Specialty Crops for Pacific Island Agroforestry (http://agroforestry.net/scps)

Farm and Forestry Production and Marketing Profile for

Bamboo

(various species)

By Andrew Benton, Lex Thomson, Peter Berg, and Susan Ruskin

PAR

USES AND PRODUCTS

Bamboos produce woody culms that may be used whole as timber, or split for a multitude of wood products. The young shoots of some species can be eaten. The major usable materials produced by bamboos are described below.

Whole poles

Whole poles are widely used for construction, for scaffolding, frameworks, and other structural components of buildings (after proper preservation treatments). Pole sections are also for round-pole furniture, handicrafts, and irrigation systems. *Bambusa vulgaris* poles are widely used for temporary building structures and rafts. The most promising construction bamboos introduced into the Pacific islands include *B. oldhamii*, *Dendrocalamus asper*, *D. giganteus* and *D. latiflorus*, and *Guadua angustifolia*. *B. tuldoides* has excellent potential for making strong, long fishing poles.

Laths

Laths are thick strips of bamboo wood. They may either be full thickness splits of a bamboo culm, or be further processed into plane-sided laths of bamboo wood which are usually shaped by hand or machine to ensure all four sides are straight, and then pressed together with glues into laminated boards, which themselves can be shaped into panels, parquet flooring, door and window frames, and so on. These are widely produced in China, Japan, and India.

Splits

Splits are thin strips that are flexible enough to be woven. Broad, thin splits are often woven into mats, which can be pressed together into mat board. Narrower splits are frequently used in weaving handicrafts, furniture, and panels. Splits of *Schizostachyum glaucifolium* are commonly used in Fiji for weaving into mats and interior panels.

Sticks

Sticks are produced by splitting laths, or thick splits, depending on the type of stick required. The process is often mechanized with hand- or electricity-operated machines.

Veneer

Veneers are produced by longitudinal shaving of the culm. Veneers, laminations, and composites are used in surfboards, boats, and furniture.

Top left: Structural components in a home, North Kona, Hawai'i. Top right: Woven baskets for picking coffee, South Kona, Hawai'i. Bottom left: Chairs made from small diameter poles, China. Bottom right: Bamboo flooring.

Left: *Schizostachyum glaucifolium* is native to some Pacific islands and widely introduced to others by ancient Polynesians. South Kohala, Hawai'i. Middle: Traditional Hawaiian nose flute (*'ohe hano ihu*) made from *Schizostachyum glaucifolium*. Right: Traditional Hawaiian bamboo pattern stamps (*'ohe kapala*) for decorating tapa cloth.

Fibre and pulp

Bamboo fibres are long and paper made from bamboo is usually mixed with 20–30% softwood pulp to give extra strength. The fibres may also be utilized to make high-value clothing fabrics, using processes similar to those used to manufacture of rayon. The chemical composition of bamboo culms is holocellulose (61–71%), lignin (20–30%), silica (0.5–4%), pentosans (16–21%), and ash (1–5[9])%.

Extracts

Bamboo tar-oil (also occasionally called bamboo vinegar) is used as a component of various medicines.

Medicinal uses

Tabasheer, a silicaceous concretion found in the internodes of some species, is used medicinally, as is leaf sap which is sometimes used as an eye drop. There are many other uses by indigenous peoples, but no commercialisation is known.

Edible shoots

Bamboo shoots are usually harvested at 30–60 cm tall, and are peeled before cooking. Shoots of many of the clump-forming tropical species contain high levels of cyanogens, and must be boiled well prior to consumption.

Fodder

Bamboo leaves make excellent fodder for livestock including cows, horses, and pigs.

Charcoal

Waste products, including branches and sawdust, can be used to produce charcoal and charcoal briquettes. These burn hot and clean. Bamboo charcoal is also highly adsorptive and is often used in purification systems, particularly the sugar industry, and in household odour treatments.

Scale of commercial production worldwide

The latest data indicates that international trade in bamboo products is worth US$2.5 billion per annum, the major importers being the affluent nations, particularly the EU and the U.S. China is the major exporter. It is not known how much is imported into or exported from various Pacific islands, but the quantities are expected to be relatively small.

BOTANICAL DESCRIPTION

Preferred scientific names

See Tables 1 and 2.

