affinities of certain other gramineous genera toward the bamboos."

In summary, we find that the principal steps in the history of bamboo classification are the following:

1623. Caspar Bauhin in his *Pinax* lists bamboos under "Arundo arbor."

1753. Linnaeus, in *Species Plantarum*, gives bamboos their first formal name in botanical nomenclature, *Arundo bambos*, a name that embraced more than one taxon.

1789. Retzius in Sweden and Schreber in Germany recognize bamboo as a distinct genus, the former calling it *Bambos* and the latter *Bambusa*.

1815. Kunth recognizes bamboos as one of his ten natural groups of grasses and thus conceptualized what we know today as the subfamily Bambusoideae.

1835. Nees von Esenbeck establishes the first system of classification for bamboos in his treatment of Brazilian bamboos, recognizing three groups—two of which were woody, Bambuseae (with *Bambusa*), and Arundinariae (with *Arundinaria*)—and one of which was herbaceous, Streptochaeteae (with *Streptochaeta*).

1961. Parodi formalizes the subfamily Bambusoideae in establishing a system of classification for the grasses of Argentina. In this system he included all of the woody bamboos in a single tribe, Bambuseae, and allocated the herbaceous members to three tribes—Olyreae, Phareae and Streptochaeteae.

Since Parodi's publication there have been numerous papers on all subjects of bamboos and this is not the place to comment upon them. While many new genera and species have been described and further work on morphology and anatomy confirms the validity of the system developed up to the time of Parodi, no basic new concepts in the classification of bamboos have really been introduced.

Presently there is a great deal of interest in bamboo systematics, and many new taxa are being described, especially from tropical America and the People's Republic of China. Research is also being made in silviculture and utilization, particularly in the People's Republic of China. A good idea of bamboo activities in Asia may be found in Lessard and Chouinard (1980), *Bamboo Research in Asia* (the proceedings of a workshop held in Singapore May 28-30, 1980). I commend the horticultural efforts of the American Bamboo Society, which is introducing new taxa for cultivation as ornamentals. There are so many beautiful species worthy of cultivation in this country, especially temperate genera like *Drepanostachyum* of the Himalayas and *Chusquea* of the Andes and tropical genera like *Schizostachyum* and *Thyrsostachys*. Because of the economic value of bamboo, most research will continue to focus upon practical problems, but I would like to point out the kinds of scientific studies that I feel should be pursued as well.

1. **Fieldwork**

Highest on my agenda would be extensive fieldwork and field observations. While new laboratory techniques and methods of analysis are useful in studying species we already know, there is nothing to compare with completely new material. Each collecting trip that we have made to eastern Brazil, for example, has yielded new taxa, the study of which helps us to understand other genera to which they are related. One example is a new genus from Bahia, which is related to *Guadua*. A study of it has helped us define the genus *Guadua* itself and recognize its distinctiveness from *Bambusa*, with which genus McClure (1973) and others had merged it. New genera are not always in out-of-the-way places. *Olmeca*, a genus that I recently described (1981), grows abundantly on both sides of a road in Veracruz that leads to the Biological Station of the University of Mexico. For years students and professors of botany have driven by this bamboo, little realizing that it was a genus unknown to science.

The area of most interest for collecting is the Malagasy Republic where almost all of the bamboos are endemic and of which we have little well-collected material. There are more different kinds of bamboo on the island of Madagascar than there are on the whole continent of Africa! Other areas most likely to yield new taxa of bamboos are the eastern coastal forests of Brazil and other regions of lowland tropical America, particularly the Guianas and low hilly regions between the Amazon basin and the Andes. The mountains of eastern India and bordering Burma and China are extremely rich in bamboos and should continue to yield novelties to science. The forests of tropical West Africa must also be explored and I hope they will provide us with further species of herbaceous bamboos.

2.. **Morphological and anatomical studies**

Characters from leaf anatomy are useful in classifying grasses in general, and the similarity in basic structure among woody and herbaceous bamboos has been a strong factor in maintaining the groups within the same subfamily. A survey of leaf anatomy of bamboos, which I have made with Dr. Roger Ellis of Pretoria, has allowed us to discern the major lines of evolution in the subfamily.

Once we have studied the anatomy, the next most important organ to survey is the flower, particularly the gynecium and resulting fruit, including the embryo and seedling. Holttum, in his important paper of 1956 on bamboo classification, stressed the importance of the ovary. Few studies have been made to date on the gynecium but we are presently sectioning ovaries of all bamboos for which we have material. Careful analyses should also be made of rhizomes for only the general nature of the sympodial, amphipodial and monopodial systems is known.

3. **Biological studies**

This is the area in which we have the least amount of information. Perhaps because scientists have found bamboos difficult to collect and name, they have left them alone. The unusual cyclic flowering behavior of bamboos is well known, and while anecdotal information is plentiful, few scientific studies of an experimental nature have ever been made on the subject. We are trying to rectify this situation in a bamboo flowering research program at the Tropical Agriculture Research Station at Mayagüez, Puerto Rico. While one objective of this program is to induce flowering outside of the normal cycle, we are interested in a number of related problems. For example, are bamboos self-crossing, outcrossing or both? We need more information on seed-set and data on seed germination. Chromosome counts, although known for some bamboo taxa, are few, mostly because flowers are seldom available. For this reason efforts should be directed toward processing of root tips for chromosome counts.

Fruit dispersal in the Bambusoideae is also a subject worthy of further investigation. In many taxa the fruits fall to the ground and grow near the parent plant, the situation we find in most bamboos. Herbaceous bamboos, however, have evolved various adaptations to enhance their dispersal. The infructescence of *Pharus* clings to the fur of passing animals, a phenomenon known as epizoochory. A specialized movement of the glumes of

Raddia at spikelet maturity causes the fruits to be ejected, a phenomenon known as ballistochory.

4. **Physiological and biochemical studies**

The study of enzyme systems in plants has received much attention in recent years and may prove useful in bamboos, although few papers on the subject, such as that of Chou et al. (1984), have yet been published. In many plant groups, differences in isozymes have been used to distinguish clones, and we are hopeful that this technique may work to distinguish bamboo clones as well. New techniques, such as DNA hybridization, will doubtless prove to be an important means of measuring relationships between taxa of the Bambusoideae.

Many of the bambusoid grasses exhibit leaf movements at night. While Brongniart (1860) commented on sleep movements in *Raddia* (as *Strephium*) *guianensis*, the general extent of this phenomenon in herbaceous bambusoid grasses was not reported in the literature until recently (Soderstrom, 1980). In all of the taxa that we have observed, the leaves fold upward at night, but in *Lithachne* they fold downward. Here is a phenomenon we have observed only because we have cultivated these bambusoid grasses and been able to observe them at night.

Studies presently being undertaken by Dr. Gerald Deitzer of the Smithsonian's Environmental Research Center in Rockville, Maryland, and by David Edelman in Puerto Rico show that the seeds of *Lithachne* do not germinate immediately but do so only after several months. There are few published studies on seed germination in bamboos and none to my knowledge in the herbaceous species.

The successful tissue-culturing of bamboo would be most desirable, not only to produce material for experimental purposes but to provide new plants for cultivation. I do not know of any case in which mature plants have yet been produced by this method. Some success has been made at the early stages of growth in a few bamboos by Huang and Murashige (1983).

5. **Taxonomy**

Revisions must be made of all genera, with keys to the species and descriptions of them, and should include all studies on the plants that are practicable, from anatomical and morphological to biological and chemical. The data can now be analyzed in new ways and with the aid of computer programs.

Primitive and advanced (derived) characters in the species can be compared in a relatively new method called "cladistics" (see Humphries and Funk, 1984). In collaboration with Dr. H.S. Blommestein of the Netherlands I have completed a cladistic analysis of the genus *Olyra* and the tribe Olyreae and anticipate making similar analyses of the remaining tribes of the Bambusoideae.

The ultimate aim in the systematics of the Bambusoideae is to have an understanding of all bambusoid taxa that occur on the surface of the earth and to know their distribution, how to recognize them, how they are related to one another and how they got to where they are. Each new study helps to confirm or disprove what we have previously believed.

Of all the grasses the Bambusoideae are still the most poorly known. Apart from their beauty and utility, bamboos offer unlimited opportunities for scientific investigation.

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Julian J.N. Campbell*: **Bamboo Flowering Patterns: a Global View with Special Reference to East Asia**

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ABSTRACT

Many bamboo species flower rarely, with a vegetative period of 15-60 years or more preceding a flowering period of only 1-10 years. After flowering, the plants often die, especially if seed production is heavy. Complete recovery of biomass may take 15-20 years, even if some rhizomes survive to regenerate instead of seeds. Regular flowering periodicity does occur in some species, but perhaps not the majority. Flowering is more sporadic or continual in warmer (and perhaps drier) regions. Among periodic species, there is a remarkable concentration of intervals round multiples of 15-16 years. Moreover, there is some synchrony between species, with a general periodicity of about 30 years in East Asia. This periodicity appears related to a climatic cycle, with flowering peaks in dry periods. The more limited data from America and Africa suggest shorter periodicities in individual species, on average, and a general cycle similar to East Asia, but phase-shifted. Some relatively sporadic species in peripheral bamboo regions may have weak 10-11 year periodicity, related, through climate, to the sun spot cycle. I suggest that climatic relationships be explored more thoroughly, in addition to hypotheses involving consumers and purely internal control. Monocarpy itself, though not the timing, may have evolved in connection with the unusually continuous vegetative form of bamboo stands, requiring death of parents for survival of seedlings.

Introduction

The study of bamboo flowering, currently, is bedeviled by the problem that flowering is so rare in many species, historical records are fragmentary, and adequate verification is not possible. However, spurred by the practical importance of bamboo flowering (e.g., Hidalgo Lopez 1981, Campbell 1984), I attempt in this paper to clarify what patterns can be gleaned from existing records. Proper study of flowering mechanisms and ecological interactions will require many decades of planned observation at permanent reference sites, and such programs are only now beginning. It is encouraging that, in the past decade or so, some research has at last been directed towards proposing general evolutionary hypotheses, measuring reproductive parameters and investigating stimuli (e.g., Marsh 1971, Janzen 1976, McClintock 1979, Numata 1979, Hsiung et al. 1981, Gopal 1982, Watanabe 1982-83, Gadgil and Prasad 1984, T.R. Soderstrom and G. Deitzer, pers. comm.). I aim now to provide a general framework for focusing further efforts on the central issues.

As summarized by earlier authors (e.g., Brandis 1899, Blatter 1929-30), the following broad classification of life-cycles is possible, though some species appear intermediate:

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(a) continual or seasonal flowering each year, without sudden resultant mortality;

(b) sporadic flowering at irregular intervals, generally with some recovery of the clone, or in other cases with complete mortality (monocarpic);

(c) periodic gregarious flowering at approximately regular intervals, generally monocarpic, but still in some cases with partial survival of weakened rhizomes (e.g., some *Phyllostachys* spp.; McClure 1966, Numata 1979, Hsiung et al. 1981).

Mortality appears to be more frequent under suboptimal growing conditions, and when seed production is heavy, which may vary depending on the success of cross-pollination or other factors (see individual cases cited by Hughes 1951, Janzen 1976, McClintock 1979, etc.).

Taxonomic difficulties, largely due to the scarcity of flowering material, provide a further problem in this study. Because flowering and other data are so fragmentary, it is useful to pool data under genera or higher taxa. However, any arrangement currently adopted must still be regarded as provisional. Almost all temperate and subalpine species in Asia, except *Phyllostachys*, were referred to the genus *Arundinaria* when descriptions were first made in the previous century, and this usage persists in some work today. While there is no doubt that some division into separate genera is warranted, there is great uncertainty and disagreement about how far to go. In collaboration with T.R. Soderstrom (U.S. National Herbarium), I will review these problems in future papers, with some formal revision (now in preparation). In the meantime, some provisional and informal generic assignments are shown here in single quotation marks (' ').

The Extent of Regularity

There has been some tendency to exaggerate the evidence for regular gregarious monocarpic periodicity as the general pattern in bamboo (e.g., Seifritz 1950, Janzen 1976). The majority of species, with hundreds described, are too poorly known for classification. Evidence for regularity, with at least two consecutive interfloral periods of approximate equality ($\pm$ 10%), exists in only about 20 taxa (listed under Fig. 3). At least as many others have sporadic or continual flowering (e.g., Holttum 1958, McClure 1966, McClintock 1967, 1979, Hidalgo Lopez 1981). From a reassessment of bamboos in India, which is the best documented region, Gadgil and Prasad (1984) indicated that only about 8 species could be considered in the regular gregarious class. For contrast, regular gregarious species appear to predominate in Japan and Eastern China (e.g., Ueda 1960, Anon. 1974), while there are few records of gregarious flowering in lowland Malaysia and Indonesia (e.g., Holttum 1958, Whitmore 1975:57, Dransfield 1981). In this tropical rain forest region, there are no definite records of monocarpy, except for some cultivated species introduced from more seasonal climates (also W. Meijer, pers. comm.).

Within some whole genera (e.g., *Merostachys*; Hidalgo Lopez 1981), different species appear no more than 5-10 years out of phase. In contrast, within some other species (e.g., *Phyllostachys* spp.), different clones or populations appear as much as 10-30 years out of phase (in addition to the above references see Lawson 1968, Hubbard 1970, Adamson et al. 1978, Numata 1979, Lu 1981). Spread of flowering across a species' geographic or altitudinal range has sometimes been observed (Brandis 1899, Janzen 1976, Lu 1981, Gopal 1982, Campbell and Qin 1983), though in other cases there has been no such trend (e.g., Gadgil and Prasad 1984).

In some cases where species are introduced and cultivated in different continents, there have been striking coincidences of flowering dates with native plants, the best examples being some *Phyllostachys* spp., *Chusquea abietifolia*, *Bambusa arundinacea* and *Melocanna bambusoides* (as documented by Janzen 1976; also, from my unpublished herbarium census, *'Drepanostachyum' falconeri*). However, shifts of 5-15 years or more are indicated in some of the poorer examples (see also Fig. 4 below). In addition, it appears that some cultivated species have flowered never or much less often than in the wild, e.g., *Chusquea culeou*, *Arundinaria gigantea*, *Sasa veitchii*, *Fargesia spathacea* and *'Fargesia' maling* in Britain (Lawson 1968, Hubbard 1970, McClintock 1967, 1979), and perhaps *Bambusa vulgaris* and *Dendrocalamus strictus* in different parts of Asia (McClure 1966, Widjaja 1982, etc.). In the case of *Fargesia spathacea* Franchet, gregarious flowering has been widespread in northern Sichuan (China) during 1969-1983. But, cultivated widely in Europe and North America under the name *Arundinaria murielae* Gamble since 1910, the only reported flowerings have been of a few stunted plants in one Danish nursery during 1974-79 (Soderstrom 1979; M. Riedelsheimer, pers. comm.), and three clumps in San Francisco during 1983-84 (Haubrich 1985).

The opposite pattern is indicated in fewer species, but at least *'Fargesia' jaunsarensis* Gamble (*A. anceps* Mitford) is one example. There are several records of this species flowering in Europe during the 20th century, especially since 1960, and gregariously in the 1980s. Despite botanical expeditions to its native range (e.g., Bahadur and Naithani 1978), there is not a single flowering record in the area of northern India where this species was introduced from, though there is one collection from adjacent Nepal made in 1967 (N. Ecker-Racz in U.S. Nat. Herb.). The three other west-central Himalayan species also have as many or more flowering records in Europe, where all are cultivated (*Thamnocalamus spathiflorus*, *'Drepanostachyum' falconeri* and *D. falcatum*; unpublished inventory). In contrast, Asian species with apparent suppression of flowering in Europe (*'Fargesia' maling*, *F. spathacea*, *S. veitchii*, etc.) are East Himalayan, Chinese or Japanese.

Biogeographic Trends

Based on available data, much already summarized and cited by Janzen (1976; also additional references cited in this paper, and my unpublished herbarium census of Sino-Himalayan taxa), there is some trend towards shorter periodicity, or more sporadic or continual flowering, from cool to warm zones of East Asia (Fig. 1). A corresponding trend is evident at the tribal level (arrangement following Keng 1982-84, with some modifications).

(a) The *Sasa* group (including *Sasamorpha*, *Pseudosasa*, etc.) are mostly subalpine or temperate Sino-Japanese species, with gregarious flowering intervals of 60-100 years or more, monocarpic when much seed is set.

(b) The *Arundinaria* group (including *Pleioblastus*, *Indocalamus*, etc.) are mostly temperate Sino-Japanese, with intervals of 30-100 years or more, but rhizomes often survive.

(c) The *Thamnocalamus* group (including *Drepanostachyum*, *Fargesia*, etc.) are mostly subalpine or temperate Sino-Himalayan, with intervals of 30-100 years or more, largely monocarpic, though flowering episodes may last for 10-15 years (even in the same plant, e.g., *'Fargesia' jaunsarensis*; McClintock 1979).

(d) The *Phyllostachys* group (including *Semiarundinaria*, *Chimonobambusa*, etc.) are mostly temperate or subtropical Chinese, with intervals of 15-60 (rarely 120?) years, but rhizomes often survive and some taxa have sporadic flowering.

(e) The *Bambusa* group (including *Dendrocalamus*, *Dinochloa*, etc.) are mostly subtropical or tropical, with a broad east-west range, with continual, sporadic or periodic flowering at 10-50 (rarely 70) year intervals, and with various degrees of mono- versus polycarpy.

(f) The odd genus *Racemobambos* is on mountains in the tropics, apparently rather sporadic in flowering, though gregarious flowering or mortality has been observed at its highest altitude (*R. gibbsiae* at 2000-3000 m in Sabah; Dransfield 1983) and highest latitude ('*R.*' *prainii* in Assam; J. Rollo in Kew Herb.).

(g) The *Schizostachyum* group (including *Cephalostachyum*, *Ochlandra*, etc.) are mostly tropical (though with a subtropical extension to the eastern Himalayas), and most have continual, sporadic or periodic flowering at intervals of only 3-20 years, rhizomes often surviving. *Melocanna bambusoides* of Assam/Burma is exceptional with 30-50 year intervals, large 50-100 gm fruits, and general mortality.

(h) The odd genus, *Nastus*, is strictly tropical, with flowering patterns little known, except for a 3 year period reported in *N. elegantissimum*.

(i) The bambusoid grasses, *Leptaspis* and *Streptogyna*, are strictly tropical, with continual or seasonal flowering (Soderstrom 1981, pers. comm.).

Similar temperature-related trends may exist even within some individual species, e.g., *Dendrocalamus strictus* (compare reports from north and south India cited in Janzen 1976) and *Phyllostachys pubescens* (Qui 1982).

There is no pronounced east-west trend, or relationship with precipitation, independent of the subalpine to tropical trend (Fig. 1). However, some observations deserve further investigation. Within India, the widespread *Dendrocalamus strictus* is reported to flower more sporadically in drier Western regions (Nicholson 1922), and the species in general may be considered more sporadic than periodic (Gadgil and Prasad 1984). However, in wetter regions east of India, reports of clear periodic behavior are more prevalent (cited in Janzen 1976; see also Widjaja 1982). Combined flowering records of this species throughout India exhibit weak overall periodicity of about 10 years (Gadgil and Prasad 1984). In contrast, *Bambusa arundinacea*, which is the other major bamboo species in India but more restricted to moist sites, exhibits a dominant period of about 45 years (Gadgil and Prasad 1984) or, locally, about 30-32 (cited in Janzen 1976). Reports of longer periods in other species of the *Bambusa-Dendrocalamus* group all come from further east in Asia (cited in Janzen 1976).

Some east-west trends may also exist in temperate and subalpine bamboos, though there are less data from the wild (Fig. 1). The greater flowering frequency of more western Himalayan species in cultivation has already been noted. The longest completely vegetative periods documented in any bamboos, 100-140 years, are in cultivated species from east-central China: *Phyllostachys bambusoides*, *Chimonobambusa quadrangularis*, '*Fargesia*' *nitida*, *Indocalamus tessellatus* (Janzen 1976, McClintock 1979, etc.)

Outside of Asia, flowering data may be less comprehensive, but it is notable that the longest documented periodicities are only 30-32 years, i.e., in Latin America: species of *Chusquea*, *Bambusa (Guadua)* and *Merostachys* (cited in Janzen 1976, Hidalgo Lopez 1981, etc.). Also, herbaceous bambusoid grasses are much more numerous (at least species) in the American tropics than the Asian, mostly with seasonal flowering (Soderstrom 1981). Flowering patterns in the few African bamboos are not well documented. Sporadic to periodic intervals of about 7-20 years are reported in tropical *Oxytenanthera abyssinica* (Janzen 1976), and similar intervals of 7-40+ years are reported in tropical montane '*Fargesia*' *alpina* (Wimbush 1945, Hubbard 1962; A. Faden, pers. comm., see also Fig. 4a). Only the South African '*Thamnocalamus*' *tessellatus* appears to have general vegetative periods longer than 30 years, with no flowering records since 1908 (T.R. Soderstrom, pers. comm.).

In North America, the only bamboo species is *Arundinaria gigantea* (sensu lato), which is generally restricted to moist soils. Its flowering can be classified as sporadic. Despite frequent observation for 200 years, it has never been reported to flower gregariously, except in small populations covering on the order of 1-100 hectares (unpublished review of literature and herbarium data). Though culms may die after flowering, there are few reports of complete mortality below ground (Hughes 1951). Its flowering appears to be relatively rare, with completely vegetative periods of 20-30 years or more in some individual populations. Flowering records pooled from all over the species' range suggest a weak quasi-periodicity of about 10 years, with significantly greater frequencies during sunspot maxima than minima (Fig. 2). This trend is stronger for records since 1947, which also show a weak correlation with early summer rainfall (Fig. 2). Evidence of a weak relationship between climatic fluctuations and sunspots is accumulating in this region (e.g., Vines 1984).

Correspondence Between Taxa

Among those 20 taxa with some evidence of regularity, there is a remarkable concentration of mean periods about multiples of 15-16 years (Fig. 3). These means all fall within the limits of 7-8 years (1 taxon), 14-17 (3 taxa), 29-36 (8 taxa), 42-48 (5 taxa), 61-64 (2 taxa), and perhaps about 120 (some *Phyllostachys bambusoides*). A similar but weaker concentration exists among those 23 other taxa with only one documented gregarious flowering interval (Fig. 3). This overall concentration (using 43 taxa) can be quantified by breaking the time-scale of flowering intervals into equal divisions for each periodicity to be tested, then superimposing the divisions. The "telescoped" distributions exhibit "resonance", showing depression in the central half versus extreme quarters, only for divisions of 15 and 16 years ($P < 0.001$ and $P < 0.01$, respectively, with chi-square tests against uniform distribution; Fig. 3 inset shows test results, not individual distributions).

The reported periodicities of about 7 and 3 years (the latter only in *Nastus*) might be considered an extension of this series (3-4 x 2 = 6-8; 6-8 x 2 = 12-16). *Ochlandra travancoria* is the only adequately documented case. However, two other *Ochlandra* species of Southern India have had coincident gregarious flowering dates (Blatter 1929-30), while 7 year intervals have also been reported in some populations of *Oxytenanthera abyssinica* (Janzen 1976) and '*Fargesia*' *alpina* of Central Africa (see above). Culm mortality occurs in these *Ochlandra* spp. after flowering, but it is not clear if rhizomes die as well. Two more *Ochlandra* spp. have been reported to flower annually without dying (Blatter 1929-30).

In addition to this common periodicity base of about 15 (or 7?), there is some evidence of a general synchronous tendency over large continental regions (Fig. 4). Only two of the ten taxa with 29-36 or 61-64 year periodicity have flowering episodes centered most cases appear to be from relatively sporadic taxa, with gregarious flowering, if at all, only at longer intervals. Some reports listed by Janzen (1976) are not well supported by dates (e.g., *Dendrocalamus strictus* cited from Deogan), or dates are too selective (e.g., separating dates of '*Arundinaria*' *spathiflora* from *Thamnocalamus spathiflorus*). Even the two cases included in Fig. 3 as examples of single gregarious flowering intervals are tentative: 23 years in *Chusquea ramosissima*, from an unchecked source; 10-11 years in '*Drepanostachyum*' *intermedium*, which my herbarium census now suggests has somewhat irregular or spread-out gregarious intervals of 21-50 years (mean 31).

Despite these reservations, it does appear that weak 10-11 year periodicity, with some synchrony, may be widespread among relatively sporadic species. Further examples may be found in the Southeast Asian genera *Racemobambos* and *Dinochloa*, as recently revised by Dransfield (1981, 1983). Flowering collection dates in these two genera are clustered about 1892, (missing?), 1910, 1919-22, 1932-34, (war - missing?), 1954-57, 1964, 1975-79. This periodicity is partially in phase with that of *Dendrocalamus strictus* in India (Gadgil and Prasad 1984): peaks about 1869?, 1879?, 1890?, 1901, 1910, 1920, 1931, 1941, 1949, 1959, 1968? (Janzen 1976), 1978?. *D. strictus*, in turn, is almost in phase with *Arundinaria gigantea* of N. America (Fig. 2 plus earlier records): peaks in 1850, (war), 1878, 1889, 1898, 1906, 1921, 1928, 1938, 1949, 1958, 1969, 1979. If all these dates are pooled (including the tentative early cases of 9-12 or 17-24 year periodicity listed in the previous paragraph) the overall clustering shows some shifting relationship with the sunspot cycle (peak years in parentheses; see also Fig. 2): 1848-50 (1848), 1859-62 (1860), 1865-70 (1870), 1875-82 (1883), 1887-93 (1894), 1906-10 (1907), 1916-22 (1917), 1928-34 (1928), 1938-41 (1937), 1947-49 (1947), 1954-58 (1957), 1964-69 (1968), 1975-79 (1979). These weak clusterings do not allow conclusive statements, but they do suggest profitable avenues of research based on further taxonomic revision and collection history.

Evolutionary hypotheses

Direct physiological mechanisms of flowering in bamboos remain completely unknown, and with the difficult progress of flowering physiology in general, among other plants (Halevy, in press), there is little prospect of major advances with long-lived bamboos through typical research projects funded for only a few years. This ignorance need not, however, inhibit some useful provisional discussion of evolutionary forces that may have led to such unusual life-cycles. Some evolutionary perspective, if allowed to guide proper long-term experiments, should eventually deepen understanding of mechanisms. There are essentially three types of hypothesis to be considered in attempting to explain the various degrees of monocarpy, regularity and synchrony outlined above. These address different aspects of the problem, and a complete explanation can not be founded on one alone.

(1) Parental competition hypothesis.

Since some bamboo species form such extensive continuous stands, with no temporary gaps as in tree populations, competition from parent plants may have to decline through monocarpic mortality if seedlings are to survive. This idea was first alluded to by Nicholson (1922; see also Simmonds 1980, Campbell and Qin 1983, Gadgil and Prasad 1984). Janzen's (1976) objections are not serious; for the parent merely to "drop its leaves for a year" without dying would not allow enough seedling growth. Even if parent stands do not completely fill the variable habitat space, poor dispersal of bamboo seeds (with no special vectors; cf. Ridley 1930) may limit escape from competition. Sexual reproduction at some optimal frequency is presumably of value in promoting genetic diversity, providing the fundamental cause in this hypothesis. It does not, however, account for the detailed timing of flowering.

An extension of this hypothesis may explain the overall increase in flowering frequency from subalpine to tropical taxa (Fig. 1). Bamboo stands are particularly continuous in cool monsoonal montane forests (e.g., Campbell and Qin 1983). In contrast, within warm lowland forests, especially rain forest as opposed to monsoon forest, bamboos are less common and more restricted to open sites (Whitmore 1975, Numata 1979), as caused by rivers, fires or large animals (now mostly human). Competition from lowland rain forest trees may be more severe, due to low climatic stress and deep stable soils. Since suitable sites for bamboo colonization in this environment would appear to have been relatively isolated in space and time, life-cycles may have been selected that result in more frequent seed-dispersal to such sites.

(2) Consumer satiation hypothesis.

As argued forcibly by Janzen (1976), consumer pressure may have selected life-cycles that alternately satiate then starve. He developed this argument with special reference to the many accounts of rodents, birds and other animals that increase or converge on bamboo stands after gregarious seed-production. However, potential relationships with consumers of vegetative parts should also be considered, at least so as not to confuse increases, due to seed-consumption, with migrations, due to vegetative death (e.g., Campbell and Qin 1983). This hypothesis must assume that a physiological "clock" exists, controlled by a precise genetic program, and with sufficient buffering against environmental variation to ensure synchrony between neighboring clones within range of potential consumers. If this idea of a genetically fixed period is accepted, despite some reports of environmental effects, it would then be reasonable that evolution of long life-spans proceed by multiplication of some base period, so as to maintain a partial synchrony between successive genotypes (Janzen 1976). Such evolution might lead to the clustering of periods shown above (Fig. 3).

Though the circumstantial evidence for this hypothesis is compelling, it is unlikely to provide a complete explanation of flowering patterns. After the successful establishment of a seedling stand, it may take only 15-20 years to recover biomass and reserves sufficient for the next gregarious seeding, based on available data from a range of species (e.g., Gopal 1982, Watanabe et al. 1982, Gadgil and Prasad 1984; also miscellaneous cases cited in McClure 1966, Janzen 1976, Campbell and Qin 1983). Thus, the much longer life-spans of some bamboos are not explained. Moreover, this hypothesis can not account for the synchronous tendency of many species over large continental regions (Fig. 4). It is difficult to believe that consumer dynamics are so uniform. There is also no clear explanation of why monocarpic bamboos differ so from the grasses, though grass seeds tend to be smaller, perhaps under less consumer pressure.

(3) Climatic periodicity hypothesis.