Family

Poaceae

Subfamily

Bambusae

Common names

The local names for *Bambusa* spp., the most common bamboo of the Pacific, include (PEIR 2010):

Carolinian: *bwai, bwai*
Chamorro: *piʻao, piʻao palaoan, piao paloan*
Chuukese: *iich*
English: bamboo
Fijian: *mbitu vavalangi*
French: *bambou*
Hawaiian: *ʻohe*
I-Kiribati: *te kaibaba*
Kosraean: *bambu*
Maori (Cook Islands): *koe, koʻe, koʻe papaʻ?, koʻe tinit?*
Marshallese: *bae, koba*
Nauruan: *ebarabaratu*
Niuean: *kaho palangi, kaho papalangi*
Palauan: *bambuu, esel*
Pohnpeian: *pehri, pehri en sapahn*
Pukapukan: *koe*
Rakahanga-Manihiki: *kohe, kohe*
Samoan: *ʻofe, ʻofe Fiti, ʻofe palagi*
Solomon Islands (Kwaraʻae): *fiʻi kako*
Spanish: *caña amarilla, caña verde*
Tahitian: *ʻofe, ofe, ʻohe*
Tongan: *kofe, pitu*
Tuvaluan: *kofe, pampu*
Yapese: *moor*

See Table 1 for local common names of other indigenous bamboos of the Pacific.

Brief botanical description

Bamboos are woody grasses that range in height from 0.5 m to 40 m. The main structural component is the underground rhizome system from which the above ground stems (called "culms") emerge. There are two major types of bamboos, based on the type of rhizome they possess. Those with short bulbous rhizomes that turn upwards to produce culms from their apical buds produce bamboos with culms growing in closely-packed clumps are called "sympodial" bamboos. Those with long rhizomes that grow horizontally through the soil and produce culms from lateral buds in widely-spaced groves are called "monopodial" bamboos. There are a few exceptions: invasive sympodial bamboos that form huge groves and monopodial bamboos that form open clumps, and even a few bamboos with both types of rhizome.

Culms are woody but hollow, except at the nodes, which are periodic ring-like thickenings all the way up the culm. The distance between nodes varies with species. Culms are usually very hard and contain large amounts of silica. Branch buds are borne only at the nodes and the number of branches that emerge varies by species. Branches also have nodes and internodes, and can produce branchlets. Leaves are borne in groups at the tips of the branchlets.

Bamboo flowers and seeds are rare. Individual flowers are small, but borne in longitudinal inflorescences, and seeds of most bamboos are about the size of a grain of rice.

DISTRIBUTION

Native range

Only one bamboo (*Bambusa vulgaris*) is pantropical and may be regarded as naturalized in many parts of the Pacific. This species was introduced into Fiji in 1860 and Hawaiʻi in the early part of the 19th century. Two other widely cultivated and naturalized bamboos in the Pacific islands are *Bambusa blumeana* and *B. multiplex*. *Schizostachyum glaucifolium* is indigenous (e.g., Fiji) or an ancient Polynesian introduction (e.g., Hawaiʻi, Samoa) in the Pacific islands.

Native species recorded for PNG include *Neololeba attra* and *Nastus elatus* and for Solomon Islands *Nastus obtusus* and *Schizostachyum tessellatum*.

Current distribution worldwide

Clump-forming bamboos are native to tropical and subtropical areas of Asia, Asia-Pacific, Africa, and Latin America. Many species have been introduced to countries within Asia and Latin America, and to Africa, but less than 100 species are grown on a commercial scale worldwide. Clumping species brought into Fiji (Nadurulolo) in the 1950s included *Bambusa tuldoides*, *Dendrocalamus giganteus,* and *Gigantochloa apus*, but these species remain rare and localized. Species introduced into Fiji in recent times (2001) in several locations (Pacific Harbour and Colo-I-Suva) include *Bambusa lako, B. malingensis*, *B. oldhamii, B. textilis, B. vulgaris* cvs. Vittata and Wamin, *Dendrocalamus latiflorus,* and *Gigantochloa atter.* Some of these same species and varieties have also been introduced into Kiribati, Niue, Samoa, and Tonga. For a comprehensive compilation of nomenclature and distribution see Ohrnberger (1999).

Lists of species growing in and recommended for Pacific islands are given in Tables 1 and 2. Note that of the most useful genera, experience in the Pacific indicates that *Gigantochloa* spp. seems to be adaptable over a wider range of environments than *Dendrocalamus* spp. (which generally require more water) and can grow in soils of higher pH. *Bambusa vulgaris* may be regarded as naturalized throughout the Pacific, as indicated by the extensive list of its common names presented above.