Since climatic fluctuations must influence bamboos, it is possible that the timing of sexual reproduction is related to such fluctuations, independently from the origin of monocarpy itself. Several observers in East Asia have suggested that flowering is partially associated with droughts, but this idea has remained controversial since adequate quantitative analysis has never been presented (e.g., Brandis 1899, Nicholson 1922, Blatter 1929-30, Ueda 1960, Janzen 1976, Numata 1979, Gadgil and Prasad 1984). Bamboos may be generally sensitive to hot or dry conditions, being most common in the more humid temperate to subtropical regions (e.g., Campbell and Qin 1983), and without Kranz leaf anatomy typical of C-4 grasses in drier or sunnier environments (T. Soderstrom, pers. comm.). With sufficient drought, growth would decline even without flowering, and then may be the optimal time to produce seeds. While it is unlikely that seeds can remain dormant for more than 1-3 years (and that only in cooler regions, cited in Campbell and Qin 1983, unpublished), there could be some long-term benefit from dispersal of seeds to moister microsites. Also, young plants may be more tolerant of drought than their parents, due to lower transpiration rates. While such ideas might apply even within a single unpredictably dry year, it is easier to apply them if there is a degree of periodicity in climatic fluctuations, and if there is a potential for the life-cycle to evolve some relationship with that periodicity. Flowering might then be controlled by some combination of an approximately fixed genotypic life-span, and direct phenotypic response to climatic irregularities.

There is, indeed, some evidence for various periodicities of 30-40 years or more in precipitation data from temperate East Asian regions (e.g., Chang et al. 1979, Wang and Zhao 1981), with shorter periodicities in tropical regions (e.g., Jagannathan and Bhalme 1973, Mooley and Parthasarthy 1984; further sources cited in Campbell and Qin 1983). At least in Southeast-central China, droughts have been concentrated in 1814-36?, 1863-74, 1887-98, 1927-34, 1958-79. There is some similar evidence from Japan, the Himalayas, Central India and Africa (Fig. 4H), though with a general phase-shift from north to south, which is evident even within China (Chang et al. 1979). There has been less analysis of Latin American data, but there are indications of similar patterns there as well (sources cited under Fig. 4H). In general, these dry periods do correspond with the flowering periods indicated above, though more rigorous analysis is clearly needed, with more local data and extension to other continents.

Climatic periodicities based on 10-11 or 20-22 years, related to sunspots, have often been indicated (Pittock 1983), rather than periodicities based on 15-16 years, as predominate in bamboos. However, recent analysis of precipitation data has shown that periodicity of 14-16 years is widespread in the Southern Hemisphere and some northern regions (e.g., Mooley and Parthasarthy 1984, Vines 1984). Although possible causes of such periodicity remain obscure, as Vines notes: "A pronounced cycle of more than 30 years would result if each alternate '16 yr' fluctuation were reinforced by every '11 yr' fluctuation. . ." The periodicities of 42-48 years in some bamboos of NE. India are also close to multiples of 11 (44) and 15 (45). Climatic cycles of about 45 years have not yet been shown there, but some data are suggestive (e.g., Ramdas 1974). It is conceivable that the flowering series based on 15-16 years, rather than 10-11, evolved because 15-20 years is generally needed to accumulate reserves sufficient for seed-production (see also Janzen 1976).

Precipitation periodicities of about 7 years have also been shown in several regions, especially in the Southern Hemisphere (Vines 1984, etc.). Moreover, the gregarious flowering years of *Ochlandra* spp. in Southern India (Blatter 1929-30) were almost in phase with peak drought years (in parentheses, from Ramdas 1974, etc.): 1868 (1868?), 1875-76 (1876-77), 1882 (1884), missing? (1891), 1896 (1899); 1905 (1905). However, since 1905, drought frequency decreased in that region, and there have been no further reports of gregarious flowering until 1982 (Venkatesh 1984). This pattern would accord with the general classification of *Ochlandra* as sporadic or continual flowering (see above). *Ochlandra* is considered by some taxonomists to have relatively primitive morphology among Asian bamboos (e.g., Holttum 1956), and one might speculate that its flowering patterns are primitive as well.

In contrast with the tendency of major flowering periods to coincide with droughts in subalpine to subtropical zones of East Asia, there are a few indications elsewhere of weak association with wet years. Though such cases have little or no statistical significance, it is of interest that they all come from regions at the margin of global bamboo distribution, perhaps with less favorable moisture supply: *Dendrocalamus strictus* and *Bambusa arundinacea* of Southwest India (Gadgil and Prasad 1984); *Chusquea abietifolia* of Jamaica (Seifritz 1950); *Arundinaria gigantea* of Southeast North America (Fig. 2). In marginal environments, there may be a stronger direct response to good conditions in flowering years, both through seed-production and seedling survival. Such potential complexity underscores the need for a careful multiple-hypothesis approach to the whole problem.

General Discussion

These hypotheses and their various extensions are considered further elsewhere (e.g., Ueda 1960, Janzen 1976, Numata 1979, Campbell and Qin 1983, Gadgil and Prasad 1984). For example, nutrient and forest succession cycles may be worked into the Parental Competition Hypothesis; other herbivores and pathogens, into the Consumer Satiation Hypothesis; fires and other indirect climatic effects, into the Climatic Periodicity Hypothesis. Some association of flowering with earthquakes has been found in China, with suggestion of hydrological interaction, but it is difficult to conceive a physical connection (Wallace and Teng 1980, Yang et al. 1981, Campbell and Qin 1983).

In attempting to explain monocarpy, Gadgil and Prasad (1984) recently proposed that bamboos have unusually persistent exponential growth, so that early reproduction would waste the potential from future growth. However, they did not actually present data indicative of exponential curves. Bamboo growth, as net increase in biomass, is essentially constrained to the periphery of a plant (radius r), once maximum height is achieved, so that one might expect growth (proportional to r) relative to standing biomass (proportional to r^2) to decline with time. A constant relative growth rate is required for exponential growth. It is difficult to believe that bamboos differ so fundamentally in their growth curves, in comparison with other woody plants or rhizomatous herbs, the vast majority of which remain polycarpic.

Bamboos do, however, have a special growth form, with woody rhizomes producing culms that reach maximum height in one season. It is this growth form that leads to the uninterrupted nature of much bamboo vegetation. This consideration returns discussion to the Parental Competition Hypothesis, which I suggest is the fundamental internal explanation for monocarpy in bamboos. After monocarpy evolved along with the woody habit, its exact timing may have become linked with various environmental factors. In warmer zones, where high productivity in general (and large seeds in some taxa) may promote more consumer pressure, satiation-starvation cycles may have become a secondary function of monocarpy. In cooler zones, where climatic cycles may be more pronounced and longer, the exceptionally long life-spans of some taxa may allow sexual reproduction to occur at some optimal climatic phase. In addition to examining the hypotheses suggested here for bamboos, an obvious extension of this work is to compare the general biology of other long-lived monocarpic plants, which are scattered in various families, though nowhere with the diversity of bamboos. Are there common eco-morphological factors? Simmonds (1980) has provided an excellent introduction to this interesting topic.

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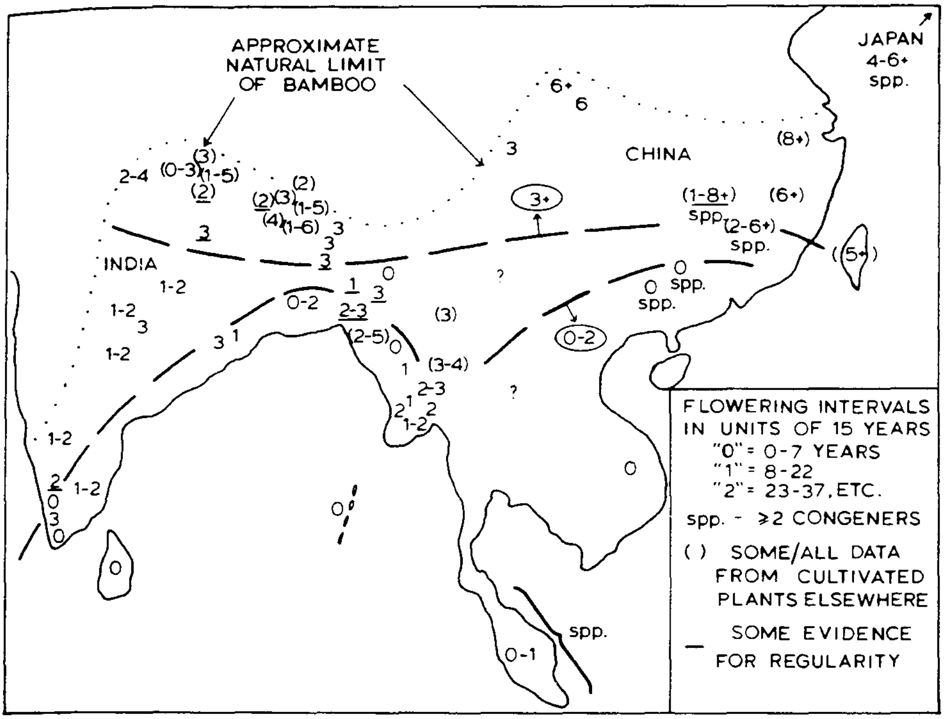


Figure 1. Geographic trends in flowering intervals of Asian bamboos (units of 15 years). Data are compiled from Janzen (1976) and many other sources (see References). Most intervals refer to individual species in their native ranges, but in several cases data come from plants introduced elsewhere (especially Europe), and the source locality shown may only be approximate. Several localities with different intervals are shown for the two major Indian species, while congeneric species with similar range and intervals are combined in some other cases. The "O" symbol is used for species with gregarious flowering at only 3-7 year intervals, and for species with continual or sporadic flowering at relatively short intervals.

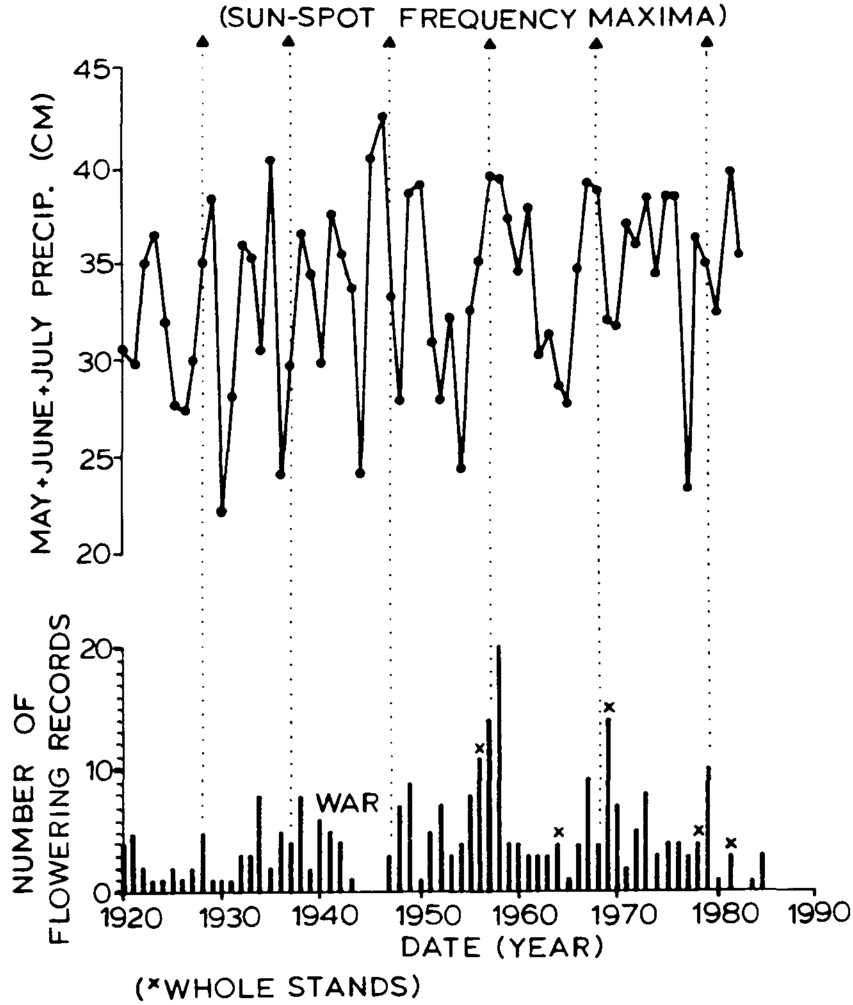


Figure 2. Flowering records of *Arundinaria gigantea* (*sensu lato*) throughout its range in the Southeastern U.S.A., showing relation to sunspots and early summer precipitation. Records have been compiled from major herbaria (mostly Harvard, U.S. National, all KY, Knoxville-TN, Chapel Hill-NC, Athens-GA, Gainesville-FL), with duplicates from the same county in the same year excluded, to minimize any exaggerations from clustered field work. Precipitation data are means of 20 stations scattered throughout the range (Anon., 1927-84); sunspot data are from Svenonius and Olausson (1979). Chi-square (χ^2) tests against uniform distribution show that records are more frequent in years with sunspot maxima plus two adjoining years, in contrast to minima plus adjoining ($P < 0.0001$ for 1947-80; $P = 0.03$ for pre-1947, including interrupted records as old as 1780). Among the eight known records of flowering by whole stands (ca. 1-100 ha), seven occur closer to sun-spot maxima than to minima (recent ones shown as "x"). For 1947-80, there is also a weak correlation between flowering records and precipitation in each year (Kendall's Tau = 0.29, $P = 0.03$). However, precipitation-sunspot association may be even weaker (with chi-square tests as above, $P = 0.15$).

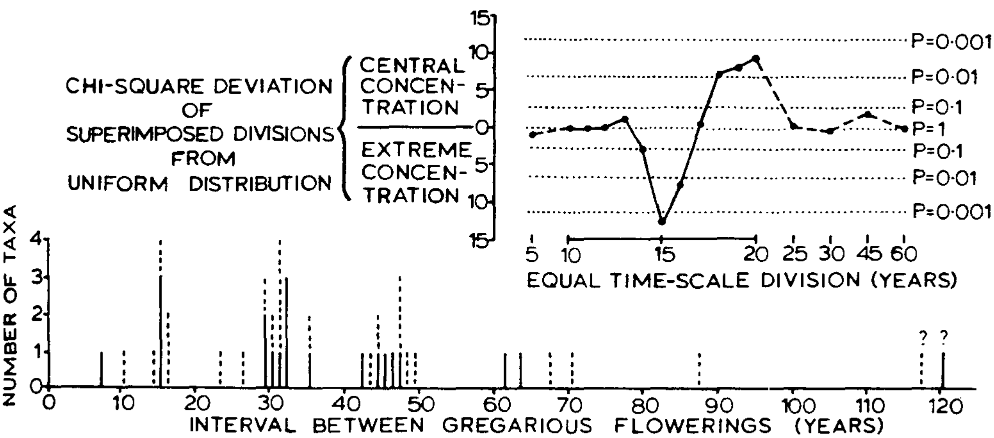


Figure 3. Distribution of mean flowering intervals in the 20 taxa* that appear to have regular periodicity (solid bars), plus single intervals in 23 other gregarious taxa (broken bars). The inset shows results of applying chi-square tests against uniformity to distributions (not shown) created by "telescoping" the time-scale: the original distribution was divided into pieces of equal length, which were superimposed. Results are shown for a range of division lengths. Each chi-square test was applied to frequencies in the central half and the combined extreme quarters of the "telescoped" distribution; these two frequencies were contrasted with those expected from the null hypothesis of a uniform distribution (with one degree of freedom).

* The 20 taxa are *Ochlandra travancoria* (7-8 years); *Chusquea tenella*, *Neohouzeaua dulloua* and *Phyllostachys aurea* (15-16 years); *'Drepanostachyum' falconeri*, *Melocanna bambusoides* (Mizoram), cf. *D. falcatum* (*A. gracilis*), *Bambusa arundinacea* (Kanara/Brazil), *C. abietifolia*, *B. trinii*, *Merostachys* spp. (combined) and *B. nutans* (29-36 years); *Dendrocalamus strictus* (Northeast India), *D. hookeri*, *B. arundinacea* (general), *M. bambusoides* (Lushai/Chittagong) and *B. tulda* (42-48 years); *P. bambusoides* (Japan) and *P. nigra* cv. *henonis* (61-64 years); *P. bambusoides* (with old Chinese records; ca. 120 years). Most dates are listed by Janzen (1976) already, but I have made some modifications and additions based on other reports cited in this paper (especially Hidalgo Lopez 1981).

Figure 4. Historical trends in flowering records.
Each graph comes from a different set of records, except for the flowering peaks of regular species extracted in (G). Solid lines refer to percentages of flowering versus sterile collections in major herbaria (U.S. National, Kew Gardens, British Museum, Dehra Dun, Calcutta, Sichuan) or reported in the literature. Percentages are based on 5 year periods, except where total records would be less than 5, in which case 10 year periods are used. Broken lines mostly refer to records from other continents (especially Europe), with flowering years of individual species summed for all species within each decade, and the total flowering years expressed as a percentage of the maximum observed in a decade (maximum totals shown at left in parentheses).

(A) Solid line: '*Fargesia*' *alpina* of Africa (collections at Kew B.M.).
Broken line: Latin American records in Hidalgo Lopez (1981).

(B) Solid line: *Arundinaria* and *Sasa* groups from Japan and E. China.
Broken line: same taxa cultivated elsewhere.

(C) Solid line: *Phyllostachys* group from Japan and E. China.
Broken line: same taxa cultivated elsewhere.

(D) Solid line: *Fargesia* and *Arundinaria* groups from W. China.
Broken line: *Phyllostachys* plus *Bambusa* groups from same region. (Collections from Sichuan and adjacent provinces.)

(E) Solid line: *Drepanostachyum* spp. from the Himalayas.
Dashed line: same taxa cultivated elsewhere.

(F) Solid line: *Fargesia* and remaining temperate Himalayan taxa.
Dashed line: same taxa cultivated elsewhere.

(G) Mid-points of gregarious flowering episodes in the 10 taxa with regular intervals of 29-36 and 61-64 years (Fig. 3). Upper bars indicate Asian taxa; lower bars, American. *Chusquea abietifolia* is shown by arrows (plus an early record of Mexican *C. muelleri*).

(H) Dry climatic periods in bamboo regions (based on Anon. 1927-84, and cited analyses). From top to bottom, the five lines are from the following places:

(1) Tokyo (the only station from Japan with 100 years of data);

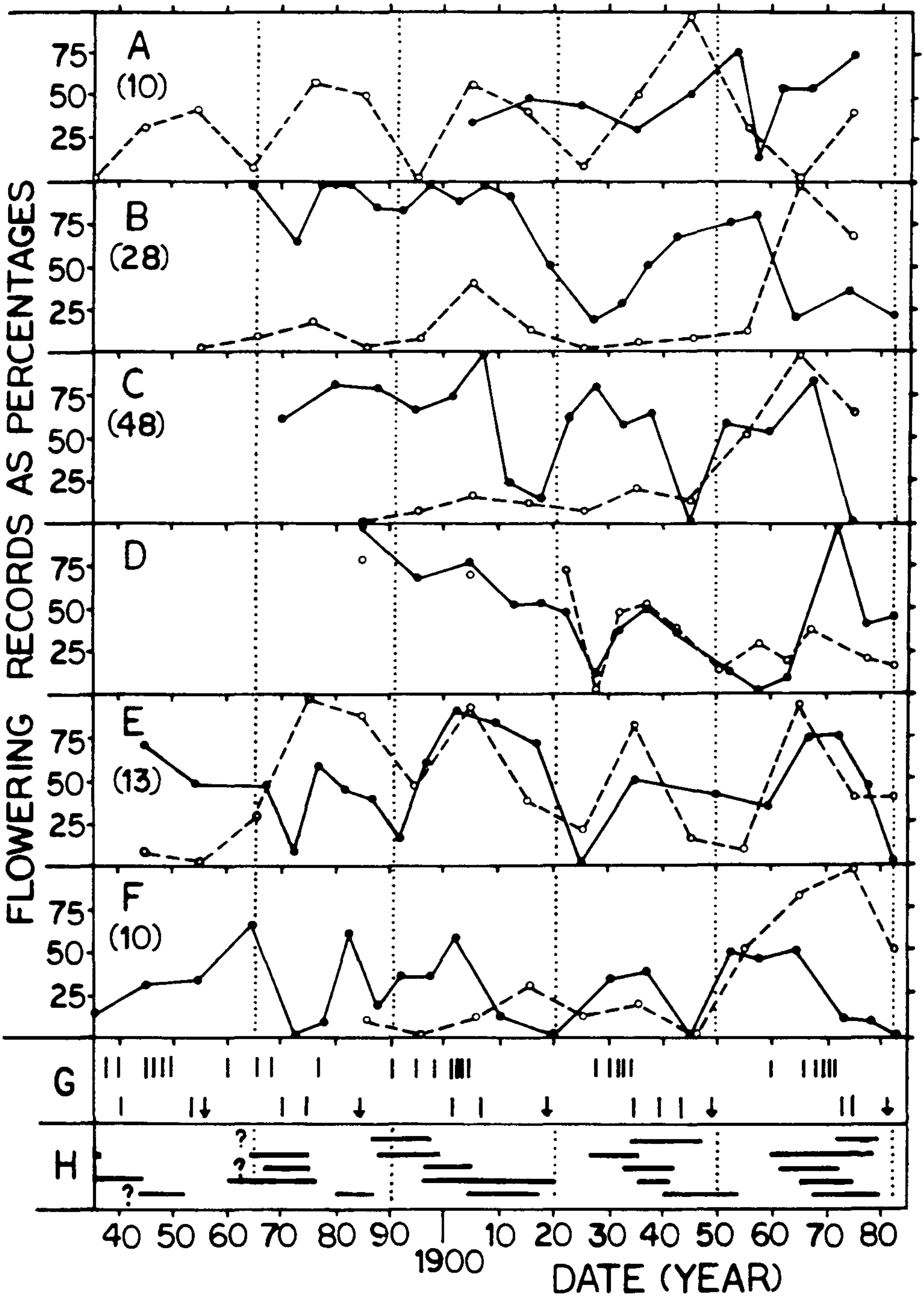
(2) Southeast-central China (Chang et al. 1979, Wang and Zhao 1981);

(3) The Himalayas (with Simla and Darjeeling the oldest stations);

(4) Central India (Ramdas 1974, Mooley and Pant 1981):

(5) South and Sub-Saharan Africa (Tyson 1980, Faure and Gac 1981).

Minor dry periods have occurred between the major ones shown, but only in S. Africa have these approached the intensity of the ca. 30 year cycle.


FLOWERING RECORDS AS PERCENTAGES
A
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DATE (YEAR)

G.F. Deitzer*, T.R. Soderstrom** and D.K. Edelman**: **Flowering Physiology of Bamboo in Puerto Rico**

Revised manuscript received July 5, 1986

ABSTRACT

The Smithsonian Institution has initiated a project to study the physiology of flowering in bamboo. The research is being conducted primarily at the USDA/ARS, Tropical Agriculture Research Station (TARS) in Mayagüez, Puerto Rico, in order to take advantage of the unique opportunity to study its large populations of six species with known origins that are currently in flower. Selected stands were cleared, tagged and vouchered in the herbaria in Washington and Mayagüez. Culms of each species were tagged and divided into two groups, those that still had culm leaves attached (new culms) and those that were already flowering (old culms). The lowest 6-14 nodes of the new culms were observed for loss of culm leaf, release of lateral buds from dormancy and length of subsequent branches through anthesis. Half of the flowering culms were cut below the last flowering node in an attempt to release lateral buds from apical dominance. However, releasing dormancy by removing the culm leaves and bud scales was found to be more effective than cutting. All buds broke within 10-20 days at treated nodes while alternating control nodes on the same culm remained dormant. Peeled buds will be used in the future for the application of plant growth regulators. Comparisons were made between seedlings left *in situ* near the parent clumps and those transplanted to field plots and to a greenhouse. All *in situ* seedlings grew poorly without producing new culms while those in the greenhouse are still growing and producing new culms. Those in field plots were much more successful than either those in the greenhouse or *in situ* and so reduced viability *in situ* appears to be a function of inhibition by the parent clump. A randomized complete block of planting was also made of flowering culms with rhizomes attached. Two culms, or the two halves of one culm, were planted in furrows in each of nine randomized plots. These will be followed through anthesis and used to establish clonal material for future experiments. Growth rates and times to anthesis were subjected to polynomial regression analysis by computer in Rockville to provide a data base for future experiments.

This investigation was initiated in order to take advantage of the unique opportunity to study quantitatively a number of physiological parameters related to flowering in a number of species of bamboo currently flowering simultaneously on the island of Puerto Rico. The intent of the project is to influence the rates of flowering by using physical and chemical treatments in a way that may provide some insight into the natural regulation of flowering in bamboo. Bamboo is unusual in the sense that it is monocarpic, i.e., it flowers only once and then dies, but requires many decades of vegetative growth before flowering. This long interval between flowering events appear to be genetically regulated and based on endogenous factors rather than responding to environmental signals. There exists a large amount of descriptive and anecdotal evidence reporting simultaneous flowering in

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bamboos in many different locations around the world, a phenomenon known as gregarious flowering. However, no experimental evidence exists to explain the mechanism responsible for this remarkable timing.

The reason for this lack of experimental data is the enormously long periods between flowering events, which can be as long as 120 years, although 30-60 years is more typical. Complicating this is the fact that a certain percentage of sporadic flowering occurs in many species at irregular intervals. Thus, the effectiveness of an experimental procedure is difficult to distinguish from random sporadic flowering.

We have chosen several approaches to circumvent these problems, the first of which involves work with species that are already flowering. At the start of the study in August 1984, three species were found to be flowering in Puerto Rico: *Bambusa longispiculata* Gamble ex Brandis, *B. multiplex* (Loureiero) Raeuschel and *B. tuldoides* Munro. All were identified on the grounds of the USDA/ARS, Tropical Agriculture Research Station (TARS) in Mayagüez. All of these stands correspond to map sites of the original plantings from the 1920's and 30's and can therefore be assigned Plant Introduction (PI) numbers and cultivation records traced over six decades. Other stands of these three species were also found flowering at other locations around the island that are more similar to the areas from which they were derived, especially in terms of elevation and rainfall. During subsequent expeditions to make collections in Las Mesas, Maricao, Toro Negro, Luquillo National Forest, Caguas and Rio Piedras, three other species were observed flowering in April 1985: *Bambusa textilis* McClure, *B. vulgaris* Schrader ex Wendland and *Guadua angustifolia* Kunth. It was thought that another species, *Bambusa ventricosa* McClure, was also in flower, but examination of floral material sent to the Smithsonian revealed it to be a variant form of *B. tuldoides*. It is interesting to note that this variant still flowers with the same timing as the unaltered *B. tuldoides*.

From the three species flowering in August 1984 a number of sites were identified for use in experimental studies. Following clearing, culms were divided into two groups and tagged. The first group consisted of culms that were newly formed during the current growing season and either had not yet begun to branch or showed no evidence of flowering at nodes that had produced branches. The second group consisted of older culms that were already flowering, at least at upper nodes.

Based on the assumption that both groups belonged to the same rhizome systems, with new culms arising from rhizomes that had earlier produced flowering culms, the fate of branches formed at the lower nodes were followed at weekly intervals. Measurements were made of the time of bud break and the length of each of the three primary branches at each node through anthesis. The data were sent to the Smithsonian Environmental Research Center (SERC) in Rockville, MD where they were entered into the computer for calculations of growth rates. These data were analyzed using a third degree polynomial regression equation, and the coefficients were used to calculate a maximal growth rate from the first derivative of this equation. Such an analysis (see Fig. 1 for one example) allows a precise prediction of: (1) the time of bud break, even from nodes that had branches before the start of the measurements, (2) the time from bud break to the cessation of vegetative elongation, even for branches that die before reaching this state, (3) the maximal growth rate and (4) the time from bud break or maximal elongation to anthesis. A data base has been accumulated from the three branches on each of six nodes in *B. longispiculata* and *B. tuldoides* and twelve nodes in *B. multiplex*. Twenty culms of each species were examined resulting in more than a thousand individual weekly measurements. Statistical averages (means and standard deviations) for each parameter for each species are given in Table 1. Few of the buds in *B. tuldoides* ever broke dormancy and of those only two yielded a sufficient amount of data for analysis. It appears, however, that this species has the fastest growth rate and produces the largest branches in the shortest period of time. A new set of twenty culms is currently being measured to confirm this. *Bambusa multiplex* grows more slowly than the other two species, but since it produces branches that are on average only half as long, there is no significant difference in the time required to reach maximal length. In *B. multiplex*, the branches at upper nodes are significantly shorter than at the lower nodes; however, there is a corresponding decrease in growth rate so that the time taken to reach maximal length remains remarkably constant. Unfortunately, the most important parameter, the time of anthesis, was not obtained in this study since only three of the sixty culms eventually flowered. Nevertheless, the growth rate measurements can be used as the basis for comparison with culms that flower as a consequence of hormonal treatment of dormant buds.

Table 1
Statistical Analysis of Branch Growth Rate Measurements in New Culms

Species	Node Number	Number of Observations	Growth Rate cm/day ± SD	Maximal Length cm	Time from Bud Break to Maximal Length
Bambusa	1	0			
tuldoides	2	1	8.9	266	55
	3	0			
	4	0			
	5	0			
	6	1	6.0	231	56
	All	2	7.5 ± 2.1	249 ± 25	56 ± 1
Bambusa	1	3	4.7 ± 3.0	187 ± 70	75 ± 10
longispiculata	2	4	5.0 ± 2.1	207 ± 35	74 ± 19
	3	3	3.6 ± 1.0	201 ± 21	87 ± 5
	4	4	5.3 ± 1.7	212 ± 27	73 ± 16
	5	4	5.3 ± 3.2	208 ± 37	71 ± 11
	All	18	4.8 ± 0.7	203 ± 10	76 ± 6
Bambusa	1	2	2.3 ± 0.3	78 ± 8	70 ± 3
multiplex	2	5	3.5 ± 1.4	94 ± 16	68 ± 14
	3	9	3.8 ± 1.5	102 ± 28	63 ± 8
	4	11	3.1 ± 1.5	103 ± 28	70 ± 6
	5	10	2.2 ± 1.5	88 ± 40	67 ± 7
	6	8	3.1 ± 1.9	99 ± 24	64 ± 9
	7	6	2.9 ± 1.7	90 ± 21	64 ± 11
	8	7	2.3 ± 1.5	80 ± 23	69 ± 12
	9	9	1.6 ± 0.7	66 ± 21	67 ± 8
	10	6	1.5 ± 0.7	57 ± 26	69 ± 7
	11	8	1.5 ± 0.7	55 ± 19	68 ± 8
	All	82	2.5 ± 0.8	83 ± 17	67 ± 2

The second group of tagged culms, those that were already flowering in August 1984, were also observed at weekly intervals to determine how long vegetative branches required before flowering. All nodes on twenty culms of each species were followed, but again it was found that an insignificant number of dormant buds broke dormancy or produced branches that reached anthesis. Of those that had already formed branches only a few did not have some indication of flowering at the start of the observations. Thus rates of flowering could not be assessed without a constant reference point. It was found that in *B. multiplex* the most rapid flowering did not occur at the tips of the culms but rather about six nodes down from the tip. Flowering continues from the sixth to about the eighteenth node with all other nodes remaining as dormant buds.

Since buds at lower nodes remained dormant over long periods of time, it was reasoned that this dormancy might be a function of apical dominance. In order to test this hypothesis, another group of flowering culms of each species were tagged and divided into two equal groups. In one group the culm was cut off just below the last flowering node. The culms in the other group were left intact as a control. Although several buds did break dormancy after several months, the number was not significantly greater than the controls. It was therefore concluded that dormancy in the lower nodes was not controlled by apical dominance at the tip of the culm and must be a function of the bud itself.

Table 2
Release of Lateral Buds from Dormancy by Removal of Culm Leaves and Bud Scales in *Gigantochloa apus*

Date	Number of Days from Start of Treatment	Number of Buds		Number of Buds with Branches		Percent of Buds with Branches	
Controls with Culm Leaf		Peeled	Control	Peeled	Control	Peeled	Control
1 Apr 85	0	132	132	0	0	0	0
5 Apr 85	5	132	132	0	0	0	0
10 Apr 85	10	132	132	0	0	0	0
22 Apr 85	22	132	132	96	0	73	0
8 May 85	38	132	132	96	0	73	0
4 June 85	65	132	132	96	0	73	0
Controls without Culm Leaf		Peeled	Control	Peeled	Control	Peeled	Control
12 Apr 85	0	63	63	0	0	0	0
22 Apr 85	10	63	63	8	0	13	0
8 May 85	26	63	63	13	1	21	2
4 June 85	53	63	63	14	3	22	5

A new experiment was designed to test this possibility. We took advantage of a large stand of the completely vegetative species, *Gigantochloa apus* (Schultes) Kurz, which has persistent culm leaves covering dormant buds. Sixty-four culms were tagged and the culm leaves and bud scales were removed from alternate nodes in 44 culms. The culm leaves were removed from all nodes on the remaining 20 culms but the bud scales were removed only from alternate nodes. Table 2 shows that within 22 days, 73% of the peeled buds broke dormancy while all of those retaining their culm leaves remained dormant after at least 65 days. However, in those culms where the culm leaves were removed from all nodes, 5% of the control buds produced branches while only 22% of the peeled buds broke dormancy. Although the number released from dormancy was lower in this group, they were released after only 10 days. No explanation is offered for this reduction of bud release when all of the culm leaves are removed, but clearly the culm leaf itself is important in maintaining dormancy. Based on these results another experiment is currently being conducted in a new stand of *B. tuldoides* where the bud scales have been removed from alternate dormant nodes. If successful, buds will be peeled to release dormancy and chemicals such as gibberellic acid, abscissic acid, and ethylene will be applied directly to these buds in order to test their effects on flowering.

Eventually it will be necessary to reduce the amount of variability inherent in the natural populations of bamboo by establishing clonal populations of material derived from single individuals. To this end we have established both vegetative generation seedlings and parent generation plants propagated from culms cut during the apical dominance experiment. Seedlings were either transplanted from *in situ* populations near the parent clump or were germinated from seed in the greenhouse at TARS. After being established in the greenhouse, they were transplanted in a random complete block planting into field plots. Whole cut culms, or those split in half, were also planted directly in a random complete block design in the field plots. A number of problems especially with the local dog population caused considerable damage to the field plots, and new material had to be incorporated to replace dead and dying culms.

In the process of this propagation, a study was made of the viability of seedlings. These were observed to be very few in number and not very healthy while growing *in situ* beneath the parent clump. The reason for this poor growth was tested by measuring the growth rates of *in situ* seedlings and comparing them with those of seedlings transplanted to both the greenhouse and to the field plots. The heights of culms, number of culms and numbers of leaves are being measured and the data has been entered into the computer at SERC-Rockville. Since it is not yet complete, it has not yet been reduced. It is, however, apparent that the poor growth *in situ* is not the result of poor seedling viability but rather due to an inhibition of growth near the parent clump. The nature of this inhibition will be tested by attempting to reverse the inhibition in sections of *in situ* seedlings using fertilizer and careful watering. Some *in situ* seedlings will also be transplanted to open areas near the parent clump to determine the extent to which the lack of light may be responsible for this inhibition.

Laboratory experiments with seedlings of herbaceous species have been initiated. We have found that seeds obtained from wild populations require long periods to germinate. The most prevalent species, *Lithachne pauciflora* (L.) P. de Beauvois, required more than five months to produce only about 10% germination. The best germinating species, *Pharus latifolius* L., yielded about 90% germination but still required more than two months to complete this germination (Fig. 2). Attempts to improve the rate of germination, using surface sterilizing agents, have proved unsuccessful. Other treatments will be attempted.

Work during the next year will concentrate on attempts to influence flowering in the six species flowering in Puerto Rico. Using the data base already accumulated, and the knowledge of how to stimulate bud break uniformly in a large number of culms, hormones and other chemicals will be applied to these buds and rates of flowering recorded in comparison with controls. Gibberellic acid may offer the most promising approach since it is known to influence flowering in other grass species. However, other hormones that retard vegetative growth such as abscissic acid or ethylene may promote flowering. Similarly, anti-gibberellins may also prove effective. These chemicals will also be applied to herbaceous seedlings and terminal leaf complements in the laboratory or greenhouse. The effects of altering the photoperiod and light quality will also be tested in such species as *Pharus latifolius*, *Lithachne pauciflora*, and *Pariana* sp. A species of *Pariana* from Peru has been found to flower on what appears to be an annual or seasonal cycle and also appears to be monocarpic, flowering only once and then dying. Unfortunately, no seed is currently available but we will attempt to obtain propagules from Peru.

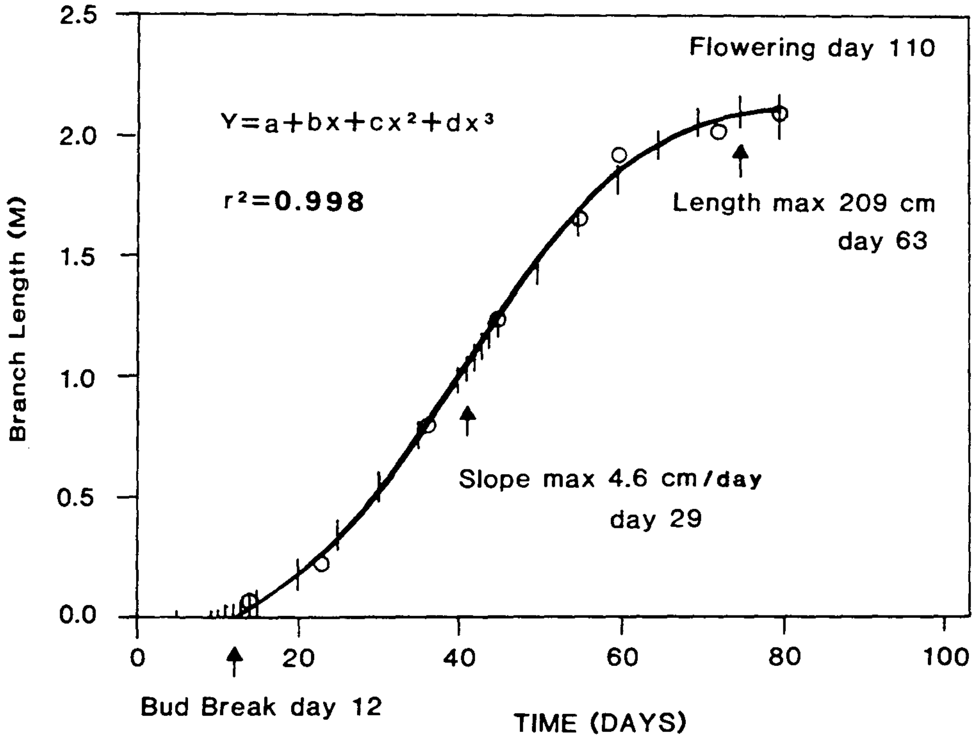

Figure 1. Statistical analysis of branch growth in meters at a single node (node #1) for a single representative culm (culm #1) of *Bambusa longispiculata*. The open circles represent individual measurements of branch lengths and the solid line is a computer generated least square fit of those data points to a third degree polynomial regression equation shown in the upper left-hand corner where Y is the branch length in meters and x is time in days from the start of observations. The error bars represent the 95% confidence interval of each calculated value of Y for selected values of x. The correlation coefficient, r^2, is also shown in the upper left-hand corner. Bud break occurred in this case 12 days after the start of observations and the branch reached its maximal length of 2.09 m 63 days later. The maximal growth rate was 4.6 cm/day and this occurred 29 days after bud break. Flowering occurred 110 days after bud break.

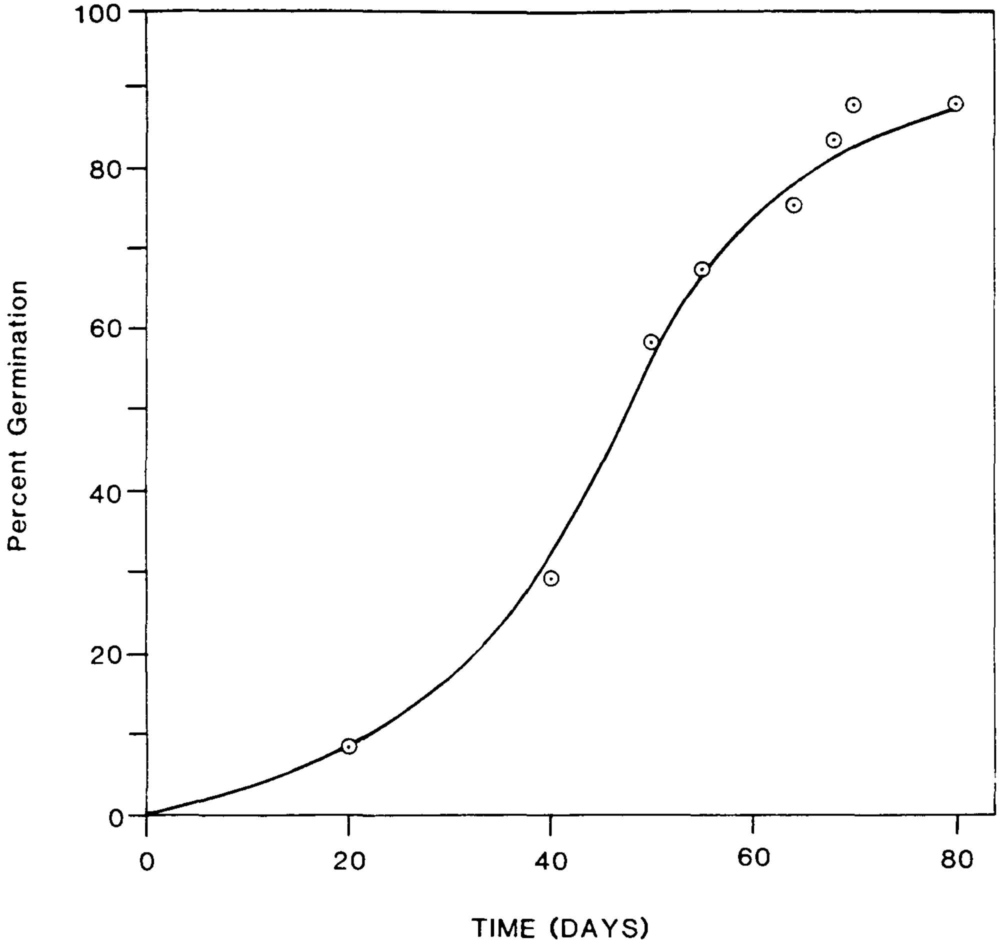

Figure 2. Rate of germination of *Pharus latifolius* seeds on vermiculite. Seeds were stored at 5° C prior to sowing and allowed to germinate in a dim light growth room at 25° C and 12 hour daily photoperiods for the times indicated. The curve was fit to the data points by eye.

D.K. Edelman*, T.R. Soderstrom*, and G.F. Deitzer**: **Bamboo Introduction and Research in Puerto Rico†**

Revised manuscript received August 4, 1986

The United States Department of Agriculture (USDA) began an ambitious program in the early 1900's to promote the use of exotic bamboos in industry and manufacture in the United States, and to aid development in the Caribbean basin. Little of economic importance was ever done with these bamboos and the program was terminated. What did not fail, however, were the bamboos themselves. Many species were sent from around the world by USDA Plant Explorers and others, for growth and utilization trials. The best adapted species still survive in Mayagüez, Puerto Rico and other USDA stations in the continental United States.

The Tropical Agricultural Research Station (TARS) in Mayagüez, P.R. was the foremost site of tropical Bamboo introduction and research in the USDA. Records remain of 119 bamboo introductions at TARS, consisting of some 50 species in 18 genera. Some of the bamboos accessioned were misidentified initially, some were confused in handling, while others came with only a generic or common name. Subsequently many had to be reclassified taxonomically. The authors have been able to locate and voucher 16 species in 7 genera on the grounds at TARS as they are classified currently (Appendix). Some of these are represented by different varieties or cultivars. Other bamboos have not been found in flower and thus their identities are still uncertain.

As the newly introduced bamboos became established, tests were conducted on them for their ease of propagation and usefulness. The best of these were distributed throughout the continental United States, Central and South America, and locally in Puerto Rico. Island Programs of the Puerto Rico Reconstruction Administration, the Civilian Conservation Corp., the Agricultural Extension Service of the University of Puerto Rico, the Insular Forest Service, the Soil Conservation Service and other organizations prompted the culture and utilization of bamboo for erosion control, construction and manufacturing in cooperation with the USDA in Mayagüez.

Tests were also conducted by the Station's scientists on propagation, culture, curing, handling, pest control, and relative qualities for utilization. Other studies were conducted on the behavior of the plants themselves. The most important of the 25†† works on bamboo published from the Station will be briefly reviewed here, as will the USDA program of bamboo research in Mayagüez.

From the inception of the Mayagüez Station in 1901 until 1934, there were some 10 routine introductions of bamboo[1]. In the year 1934, studies on bamboo began and the rate of introductions increased. It was also the year that H. Atherton Lee became director. Lee worked with bamboo himself and it quickly became a priority of the Station. Two of the first priorities of the new program were to obtain more economically valuable types of

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†† This number does not include the works printed by the United States Government.

bamboo for rapid multiplication and to construct articles made from bamboo. The latter was carried out in a newly built shop for developing techniques and producing examples for utilization (Figures 1 and 2).

In 1937 Lee published a paper[2] on the use of bamboo for construction of homes and barns. He also wrote a paper entitled "Bamboo as a Farm Crop in the Tropics of the Western World" for presentation at the 8th International Congress of Tropical and Subtropical Agriculture. The meeting, that was to have been held in Tripoli, Italian Libya, in March of 1939, never took place due to the outbreak of World War II.

Bambusa vulgaris had already become naturalized over much of the island, apparently having been introduced sometime before 1840 by the Spaniards[1]. Lee made it a policy not to use this species in the work because of its high susceptibility to a boring insect, *Dinoderus minutes* (F.), commonly called the "bamboo powder-post beetle." Although shop-work could have proceeded faster by using the ample supply of *B. vulgaris* in Mayagüez, it was slowed until enough culms of the more resistant species were produced. Lee feared that the reputation of bamboo for construction in Puerto Rico would be hurt if anv articles became borer-damaged[3].

Figure 1. Furniture of bamboo designed and constructed at the Station during 1936. The Station was awarded a silver cup that year at an agricultural fair "in recognition of the merit of its bamboo propagation and utilization project and its potential value for the rehabilitation of Puerto Rico." Puerto Rico was still known as the poorhouse of the Caribbean at the time.

From: Report of the Puerto Rico Experiment Station, 1936, reference 6.

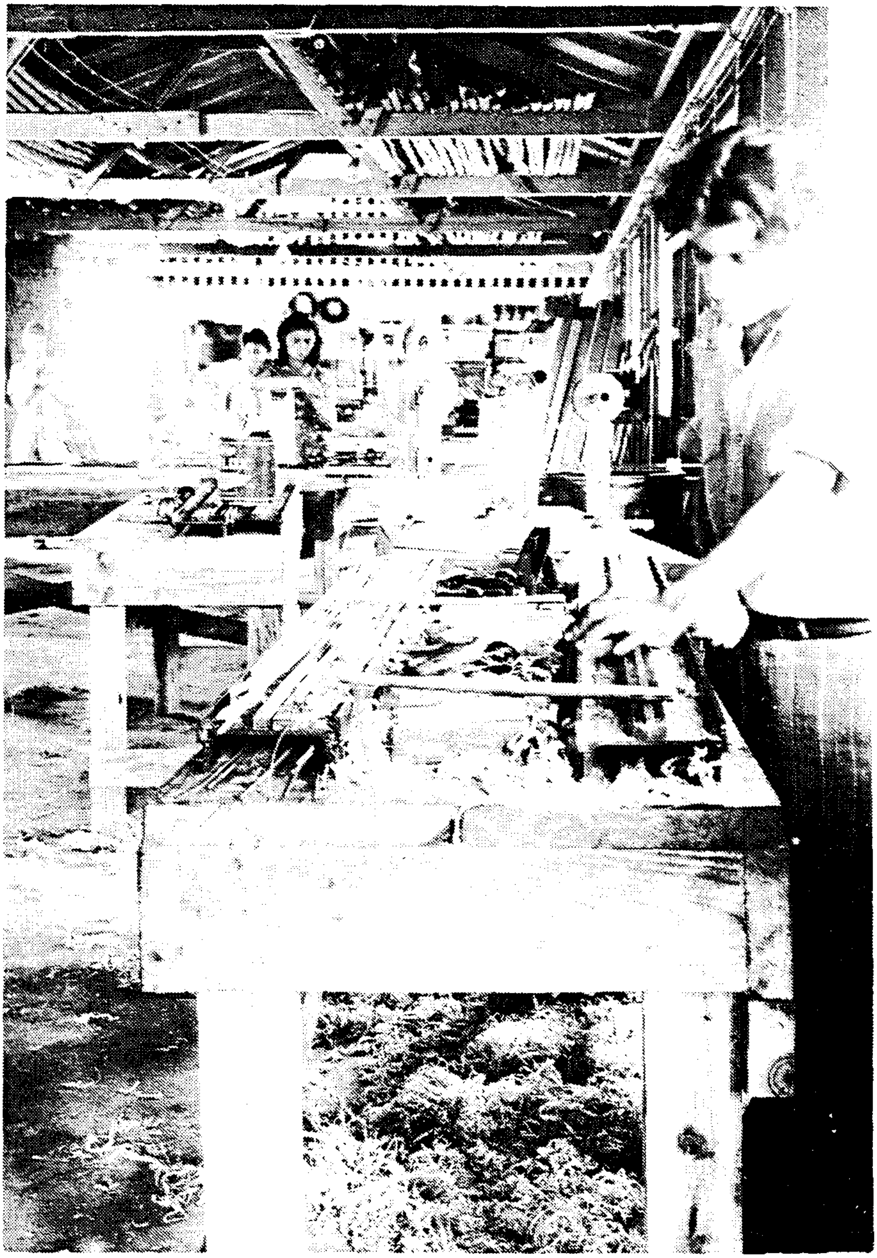

Figure 2. Inside the bamboo workshop at the Station showing the shaping of bamboo splits for use in laminated fishing rods, 1937. Furniture was constructed in another part of the same building. USDA photograph, unpublished.

In place of *B. vulgaris*, the shop began working with culms that were available from the other previously introduced species. Studies were initiated to test the susceptibility of different species to attack and develop treatments against *Dinoderus minutes* for those bamboos that were susceptible. By 1940, standard practice had been adopted to minimize attack, which included leaving cut culms standing in the field to dry or soaking them in water[3]. More complete experiments on these and other techniques would be conducted later by the station's scientists.

Because of the policy not to use *B. vulgaris* in shop-work, emphasis was directed toward the multiplication of resistant species to provide a steady supply of usable culms for the future[4]. The 1938 report of the Experiment Station[5] explained how numerous rooted plants could be obtained by layering whole culms with their rhizomes attached, an advancement over the earlier techniques used. Distribution of small rooted plants was begun and soon there were enough culms of borer-resistant species to supply the shop and to sell to manufacturers locally. Research on propagation techniques continued until the mid-1950's.

The 1936 report of the Station also mentions the distribution of 391 offsets of bamboo other than *B. vulgaris* to planters of the island[6]. In 1944, the number of plants distributed had increased to 16,280, along with 10,000 linear feet of cured culms, which went to the U.S. Military Forces. The majority of rooted plants was sent to the Forest Service for forest plantings and to the Department of the Interior of the Insular Government for roadside improvement projects[7].

At the same time that this propagation and distribution work was being carried out, Kenneth A. Bartlett, an entomologist, began looking for a control measure for scale insects, another pest of the introduced species in Mayagüez. He published papers in 1938 and 1939 on his searches in the Guianas, Trinidad, and southern Brazil for predator beetles of the scale and their subsequent introduction into Puerto Rico[8,9]. The scale insects were thought to reduce the growth of culms and to damage their surface, making the culms less attractive for use in furniture manufacture. In the 1939 report of the station, Bartlett claimed "Notable control of the widespread infestation of scale insects..."[10] by the coccinellid beetles that he had introduced.

Bartlett was director of the Station between 1942 and 1953, which were the most active years of the bamboo program. Distribution of bamboo throughout the island, in cooperation with local farmers and various agencies, continued to increase, reaching a peak of 24,789 offsets in 1947[11]. That same year the Station, in cooperation with the Puerto Rico Industrial Development Co., also distributed 74,322 feet of cured culms and 2,394 pounds of side branches to local manufacturers, especially the split bamboo fishing rod industry that was just getting started.

Distribution of the introduced bamboos to other countries also increased during Bartlett's term as director, and was eventually extended to Antigua, Cuba, Dominica, Dominican Republic, Ecuador, Grenada, Haiti, Honduras, Jamaica, Nicaragua, Peru and Trinidad. Eighteen published works on bamboo were also produced during this time, the first of which was entitled "New Bamboo Revetment Construction"[12]. This work, done for the U.S. Army during World War II, involved building living barricades out of *B. vulgaris* (Figure 3). The station continued to cooperate with the military throughout the war, supplying over 23,000 linear feet of cured culms to the U.S. Navy in 1943 alone[13].

Two prominent bamboo researchers at the Station under Bartlett were Harold K. Plank and David G. White. Plank, also an entomologist, began working on the problem of bamboo culm infestation by *Dinoderus minutes*, building on the knowledge gained in earlier research. Others had been working on this problem since 1935 and their findings were updated that year and for four of the next six years in Station reports. Plank's first paper on this subject appeared in 1939[14], where he discussed a natural predator of the powder-post beetle in Puerto Rico. Plank published six more articles or bulletins on bamboo and the powder-post beetle by 1951[15-20]. In over a decade of meticulous work on this problem, he was able to develop techniques to insure that high quality culms could be used by the Station's shop and local manufacturers without fear of later infestation.

Figure 3. The inside face of a 16 foot high bamboo revetment. A technique was developed at the Station to make walls of *Bambusa vulgaris* that would root and leaf out as in the photograph, forming a living palisade.
From: New Bamboo Revetment Construction, 1943, reference 12.

While working on the chemical control of the powder-post beetle, Plank also studied the life history and natural enemies of the insect and worked with curing and harvesting techniques to prevent attack. He found great variation in the susceptibility in cut culms of different ages. The degree of infestation was found to be directly related to the starch and carbohydrate content of the culms, which meant that older culms were less attractive to the borer. Thus, if culms could be cured without infestation until the carbohydrates were mostly gone, they were less likely to be attacked later.

David G. White published five papers from 1945 to 1948 on bamboo for soil erosion control[21] (Figure 4), uses on the farm and in the home[22], curing and durability of *Bambusa tuldoides*[23] (Figure 5), longevity of bamboo fruits[24], and propagation by branch cuttings[25]. He also authored *USDA Circular #29*, "Bamboo Culture and Utilization in Puerto Rico"[26], which detailed the Station's program up to 1948 and summarized the findings.

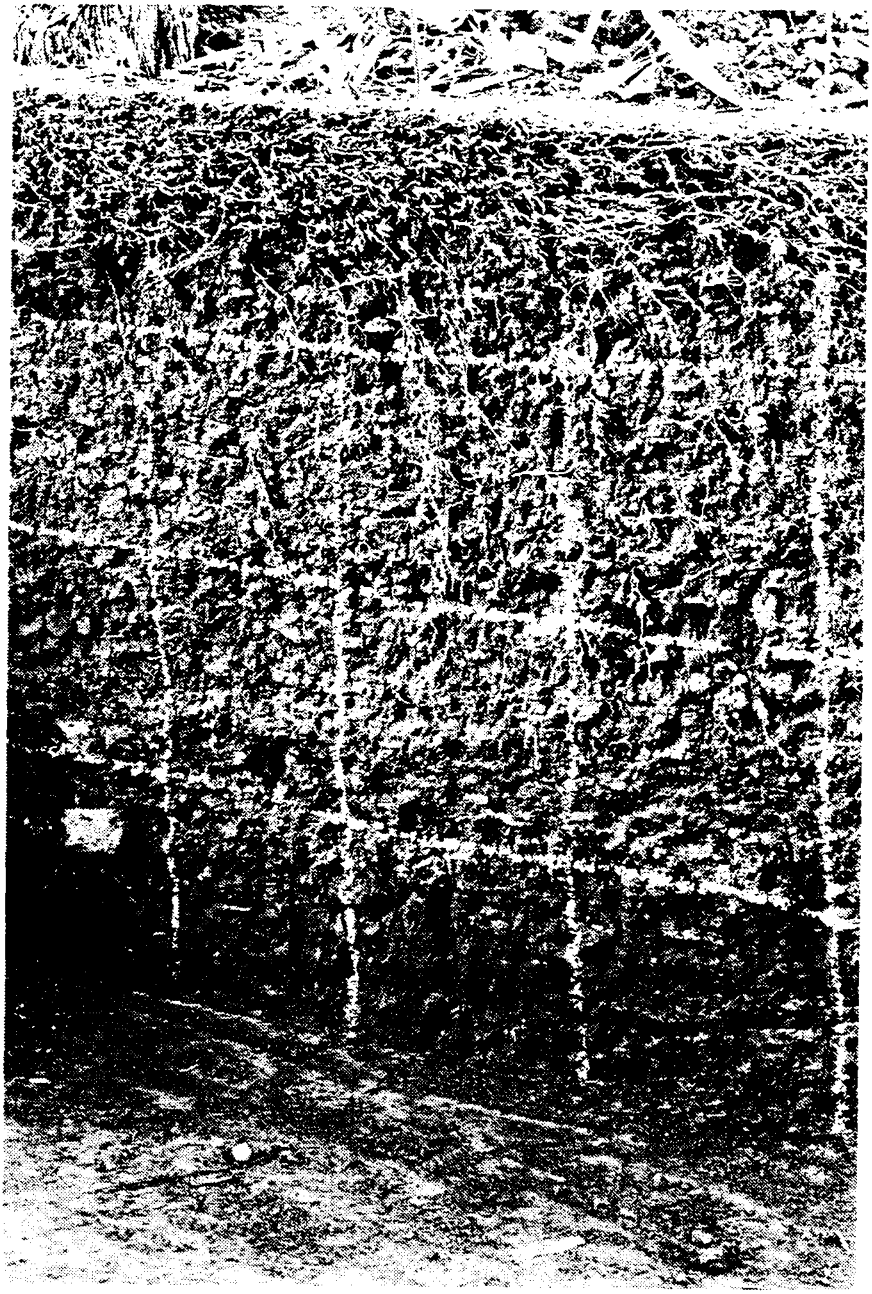

Figure 4. Vertical exposure of the roots of an eight year old clump of *Bambusa tulda* showing 83% of the roots in the top 1 foot of soil. The cut shown is four feet deep. The leftmost square shown starts at 1 foot away from the outermost culm of the clump.
From: Bamboo for Controlling Soil Erosion, 1945, reference 21.