Table 1. Bamboos that are indigenous to Pacific islands.

Species name	Height	Culm diameter	Common English name(s)	Local names in South Pacific	Brief description
Bambusa atra/Neoleleba atra	8–10 m	2–4 cm	New Guinea thin walled bamboo	*koya* (PNG)	Small- medium sized bamboo with long internodes (35–70 cm).
Bambusa vulgaris	8–20 m	5–10 cm	Common bamboo	*bitu vavalagi* (Fiji); *ʻofe Fiji* (Samoa); *fiʻi kako* (Solomon Islands)	Medium sized bamboo, open clumps, internodes 25–35 cm, culms often not straight.
Nastus elatus	to 20 m	n/a	New Guinea green bamboo	*konya* (PNG)	Internodes short, 30–40 cm
Nastus obtusus	to 20 m	5 cm	New Guinea edible bamboo	*fiʻi kaʻo* (Solomon Islands)	Internodes long, 70–80 cm, scandent.
Schizostachyum glaucifolium	9–12 m	n/a	Native bamboo, Polynesian bamboo	*bitu dina* (Fiji); *ʻofe Samoa* (Samoa)	n/a
Schizostachyum tessellatum	n/a	n/a	Anyone in SP known/a	*fiʻi keketo* (Solomon Islands)	n/a

Species name	Propagation system	Flowering habits	Main uses	Notes	Yields	Approximate planting density
Bambusa atra/Neoleleba atra	Offsets, culm and branch cuttings	Not known—no gregarious flowering reported	Basketry and handicrafts, thatching	Grows well on slopes on wet soils and water margins. Excellent for developing village handicraft industries.	n/a	n/a
Bambusa vulgaris	All	Never known to flower gregariously, only very occasional reports of sporadic flowering	Construction, furniture, handicrafts, paper and pulp, ornamental	Very adaptable species, good on poor or flooded land. Cultivars include Wamin and Striata.	20 MT/ha	6+ × 6+ m
Nastus elatus	n/a	Not known	Shoots can be eaten raw. Hollow stems sometimes used as water containers.	Light green culms turn yellow when older.	n/a	n/a
Nastus obtusus	n/a	Only sporadic flowering reported	n/a	n/a	n/a	n/a
Schizostachyum glaucifolium	Offsets and culm cuttings	n/a	The ash is used to treat sores and abscesses mixed with *Diospyros* and *Cyperus*, and culms are used for nose flutes, rattles, and household items	n/a	n/a	3 × 3 m
Schizostachyum tessellatum	n/a	n/a	n/a	n/a	n/a	n/a

Range

Asia and Oceania

West to east: Japan to India (possibly Pakistan); and north to south: South Korea to Northern Australia.

Africa

Senegal to Madagascar, Ethiopia to Zimbabwe.

Americas

Baja California to Eastern Brazil, southern Chile to southern U.S.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Bamboos grow at latitudes between 46°N and 47°S and elevations from near sea level to 4,500 m ASL, in the tropical, subtropical, and temperate regions of Australasia, Oceania, Africa, Asia, and the Americas. The vast range of bamboo species means that a wide range of climates are suitable, depending on species.

Left: *Guadua angustifolia* culms, North Kona, Hawai'i. Right: *Guadua* sp., Ecuador.

Tropical clumping bamboos often have broad climatic tolerances, although the vast majority are sensitive to frost. Minimum annual rainfall of about 600 mm is adequate for some species, but most prefer 1,200 mm or more.

Soils

Bamboos will grow in most types of soil, except extremely sandy, saline, or waterlogged soils. In the Pacific, experience indicates that well drained soils are best for bamboos grown for timber, and moister soils are better for those grown for shoots. Bamboos prefer soils with slightly acidic pH, but some of the *Gigantochloa* spp. can handle alkaline soils with pH of up to 8. They prefer fertile soils with high organic matter content. Bamboos have a fibrous root system, with 80% of their rhizome and root systems growing in the top 50 cm of soil, and accordingly can grow well on relatively shallow soils. Once established, bamboos respond well to heavy (ideally bulky organic) fertilizer application and even have a great capacity to absorb nutrients from wastewater.