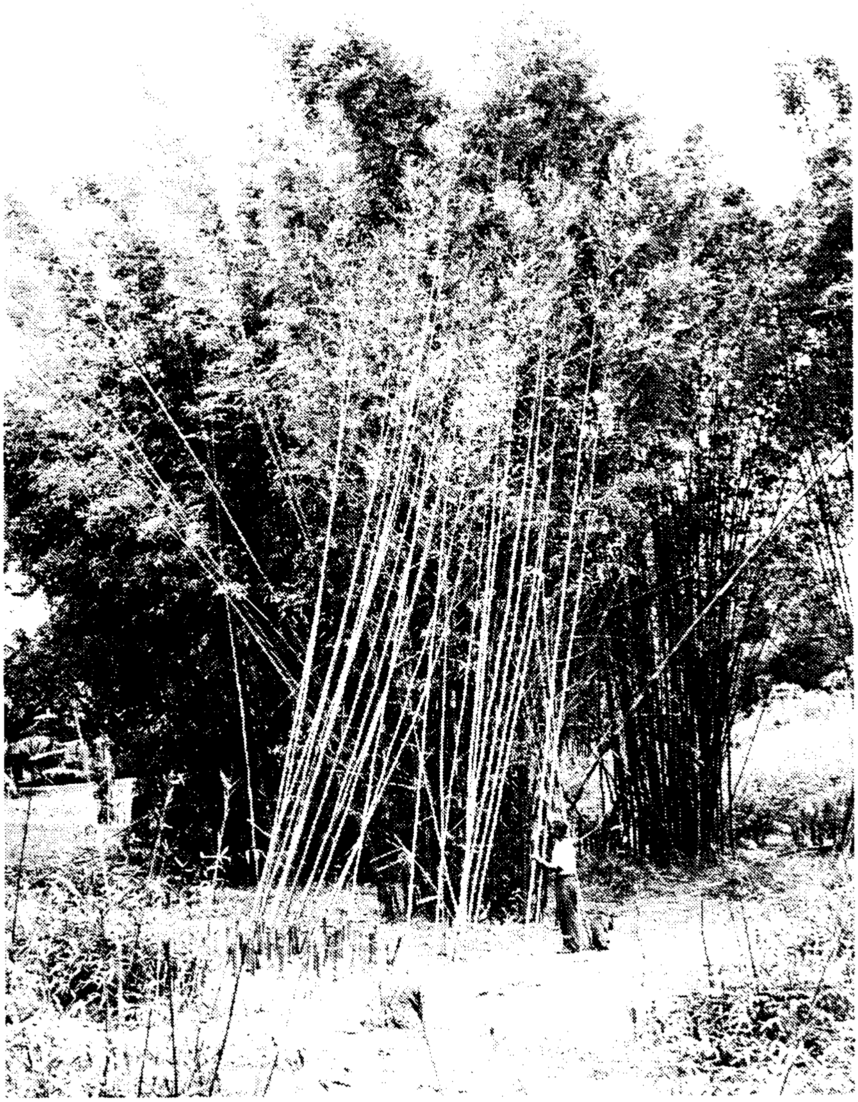

Figure 5. The most practical method of curing culms developed by the Station is shown. Freshly cut culms are leaned upright against another clump for about four weeks. All lateral branches and leaves are left attached to hasten drying. This method increases resistance to attack by *Dinoderus minutes* without the splitting and staining caused by curing under water.

From: The Relationship between Curing and Durability in *Bambusa tuldoides*, 1946, reference 23.

Four other publications on bamboo appeared during this time. The first, published in 1948, is on the propagation by branch cuttings[27] by R. Ferrer Delgado. Ferrer Delgado also collaborated on "The Use of Dynamite in Lifting Bamboo Clumps for Propagation"[28]. This was found to be an economical way to obtain numerous rhizome propagules. He published "The Effect of Bamboo on Succeeding Crops"[29] in 1951, where he described the growth of four types of crops grown on land that had previously been planted with *Bambusa longispiculata* for ten years or more. The bamboo was found not to have a deleterious effect on succeeding crops. The last paper during this period was by Thomas J. Muzik of the Station, and Carl D. LaRue of the University of Michigan, entitled "The Grafting of Large Monocotyledonous Plants"[30]. The authors claim to have made the first graft of a large monocot using *Bambusa longispiculata*. A later paper on grafting monocots by the same authors[31] claimed no further success with *B. longispiculata* nor any permanent unions with other taxa of bamboos that were tried.

Harry E. Warmke, a plant geneticist, became director of the Station in November 1953. The bamboo program by this time had begun to change. The last quarterly Station report of 1953[32] only mentions bamboo in passing, noting that 35 clump divisions were distributed and 320 feet of cured culms were sold locally. Distribution of both offsets and cured culms had been declining since its peak in 1947. The Station's shop-work had not even been mentioned in a report since 1943, and only a negligible amount of local industry with bamboo continued.

Only four papers on bamboo were published during the period from 1953 to 1961, and all four were either authored or co-authored by William C. Kennard. Kennard, a horticulturalist, continued some harvest-schedule testing that had been conducted at the station, and also continued the propagation research. A paper entitled "Propagation of Whole Culm Cuttings" by McClure and Kennard[33] reviewed the techniques of vegetative propagation developed at the Station and elsewhere, and experiments in Mayagüez to propagate plants from whole culms without their attached rhizomes. Earlier the Station (1938) had reported on successful propagation by layering whole culms with the rhizome attached, but this method necessitated digging out the rhizome and dividing the mother clump. The later study found that many of the 11 species tested would produce numerous rooted plants either from the by-products of rhizome propagation or from culms cut without disturbing the roots of the parent clump. This technique worked with most of the species tested.

Although McClure was never on the staff of the Mayagüez Station, his work was an important part of the bamboo program since its inception. He had gone to China to become professor and curator of the herbarium at Lingnan University in Canton. There he established a living collection of 600 kinds of bamboo. Later he served as a plant explorer in Asia for the USDA and sent back many of the bamboos that became established at USDA stations in Mayagüez and elsewhere. McClure served later with other offices of the USDA as a bamboo specialist, and as honorary research associate of the Botany Department of the Smithsonian Institution[34]. He made numerous visits to Mayagüez from World War II until the mid-1950's and with these visits, and voluminous correspondence with the Station, he helped to clarify the identities of the bamboos and to act as a senior consultant on many aspects of the research. In his work with the Mayagüez Station, McClure continued to develop his understanding of the bamboos and in his 1966 work, *The Bamboos: A Fresh Perspective*[35], he cites examples from Mayagüez, as well as some previously unpublished data from the Station.

Kennard also worked on other aspects of the growth and use of bamboo, in addition to propagation and harvesting techniques. In 1955 he published "Flowering of Bamboo *Guadua amplexifolia* Presl in Puerto Rico"[36] in which he briefly reviews the flowering of bamboos in general and those which had been known to flower in Puerto Rico, relating these observations to species then in flower. Kennard also worked with Ruben H. Freyre on the edibility of the shoots of some of the introduced taxa[37], and found some of them of excellent quality for canning and eating. This work was published in 1957. His last publication on bamboos (1961) was also the last one of the era. The study, entitled "Control of Bamboo in Puerto Rico by Herbicides"[38], detailed the effects of various herbicide treatments on 11 species of the bamboos of Mayagüez.

In an internal paper of the USDA listing active programs in Mayagüez as of November 27, 1961, bamboo was not mentioned. Little more would be done with the bamboos in Mayagüez through the remainder of the 1960's. A few offsets were still being distributed in Puerto Rico and abroad, but the numbers were minor compared to earlier years. No more culms were distributed for use by local industry.

Thomas R. Soderstrom first visited the Station in Mayagüez in 1970. At that time, the most impressive bamboo plantings were at Paris Field, where many rows of different exotic bamboos had been planted. He studied the bamboos there at the time, including the only plants of the lovely blue-culmed *Lignania* sp. (Plant introduction #128753), which had been introduced in 1949. When McClure died later that same year, Soderstrom took on the task of assembling his papers at the Smithsonian and editing the unfinished manuscript, "Genera of Bamboos Native to the New World (Gramineae: Bambusoideae)"[39]. Notes on the bamboos in Mayagüez were included in McClure's files with maps of the plantings. The U.S. National Herbarium at the Smithsonian had also preserved numerous specimens of the bamboos, as well as photographs and color transparencies.

Shortly after Soderstrom's visit to Mayagüez, Paris Field, which had been deeded over to the insular government, was bulldozed and replaced by a city sports coliseum. Unique accessions were lost and have not been found in Puerto Rico since. *Lignania* sp. and *Guadua amplexifolia* (Plant introduction #132894) which were introduced in 1949 and 1942 respectively, were two such losses. It is unfortunate that these plants were not saved, since they had already withstood the test of their introduction and subsequent neglect, and since great effort and expense had been expended sending plant explorers to find them and send them back to Puerto Rico.

Nevertheless, extensive bamboo plantings still remained in Mayagüez and Soderstrom made four more trips to the Station to study and make collections of them up to 1984. The well established and documented plantings offered a unique opportunity to study the flowering physiology of the bamboos. In 1984 the authors began a project to try to understand the controlling mechanism of long-term gregarious flowering in bamboos, with the ultimate goal of being able to induce or inhibit flowering.

Because of the documentation of the plantings saved by the USDA and the Smithsonian, it has been possible to observe the bamboos in Mayagüez in their present state with reference to their provenance and history. This is especially important for the study of the long-term flowering cycles of bamboos, where some taxa have never been known to flower or where their cycles cannot be ascertained because of lack of information available from consecutive flowerings of one line. Often information on bamboo flowering cycles in the literature is of little value due to lack of authoritative identification and vouchering of specimens of the taxa under discussion.

In the case of the introduced bamboos in Puerto Rico, past flowerings have been documented by White[24,26], McClure[35], and Kennard[36]. Soderstrom was fortunate to encounter many of the bamboos in flower at Mayagüez, including *Cephalostachyum pergracile* Munro in 1974. Numerous plants of this species are surviving at the Station and will provide further information on their flowering in the future. At the start of the current project in Mayagüez, seven species were found in flower at or near the Station: *Bambusa longispiculata, B. multiplex, B. textilis, B. tuldoides, B. vulgaris, B. ventricosa,* and *Guadua angustifolia*.

Bambusa ventricosa (Plant introduction #77013) was described in USDA plant introduction records by McClure in the late 1920's when plants were sent from China to the United States. The measurements included in this description were of plants in pots and the plants that reached Mayagüez in 1932 were derived from a plant McClure purchased in a Canton nursery. It was, therefore, apparently unknown in the wild or McClure was uncertain that the wild plants were of the same taxon. In the above USDA description of *B. ventricosa* it was noted that the plants did not usually exceed one meter, and "were usually only 2/3 this height." In McClure's published description of the species in 1938[40], he noted that normal (non-ventricose) culms would reach a height of 2.5 m. Later McClure would note in correspondence that clones of the same introduction in Mayagüez were much larger than he had known them in China and that they were putting forth fewer ventricose culms and more cylindrical ones.

In a 1961 publication by Young, Haun and McClure,[41] it was noted that *B. ventricosa* had reached heights up to 55 feet in Puerto Rico and Florida under favorable conditions and that the distortion of the internodes tended to disappear, except under unfavorable conditions. These plants have apparently reverted to their original wild form, and have recently been collected in flower by Edelman at the USDA Station in Mayagüez, at the former USDA property in Las Mesas, Puerto Rico, and at the Fairchild Tropical Garden in Florida. These specimens have been determined by Soderstrom to be identical to *B. tuldoides*, which is flowering nearby in all three locations.

McClure described *Bambusa ventricosa* as a unique species without the benefit of flowering material, not realizing the inflorescence would prove to be identical to *B. tuldoides*. However, the current flowering of another species, which McClure also described on vegetative characters[42] alone, *B. textilis* has proven this species to be valid. Four clones of a plant of this species, sent back from China by McClure, reached Mayagüez in 1935. It has recently been collected in flower there, in Luquillo National Forest and Rio Piedras, Puerto Rico, as well as at Stock Island, Florida, and the USDA Station in Miami, Florida.

Although the USDA program to promote utilization of bamboo failed, the need for these exotic species may arise in the New World in the future. In that case the research conducted in Puerto Rico can serve as a sound base for their use, and diverse species will be available from TARS in Mayagüez (Figure 6). In the meantime the bamboos of Puerto Rico will continue to perform an important role in research on the flowering behavior of these woody grasses.

Figure 6. Pedro Torres-Rodriguez, a gardener with the Station, with a young *Dendrocalamus strictus* plant in a propagation trial, circa 1948. Don Pedro is still with the fully grown *D. strictus* and the rest of the bamboo germ plasm collection after 42 years of service at the Station. USDA photograph, unpublished.

Appendix

Bamboos remaining at the USDA Agriculture Research Service, Tropical Agriculture Research Station, Mayagüez, Puerto Rico.

Bambusa bambos (L) Voss in Vilmorin
B. longispiculata Gamble ex Brandis
B. multiplex (Loureiro) Raeuschel
B. polymorpha Munro
B. textilis McClure
B. tulda Roxburgh
B. tuldoides Munro (*B. ventricosa* McClure)
B. vulgaris Schrader ex Wendland
Cephalostachyum pergracile Munro
Dendrocalamus asper (Schultes f.) Backer in Heyne
D. strictus Nees
Gigantochloa apus (Schultes) Kurz
Guadua angustifolia Kunth
Melocanna baccifera (Roxburgh) Kurz
Phyllostachys bambusoides Siebold and Zuccarini
P. meyeri McClure

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Yves Crouzet*: **The Bambuseraie of Prafrance and the Distribution of Bamboo**†

Prafrance is a privately owned park located in the South of France about 60 km (37 miles) from the Mediterranean not far from the cities of Nîmes and Montpellier. It owes its origens to the noted plant lover and amateur botanist, Eugène Mazel. Starting in 1850, Mazel brought together at Prafrance plants from around the world but mostly Asian plants, which he loved the most. He was lucky, and his efforts were rewarded because he found in Prafrance ideal soil and climate allowing him to realize the most beautiful bamboo collection in Europe.

The bamboo, consisting of 100 different species and varieties, covers 12 hectares (30 acres) in a river valley with deep alluvial soil. The general design of the park has never been changed since its beginning. The entrance leads into a majestic corridor bordered by redwoods (*Sequoia sempervirens*) under which there is a hedge of *Phyllostachys viridis* on both sides for a length of almost 400 m (¼ mile). At the end of all this, a little hidden in the middle of a green, there is a building several centuries old made from the local stone. Here one encounters four paths leading in different directions, which invite the visitor to explore the rest of the park. Among all these spectacular bamboos, it is *P. pubescens* that makes the greatest impression. The size and shape of the base of the enormous culms remind one of elephant feet. The culms reach up to 25 m (82 feet) in height ending in tops engulfed in small leaves which give the plants an appearance of fine texture and grace. In 1905, Houzeau de Lehaie, a noted bamboo specialist, on visiting Prafrance wrote: "For anyone who has not lived in the tropics, it is difficult to imagine the majesty of a bamboo forest. Europe has a few, but Prafrance is perhaps the only place where the mass and size of the vegetation gives a proper impression of this admirable plant in its full development."

For the last 30 years, the park has been open to the public from the first of March til the end of October. Each year, there are over 200,000 visitors, a number that is constantly increasing due to growing public interest. This plant, which was relatively unknown a few years ago, now enjoys an increased interest justified by its many popular qualities. It is exotic, fast growing and available in a multitude of colors and forms. Its evergreen foliage make it a valuable wind break, sound screen, etc.

At Prafrance we have established a nursery specializing in bamboos. We have developed the techniques for growing the plants in containers, and this has led to new methods of propagation. Plants are sold locally to park visitors, who usually want small, 2 to 7 liter specimens they can easily carry away. Larger plants are sold to landscapers, cities and nurseries who want sizes 1½ to 2 m tall in 14 liter pots up to 6m plants in 110 liter pots. We also sell some big ones, up to 12 m tall in 300 liter containers.

Improved techniques have produced higher quality plants, which are much appreciated by landscapers. Still, many were not convinced of the possibilities for using the plant. They believed that bamboos require a narrow range of soil, temperature and humidity found in few gardens. It took some time to try different varieties and realize that bamboo

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† Translated by Wolfgang Eberts.

does not need a greenhouse and that many varieties withstand cold winters and do well in a variety of soils.

Recently, many bamboo gardens have been planted, especially in the region near Paris, which have proven the adaptability of the plant. Right now, some big projects like the Musée des Sciences et des Techniques de Paris à la Villette, where the new Finance Ministry is currently under construction, have set aside large areas for bamboo in the green space.

The first step has been to recognize bamboo as an ornamental for all gardens, but we should not stop here. We should also permit the general public to discover bamboo, to become more interested in it and to know it better. For this, large circulation newspapers and magazines are a big help, especially those that deal with gardening, horticulture and decorative design. I must admit that articles in such publications are popular because the subject is new and fashionable. Certainly it will not always remain new, but we can keep readers informed of new possibilities with bamboo once they are introduced to it. The subject is broad and rich enough to constantly present new material. The press is not the only medium. We are also considering the more modern audio-visual technology. At Prafrance we are preparing a video tape on the park and its bamboo.

Along similar lines, I might mention that the first exhibition on Bamboo and Orchids, held recently at Versailles, was a real success. Although visitors could enjoy the beauty of the orchids, they suprisingly showed more interest in the bamboo because to most of them it was something new. The bamboo was shown as an ornamental in a setting created by the landscaper, Robert Bazelaire, who by arrangement of form, color, leaves and culms showed the plants at their best. He also gave instruction on bamboo, its history, uses, morphology, etc., all greatly appreciated by the public. We are already preparing a second bamboo exhibit... the path is open, lets follow it.

A few people think the current bamboo interest is just a fad. This could be true if bamboo is presented as just another new, exotic plant. But bamboo is many other things because it plays an important role in botany, geography, art, ethnology and even philosophy. Is there any other plant which can lead to so broad a field of investigation? Bamboo is not a fad but a reality. To be convinced of this, one needs only to travel in countries like China and Japan where one can see how it is used and even how it is sometimes worshiped. There, one senses the centuries of tradition attached to it.

Dicken Castro*: **Contemporary Perspectives for the Use of Bamboo****

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In the middle of the last century, in the central region of Colombia, a group of people emigrated from the department of Antioquia where they had been established since colonial times, to the lowland wilderness where they were confronted, in a majority of cases, with completely unknown and adverse conditions. They had been the inheritors of construction techniques of Spain, which consisted of dried and hardened soil in conjunction with existing materials of the region, but they developed original methods of construction that still exist today. They especially used a type of bamboo, which is locally called guadua (*Bambusa guadua* Humboldt & Bonpland), that is used in every form of construction: as basic structural units, as a surface that is covered by other materials, for roof supports, floor supports and for all types of utensils and furniture.

Incentives for the colonization of these places, until now inhospitable, required the building of a house to obtain the land. It was because of the ease and quickness of building with guadua, and the abundance of this material, that the colonists became experts in the use of this versatile raw material.

So notable are the diverse uses of this bamboo that people have come to speak of the "bamboo culture" to denote all that has been developed by this group of people.

Colombia is a country that is now in a rapid process of industrialization, urbanization and development, with all of the advantages and inconveniences that this represents, especially with respect to the diverse makeup of the city and the country.

I want to point out the importance that the use of guadua has had for Colombia, and what it will mean to us to forget its existence and thus contribute to its total disappearance, if we do not tend to its growth and conservation and do not promote its proper use.

The topography of this region is very broken so that in some places buildings have two stories on one side and, because of the slope of the terrain, up to six stories on the other side. After having completed the basic structure, the residents slowly begin to complete the floors from top to bottom according to their ability to afford it and for the necessities that they require. Upon having a structure where the necessary space had been provided, a rich and varied relationship of spaces and volumes is produced, controlled by the ordering of the already existing structural dimensions.

The urban dwelling of this region of Colombia is organized based upon a plan of square city blocks, as in the geometric scheme of the Spanish square, where the house occupies a front along the street leaving a free space at the back of the lot for domestic activities, garden, animals, etc. There is no lateral separation between the houses, thus forming a compact structure that gives a sense of form to the block.

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Large eves cover the sidewalks, protecting them and the people walking there, as well as the facade of the house, from inclement weather. The street, besides serving its traffic functions, serves as a common exterior space and is the place where a tight social relation between neighbors of all ages is maintained, especially during the evening hours when chairs are taken out on to the sidewalks. Conversations are begun and the day's happenings are commented upon. The proportion between the width of the street and the height of the houses makes it an alluring open space, propitious to all kinds of human interaction. The street presents a strictly urban aspect by the absence of trees and plants, in contrast to the rear facades of the houses where neighbors take time to decorate them with flower pots and plants useful for cooking.

The houses are distributed in such a manner that the areas utilized for social functions are near the street, becoming a part of it during the day through various openings usually consisting of Dutch doors.

There exists a great desire to establish an identification, in order to symbolize a belonging, and to that end they use strong colors. The general use of the same materials in all the structures of the urban groups give them a homogeneous character (a character that is lost in the urban conglomerate recently constructed). There are wooden planks called "zocalos" that protect the wall from the street traffic and these are painted the same color as the doors and windows. Likewise, the walls are brightened with whitewash and serve as a neutral background to the color, with a great liberty of combinations and imagination on the doors and windows, and in general on all woodwork, serving to individualize each one of the houses without losing the sense of a group.

The disciplined and harmonious relation between the surface of the walls and the openings gives an aspect of a pleasing and quiet architectural group.

With the Dutch doors, possibly the most characteristic architectural element of these structures, there is established an interaction between the street and its activities and the house, that gradually grows during the day. A windowsill made of bars of "macana," a wood that comes from the trunk of a palm, marks the border between the house and the street, allowing a view to the rooms and salons. In the afternoon, people are accustomed to watching from the Dutch doors the people that pass by in the street. Until recently, they also served as a romantic place of encounter between people in love. At night the doors are closed, leaving open either small portholes at the top or the upper half of the windows, thus permitting an absolute independence with adequate ventilation. The front door is often adorned with decorative wooden panels.

The street facade is the appearance that one wishes the people to see. In contrast, the interior facade is more intimate. In it the inhabitants are presented as they are, in their most hidden imperfections without decoration for show; and here the building material appears without any sign of paint, producing surfaces with natural textures and colors and the transformations that result with time.

The posterior facade, windows, spaces and balconies have a more spontaneous aspect than that of the street, having areas where domestic work is done in its appropriate way. Here the bathroom, kitchen and laundry areas are found. Behind it there is reserved an area that serves as a garden, a place to care for domestic animals, a clothes drying area and a space for simple children's games like swings, seesaws, marbles, etc.

There they enjoy their plants, herbs and flowers, grown in a variety of containers: cans that at times served as containers for industrial products and others such as coffee and garbage cans.

These facades are built at the rate that economic necessity dictates. Because of this the exteriors can be seen in very diverse stages of completion: from the base of the structure, with its columns and diagonals of guadua, over the stuccoed surfaces to the whitewashed walls at the top there is a wide variety of workmanship, colors and textures that gives an interesting aspect to the urban landscape.

The fences, made from various weavings of guadua, complete this urban panorama delicately marking off each property without breaking the natural lines of the exterior spaces - as a brick wall could do. This facade, in sum, is not to be seen and contemplated from the street, so its appearance is not taken into account. Sewage pipes are often exposed for easy maintenance and look like premonitions of the styles used in contemporary architecture.

The street facade is the face that the family presents to everyone else. It is like their social personality. The interior is the area of deep family feelings, where conveniences and appearances do not intervene. It is introspective and completely sincere. In one, a relation is established with the city, with the outside world. In the other, there is a relation with work and with nature, with oneself and with others in the house.

The front facade is the "appearance" and the interior is the "being."

This panorama began to change about 20 years ago. The principal activity of the people in this region is the cultivation of coffee, but at that time it was still a family activity. Coffee used to be cultivated under shade and was replaced with coffee not needing shade but that needed more technical care. This caused the owners of the small farms to sell out and go to the city to look for better work opportunities. Those that stayed looked for ways to integrate all of their lands to coffee cultivation and cut existing areas of bamboo. In Caldas, a department of Colombia, the number of farms diminished from 80,000 to 39,000 in less than ten years. The little they obtain from the sale of their farms, they spend quickly and are converted into urban parasites without any capacity to survive in the city.

Industrial products that do not require any kind of craftsmanship for their selection, preparation and use, replace the traditional structure that has been described: the walls, made of bamboo, are now made of brick, the roof of red tile has changed to asbestos cement, the woodwork to frames of metal. The beauty and craftsmanship of the structure is forgotten and also the homogeneity that this gives to the urban landscape. It is replaced by a chaotic vision produced by using indiscriminate construction methods that have recently been developed.

The predominance of car traffic over the pedestrian makes the street a forgotten place for social interaction and only a way to get from one place to another as fast as possible. Protective eves are forgotten, the houses deny the street, the interaction of the street and the house, and vice versa, is ended.

The urban spaces that have not been used for housing because of the danger of landslides are now used by slum-dwelling squatters where the basic material used is bamboo for its economy and ease of working, as a last minute solution without taking into account any special construction techniques. This is something that completely disregards the many advantages of guadua and converts it into a material that indicates poverty and improvisation.

In Colombia, the energy of one man, Oscar Hidalgo, has interested groups of students at the National University until they have come to constitute a center of bamboo study where they investigate traditional methods, write handbooks and instruct others.

The Craftsman Guild in Colombia has brought over groups of Chinese to train others in the working of bamboo and to consult in its cultivation. The enthusiasm of Architect Jorge Arcila has permitted the construction of 123 experimental houses in Manizales that the people have built themselves. They have made sporadic investigations of the use of guadua for furniture.

Besides these laudable beginnings, little has happened in Colombia for the rescue of guadua. During the last four years, government agencies in charge of public housing have produced 200 dwellings of guadua by means of self-construction, and have plans for a program of 600,000 dwellings which is not just a romantic gesture.

If we also keep in mind that clumps have disappeared for coffee plantations, sugar and other crops, we see the need to establish programs of conservation in the areas where guadua grows naturally (which still exist), to start scientific plantings, to look for new varieties for other uses, and to experiment with appropriate harvesting methods for a more rational and economic use, without the waste that is presently occurring. We need to look for new uses in places where it can be applied to its maximum condition of beauty, economy, flexibility, strength and ease of working. We should not reduce such a splendid material to its most obvious uses like scaffolding, concrete molds, and inexpensive housing and start using it for flooring, walls, screens, furniture, basketry, utensils, containers, tools and suitable adornments for the consumer society.

For Colombia, I try to visualize the creation of important industries like paper that could employ bamboo fiber, but I have limited myself to mentioning aspects related specifically to design, a field in which I work professionally.

Other Latin American countries have begun campaigns like the ones I have described. In Ecuador, and specifically in Guayaquil, the Universidad Laica Vicente Rocafuerte has begun a study of the coastal dwellings made of guadua. Father Garcia, also in Guayaquil, has established a kind of prefabricated wall to satisfy the serious problem of housing for the poorest people of that city. In Guatemala, the Universidad Francisco Marroquin has held seminars about the use of bamboo in contemporary structures.

Jorge A. Morán Ubidia*: **The Use of Bamboo in Ecuador: Past, Present and Future****

Revised manuscript received June 4, 1986

1. Introduction

When discussing the use of bamboo in Ecuador it is necessary as well to discuss her culture and even her history. Bamboo has served, and still serves hundreds of thousands of Ecuadorians as construction material for their dwellings and objects in daily use. It is also found in clusters adjoining the rivers and estuaries of the Ecuadorian coast, acting as an extraordinary agent against erosion and an outstanding contributor toward ecological maintenance.

In this paper I will explore the works of outstanding archaeologists who have shown that all cultures that have lived on the Ecuadorian coast used "caña," or bamboo†, and "guadua," or giant bamboo, as construction material for temples and dwellings. I will examine the first written and graphic accounts that chroniclers of the period of discovery and colonialization left about the use of this plant, with special emphasis on the commentaries about guadua left by Humboldt in his passage through Ecuador.

Humboldt notes how peasants and migrants living around the edges of cities used guadua to create large neighborhoods of bamboo, highlighting the case of Guayaquil. The history of Guayaquil has been bound to the use of bamboo from the days of its founding until present times, where living in a house of bamboo has become synonymous with uncertainty, misery and poverty. I will conclude the document by noting the temporary residence in Ecuador of Floyd A. McClure, reviewing the first successful housing projects in the country, and highlighting the investigations of the University Laica Vicente Rocafuerte of Guayaquil into ways of salvaging and constructively using one of Ecuador's most important resources, its bamboo.

2. Archaeological Evidence

> "...Scientific investigations have earned the Ecuadorian coast recognition as the source of New World ceramics; together with Puerto Hormiga in Colombia it includes the oldest known centers..."[1]

This is how Olaf Holm[1] begins his study of the prehistoric dwellings of the Ecuadorian coast. He gathered the observations of well-known investigators on the materials, forms, and construction techniques used in Ecuador's first dwellings.

Climate and natural resources have determined the type of construction material available to Ecuadorians, thus giving form to the dwellings and the construction system best suited for building. While the Peruvian coast, dry and desert-like, requires bricks and

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** Translated from Spanish by René Lewis. Edited by W.A. Brewer.
† In this document the words "caña" and "bamboo" will be used somewhat interchangeably, though "caña" often refers specifically to the bamboo cane and "bamboo" to the plant as a whole. Translator's note.

adobe, that of Ecuador is warm, humid, and full of the plant resources required for the construction of temples and houses. Reason dictates that the trunks of trees and guadua are suitable materials for the supports, that palm and bijao leaves are destined for roofs, and that the same guadua cane, opened and flattened, is the best material for floors and walls.

I will examine some ruins and how they were interpreted by archaeological investigations. Dr. Karen Stothert, together with the Anthropological Museum of the Central Bank of Ecuador, discovered the oldest dwelling of the preceramic period in the Peninsula of Santa Elena[2], where the vestiges of foundation trenches show where posts of wood or caña once were buried to form the framework and support the roof. Radiocarbon readings date the few other cultural remains at between 8900 and 9400 B.C., making this dwelling the oldest in Ecuador and all of America.

Figure 1. Circular plan of a cabin in Las Vegas, on the Peninsula of Santa Elena. Only the trench and the places where the structural posts were once buried remain (9000 years B.C.).