GROWTH AND DEVELOPMENT

New culms emerge during the rainy season from rhizomes produced the previous year. While culm extension in monopodial species can reach 1 m per day, the sympodial bamboo culms grow much slower. The shooting season in Hawai'i is generally summer (approximately May–October), regardless of the rainy season, which varies in different parts of the islands. For the most part, the tropical clumping bamboos will reach 80% of their potential height within a couple of months. The remaining 20% of growth can take a few more months to complete. At the end of each growing season it is normal for some new shoots to abort.

The height and diameter of culms in a clump increases incrementally with age over a period of up to 7–8 years, depending on propagation method employed and growing conditions, up to a species-determined maximum. Each succeeding generation of culms will normally show an increase in height and diameter until a maximum is reached for that species in its particular environment.

Culms are too soft to use when young, and are usually harvested when they are 3–4 years old. For recently propagated bamboos, selected harvesting of shoots can begin after 3 years, and culms after 4 years, but yields will be low, and over-harvesting can significantly reduce the long-term productivity of the plant. Culms can be harvested year-round except during the shooting season when harvesting may cause damage to emerging and young shoots. Shoots should be harvested shortly after they emerge in the rainy season when they are about three times as high as they are wide at the base.

Branching occurs from buds at the nodes usually once extension growth has been completed, and lasts a few months. Culms of older plants often do not have buds at the lower nodes, resulting in clear culms for many metres and a clearly defined canopy layer above.

Flowering and fruiting

The flowering habits of most species of bamboos are too poorly known to state with certainty. In general, three types of flowering behaviour are recognized:

Gregarious flowering

Populations of one species flower, produce seed, and die, simultaneously over very large areas (often many square

kilometres), to be replaced by offspring grown from their seed. There are only about 20 species whose flowering is sufficiently well known to be placed in this group. Examples of gregariously-flowering economic species are *Melocanna baccifera* (48 years), *Bambusa bambos* (45–48 years), *Dendrocalamus strictus* (36–44 years), and *Thyrsostachys siamensis* (48 years).

Sporadic flowering

This is the most commonly seen type of flowering, and includes a wide range of flowering behaviours, from a handful of plants flowering and fruiting on all culms, setting seed and the plant subsequently dying, to a single culm flowering and dying on just one plant. In some cases, especially where seed set is low or nonexistent, the flowering culm may survive. Examples of this type of flowering include many of the *Bambusa*, *Dendrocalamus,* and *Gigantochloa* species.

Continuous flowering

Some of the equatorial species flower all the year, and the culms do not die. This behaviour is often recorded in tropical *Schizostachyum* species.

One bamboo, *Bambusa vulgaris*, almost never flowers, and has never been recorded as flowering on more than few culms when it does. *B. vulgaris* is one of the most vegetatively vigorous and easy to grow of all bamboos.

Fruit (seed) usually has short viability under different conditions. One month is common in subtropical regions, but those in tropical regions may retain viability for a few months, such as those of the genera *Bambusa*, *Dendrocalamus*, *Gigantochloa,* and *Guadua*. Seeds of species with large fleshy seeds, such as *Melocanna baccifera*, may remain viable up to 6 months or more. Seed viability can be extended by refrigerating or freezing dried seeds. Flowering habits are included in Tables 1 and 2.

AGROFORESTRY AND ENVIRONMENTAL SERVICES

Agroforestry/interplanting practices

Intercropping is easily accomplished with wide range of annual crops during the early years of establishing a bamboo plantation in which the annual crops can provide cash income while the bamboo is maturing sufficiently to be harvested. Practices for intercropping mature plantations with timber species exist.

There is limited deliberate cultivation of bamboos on family farms in Pacific islands. Given the increased interest in growing bamboos for multiple products in various Pacific islands, including Hawai'i, Fiji, and Samoa, the new exotic species will be increasingly incorporated into multi-species, multipurpose agroforestry systems as supplies of planting materials become available.

Three promising species used for construction timber and edible shoots. Left: *Gigantochloa atter.* Middle: *Bambusa lako* (lesser timber quality). Right: *Dendrocalamus asper* 'Betung Hitam'. All photos from North Hilo, Hawai'i.

Table 2 (part 1). Characteristics of suggested priority species for Pacific islands.

Species name	Height	Culm diameter	Status (see key below)	Common English name(s)	Brief description	Propagation system	Flowering habits
Bambusa lako	x–20 m	x–10 cm	Introduced—F, H, W&F	Timor black bamboo	Medium sized bamboo with black culms	Offsets, culm cuttings	n/a
Bambusa multiplex	3–7 m	1–3 cm	Introduced—common	Multi bamboo	Eight varieties of differing sizes; a small bamboo with thin culms	Offsets	Not known—sporadic flowering observed occasionally
Bambusa oldhamii	6–15 m	3–9 cm	Introduced—CI, F, FSM, H, K, N, S, T, W&F	Green bamboo	Medium bamboo, internodes 20–35 cm long	Offsets, culm and branch cuttings	Not known—sporadic flowering observed occasionally
Bambusa textilis	9–15 m	3–5(+) cm	Introduced—CI, F, H, W&F	Weaver's bamboo	Medium sized bamboo, internodes 25–60 (+) cm long	Offsets, culm and branch cuttings	Not known—sporadic flowering observed occasionally
Bambusa tulda	x–30 m	x–8 cm	Introduced—rare in Samoa	Indian timber bamboo	Large bamboo with thick walls	Offsets	Gregarious (25—40) yr and sporadic flowering
Bambusa tuldoides	6–14 m	3–5 cm	Introduced—F, H	Verdant Punting Pole Bamboo	Medium sized bamboo, branches emerging from the basal nodes, internodes up to 40 cm long	Offsets	Not known to flower gregariously, sporadic flowering often seen with varying levels of mortality
Dendrocalamus asper	20–30 m	8–20 cm	Introduced—CI, F, FSM, H, K, N, P, S, T	Asper bamboo, Dragon bamboo	Large bamboo, internodes 20–45 cm long with thick walls (11–20 mm)	Offsets, culm and branch cuttings	Thai population flowered *en masse* and died in mid-1990s
Dendrocalamus giganteus	24–35 m	10–20 cm	Introduced—F, H	Giant bamboo	Very large bamboo, internodes 40–50 cm	All	Gregarious flowering (30—40) yr
Dendrocalamus latiflorus	14–25 m	8–20 cm	Introduced—CI, F, FSM, H, K, N, P, S, T, W&F	Taiwan giant bamboo, Ma bamboo	Medium-large bamboo, internodes 20–70 cm long	Culm cuttings, offsets, air and ground layering	Sporadic flowering common
Gigantochloa apus	8–30 m	4–13 cm	Introduced—F, H	Tabashir bamboo	Medium-large bamboo, internodes 35–45 cm	Culm cuttings	Not known—no gregarious flowering reported, but plants are thought to flower sporadically after about 50 yr old
Gigantochloa atter	x–25 m	5–10 cm	Introduced—CI, FSM, H, K, N, P, T, S, W&F	Pring legi bamboo	Medium-large bamboo, internodes 40–50 cm long	Offsets and culm cuttings	Thought to flower gregariously after 50—60 years then die.
Gigantochloa levis	15–20 (30) m	5–16 cm	Not currently grown in Pacific	Levis bamboo	Large bamboo with internodes about 45 cm long	Culm cuttings	Sporadic flowering common
Gigantochloa pseudoarundinacea	to 30 m	5–13 cm	Introduced—H	Maxima bamboo	Medium sized bamboo with internodes 35–45 cm long	Offsets, culm and branch cuttings, air-layering	Gregarious (50—60 yr)
Guadua angustifolia	to 30+ m	to 25 cm	Introduced—H, S	Columbian giant thorny bamboo	Large bamboo, internodes 10–25 cm long, clumps open	All	Not known—no gregarious flowering reported
Ochlandra spp.	5–10 m	2–5 cm	Not currently grown in Pacific	Reed bamboo (*O. travancorica*)	About ten species endemic to the Western Ghats of India	Offsets, culm cuttings.	Various
Schizostachyum spp. *(especially S. diffusum, S. dulooa, S. glaucifolium, S. grande, S. lumampao, S. tesselatum, S. trachcladum, S. zolingeri*)	5–15 m depending on species	to 5–10 cm	Introduced and indigenous in some islands	Various	Small to medium–sized bamboos, up to about 15 m tall, with thin–medium walls	Offsets, culm and branch cuttings	Sporadic, but not usually dying after flowering. Some flower every year or every other year.
Thyrsostachys siamensis	8–16 m	3–8 cm	Introduced—H	Monastery bamboo	Medium sized graceful bamboo, internodes 15–30 cm long	Offsets, culm cuttings	Gregarious (approx. 48 yr cycle) and sporadic

Table 2 (part 2). Characteristics of suggested priority species for Pacific islands.