From the later Formative Period (3550 to 500 B.C.) are the remains of the dwelling of Valdivia I in Real Alto, where one can make out the remains of the posts in the oval floor plan. In 1979 J.E. Damp[3], using the radiocarbon method, dated the remains at 3500 B.C. D.W. Lathrap and J. Marcos of the University of Illinois[4] concluded that the dwelling in Real Alto had its walls plastered with *bahareque*, or caña, mud and straw. This construction technique is still used today.

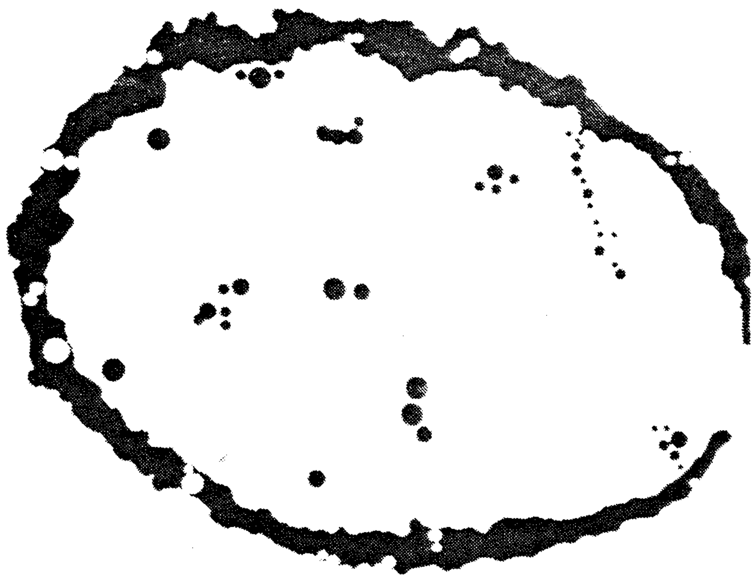

Figure 2. Excavation in the Real Alto site with vestiges of interior divisions. It can be seen where the bamboo posts were located (3500 B.C.).

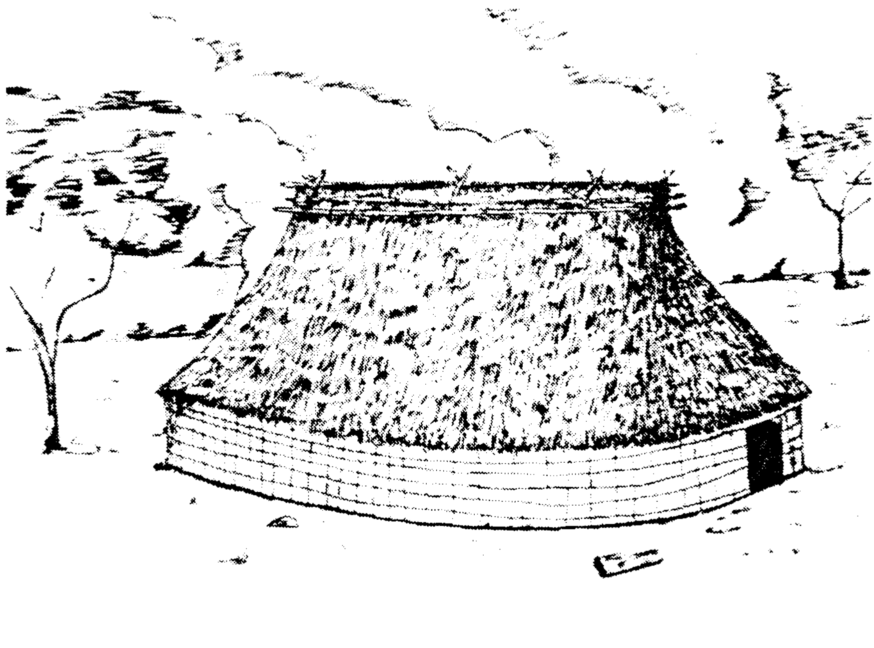

Figure 3. Reconstruction of the dwelling of Real Alto.

Clay maquette-vessels from the Chorrera culture (Bank of the Pacific Museum, Guayaquil) reflect the forms and techniques of construction of the times, and show the same materials in use as those suggested by the cylindrical vessel of the Jama Coaque culture (Central Museum of Ecuador) that represents a cellar or grain storage area with walls of guadua. The decorative elements are made by using fixed or mobile "stamps," the latter in cylindrical form, made by fastening together sections of guadua, as shown by the archaeologist M. Molina[5].

In 1907 M.H. Saville[6] described the ancient town of Manta, then called Jocay. From examining its remains, called "corrals," he concluded that the foundations were of uncut rock and the walls of adobe, caña, or both, permanently joined by the *quincha* system of construction still predominant in the Province of Manabi. In 1962 V.E. Estrada[7] also described the ancient Manta, and together with Clifford Evans and Betty Meggers[8] of the Smithsonian Institute made several archaeological investigations. After analyzing a multitude of maquette-vessels from different periods they concluded that

> "...the buildings had stone floors in some cases, and walls possibly of *bahareque*, and roofs of straw..."

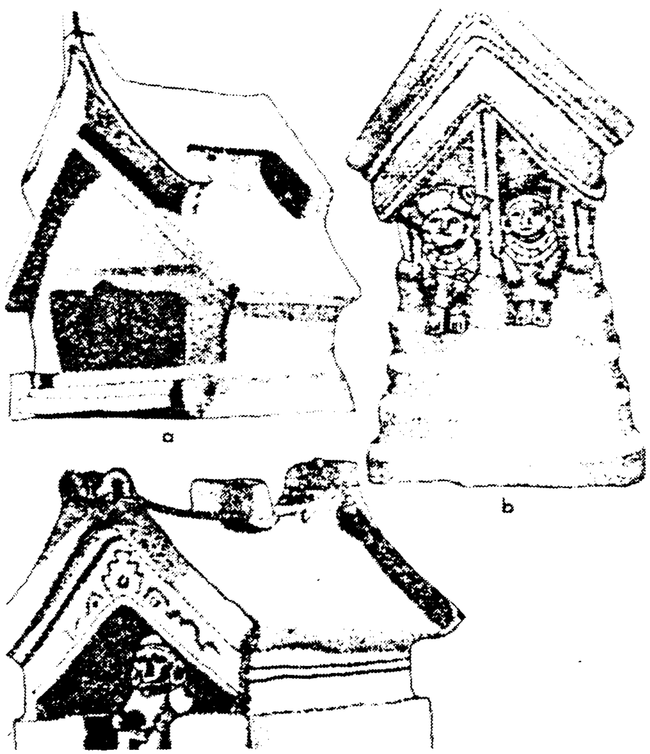

Figure 4. Maquette-vessels from the Jama-Coaque culture (500 B.C. to 500 A.D.).

Each archaeological investigation points to guadua as the basic pre-Columbian material for construction, as indicated by the work of Dr. Merino:

> "...in the archaeological site Milagro I, (5500 B.C. to 3800 B.C.), they have found numerous fragments of bahareque, a clay covering, on top of the walls

of caña. We can safely conclude that the inhabitants of Milagro I constructed their houses with walls of caña and surfaced them with clay or bahareque..."[9]

The purpose of Gustavo Borja's[10] study of pre-Columbian maquettes is also to better understand the structural behavior of guadua in construction.

The Chirije site[11] explored by Estrada shows the remains of perforated columns - unique molds of the primitive guadua structures - that would later draw the attention of the first chroniclers who, with the discovery of America, would arrive in Ecuador.

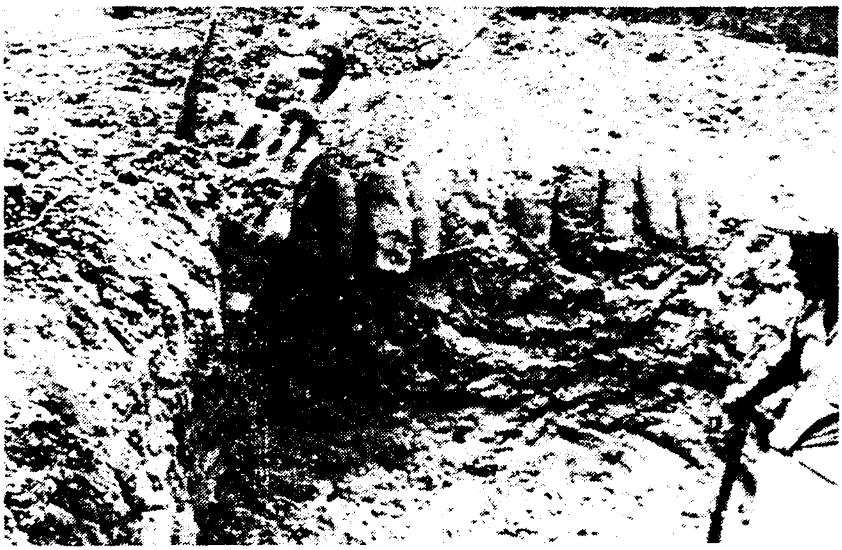

Figure 5. Excavation that shows the perforated columns of corral A of the Chirije site.

It is necessary to note that guadua was also brought from time immemorial to Peru. The Harth-Terre chronicle notes the ruins of the city of Chan-Chan, as described by Francisco Iriarte:

"...the adobe was made in *gaveras* (molds). In Huaca Blanca, adobes have been found made in gaveras of guadua..." (p. 6)

"...as increasing numbers of the tall walls surrounding each of the complexes are disassembled, stuck in each of their centers, lengthwise and at regular intervals, there appear large cañas of a diameter varying from 4 to 6 cm at the tip..."[12]

That is to say, not only the Ecuadorian cultures used guadua, but those of Peru also used it during the pre-Columbian period, as demonstrated by the ruins of Chan-Chan, and during the colonial period, as demonstrated by the Palace of Perichole and many buildings still present in Lima. This made Christopher Alexander recommend

"...bring caña from Ecuador at convenient prices to implement housing plans in Peru..."[13]

3. First Graphic and Written Accounts

Since the Spanish conquistadors first visited the coasts of Ecuador, chroniclers and reporters of the period have left numerous documents mentioning the existence and use of "caña" or "guadua." I will present some testimonies which, taken in chronological order, give the reader a panorama of the traditional way to use bamboo, and the technology that has maintained itself through the passage of the centuries until present times.

1526 Juan de Samano, Secretary to Emperor Charles V, transmitted to the royal family of Austria the description given by the chronicler Francisco de Jerez about the exploration voyage of that greatest of pilots, Bartolome Ruiz, carried out for the first time on the Ecuadorian coast. In part of his account, while referring to a *balsa* - a type of indigenous boat made of caña, which approached his vessel, Ruiz wrote "...it was made with a keel of cañas as thick as posts..."[14] This is the oldest reference to Ecuadorian caña.

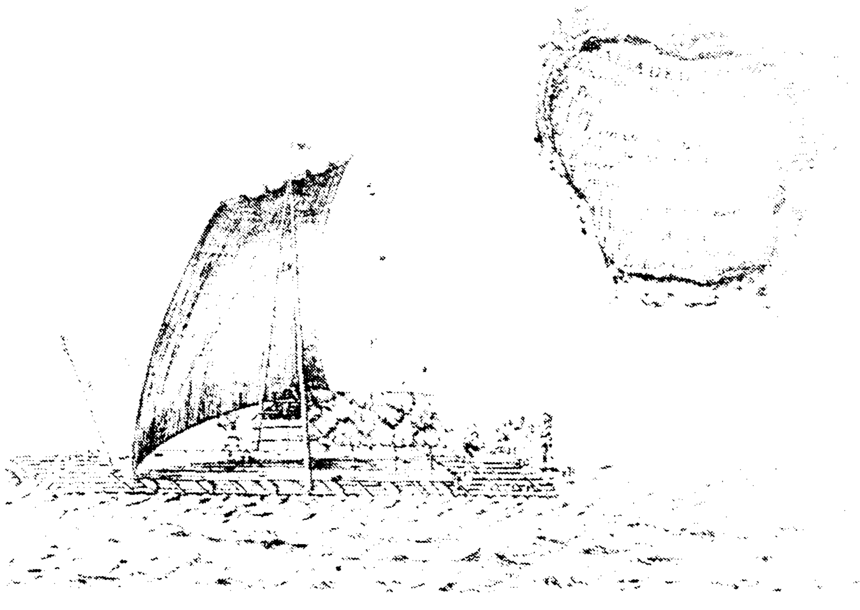

Figure 6. Balsa of Guayaquil. Picture by Jorge Juan y Antonio de Ulloa, 1740.

1534 The historian Herrera in his *General History of the Works of the Spaniards*, refers to the expedition of the Captain General of Guatemala, Pedro de Alvarado, from Bahia de Caraquez to Quito in 1534, recalling how guadua saved the lives of the explorers:

> "...thirst cruelly tormented them in the suffocating climate of the mountains and their distress grew with the lack of water... They found a spread-out canebrake of guaduas; they thought that there would be water, but they did not find any. It had been more than two days since they had found a way to quench their thirst,... A black man began to cut cane to form an arbor and with great surprise saw that the *cañutos*, (the culm internodes), contained more than an azumbre (four pints) of pure,

fresh water; within the cut canes they found a sufficient quantity of water for the horses and themselves..."[15]

1559 From the pre-Columbian period until now the coasts of Ecuador have provided wood and caña for Peru, according to the account "The Relation of the Canon" of the Cathedral of Kings (la Catedrál de los Reyes) in Lima, cited by Dr. Julio Pimental Carbo, an illustrious Ecuadorian historian. The account states that up to a distance of many leagues from Lima there existed no wood of any sort, and that because of the need to build houses "...they brought wood and caña from the city of Guayaquil..."[16]

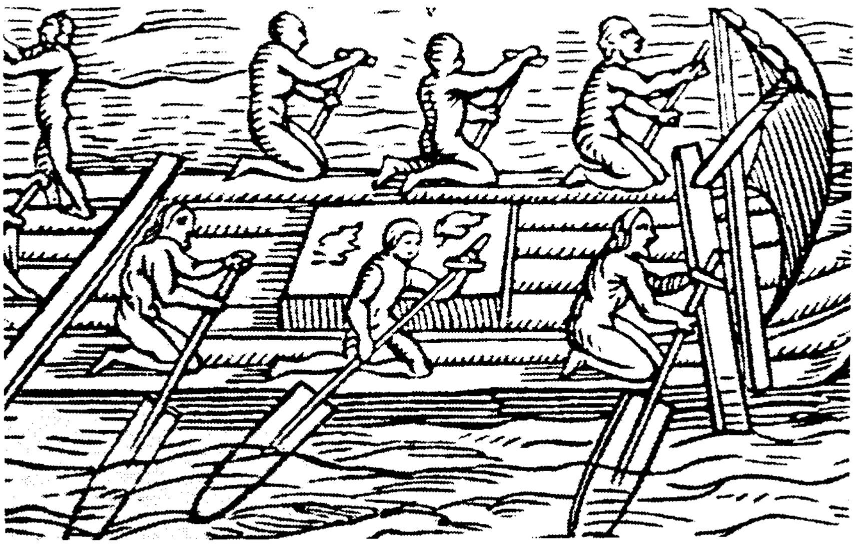

Figure 7. Picture of a *balsa*, by Girolamo Benzoni, 1565.

1565 One of the first pictures of the Ecuadorian *balsas* was left us by Girolamo Benzoni. He also left one of the first descriptions of the use of bamboo in work with precious metal. When referring to the process of casting gold and silver that uses bamboo to fan the fire: "...with 5 or 6 *cañutos* of caña, now more, now less, they blow so much that the metal melts and can be poured..."[17] In the province of Manabi, Ecuador people still use sections of bamboo from 25 to 30 cm long, called *sotos*, that when perforated serve for blowing and aerating kitchen fires.

1605 The public service buildings also were built with caña, as shown by the petition for income in July, 1605, for the Santa Catalina Hospital in Guayaquil. The witnesses testified as follows:

"...the walls of most of this hospital are of bahareque and caña..." (From Don Andrés Morán de Buitron, Notary of the *Santo Officio* of the Inquisition)

"...the major part of the fences of this hospital, and its walls, are of bahareque and caña..." (From Don Alonso de Vargas, Sergeant Major and Mayor of his city)[18]

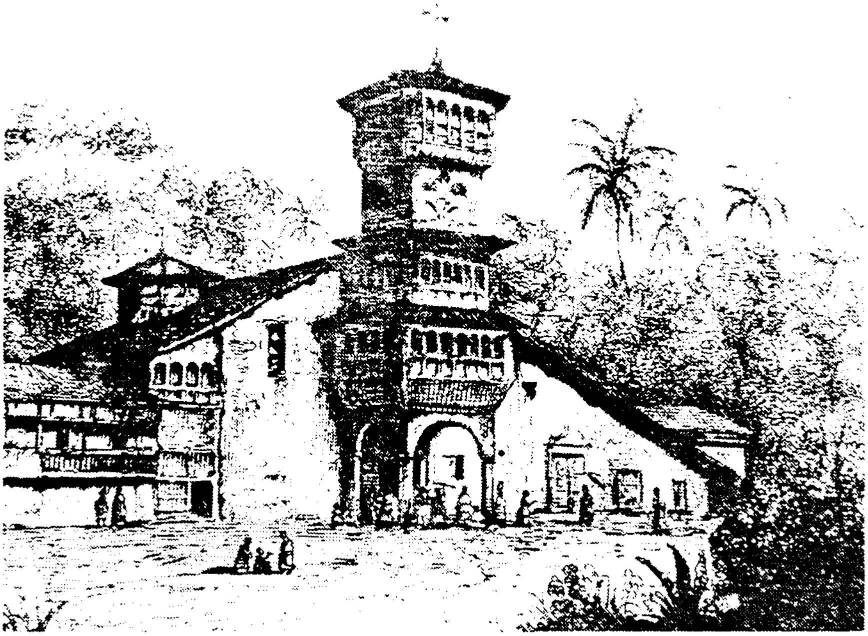

Figure 8. Santo Domingo Church in Guayaquil. Picture by La Vigny, XIX century.

1630 Fray Buenaventura Salinas y Córdova, in his *Memorial of the Stories of the New World*, (Peru, 1630; Lima, 1957), writes

> "...that from twenty to thirty ships, loaded with wood and caña, left each year from Guayaquil to Callao..."[19]

1630 In "Idolatries of the Checras and Andajes," documents from the Archive of the Archbishop of Lima, the inspector and chronicler Pedro de Celis relates the strange case of a caña that was the object of adoration

> "...there was a big caña from Guayaquil to which they offered food, coca leaf, corn liquor, and other things..."

Add the testimony of an Indian from Palpas:

> "...they obviously respected this caña a lot because they brought it to Csasa Paico from time to time..."[20] Csasa Paico was a *malqui*, or idolized mummy.

There is no evidence that caña grew near Palpas, which would explain the reference in the cited document to "...the caña of Guallaquil...," a city situated 1000 km from Palpas.[21]

Figure 9. A Chinchaysuyo Burial. Picture by Poma de Ayala. (See note 20)

1740 The description of the voyage from Lima to Caracas (1740-1741) by Don Miguel de Santisteban gives us numerous references to the use of caña or guadua in Guayaquil:

> "...houses with shelves of wood, covered with straw and strips of those cañas they call guaduas, and so thick that, split and flattened, they give a board two-thirds of a vara wide (a vara = .84 meters), and a very strong texture..."

> "...they make the floor of the wanted thickness, weaving with flattened guaduas...placing them whole, straight up, as panels to divide bedrooms..." pg. 92

> "...Saturday the 6th of August, 1740, we left this first beach...I examined the basis for the common opinion of this province that the water contained in the caña that they call guadua rises and falls with the phases of the moon...I found that in some, the water had risen to almost the caña's full height, up to 50 feet tall and 24 inches wide, and that in all, one would find water more fresh than is common and natural..." pg. 99[22]

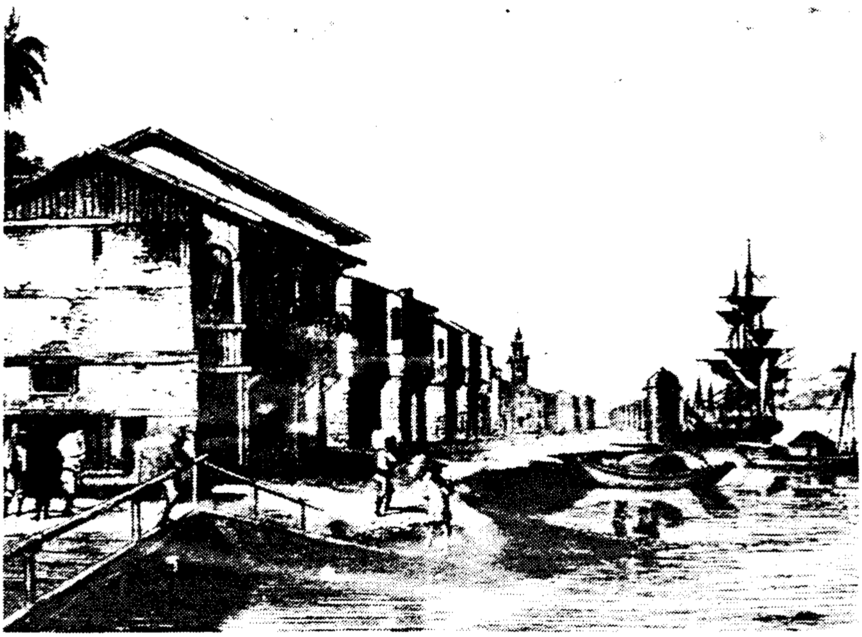

Figure 10. Engraving of Guayaquil, according to Charlton, XIX century. (Collection of Castro and Velazquez)

1741 The president of the Royal Audience of Quito, Dionisio Alcedo y Herrera, wrote a valuable document about the province, river, and port of Guayaquil containing numerous details of the period and describing the inhabitants' customs, and the flora and fauna of today's Ecuadorian Provinces of Manabi, Guayas, and Los Rios. I will cite some of his numerous remarks about the uses of caña.

In describing the *balsas' guare*, or rudder, he says:

> "...they manage it very easily, with a caña like the ancient *pinzote*..." (Chap. VI, p.32)

He notes the existence and size of the cañas:

> "...they find wild caña of such size, up to fifty feet tall and sixteen inches wide, that they are used for the frame and protection (floors and walls) of the sides of country and city houses alike..." (Chap. VIII, p.33)

In the same chapter, now referring to the water contained in the *cañutos*, he says

> "...they are natural water pipes (tubes or pipelines) that contain at the waxing of the moon a light, crystalline, and deliciously cold and healthy deposit of water..."(pg. 34)

He also describes the houses:

> "...they form spaces out of walls and roofs with bent, wild caña, opened and leaning towards the interior, that they trim and cover with awnings in such an orderly way as to close the openings, thus forming houses..." (Chap.X, p.37)[23]

1748 Jorge Juan and Antonia Ulloa were sent by King Phillip of Spain, together with French academicians, to carry out various measurements and calculations in the field of astronomy. They left, among their many written works, a description of the city of Guayaquil including the forms, materials, and construction systems of the residents' houses. They incorporated in their documents one of the first pictures of the houses, the design of which has been maintained in all the regions of coastal Ecuador. It is noteworthy that in the picture, shown below, appears a guadua plantation identified by the legend at the foot of the illustration as "caña from Guayaquil."[24]

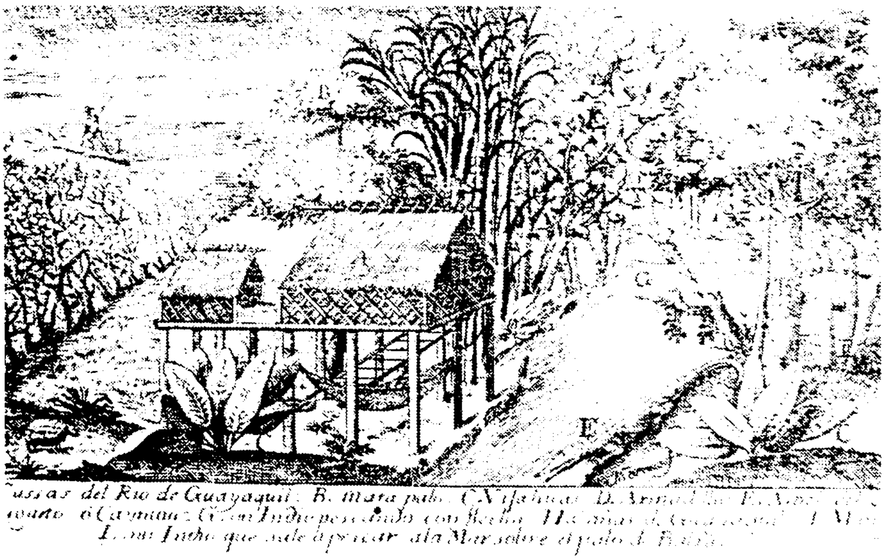

Figure 11. Drawing of house and plants of Guayaquil, by Jorge Juan y Antonio Ulloa, 1748.

1820 Andres Baleato completed a "Monograph of Guayaquil" with numerous descriptions of the use of caña as a construction material for houses:

> "...in the small houses all of the interior roof, walls, floor, stairs, handrails and so on are made of caña..." (pg. 251).

He also describes the existence of the plant:

> "...on all sides one encounters *cañas bravas*, or guadua, and bijao canes and leaves put to many uses..." (pg. 294).

He notes its dimensions, the use of the water contained in its interior, the traditional way of "curing" so it will last as long as possible, and its use as insulator in cargo boats:

> "...the cañas from Guayaquil are as unique for their length and width as they are for the water their *cañutos* contain. Their regular length is from 14 to 18 varas, the thickest are a palm in diameter; the outer circumference of the *cañuto* is 6 lines around, and one realizes that when opened

> and flattened, each one forms a board half a vara thick...during a full moon most of the *cañutos* are full of water...after cutting the cañas, they let them dry, which they call "curing." Curing leaves them strong enough to serve as beams, boards, litter poles, and sheathing for the holds of boats carrying cocoa so that the heat of this fruit will not burn the wooden hull...the water from these cañas is said to prevent welts formed by blows and falls..." pg. 305

In referring to the way of constructing *balsas*, and then in describing the method of lashing the wood with reed, he writes

> "...on these poles they form a floor of caña strips, above which they construct a hut, either a lean-to or one with a pitched roof..."[25]

This method and design is still used in today's *balsas* that transport wood and caña the length of the coastal rivers. The manner of constructing dwellings has not changed throughout the centuries, which supports earlier written descriptions of the traditional uses of caña:

1836 The historian D'Orbigny says

> "...the houses are of caña cut through the middle, without plaster or mortar to cover them, with roofs of the leaves of wild banana trees...the partition walls of all the constructions of Guayaquil are of earth (quincha) supported by cañas..."[26]

1881 Years went by and Carlos Wiener continued the description:

> "...they make the roof before constructing what is properly called a house; it serves the workers as a shelter from the sun or rain, according to the season. Beneath its cover they build the walls from boards or bamboo..."[27]

4. A Scientific Account

I want to especially emphasize the visit to Ecuador of the Baron Alexander Von Humboldt and the French botanist Aimes Bonpland, who arrived at Quito the 6th of January, 1802,[28] after beginning their scientific pilgrimage through America in Colombia. For ten months they travelled the country, making numerous, valuable observations. They travelled to Peru and returned to Guayaquil the 1st of January, 1803. There Humboldt began to write one of his most important works, "Geography of Plants,"[29] that he would publish two years later in Paris. In this work, as well as in his "Diary of the Trip,"[30] he mentions the guadua plant, giving skillfull observations about its habitat and average dimensions. He also mentions the harvesting of its fruit and calls the oily, siliceous substance (Tabasheer) that the bamboo secretes "milk of the bark," saying that they collected it for the first time to the west of the Pichincha volcano in May of 1802.[31]

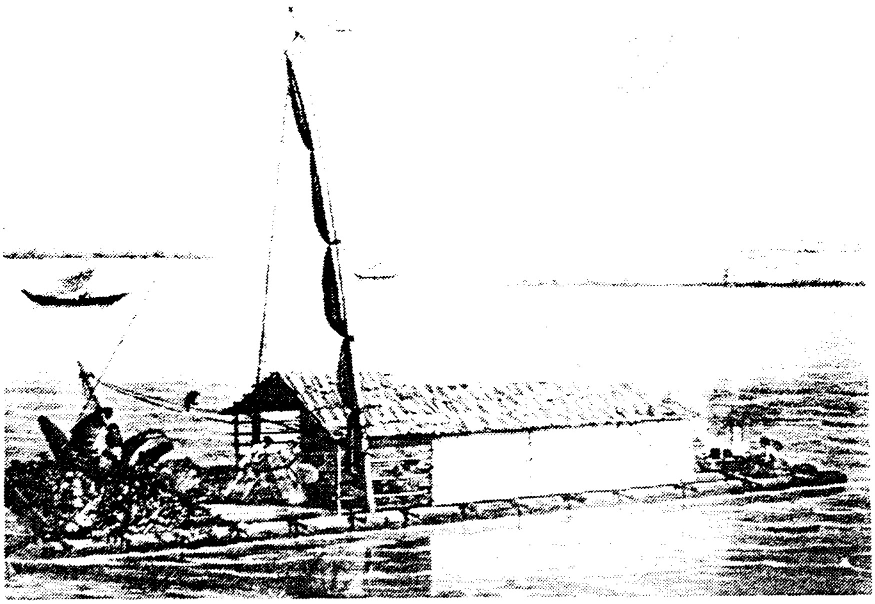

Figure 12. Traditional boat, according to a picture by Humboldt, 1803, from the L. Jijón and Caamaño Museum.

Figure 13. Bamboo flowers, picked in the experimental station of Pichilingue, in Los Rios Province.

For us, the most important and valuable contribution of Humboldt and Bonpland was to give guadua one of its first scientific names, *Guadua angustifolia*, and noting for posterity the scientific and economic importance of this grass, along with the various conditions for its optimal development.

> "...Without doubt, as social plants they offer a most luxuriant vegetation between the sea coast and an altitude of 780 m..."[32]

5. Bamboo and the Coastal Peasant

The peasants of the Ecuadorian coasts, be they montubio, cholo, moreno, colorado, or cayapa, use guadua in innumerable ways. It is not strange, therefore, to find next to their dwellings a small plantation of caña which the peasants call in their idiom a *mancha*. With the exception of the framework and the roofing material, their dwelling is entirely made of caña; walls, floors, stairs, doors, windows, and roof framework are all constructed with this material, following ancestral canons perfectly designed to meet the climatic conditions.

Figure 14. Peasant dwelling of the Ecuadorian coast, Los Rios Province.

Caña is used in various ways. They use it whole (*rolliza*), cut longitudinally in half (*guacay* or *latón*), in longitudinal sections from 6 to 8 cm wide (*latas*), in pieces 3 to 5 cm wide (*latillas*), or simply open and flattened (*caña picada*). Necessities other than houses are also made of caña; corrals, chicken pens, storage areas for grain, and objects for domestic use such as well covers, lattice frames, fishing instruments, small furniture, and poles or pruning hooks for tall fruit crops. The latter are made of bamboo poles which have been straightened by heating.

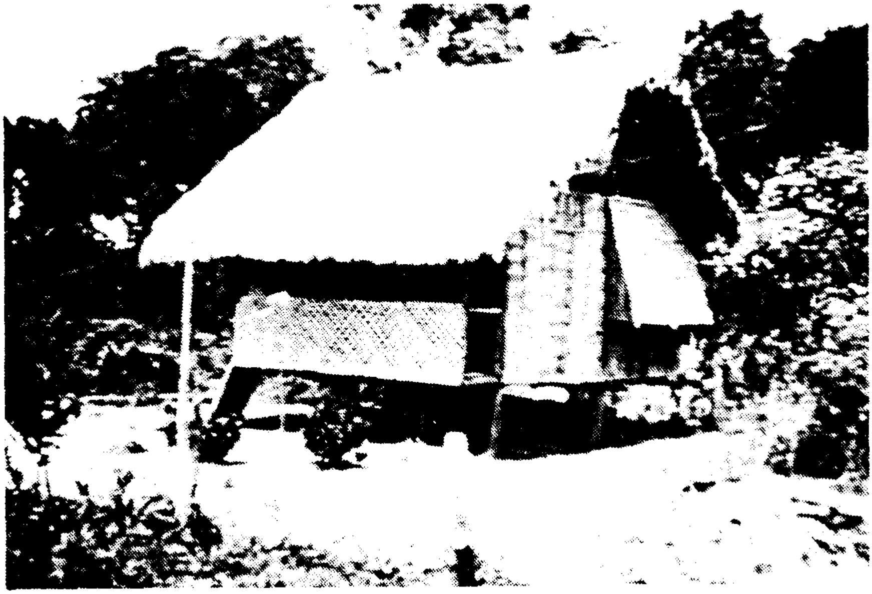

Figure 15. Peasant dwelling of the Ecuadorian coast, Guayas Province.

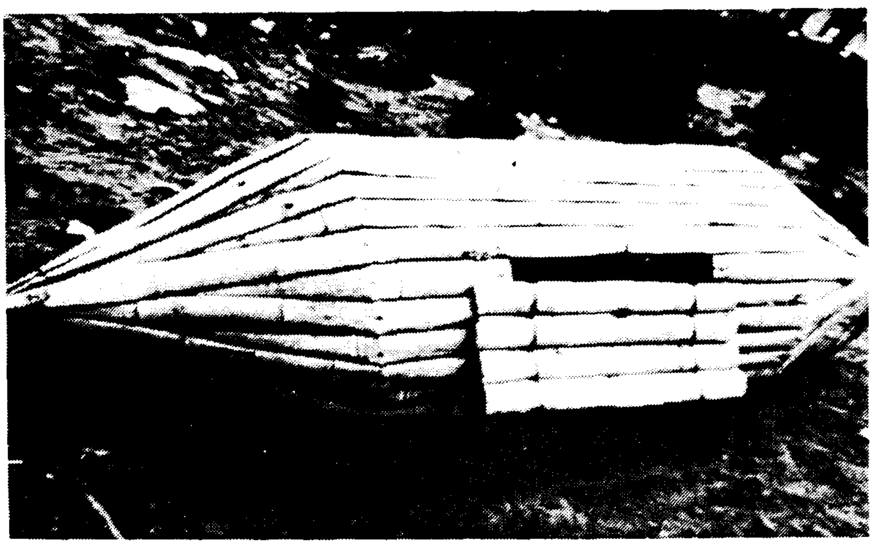

Figure 16. Fishing instrument and "cage" for live fish, Los Rios Province.

Figure 17. Pen for ducks and chickens, Manabi Province.

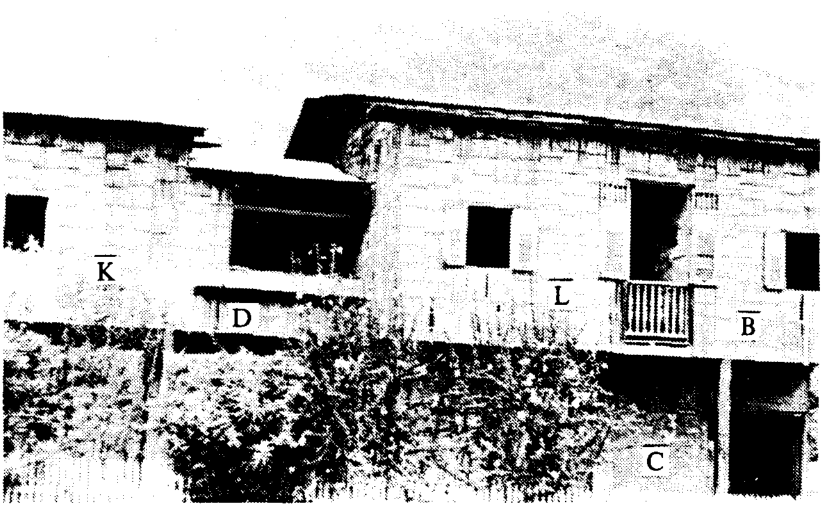

Figure 18. Peasant dwelling of "Jobo," Manabi Province. All the dwellings of this section have the same characteristics: Kitchen, Dining room, Living room and bedroom, and Cellars and grain storage areas.

Figure 19. Floating houses of the Babahoyo River, facing the city of the same name, Los Rios Province.

Today's boats preserve their traditional form, using strong, flexible bamboo as masts and rudders. The people know that one way to keep river banks from collapsing and subsequently eroding their land is to plant caña on the banks. If they need water they use an open caña to collect the rain that falls from their roof; they know that to work with bamboo they only need a machete to cut it down, open it, clean it, and transform it into the object they need. They traditionally follow the custom of cutting caña during the waning moon, at low tide, so that it will be stronger and last longer. They drink water from its *cañutos* for its medicinal effects and know how to transport along rivers enormous quantities of caña which they call *plantillas*. Bamboo helps them cultivate bananas; they support the fruit with sections of bamboo called *cujes*. Musical instruments such as flutes, marimbas, and so on are also of bamboo, as are toys such as *palos encebados* and the frames for children's kites. When "civilization" arrives they also use bamboo as poles for electrical wires and as tall bases for television antennas.

Their houses are the motif for pictures and postcards - their half-closed roofs demand a correct orientation and the perfect inclination to give them shade in hours of sun, and protection from the rain, at the same time allowing currents of air to circulate through lateral openings in the shelter, or through cracks in the floors and walls; advantage must be taken of the slightest breeze to make the hours of rest comfortable.

Bamboo, without doubt, is the most important article of the coastal Ecuadorian peasant.

6. A Special Case: Guayaquil

Both archaeological remains and the accounts of chroniclers during independence and colonial times have shown Guayaquil to be a population center that was born, grew, and developed architecturally using wood and guadua cane as the predominant materials in the construction of its dwellings. Historically,

> "...Early Guayaquil, because of the maritime commerce imposed by its geographical location, remained initially defined by its double function as provider of wood and caña for Lima and the other coastal cities of the Peruvian viceroy, and as principal port for the Audience of Quito..."[33]

As a port, it is well known that Guayaquil was the "...major shipyard in the Indies..."[34]; according to the Marqués de Selvalegre in 1754, craftsmanship and naval construction reached a state of near-perfection during the last two centuries of the colony.

Carpinteros de rivera was the name given the naval carpenters who, as the importance of the shipyards declined, began altering their trade. They even changed their names to "carpenters of the white" as they began to construct land dwellings, for which the precision of the cuts and joints of their old occupation was still necessary. This system of constructing wooden frames and walls of caña continued throughout the centuries, though later they would be covered with clay (*quincha*), and by the end of the XIX century, with galvanized sheet. One can still observe this system in construction in many sectors of the center of the Guayaquil.

Since the end of 1984 I have witnessed, through the action of local government, the demolition of numerous "old houses." I have observed that many of them, at first glance of concrete and brick masonry, had a wooden frame with walls of caña covered with a mortar of sand and cement - irrefutable evidence for the durability of those materials when properly used. During 1984 students in their first year at the School of Architecture of Laica Vicente Rocafuerte University took an inventory of the construction materials used in old houses built on the coast. There was not one coastal city that, among its houses 80 to 100 years of age, had not used wood and caña as construction materials; at the time of the inventory most were in magnificent condition.[35]

Our country has a population of approximately 8 million, half of whom comprise the urban population. The city of Guayaquil, with a population of 1.4 million, makes up 35% of the total urban population of the country. Of this total, approximately 600,000 inhabitants live in bamboo houses, or have in their buildings elements of this material. Enormous bamboo slums extend to the south, the west, and the north of the city. Their appearance is coincidental with the country's economic crisis and the lack of attention given to rural areas. Often called "squatter invasions," these uncontrolled settlements which appear between nightfall and daybreak are made from bamboo because it is the cheapest, lightest, and most adequate material available to the people of these cities. Consequently, bamboo construction has become a symbol of the misery and poverty of the country.

Precarious dwellings are constructed in mangrove swamps, with mud at low tide and water at high tide. The houses are connected by labyrinths of bridges, also of bamboo, that extend like interminable spiders of the mangrove, waiting for walls to be finished, and for the advent of electricity and public services; these are delivered in many cases according to the bribes and demands made by elected officials.

Figure 20. Suburb of Guayaquil. Bamboo houses, interlaced with bridges of the same material, raised above the swamp.

Guido Diaz says, referring to the uncontrollable growth of these dwellings, "...and they grow more quickly than plants..."[36], and like plants, they helplessly entangle the peripheries of small and large Ecuadorian cities alike.

In the year 2000, fifteen years from now, statistics and demographic projections show that Guayaquil will have a population of 3 million, with a need for 360 thousand living units. This means that it is absolutely necessary to confront housing problems not with conventional, uneconomical and inefficient systems, but by presenting alternatives that respond positively to our resources and to our traditions, and above all that better the quality of life of the people.

7. Floyd A. McClure in Ecuador

In 1945, Dr. Floyd McClure arrived in Ecuador as an agricultural advisor from the United States. According to his own account[37], the 16th of April, 1945 saw the first introduction of new species of bamboo to Ecuador. Eighty-five specimens of sixteen species of bamboo were flown to the Experimental Station of Pichilingue, Los Rios Province, today a division of the National Institute of Farming and Animal Husbandry of Ecuador (INIAP). Sixty-three of the specimens arrived alive.

Unfortunately the departure of Dr. McClure and the little importance that the federal technicians gave to the growing crop left few species surviving today. I must note that the species *Dendrocalamus asper* (Schultes) Backer, of which only one specimen arrived, has been reproduced with success in various sectors of Los Rios Province. The most notable cultivation of that species was begun in 1946 by Mr. Federico Von Buchwald, in the then Hacienda La Florida, today a military base of the Armed Forces of Ecuador.

Figure 21. Giant bamboo (*Dendrocalamus*) from Quevedo, Los Rios Province, introduced by Dr. Floyd McClure in 1945.

Figure 22. Clump of *Dendrocalamus* in Quevedo, Los Rios Province.

The attractive, beautiful plantation mentioned above was the motif of the poster of the Second Latin American Bamboo Symposium, which took place in Guayaquil in September of 1982, and which was well attended.

The contribution of Dr. McClure does not consist solely of introducing new species, but includes his innumerable observations on the use of bamboo by Ecuadorian peasants and its use in cities such as Guayaquil, Quevedo, and Manta. McClure compiled scientific and photographic material that appears in some of his works, especially in "The Bamboo as Construction Material,"[38] where he made valuable recommendations on its proper use.

8. First Experiments in Ecuador

Even though the entire history of the pre and post Columbian cultures of the coastal region of Ecuador had been linked to the use of guadua, little or nothing had been done to study the plant's taxonomy, cultivation, propagation and possible uses. It was considered to be a wild plant that naturally reproduced and grew; interest in studying it agriculturally, botanically, industrially, or as a construction material of social interest could not be found in a single profession or university. In 1970 a series of experiments was begun in Ecuador which I will now cite and accompany with a short commentary.

8.1. The Arnaldo Rufilli Laboratory of the University of Guayaquil

In January, 1975, a group of engineers from the Institute of Investigations and Advanced Studies (IIEA) of the School of Mathematical and Physical Sciences of the University of Guayaquil was asked by the National Housing Board to subject a series of bamboo specimens to physical and mechanical testing. The test results for bending, tension, compression, and impact were given in a report that, unfortunately, has not been published[39].

8.2. The National Housing Board and Bamboo

The government agency in charge of national housing has carried out a few experiments based on guadua.

8.2.1. Bamboo Use in Reinforced Concrete

Only a few slides[40] remain as evidence of the experiment carried out in the housing program of "La Pradera," where they constructed two houses using *latillas* of bamboo as concrete reinforcements instead of iron rods. The experiment was not followed up because the records of the house locations were lost, but so far there has been no news of defects or fractures in the program's houses, which indicates they remain in good shape.

8.2.2. Salto Program, City of Babahoyo

In 1976, across the river from the city of Babahoyo, Los Rios Province, a 154 unit housing program was completed with construction areas of 70 square meters in lots from 300 to 400 square meters. Constructed in three stages, using pillars of wood and then of concrete, they built walls and floors of caña, windows and doors of wood, and roofs of galvanized sheet. The houses were built on lands that were frequently flooded, but in 1984 their elevation was raised by means of hydraulic refill, which has radically changed the way the houses are settling. The value of the houses went from $1,900 to $2,400 in 1974[41].

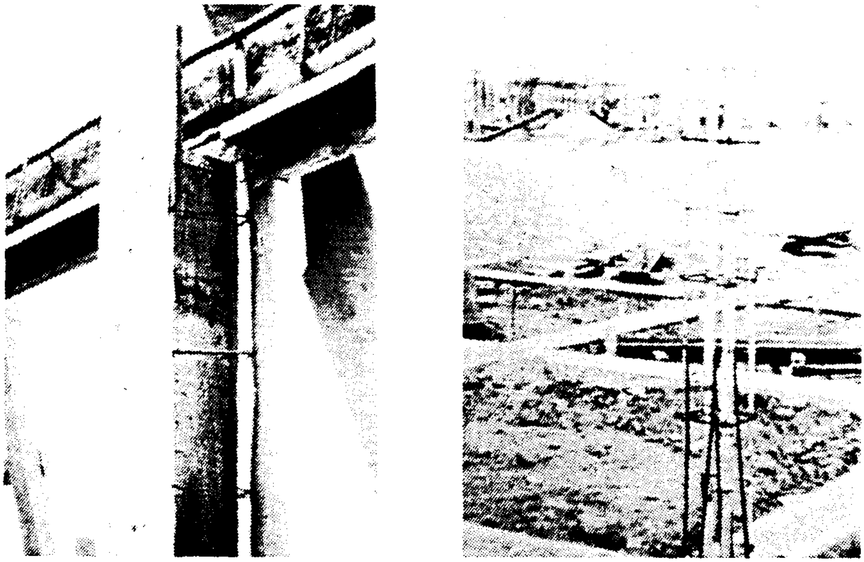

Figure 23. Use of bamboo as a substitute for iron, National Housing Board, "La Pradera" housing program.

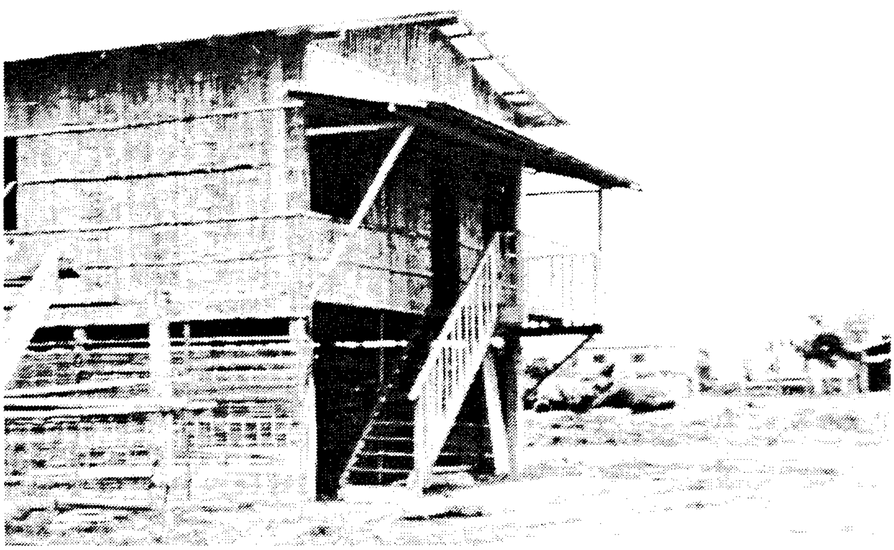

Figure 24. El Salto Housing Program, National Housing Board, Babahoyo, Los Rios Province.

8.2.3. Potosi Program, Esmeraldas Province

Also in 1974 the "Potosi" program, located in the city of Esmeraldas in Esmeraldas Province, came to a close. Financed by the Port Authority and CEPE (Ecuadorian State Petroleum Corporation), the National Housing Board constructed 62 units with living spaces of 46 square meters, each one on lots from 160 to 240 square meters, at a cost of $1,000 in 1974. The houses were built of simple blocks of concrete, with wooden frames, walls of caña, floors, doors, and windows of wood, and roofs of galvanized sheet[42].

To date the houses have deteriorated in form and condition and have not had their walls covered with mortar of any kind. Their poor appearance and deterioration, like the houses of El Salto, has contributed to the bad reputation and low prestige given bamboo houses in general.

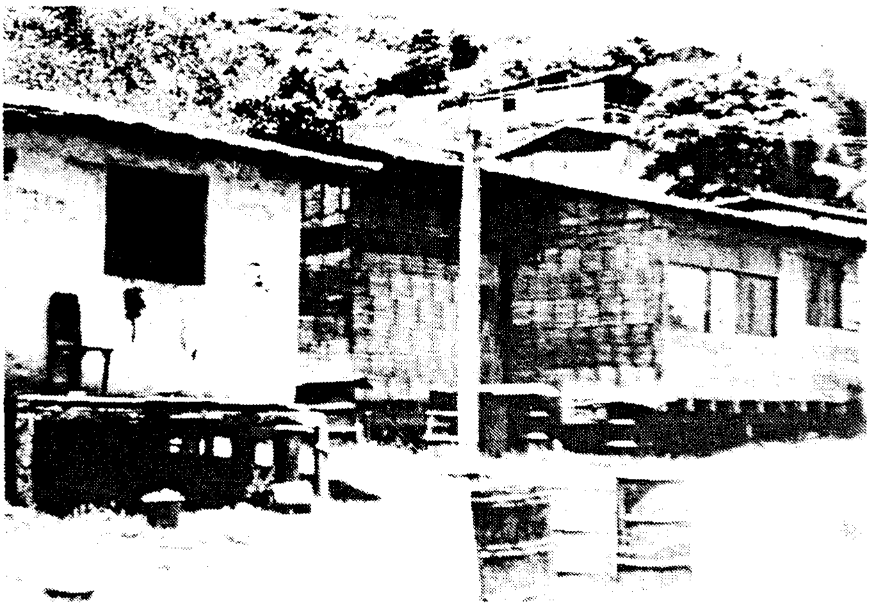

Figure 25. The Potosi Housing Program, Province of Esmeraldas.

The National Housing Board did not return to using bamboo in their housing projects until 1984 when they repeated its use in the Floresta II program overseen by Architect Oscar Hidalgo under the auspices of the United Nations. This program of barely 12 units was successfully carried out, and constitutes the beginning of the vindication of bamboo in Ecuador. I will analyze the program in a separate chapter.

8.3. The Patfoort Experimental Housing Program

Between 1981 and 1982 the construction of sixteen dwellings, financed by the United Nations and PREDESUR (Regional Development Program of the South) was completed. The technology and materials used, without a doubt, were more sophisticated than one usually associates with bamboo, which was used as a light material to support the elliptical tubes. Bamboo was also the material used for walls and certain furnishings

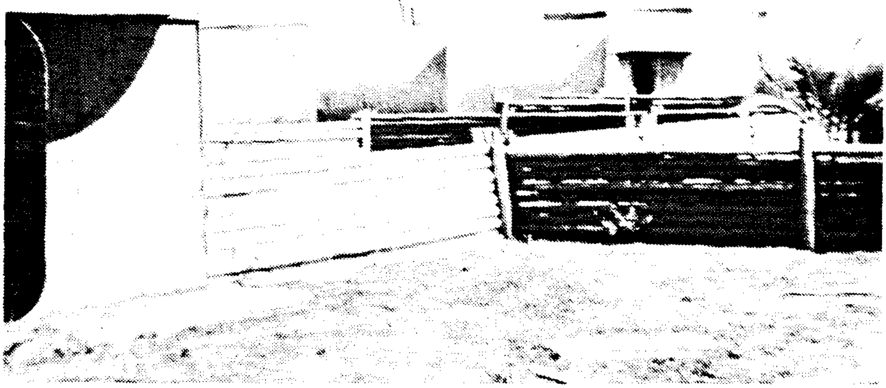

Figure 26. Experimental Program of Patfoort, Huaquilles, El Oro Provience.

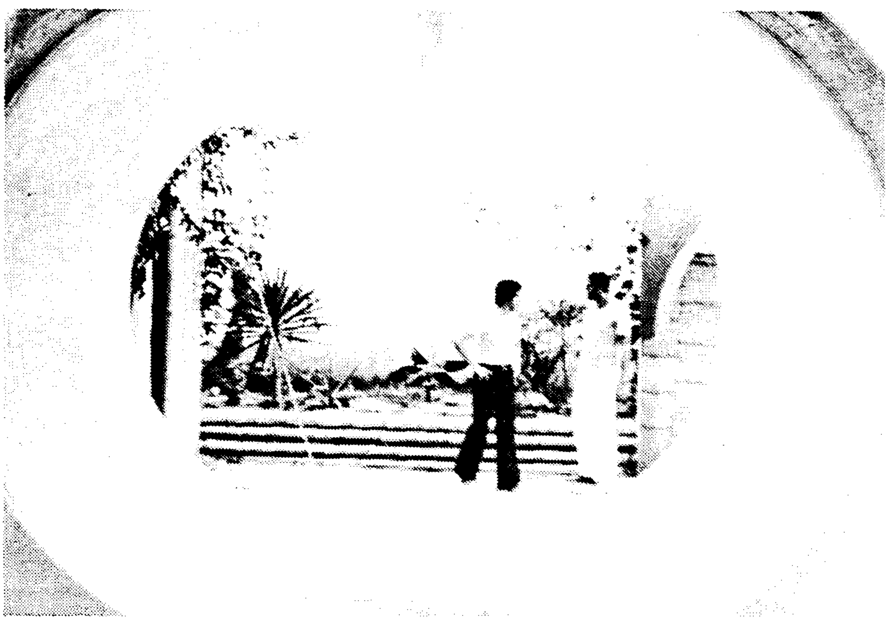

Figure 27. Experimental Program of Patfoort, view of one of the modules made from polyester resin and fiberglass reinforced with bamboo.

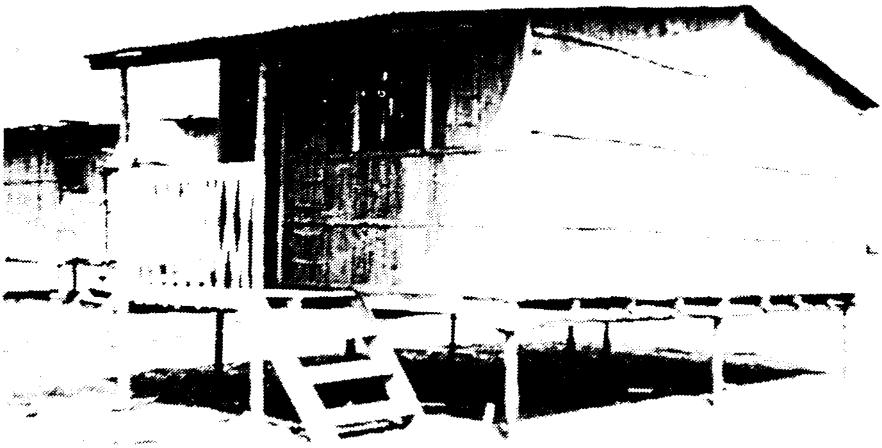

Figure 28. A Hogar de Cristo Corporation house, Guayaquil.

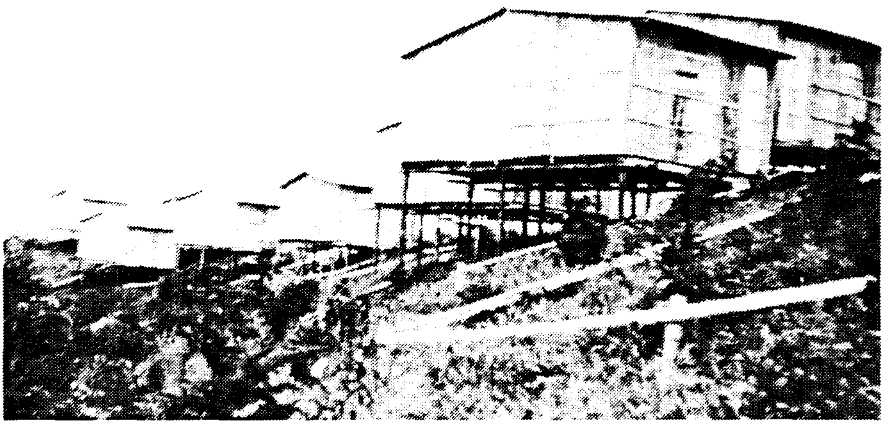

Figure 29. Hogar de Cristo dwellings, built in the settlement of Mapasingue, Guayaquil.

covered with fiberglass. The materials used other than bamboo were a polyester resin used as glue or cement, fiberglass as reinforcement, and finally, wooden floors. Each dwelling is made up of four modules or elliptical sections of tubes, with a uniform weight of 240 kg per module. The houses have a surface area of 56 square meters, on lots of 200 square meters.

The experience of the program indicates that this type of housing is feasible in an emergency, but not as something permanent, both because of the physical-thermal properties of the material and because the form of the modules was never accepted by the users, accustomed as they were to traditional forms. The building's value was $6000 in 1982[43].

8.4. Hogar de Cristo Housing Corporation

The Corporation is a nonprofit social institution. Its work was begun in 1970 by the priest Francisco Garcia S.I., who developed a housing program for low income families. The Corporation gives the beneficiaries prefabricated walls of bamboo, the frame of the roof, the roof of asbestos cement, the floor, doors and windows. The recipient prepares the foundation and raises the dwelling under the direction and control of the Corporation.

To date they have given more than 4,500 units to very poor families. Each house was worth $220 in 1984, which amounts to mortgage payments of $6 per month, making this among the cheapest housing in the world. The houses are of two types: 20 square meters and 40 square meters. The above costs are for 20 square meters giving a cost in 1984 of $11 per square meter per year. The Corporation also builds schools, community centers and convents. The walls of these houses are not covered with mortar.

9. Two Happenings

In August, 1981, supported by the National University of Colombia, the First Latin American Bamboo Symposium took place in the city of Manizales, Colombia, thanks to the help of Architect Oscar Hidalgo Lopez, professor of the School of Arts of the University of Colombia. I must here honor him and acknowledge his extraordinary efforts to popularize and further the study of bamboo.

The Latin American Association of Bamboo was set up, and with the presence of numerous delegates from all of the Americas, planned a date for a second symposium, this time in Guayaquil, Ecuador. In September, 1982, the Second Latin American Bamboo Symposium took place at the Laica Vicente Rocafuerte University.

The event had the backing of numerous institutions, and the presence of experts like Dr. Li of China, Dr. Cleofe Calderón of the Smithsonian, Dr. Ansio Azzini of Brazil, and architect Oscar Hidalgo himself among other scientists and 400 national and foreign delegates who attended. The event was reported by the national news agencies as being of high scientific value because of the quality of the exhibitions and the content of the papers.

For Ecuador in general and for the Laica Vicente Rocafuerte University in particular, the two symposiums offered more than sufficient reasons for initiating a series of studies and investigations, counting on the help of the International Development Agency (A.I.D.), Architect Oscar Hidalgo of the United Nations, the National Forestation Program (PRONAF) of the Ministery of Agriculture and Livestock of Ecuador, and other institutions and persons that understood the real scientific, economic and social value of guadua.

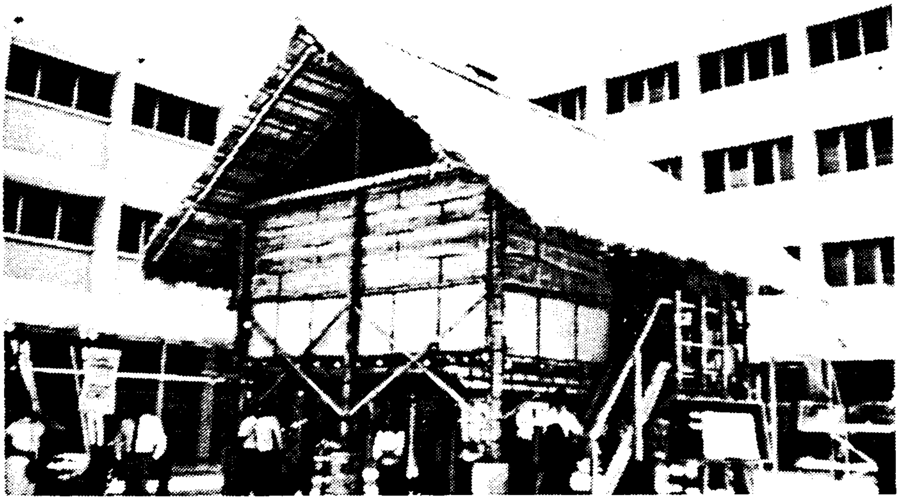

Figure 30. Experimental construction built in the Laica Vicente Rocafuerte University of Guayaquil by students of the Architectural School, for the Second Latin American Bamboo Symposium, 1982.

10. Investigations and Experiments at Laica University

10.1. Inventory of caña guadua in the coastal region of Ecuador.

Ecuador did not have an adequate record of the volume of natural guadua reserves in the country, or a summary of areas, which were or could be cultivated, either for industrial use or export. The A.I.D. and the Department of Agriculture and Livestock, through its National Forest Program, agreed with Laica University to undertake an inventory of resources, their geographic distribution and their growth habits in their native environment. The inventory was to conclude with a report describing methods and results.

Without further comment I will now list some of the results obtained by December of 1984. Guadua is distributed over a total area of 40,000 square km on the Ecuadorian coast of which 150 square km is accessible to commerce. The approximate number of plants is calculated at 27 million. Its natural habitat is defined by an altitude ceiling of 1200 meters above sea level and annual rainfall of at least 750 mm.

The major production of guaduas is in zones receiving between 1800 and 2200 mm of annual rainfall, which corresponds ecologically to very humid tropical forests.

The inventory found that the most common varieties are guadua *comun* or *mansa* (common or tame guadua) and caña *brava* (giant caña). It also found that the average caña has a diameter of 11 cm, a height of 14 meters, and a weight of 31 kg; the diameter ranges from 8 to 23 cm and the height from 11 to 23 meters. The average caña, when opened and flattened, covers an area of 4.5 square meters.

Figure 31. Laica University student constructing an experimental bamboo house, 1982.

Guaduas grow in small areas called *manchas* or clusters; of the 75,000 clusters recorded, 93% are smaller than 0.5 hectares. The size of the *manchas* ranges from 100 square meters to 10 hectares; there total area is 15,000 hectares. A conservative calculation of the number of plants per hectare is 1835 single canes, with actual counts ranging between 800 and 15,700. The inventory covered an area of 61,500 square km, almost the whole Ecuadorian coast[44].

10.2. Commercialization of Guadua

At the same time that A.I.D. and Laica University were taking their inventory of the wild guadua, they also studied its commercialization. They wanted to determine the types and commercial sizes of guadua at the producer level; the cost of transportation, cargo, and tariffs per kilo per km; points of destination; size, etc. They also determined the number of wholesalers, number of warehouses, earnings, profits, final destinations including those in bordering countries, and forms of transportation.

The resulting report established various key parameters, among which I emphasize the considerations the peasants traditionally use before cutting the cane, such as the period of the waning moon, low tides, and the small whitish growth areas on the cane - all signs that they study before harvesting the plant.

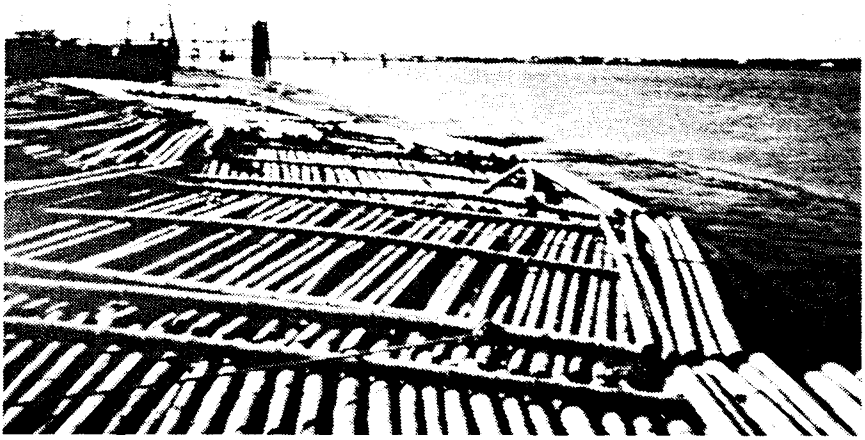

Figure 32. Transport of caña guadua through coastal rivers.

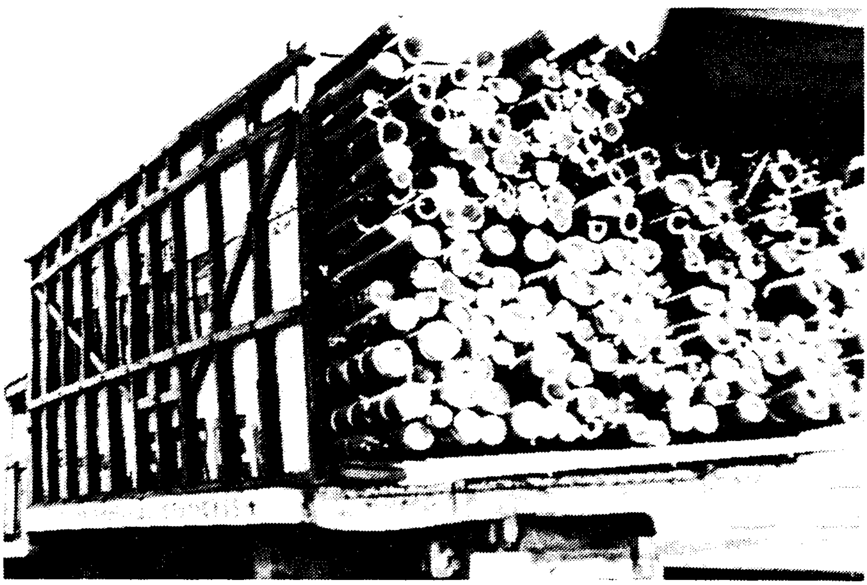

Figure 33. Transport of caña to Guayaquil and Peru using trucks.

The study determined a preference for the caña *mansa* because of the ease of cutting, transporting, and "working" it. Even though they realize that caña *brava* is more resistant than caña *mansa*, they feel it is more difficult to manage because of its spines.

Caña ready for market ranges in length from 6 to 8 varas from distributors in the cities, while at the haciendas they are between 16 and 18 varas. This produces an ample profit to the transporter-merchants who can obtain up to two units from each caña plus the tip of the bamboo, or *cuje*, which they sell to the banana plantations. They transport caña by truck and on a lesser scale by waterways as in times past.

In 1984, prices for a single cane ranged from $0.12 to $0.50 at the point of production and from $0.25 to $0.60 at the warehouse. Flattened canes brought from $0.03 to $0.06 more per unit.

It was found that two million units of caña were needed for the coast; 400,000 of these are destined for Peru, while the rest are for construction of dwellings on the outskirts of cities as well as for auxilaries to modern construction in the form of planking supports, painting and masonry scaffolding, etc.

I conclude from this study that although the cost of guadua has risen in the past few years, the increase has not been as great as for other materials in the construction industry such as iron and cement. This is because bamboo can be grown with little care. People in our country do not invest in bamboo cultivation; its production is completely natural[45].

10.3. Improvement of a House in Manta, Manabi Province

The tradition of using bamboo for dwellings has continued throughout the whole coast of Ecuador, but at the same time its poor utilization on the outskirts of cities and towns has produced considerable prejudice.

The city of Manta, through its mayor, Onofre DeGenna, Esq., solicited from Laica University and A.I.D. a model demonstration of how low income housing might be improved. They chose the neighborhood "20 de Mayo," situated on the edge of the city. The settlement consists of 300 similar dwellings built with bamboo walls. Two years after construction, they are a picture of misery and decay with a high fire risk. They are buried in dust in summer and flooded with rain in winter.

In October of 1984, a demonstration house was located. Its unemployed owner began the improvement work assisted by three neighbors and the occasional help of students from the School of Architecture of the University. The six member family moved to the back of the house and work began on the front using the material that remained in good condition and replacing the rest. They reinforced supports, changed a few floorboards, raised walls of bamboo, put up a smoothed ceiling matching the walls, added an inclined roof and erected a few sheets of asbestos cement to lengthen the eaves. They installed the electrical wiring and covered the house with a mortar of cement and sand. After putting in doors and windows, they painted the whole house.

The basic original design was not radically changed; at the end of three weeks, the house was much more comfortable. It was insulated, sanitary and secure. The cost of the improvements on 50 square meters was $500 in 1984. It is worth mentioning that the sanitary level was improved by constructing a small toilet from a bamboo frame covered with sand-based concrete.

Figure 34. A house in Manta as it looked before improvement, October 9, 1984.

Figure 35. The same house after improvement, November 4, 1984.

10.4. A Communal House in Manta, Manabi Province

The success of the prototype caused the City to seek further support under the program for the construction of a communal house in the same "20 de Mayo" neighborhood. Construction began with the design of two levels that would serve as nursery and multiple use rooms. The supporting structure of the first level and the floor of the second level were built of wood. In the secondary beams they experimented with bamboo trusses in place of iron rods, following the experiments of Hidalgo[46]. The framework supporting the roof, like the wall-covering, was done with guadua *rolliza*. The walls and the ceiling were constructed with panels of bamboo. The roof was of galvanized sheet whose high heat conductivity was mitigated by installing level insulated panels as the ceiling. The walls were then covered with mortar of cement, lime, and sand, and to finish it off, were painted.

Today the building serves the community. The building covers 110 square meters at a total cost of $4,200 in 1985.

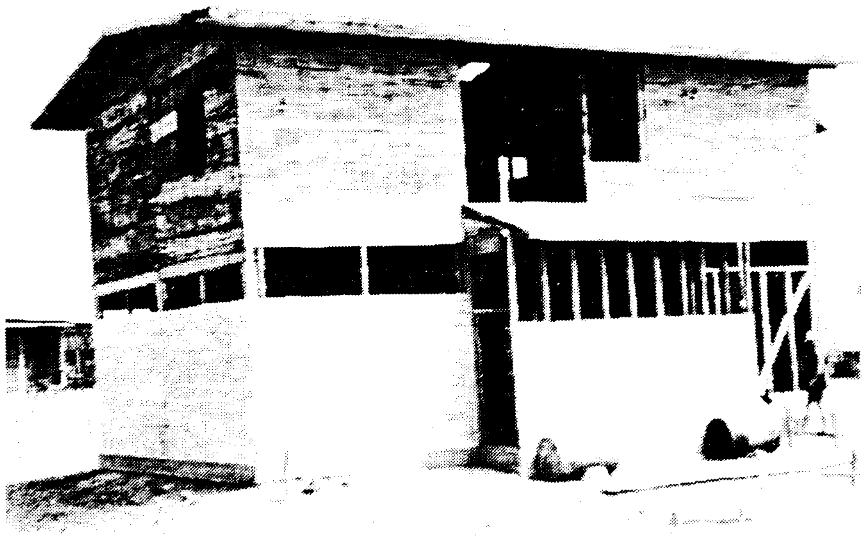

Figure 36. Communal house in Manta during construction.

10.5. Covering Bamboo Panels with Various Types of Mortar

Using traditional sand-based cement mortar to cover bamboo walls tends to create cracking. In February and March of 1985, A.I.D. financed an investigation of different types of mortars applied to bamboo panels. The investigation was carried out by Architect Oscar Hidalgo Lopez and myself. We wanted to establish which types of mortar would improve adhering conditions, lower the percentage of cement, retain optimal esthetic conditions as a covering, and diminish cost and weight of the panels.

Figure 37. Students from the Architectural School of Laica University building a frame of braided bamboo cables for use in a concrete beam.

Twenty-four experiments were carried out on a total of 400 square meters under rigorous control of variables (weight, volume, humidity, temperature, cost, resistance, etc,). Different combinations of materials were applied to open, flattened panels of bamboo set in different ways. Interesting preliminary results were obtained, and in the next months we will learn details of the investigation which no doubt will contribute towards improvements of bamboo construction techniques.

10.6. Study of Materials and Construction of Different Types of Peasant Dwellings on the Ecuadorian Coast

With the backing of A.I.D. and the United Nations, Laica University in 1984 completed an inventory of the materials and construction methods used by coastal peasants to build various types of housing. The main objective was to learn the peasant's traditional ways of using bamboo, to observe their ancestral construction techniques, to establish the basic parameters that they bring to the pragmatic design of their houses, which are extraordinarily conditioned to the environment, and finally to draw conclusions that permit the employment of their own technology, improved and more economical, for the design and construction of a house of social significance.

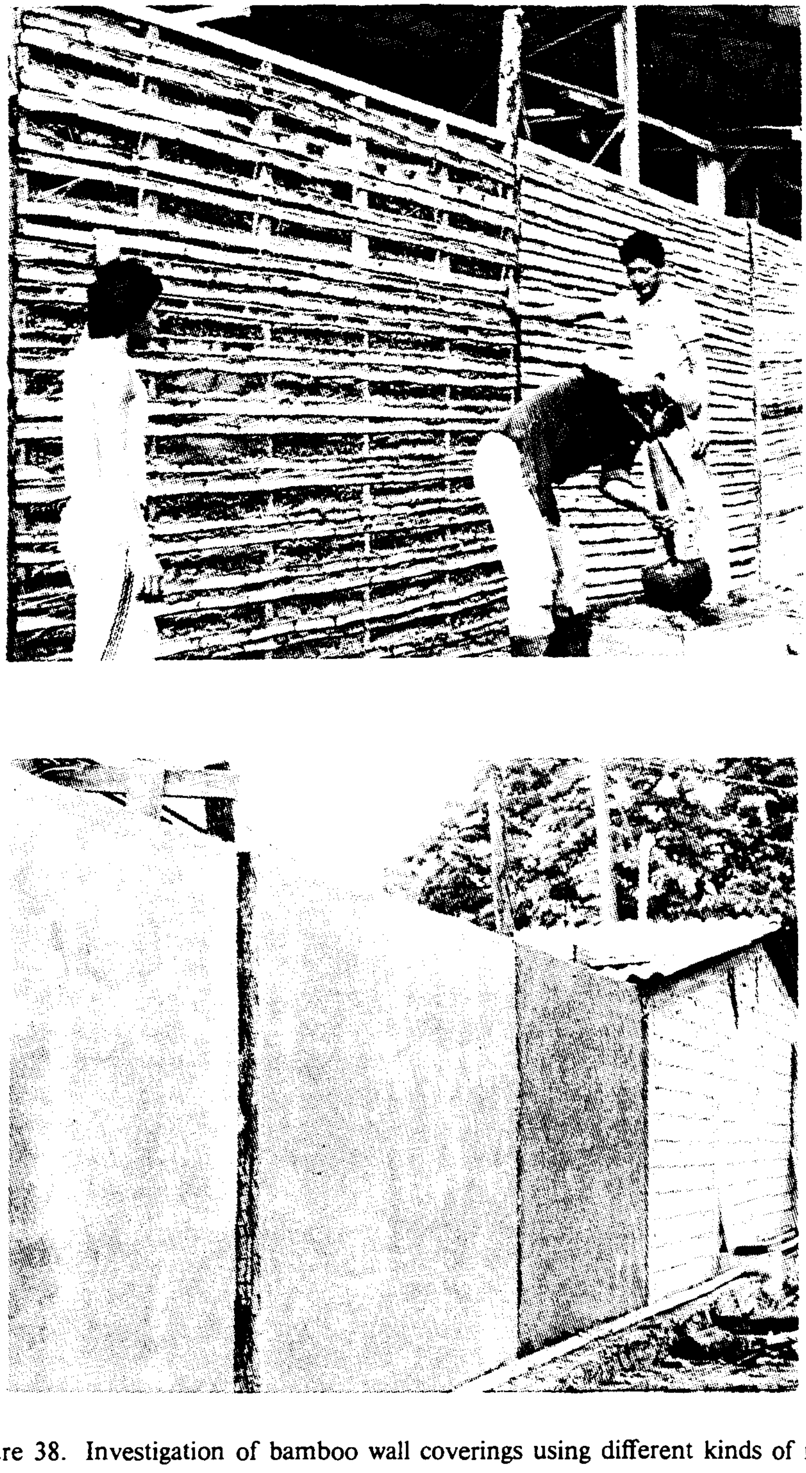

Figure 38. Investigation of bamboo wall coverings using different kinds of mortar, February, 1985.

Extensive field research took place, with the participation of students and professors alike, encompassing hundreds of cases, detailing properties of materials, in order to recover practical, and above all, Ecuadorian designs and systems. A.I.D has assumed compilation of the results along with similar focuses in other areas of the country.

11. Homes of the Shoemakers

With the cooperation of the United Nations and as part of the project ECU/79/006, the National Housing Board and the International Labor Organization (ILO) established a housing program, using bamboo, with Architect Oscar Hidalgo Lopez in charge as consultant from the United Nations for human settlements. He organized a housing construction program for twelve families whose oldest wage earners were all employed as shoemakers. The program was located in the neighborhood called "La Floresta," in the "Guasmo" sector to the south of the city of Guayaquil.

Over a compacted fill, perimetrical beams were joined to a framework of cables of braided bamboo. The foundation of the floor was poured over a rectangular mesh of bamboo. The walls were prefabricated, made from caña *rolliza* covered with caña *picada*. Reinforcing the dwelling, the walls were covered with a sand-based cement mortar, and painted with carbide.

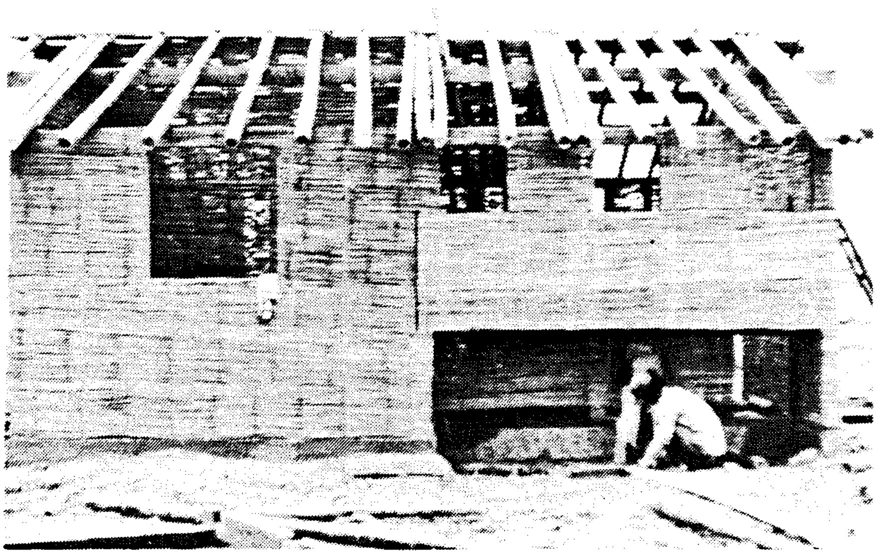

Figure 39. Construction of prefabricated houses of bamboo, "La Floresta" program, Architect Oscar Hidalgo Lopez, Guayaquil.

The doors and windows are of wood; the asbestos cement roof is supported by a bamboo framework covered by flattened bamboo both above and below. The dwellings were built on the perimeters of the land, leaving in the central part a space for future construction.

Architecturally, a flexible design was chosen and adapted to the specific needs of the occupants and site. The basic model of 3.2 x 6.4 meters might vary up to 34 and 41 square meters. The cost per square meter was $42 in 1984.

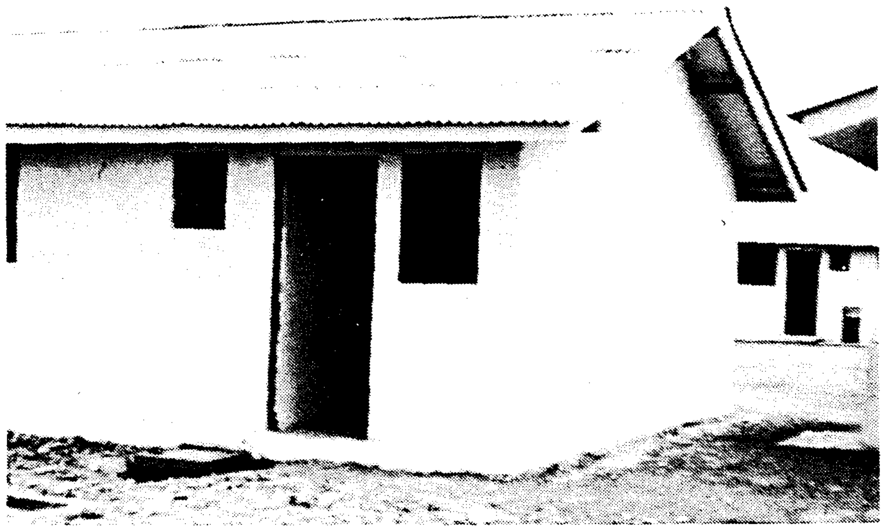

Figure 40. One of the twelve shoemakers' houses, "La Floresta" program, Guayaquil.

The houses have a pleasing esthetic aspect, and are efficient and comfortable because of the air chambers in the walls. Without doubt this is one of the best bamboo-based programs in Ecuador because of the sensibility of the system of prefabrication, completion and mounting which requires no specialized craftsmanship or equipment.

The use of guadua, a natural resource of the country, and of other techniques adapted to the needs of the people of the suburbs of Guayaquil, together with the low cost of bamboo housing, give a positive alternative solution to a grave housing problem.

12. Final Commentary

This document has not tried to be quantitatively exhaustive, but rather qualitatively representative. I have summarized the use of bamboo in Ecuador through the ages, emphasizing the first effective steps toward the rescue, conservation, cultivation and propagation of one of the most used and at the same time least understood natural resources of the country.

I am completely convinced that by using conventional systems of construction and reducing areas, heights, etc., we will never be able to design homes for, and worse, to provide homes to coastal Ecuadorian peasants. To think otherwise is cruel and utopian, especially now that the economic situation in Ecuador and the demand for houses are inversely proportional; buying power is diminishing as the need for houses is progressively increasing.

What is the answer? To continue to use alienating and anti-human construction materials for our hot and humid climate? Sheets of reinforced concrete for walls and roofs? To further reduce the already miniscule vital space for the family? Or is it not more fair and logical to look for alternatives among our own natural resources, with our own technology and design, of such form that together they permit us to glimpse some solution to the now grave housing problem that not only affects Ecuador but all the countries of Latin America.

Notes

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Wen Tai-hui*: **Some Ideas about the Origin of Bamboos**

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This paper discusses the evolution, primitive types and distribution of bamboos. In order to supply enough information for production and scientific research, it summarizes comprehensively the characteristics of both primitive and highly evolved species of bamboo.

1. Distinguishing Primitive Types by studying Bamboo Evolution

Bamboo genera fall into two categories, woody and herbaceous. There are about 78 woody genera with some 1400 species, and 29 herbaceous genera with some 170 species in the world. They are distributed over Asia, South America, North America, Africa and Oceania. China has 37 genera with more than 400 species and is considered a place with widely distributed, diverse species. There, species are not isolated from each other; they are linked together and interrelated. Despite these relationships, there are large differences between primitive and evolved types. We may keep track of bamboo evolution by studying models of the morphology of vascular bundles of bamboo culms, rhizome types, the structure of the inflorescence and the morphology of the vegetative organs.

1.1. The Relation between Evolution and the Simplification of Vascular Bundles

After examining the vascular bundle anatomy of 80 species of bamboo representing 21 genera, we agree with the four models for types of vascular bundles described by the German scientists Grosser and Liese (1973), and we add one more. The first four types were named by Mr. Zhu Hui-fang as the Double Broken type, the Broken type, the Slender Waist type and the Open type. I have named the fifth one, the Semi-open type. The five models are very useful in the study of bamboo systems, and they also play an important role in the classification of bamboo species. Simplifying the range of vascular bundle anatomy to five types appears to adequately model bamboo evolution. Both the Double Broken and the Broken types are primitive, but the former is more primitive. These two types often appear in the middle part of the same culm. When they appear together, we put them into type I, the Double Broken type. This occurs in the genera *Thyrsostachys* Gamble, *Cephalostachyum* Munro, and in some species in the genera *Bambusa* Schreber and *Dendrocalamus* Nees. Only when the Broken type is found alone, is the species classified as type II, the Broken type. This occurs in some species of *Bambusa*, *Lingnania* McClure and *Dendrocalamus*. These genera are all sympodial; they have sympodial rhizomes, which give rise to closely spaced culms forming what is called a cespitose clump. Slender Waist vascular bundles are intermediate, usually found in bamboos whose clumps are between cespitose and diffuse. However, the Slender Waist type is not found alone. In *Schizostachyum* Nees, it is found together with the Broken type, the Slender Waist type tending toward the Broken type. In *Melocanna* Trinius, the opposite is true; the Slender Waist type is found with the Open type, and it tends toward the Open type.

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The rhizomes of Open type bamboo are sympodial but form diffuse rather than cespitose clumps. The Open type can also be found among leptomorphic rhizome systems such as those in the genera *Phyllostachys* Sieb. & Zucc., *Pleioblastus* Nakai, *Pseudosasa* Makino ex Nakai and *Brachystachyum* Keng. The Semi-open type can be found in the genera *Sinobambusa* Makino ex Nakai, *Indosasa* McClure, *Sasa* Makino & Shibata, *Yushania* Keng f., *Fargesia* Franchet, *Indocalamus* Nakai and *Gelidocalamus* Wen.

The simplification process of vascular bundles is as follows. When the outer fiber strand of the Double Broken type degenerates, the Double Broken type is transformed into the Broken type, and when the inner fiber strand of the Broken type extends outside and links with the inner vascular bundle sheath, the Broken type is transformed into the Slender Waist type. When the inner vascular bundle sheath of the Slender Waist type becomes contracted and simplified, the Slender Waist type is transformed into the Open type. When the left side and right side vascular sheaths of the Open type link with its inner vascular sheath and gets contracted and simplified, the Open type is transformed into the Semi-open type. This simplification process follows the evolutionary sequence. The degeneration and simplification of fiber strands and vascular bundle sheaths manifests the strengthening of the function of conduction tissue and bamboo resistance. Also, it promotes shorter bamboo culms, which might not be desired by man. But sometimes human requirements do not coincide with the evolutionary requirements of plants.

1.2. The Evolution of Rhizomes

Bamboo rhizomes can be put into four categories: clumping sympodial, running sympodial, amphipodial and monopodial. The clumping sympodial rhizome is the most primitive type. It restricts the plant to a limited space, and only after blooming and bearing fruits, can the seeds be spread to other places by wind or animals. This type of bamboo can therefore only adapt to the local climate and environment. The running sympodial rhizome has an extended culm neck which looks like the running monopodial rhizome. It occurs, for example, in *Melocanna* Trin. and *Pseudostachyum* Munro, whose culm necks can extend as long as a meter underground producing separated culms. The adaptation is much greater than that of clumping sympodial rhizomes, because the culms can spread to other places much easier and faster. But the culm neck, which looks like a running monopodial rhizome has neither roots nor buds, so we call it a rhizoid (rhizome like). When the rhizoid develops into a rhizome with roots to absorb nutrients and buds growing out of the ground to become culms, then the sympodial type is transformed into the amphipodial type, which has much wider adaptability. For the monopodial type, the culm base has roots, but no buds; only the buds on the rhizome can grow out of the ground and become bamboo culms. The rhizome can thus form independent systems.

The developmental course of *Phyllostachys pubescens* Mazel ex Houzeau de Lehaie seedlings recapitulates the complete evolution process of bamboo rhizomes. At the beginning, the seedlings tiller with new culms growing at the base of older culms. At this stage, they have cespitose clumping, sympodial rhizomes. In the next year, a rhizoid appears and extends, producing culms away from the parent culms. Next, the rhizomes become amphipodial, and finally they develop into the monopodial type. In the beginning, the foliage leaves are large, which is characteristic of cespitose bamboo, but as monopodial rhizomes form, the foliage leaves become smaller and smaller.

1.3. The Evolution of the Inflorescence

The evolution of bamboo plants is shown in the morphology of the inflorescence. The spikelets of primitive species almost always appear directly on vegetative organs, i.e., on the nodes of culms or branches, whereas the spikelets of more evolved species almost always appear on reproductive organs, even on the rachis. The bases of spikelets of primitive species usually have buds and prophylla, but sometimes the buds degenerate. These are all characters of primitive species. Comparatively speaking, the species with prophylla but without buds are more evolved than those with both. The spikelet clump has large numbers of spikelets and the character of an inflorescence. The spikelets have no pedicel and bunch together forming a capitulum. This is seen very commonly in the primitive species. Sometimes the spikelets have pedicels and form into a racemose inflorescence. In fact, the pedicel is not a real one; it is the internode of a vegetative organ, so we call this kind of pedicel a "pseudopedicel." The species with a pseudopedicel are more evolved than those without. Another type of primitive inflorescence is one that does not grow on a culm or branch but on the top of a branchlet with foliage leaves around it. It forms a terminal inflorescence, which is more evolved than a lateral one. For the branchlet, it is a kind of vegetative organ, and on the whole it is primitive. Among the primitive types, however, it appears less primitive and a bit more evolved. As evolution continues, changes occur in the inflorescence which result in a type of spikelet appearing on reproductive organs, or we can say appearing on the fully split rachis of the reproductive organ. The base of the spikelet has neither buds nor prophylla. The pedicel of the spikelet is the reproductive organ. The pedicel of the spikelet appears on the rachis, and the rachis is also a reproductive organ with no internode, so it does not drop off easily. The whole inflorescence including its rachis has the character of a reproductive organ, which we call the reproductive inflorescence. The evolution of this type of inflorescence is from the lateral form to the terminal form.

The greater the number of stamens, the more primitive the bamboo, Conversely, it is a sign of evolutionary progress to have fewer stamens. To a certain extent, evolution produces a fixed number of stamens. Also, primitive species have larger lemmas with more veins.

1.4. The Relation between Evolution and Stability

In absolute terms, evolution does not allow plants to fix their size or other characters since these change slowly and frequently in the course of development. But speaking comparatively, the development size and other characters can be stable. The greater the number of stable characters, the more evolved the species. To have variable numbers of branches, buds, stamens, stigmas or lodicules, for example, indicates a more primitive species. Genera of this type include *Lingnania*, McClure *Bambusa* Retz., *Dendrocalamus* Nees and *Indosasa* McClure. The size of leaves on one bamboo culm can vary greatly, sometimes unbelievably; and the number of branches can vary from one to more than ten. The stamens of *Ochlandra* Thwaites can be as many as 120. The number of stamens in *Indosasa* and *Sinobambusa* varies to a certain extent.

Because primitive species usually have larger leaves, sheath blades and bracts, they have a certain adaptability to much higher humidity. However, they have less resistance to dry weather. The species with taller and bigger culms require high rainfall during their shooting period. Without sufficient water, it is difficult to maintain the turgor pressure of the shoots and achieve the high growth of the culms. These larger clumping species are more primitive than those with up-right culms.

Evolution has not progressed evenly. One evolved species is by no means well developed in every organ. It is very probable that some of its organs remain primitive, such as in the evolved genera *Indocalamus* and *Sasa*. They have well developed inflorescences, culms, branches and rhizomes, but the leaves remain primitively large. *Sasa* with 6 stamens, a sign of a primitive genus, is thus more primitive than *Indocalamus*. The inflorescence of *Ampelocalamus* S.L. Chen, Wen & Sheng is well developed, but its rhizome remains primitive. When more organs of a species remain primitive, we place it into a more primitive category.

2. The Characters and Behavior of Primitive Bamboo

We can see that most types of primitive species have sympodial rhizomes and cespitose clumping. They can have as many as 2n=72 chromosomes. They have Broken and Double Broken types of vascular bundles. The leaves, sheath blades and bracts are wider and the spikelets appear directly or laterally on the nodes of vegetative organs, one after another, in succession. Usually there are more than 6 stamens. The culm is large, and the shooting period starts in June and July lasting more than 3 months. It takes another 3 months or so to complete shooting and put forth leaves. Most young culms wait until spring to put forth leaves, showing the plants have little tolerance for cold. Also, the primitive species require an environment with high humidity to accommodate the increased evaporation from their wider leaves and sheath blades. Because of their tall culms, ample supplies of water during the shooting season are essential to maintain the turgor pressure of the shoots and expedite the transfer of nourishment.

To summarize, the primitive species require high temperatures and humidity, as well as sufficient rainfall making their distribution limited because they are intolerant to drought. They have strong natural germinating abilities, however, and artificial regeneration is easy. Because of their large culms, the primitive species are much more welcome to the local people, who use the fibers. Thus, *Bambusa vulgaris* Schrader ex Wendland and *Dendrocalamus giganteus* Munro have been introduced and cultivated in many places by people; they do not spread naturally. The evolved species, on the contrary, require low temperatures, humidity and rainfall. They have a wide distribution and strong adaptability and resistance, but their germinating ability is poor and artificial regeneration is difficult. Because of their small culm size, the fibers are poor and not welcomed by the people who use them. So the evolved species are not cultivated in many places.

3. The Distribution of Bamboos

According to the classification principles of the world's botanical distribution, we may assign the world's bamboo to four regions.

3.1 Pan-arctic Region

This includes areas north of the tropic of Cancer, such as East Asia and North America. There are 14 genera: *Phyllostachys*, *Pleioblastus*, *Semiarundinaria* Makino ex Nakai, *Sinobambusa*, *Sasa*, *Shibata* Makino ex Nakai, *Chimonobambusa* Makino, *Fargesia*, *Yushania*, *Indocalamus*, *Bashania* Keng f. & Yi, *Hibanobambusa* Maruyama & H. Okamura, *Brachystachyum* and *Arundinaria* Michaux. Most are highly evolved genera, and some are intermediate; there are no primitive nor herbaceous genera. China has the most genera in this region, about 13, and Japan has 8, of which *Hibanobambusa* is endemic to Japan.

3.2 **The Paleo-tropical Region**

This includes areas from southern parts of China's Yangtze River to Southeast Asia and most of Africa. This region has the most diverse bamboo species occupying large areas. There are 50 woody and 5 herbaceous genera. The woody genera are *Acidosasa* C.D. Chu & C.S. Chao, *Ampelocalamus*, *Bambusa*, *Bonia* Balansa, *Brachystachyum*, *Burmabambus* Keng f., *Butania* Keng f., *Cephalostachyum*, *Chimonobambusa*, *Chimonocalamus* Hsueh & Yi, *Chloothamnus* Buse, *Clavinodum* Wen, *Decaryochloa* A. Camus, *Dendrocalamus*, *Dinochloa* Buse, *Drepanostachyum* Keng f., *Fargesia*, *Gelidocalamus*, *Gigantochloa* Kurz ex Munro, *Hickelia* A. Camus, *Himalayacalamus* Keng f., *Hitchcockella* A. Camus, *Indocalamus*, *Indosasa*, *Leptocanna* Chia & H.L. Fung, *Lingnania*, *Melocalamus* Bentham, *Melocanna*, *Nastus* Jussieu, *Ochlandra*, *Oreobambus* K. Schumann, *Oreocalamus* Keng, *Oxytenanthera* Munro, *Perrierbambus* A. Camus, *Phyllostachys*, *Pleioblastus*, *Pseudocoix* A. Camus, *Pseudosasa*, *Pseudostachyum*, *Qiongzhuea* Hsueh & Yi, *Racemobambos* Holttum, *Sasa*, *Schizostachyum*, *Semiarundinaria*, *Shibataea*, *Sinobambusa*, *Teinostachys* Munro, *Thamnocalamus* Munro, *Thyrsostachyum* and *Yushania*. We can divide this region into two parts; one is the Asia division, the other is the Africa division. There are 44 woody and 3 herbaceous genera in the Asia division; it is considered the major bamboo distribution center in the world. In this division, China has 37 genera, India 19, Bangladesh 13, Burma 7, Malaysia 7, Thailand 14, the Philippines 12 and Indonesia 9. China is considered the distribution center in this division.

There are 9 woody and 2 herbaceous genera in the Africa division, among which, 7 genera are endemic to Africa. There are 2 genera in East Africa which can be found in the Asia division, and another 2 in West Africa which can be found in South America. This shows that Africa has some relationship with its two neighboring continents. The distribution center of the African division is in Madagascar of East Africa. Bamboos in this division bear some resemblance to the bamboos in India.

3.3. **The Neotropical Region**

This includes most of Central and South America. There are 16 woody genera: *Apoclada* McClure, *Arthrostylidium* Ruprecht, *Athroostachys* Bentham, *Atractantha* McClure, *Aulonemia* Goudot, *Chusquea* Kunth, *Colanthelia* McClure & E.W. Smith, *Elytrostachys* McClure, *Glaziophyton* Franchet, *Guadua* Kunth, *Merostachys* Sprengel, *Myriocladus* Swallen, *Neurolepis* Meisner, *Rhipidocladum* McClure, *Swallenochloa* McClure and *Yushania*. There are also 24 herbaceous genera. All genera except *Yushania* in this region are unique to the American Continent. They are distributed from Mexico and the Caribbean Islands to Guatemala, Honduras, Venezuela, Colombia, Peru and Brazil. Brazil is the distribution center. This region has mostly evolved genera and very few primitive ones. The dominant feature in this region is that there are many evolved herbaceous genera.

3.4. **The Oceania Region**

There are only 2 genera in this region; one is *Bambusa* and the other is *Greslania* Balansa. The later is unique to Oceania, but *Bambusa* can be found in Asia too. So the species in this region are very simple.

4. The Center of Origin of Bamboos

For a long time, it was thought that bamboo originated in two separate places, Asia and South America. The similarity of plant distribution (not bamboos) in North America and East Asia proves the close relationship between the two continents. Calculations by Sargent (in Vubyef, 1932, p. 346) show that there are as many as 155 woody genera which grow in both North America and East Asia. Both the geologic and plant distribution evidence prove that at the end of the Mesozoic Era to the middle of the Pleistocene, Asia and America were connected by the Bering Strait land bridge. In ancient times, the climate in the north was not very cold, so there was nothing to prevent plants from spreading to Asia or America. Bamboo was no exception.

Of the 17 woody bamboo genera in America, 13 are advanced, while 24 herbaceous genera are even more advanced. Though the genera *Atractantha*, *Chusquea*, *Elytrostachys*, etc., possess an indeterminate inflorescence, which is thought to be a primitive character, they have 3 stamens, indicating a certain degree of advancement. *Guadua* is the only primitive genus in America, while Asia has 18 primitive genera. Since the origin center of bamboo should be characterized by the amassment of a great number of rather primitive bamboo genera, the theory of a second origin center in South America is untenable. There is only one place in the world, from which the bamboos originated; that is Asia.

It has been generally believed that Malaysia was the origin center of bamboo in Asia. I do not think it is possible. As we know, the primitive genera of bamboos have their own characters, not only in morphology, but also in their unique shooting period which starts in June and July. That is past the beginning of the rainy season in the Southern areas. This is the result of natural adaptation of the bamboo's behavior to environmental conditions. But Malaysia does not have this kind of climate, it has plenty of rain throughout the year and a rain-forest climate with high temperature. There is no obvious rainy or dry season there, in contrast to the ecological rhythm required by the primitive bamboos.

It was pointed out by Darwin (1859, in Vubyef, 1932, p. 24-25) that every species has its center of origin, and that the concentration of many centers of many genera in one place indicates the center of origin for this kind of plant group. According to my investigation, China's Yunnan Province has the highest concentration of bamboo species in the world. In a stretch of land 700 km long and 500 km wide, a great many bamboo species are found. There are *Bambusa*, *Burmabambus*, *Cephalostachyum*, *Chimonobambusa*, *Dendrocalamus*, *Drepanostachyum*, *Fargesia*, *Ferrocalamus*, *Gigantochloa*, *Indocalamus*, *Indosasa*, *Leptocanna*, *Lingnania*, *Melocalamus*, *Neosinocalamus* Keng f., *Oxytenanthera*, *Phyllostachys*, *Pleioblastus*, *Pseudostachyum*, *Qiongzhuea*, *Schizostachyum*, *Sinobambusa*, *Teinostachyum*, *Thyrsostachys* and *Yushania*, a total of 25 woody genera, of which 14 are primitive. The area has the largest variety of bamboo species and the highest concentration of primitive types in the world.

Almost all shooting periods of bamboos coincide with their local rainy season, and it is the same with the primitive genera. Their shooting period usually starts in June, which coincides with the rainy season of the tropical monsoon region. Although Central Yunnan has a climate similar to that in the southern Asia tropical monsoon region, the special geographical conditions in Yunnan force a sharp contrast between the rainy and dry seasons, with high temperature and humidity in winter. All these characteristics of climate completely coincide with the ecological rhythm of primitive species. So Yunnan can be considered the real center of origin of bamboo in Asia; it follows that it is also the center of origin of bamboo in the world.

5. Conclusions

1. The degree of evolution of bamboos can be shown completely from their anatomical and surface morphology. The morphological characteristics of primitive species are: vascular bundles of the Double Broken and Broken types, sympodial rhizomes with cespitose clumping, many branches, large culms, lateral indeterminate inflorescences and more than 6 stamens.

2. The behaviors of primitive species are: shooting from June or July, requiring high temperature and humidity, limited distribution, weak adaptability and resistance, and easy artificial regeneration. For the evolved species there is shooting in spring (requiring low temperatures), wide distribution, strong adaptability and resistance, and difficult artificial regeneration.

3. Most bamboos with tall culms and good fibers are ancient primitive species, whereas the evolved species often appear with short culms and fibers with little economic value. To meet the needs of people, primitive species such as *Bambusa vulgaris* and *Sinocalamus giganteus* have been cultivated extensively in southeast and southern Asia, in southern China, and on the eastern coast of Africa. They have not spread naturally.

4. It is unreasonable to believe South America is another center of origin of bamboo in the world. We know East Asia and North America are in the same plant belt, the Pan-arctic region. This has been acknowledged by many botanists, and there are 155 genera of woody and herbaceous plants common to both East Asia and North America. From the end of the Mesozoic Era until the middle of the Pleistocene, Asia and America were connected. The climate was warm, so there was nothing to prevent plants from spreading to America from Asia. Bamboos also spread across the land bridge at this time. Among the 17 woody genera in South America, most are evolved genera. Therefore, South America is not likely to be the center of origin of bamboo.

5. There is only one center of origin of bamboo. It is most likely the central and southern parts of China's Yunnan Province and connected areas of Thailand, Burma and China.

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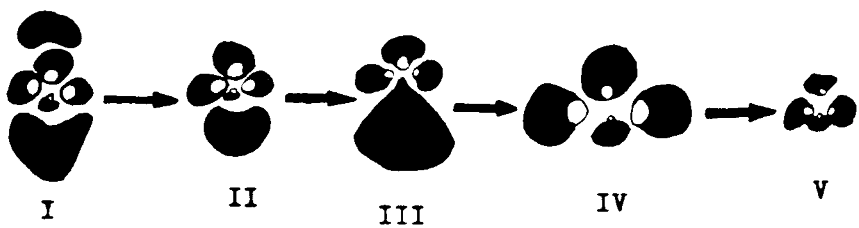

Figure 1. The types of culm vascular bundles: I. Double Broken Type, II. Broken Type, III. Slender Waist Type, IV. Open Type, V. Semi-open Type.

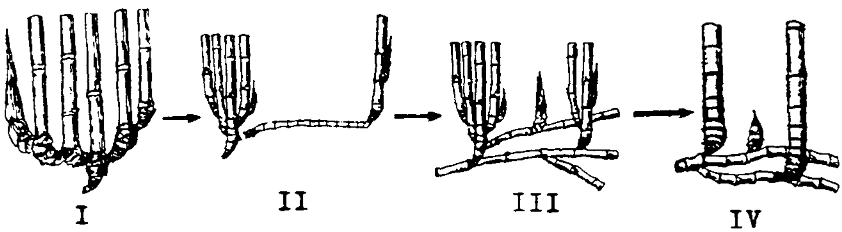

Figure 2. The types of rhizomes: I. Clumping Sympodial, II. Running Sympodial, III. Amphipodial, IV. Monopodial.

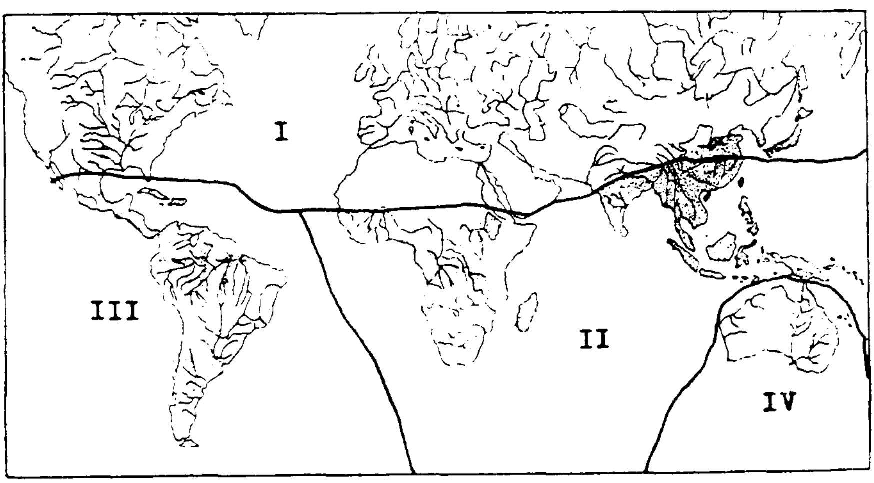

Figure 3. Distribution of Bamboos in the World: I. Pan-artic Region, II. Paleo-tropical Region, III. Neotropical Region, IV. Oceania Region.

Yi Tong-Pei*: **The Classification and Distribution of Bamboos Eaten by the Giant Panda in the Wild**

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The giant panda, so deeply loved by people all over the world, has lived only in the mountainous regions of Western China. Great numbers of investigations have shown that there are only a little over 1000 giant pandas alive at present. A small number of these are scattered over the five counties of Shaanxi Province along the Qin Ling mountain chain and the upper region of the Han Shui River, and one county of Gansu Province at the northern foot of Motian Ling mountain and the Baishui Jiang River valley. More than 90% of giant pandas are distributed over the 36 counties and the Wolong Special Administrative Area along four mountain systems located in Western Sichuan Province. From 1975 to 1976 *Fargesia denuda* Yi and *F. scabrida* Yi bloomed on a large scale in the Qingchuan, Pingwu and Songpan areas of Sichuan Province. From 1980 to 1981 *Qiongzhuea rigidula* Hsueh et Yi in the Mabian region flowered almost completely. From 1983 to 1984 *Arundinaria fangiana* A. Camus , *Yushania chungii* (Keng) Z.P. Wang et G.H. Ye flowered over a large area in the Wolong, Beichuan, Tianquan and Baoxing regions. *Yushania lineolata* Yi in the Shimian area have flowered one after another since 1978. Since 1982, each year *Fargesia nitida* (Mitford) Keng f. has flowered in succession from lower to higher elevations. As soon as these bamboo species began to flower in one section of an area, they frequently began to flower throughout a larger region. After flowering, the whole bamboo forest withers completely, and the time from flower bud to fruiting and dying is very short, about 2 years. As a result of this, a shortage of food has created a crisis for the giant pandas, bringing them great suffering and seriously menacing their lives. There is, however, not just a single species of bamboo in the giant panda habitat; a few species often grow at different elevations or even at the same elevation. This has created a good precondition for the rescue of giant pandas from starvation due to the food shortage and made the work possible. The statistics show that 19 giant pandas were saved from a seriously ill and starved state in Sichuan Province in 1984; among these 13 have been returned to forests rich in resources of bamboo species.

Our research indicates that the giant panda in its native habitat grazes on bamboos of 31 different species belonging to 8 genera. The primary species which are grazed differs from area to area. Giant pandas eat mostly *Fargesia aurita* Yi at the southern foot of the Qin Ling mountain range, which forms the northern limit of the animal's distribution. In the Min Shan mountain system, they eat chiefly *Fargesia nitida* (Mitford) Keng f., *F. oblonga* Yi, *F. denudata* Yi, *F. scabrida* Yi, *F. rufa* Yi, *F. robusta* Yi, *F. aurita* Yi, *Arundinaria fargesii* E.G. Camus, *Arundinaria fangiana* A. Camus, *Yushania chungii* (Keng) Z.P.Wang et G.H. Ye. Secondarily they eat *Phyllostachys rigita* X. Jiang et Q. Li, *P. nidularia* Munro, *P. nigra* (Lodd. ex Lindl.) Munro var. *henonis* (Mitford) Staph ex Rendle, *Fargesia angustissima* Yi and *Neosinocalamus saxatilis* (Hsueh et Yi) Keng f. et Yi. Occasionally they eat *N. affinis* (Rendle) Keng f. Along the Qionglai Shan mountain system, the primary species eaten by the giant panda are *Arundinaria fangiana* A. Camus, *Yushania*

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chungii (Keng) Z.P. Wang et G.H. Ye, *Fargesia ferax* (Keng) Yi, *F. emaculata* Yi, *Phyllostachys nidularia* Munro, *Fargesia angustissima* Yi, *F. canaliculata* Yi and *Chimonobambusa pachystachys* Hsuen et Yi. Along the Xiang Ling mountain system, the primary species are *Chimonobambusa szechuanensis* (Rendle) Keng f. *Arundinaria fangiana* A. Camus, *Yushania chungii* (Keng) Z.P. Wang et G.H. Ye, *Fargesia jiulongensis* Yi, *F. pauciflora* (Keng) Yi, *F. adpressa* Yi, *Yushania lineolata* Yi and *Y. cava* Yi. In the Liang Shan mountain system, which is the southern limit of the giant panda range, the primary species are as follows: *Qiongzhuea tumidinoda* Hsueh et Yi, *Q. macrophylla* Hsueh et Yi, *Q. rigidula* Hsueh et Yi, *Q. opienensis* Hsueh et Yi, *Arundinaria fangiana* A. Camus, *Yushania chungii* (Keng) Z.P. Wang et G.H. Ye, *Fargesia pauciflora* (Keng) Yi and *Indocalamus longiauritus* Hand. -Mazz.

Lin Wei-chih *: **The Chinese Technical Assistance Programs Concerning Bamboo in Costa Rica**

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I. Introduction

The Costa Rican government requested the government of the Republic of China to send a Bamboo Technical Mission to Costa Rica to train the rural people and to improve the bamboo handicraft industry in this country.

The Bamboo Handicraft Technical Agreements in cooperation between the two governments were signed on September 2, 1980. The Bamboo Handicraft Technical Training Center of the Chinese Bamboo Mission was established on November 1, 1981 in Limón. In the Bamboo Mission, there are one chief and five technicians including two in weaving, one in furniture, one in construction and one in cultivation.

II. Objectives

1. To train men and women of Cost Rica in bamboo handicraft.
2. To manufacture on an experimental basis various products using local bamboo.
3. To hold an exhibition of bamboo products in San José and other places every year.
4. To build the bamboo arbor and bamboo bridge in the Province of Limón in cooperation with the JAPDEVA - AID project.
5. To help graduated students set up bamboo handicraft and furniture factories.
6. To guide trainees in the technical cultivation of bamboo in Costa Rica.
7. To introduce valuable bamboos from Taiwan and other countries.

III. Bamboo Materials

Based on field observation, 30 species of bamboos belonging to 10 genera were found in Costa Rica. Among them, 10 species are important and of greatest value in the study. The species, distribution and utilization of the useful bamboos are shown in the following table.

* Chief, The Bamboo Handicraft Technical Mission of The Republic of China to Costa Rica, Apartado Postal 672, Limón, Costa Rica.

Species	Distribution	Utilization
Phyllostachys aurea A. and C. Rivière	San José, Alajuela	Furniture, weaving handicrafts, industrial arts, etc.
Bambusa guadua Humboldt & Bonpland	Siquirres, Guapiles	Construction, glue arts, etc.
Bambusa textilis McClure	Turrialba	Weaving handicrafts, glue arts, construction, etc.
Bambusa tulda Roxburgh	Guapiles, Turrialba	Weaving handicrafts, glue arts.
Bambusa tuldoides Munro	Siquirres, Alajuela Guapiles	Weaving handicrafts, etc.
Bambusa vulgaris Schrader ex Wendland	Costa Rica	Weaving handicrafts, glue arts, etc.
Bambusa vulgaris cv. Vittata McClure	Costa Rica	Weaving handicrafts, glue arts, etc.
Dendrocalamus giganteus Munro	Alajuela	Weaving handicrafts, construction, glue arts, etc.
Gigantochloa apus (Schultes) Kurz	Turrialba	Weaving handicrafts, construction, glue arts, etc.
Melocanna baccifera (Roxburgh) Kurz	Turrialba	Weaving handicrafts, etc.

IV. Training

The Bamboo Handicraft Technical Training Center was established on November 1, 1981 in Limón. The following table shows the number of men and women trained in handicrafts at the Center.

Year	Month	Class	Weaving	Furniture	Total
1982	Jan. - August	1st class	11	-	11
1982-83	Sept. - April	2nd class	17	3	20
1983	May - Dec.	3rd class	24	6	30
1984	May - Dec.	4th class	19	-	19
Total			71	9	80

The training period was eight months in weaving handicrafts and one year in furniture making. Eighty men and women were trained in handicraft at the Training Center from 1982 to 1984. Among them, 13 trainees were graduated from college, 42 from Vocational Senior High School and 25 from Elementary School. Thirty six men and women were being trained in the 5th class from February to September, 1985.

V. Training Items

In Costa Rica, men and women with eight months training in handicrafts will be able to make only rough handicrafts. To make furniture they need at least one year of training. The basic training items are as follows :

1. Cutting methods
2. Selection methods
3. Storage methods
4. Oil extraction from bamboo culms
5. Bending and correction of bamboo
6. Joining bamboo culms
7. Cutting holes in bamboo culms
8. Bamboo furniture manufacturing
9. Splitting bamboo culms
10. Fundamental interweaving
11. Bamboo ware manufacturing
12. Dyeing sliced bamboo
13. Painting
14. Insect and disease control
15. Others

VI. Experimental Samples

There are thirty species of bamboo in Costa Rica of which ten were chosen to use in making the following experimental samples of various handicraft products. They all turned out very well. In rating the species below, a "+++" indicates excellent, a "++" is good and a "+" is fair.

1. Weaving: Requires culms that are strong but very pliable.
   a. Species: *Bambusa vulgaris* cv. Vittata^{+++}, *Melocanna baccifera*$^{+++}$, *Bambusa textilis*$^{++}$, *Bambusa tulda*$^{++}$, *Bambusa tuldoides*$^{++}$, *Gigantochloa apus*$^{++}$, *Bambusa vulgaris*$^{++}$.
   b. Handicraft products: 5 kinds of desk lamps, 20 kinds of lamp shades, 23 kinds of baskets, 10 kinds of candy and fruit trays, 22 kinds of flower vases, 6 kinds of bags and several kinds of other fine arts.
2. Furniture: Require culms that are very straight internally and very smooth on the surface; of uniform diameter with no twigs on the nodes. Culm walls should be thick and flexible with high compressive and bending strength .
   a. Species: *Phyllostachys aurea*$^{+++}$.
   b. Furniture: 12 kinds of chairs, 6 kinds of tables, 2 kinds of beds, 5 kinds of cupboards, 12 kinds of bamboo cases, 4 kinds of bamboo screens and 10 kinds of other articles.

VII. Plantations of Exotic Bamboos

Although there are 30 species of bamboo in Costa Rica, only a few are economically valuable and even fewer can be used for furniture manufacturing. The Chinese Bamboo Handicraft Technical Mission has introduced two valuable species from Taiwan:

Phyllostachys aurea and *Dendrocalamus latiflorus* Munro. The former has been planted experimentally at San Isidro and Moravia; the latter is planted at four other locations in Costa Rica. The following table shows the results for three years.

Place	Altitude (m)	Date Planted	No. of Culms Surviving	Average Height (m)	Average Diameter (cm)
			Phyllostachys aurea		
San Isidro	700	3-12-1982	150	3.00	1.2
Moravia	1500	3-10-1982	350	5.00	2.3
			Dendrocalamus latiflorus		
Rio Blanco	50	3-13-1982	97	8.8	7.9
Bataán	80	3-20-1982	260	10.7	7.9
Guapiles	215	3-12-1982	53	6.4	4.0
Coto Sur	100	3-15-1982	33	6.1	5.0

From the results shown above, *Phyllostachys aurea* grows better at Moravia which is at 1500 m than at San Isidro at 700 m. The growth rate at Moravia is twice that in Taiwan. *Dendrocalamus latiflorus* grows well in all the above planted areas, and its growth rate is 100% better than in Taiwan. To cope with the demand of materials for future development of the bamboo handicraft industry in Costa Rica, one should begin to grow and propagate both of these species

VIII. Exhibitions of Bamboo Handicrafts

Seven exhibitions of bamboo handicrafts have been held by the Chinese Bamboo Handicraft Technical Mission, four in San José and three in Limón. These exhibitions have displayed over two hundred exquisite handicraft samples and attracted over 120,000 viewers, including the Vice President of Costa Rica and other Senior Government Officers. The First and Second Lady of the Republic of Costa Rica participated in a ribbon cutting ceremony for the opening of the inaugural exhibition. It gives a great deal of publicity for utilizing bamboo.

IX. Assistance and Promotion of Bamboo Handicraft Education.

1. At the college level: The cooperation between the Chinese Bamboo Handicraft Technical Mission and Costa Rica Institute of Technology is underway. One expert from the Mission has instructed the bamboo handicraft course for one semester. A project for planting bamboo is being planned.
2. At the high school level: Twenty seven students of two classes from Pococi Vocational Senior High School are being trained and educated in bamboo handicrafts.

X. Establishment of Bamboo Arbors and Bridges

To match the project of JAPDEVA-AID, the Chinese Bamboo Handicraft Technical Mission plans to build bamboo arbors and bridges for the rural people. Three bamboo arbors have been completed and students are being trained in the architectural techniques for making bamboo arbors and bridges.

XI. Conclusions

The Chinese Bamboo Handicraft Technical Mission has been in Costa Rica for three years and six months. It has had much effect on the development of bamboo handicraft industry there. Three years ago, no bamboo handicrafts were produced in Costa Rica. Today, there are two bamboo handicraft factories and their products are popular in the market with large sales. Since the Costa Rican Government places great emphasis on the development of the bamboo handicraft industry, full development can be expected in the next 4 to 5 years. At the end of that time, in addition to supplying the domestic market, we can expect the industry to also export all kinds of bamboo handicrafts from Costa Rica.