Species name	Main uses	Notes	Yields	Approximate planting density
Bambusa lako	Noted for colourful culms/ornamental, good for furniture, sometimes used for light construction, crafts, furniture, and edible shoots	n/a	n/a	4 × 5 m
Bambusa multiplex	Mainly used as an ornamental. Also for hedging and windbreaks. Some varieties can grow to 8 m.	n/a	n/a	n/a
Bambusa oldhamii	Construction, woven articles, pulp, shoots, windbreaks, and green screens.	Can be poor in suboptimal growing conditions, much more susceptible to insects.	n/a	n/a
Bambusa textilis	Woven articles (excellent quality), ornamental	Several cultivars and varieties known, incl. var *gracilis*, var *glaba*, cv Albostriata.	n/a	5 × 5 m
Bambusa tulda	Construction, round-pole furniture, paper and pulp, handicrafts and implements.	n/a	n/a	7 × 7 m
Bambusa tuldoides	Fishing rods, poles	n/a	n/a	n/a
Dendrocalamus asper	Construction (culms are large). Also for good quality furniture, woven items, utensils. Shoots are high quality.	This guide refers only to Indonesian plants, which are excellent multi-purpose bamboos. Thai types have lesser quality timber.	20 MT shoots/ha	5–6 (10) × 5–6 (10) m
Dendrocalamus giganteus	Culms are large and excellent for construction, shoots are high quality, pulp and handicrafts, laminated boards. Striking ornamental due to its vast proportions.	Culms rarely straight.	200 culms/shoots per ha	10 × 10 m
Dendrocalamus latiflorus	Widely grown for its excellent shoots. Also used for furniture, crafts and pulp.	Commercially very important shoot species in Asia. Grows in Indochina and southern China, leaves traditionally used for cooking rice. The larger cv Mei Nung provides excellent contruction-use culms.	12–30 MT shoots/ha	4–5 × 4–5 m
Gigantochloa apus	Construction, furniture, woven articles. Shoots are poor quality.	Its overlapping fibres render it unsuitable for stick-type products	1,000 culms/ha	5–7 × 5–7 m
Gigantochloa atter	Good for construction, sweet edible shoots.	Many populations have straight culms.		5 × 5 m
Gigantochloa levis	Good construction bamboo, shoots very good quality, also used for woven articles.	One of the main bamboos of the Philippines handicraft industry.	100+ MT/ha	6–7 × 7 m
Gigantochloa pseudoarundinacea	Construction, woven articles and handicrafts, shoots good quality	Said to be native to Java. Variegated var Malay Dwarf is a good ornamental. Several forms exist.	1,650 culms per ha	6 × 6 m
Guadua angustifolia	Excellent construction-use bamboo, furniture, handicrafts, woven articles, pulp, boards.	The most widely used bamboo in Latin America, highly versatile. Culms usually straight, or at least have long, straight sections. Large thorns on branches present serious handling problems. There is large variation in timber quality between populations.	20–40 MT/ha	7 × 7 m
Ochlandra spp.	Excellent for binding soil. Excellent for pulp, also for walling and woven articles.	Grow well in heavy rainfall areas.	Various	Various
Schizostachyum spp.	Variously for construction, woven articles, boards, pulp, ornamental.	About 30 species from Asia, widely used in their locales, but rarely introduced to other areas.	Various	Various
Thyrsostachys siamensis	Construction, shoots, woven articles and handicrafts, furniture. Good windbreak and ornamental.	Many populations have straight culms.	9–15 MT/ha	4 × 4 m

Key: CI = Cook Islands; F = Fiji; FSM = Federated States of Micronesia; H = Hawai'i; K = Kiribati; N = Niue; P = Palau; S = Samoa; T = Tonga; W&F = Wallis and Futuna

Note: Experience in the region with other bamboos, particularly *B. dissemulator, B. glaucophylla, B. oliveriana, B. pervariabilis, Dendrocalamus brandisii, D. membranaceous, D. sikkimensis,* and *Oxytenanthera glauca* suggests these also have considerable potential.

Top left: Many bamboos have good windbreak qualities. Top right: *Bambusa tuldoides* windbreak. Bottom left: Timber bamboos planted in open pasture with groundcover of squash (*Cucurbita* sp.) grown to suppress vigorous grasses, North Kohala, Hawai'i. Bottom right: *Bambusa oldhamii* windbreak, Maui, Hawai'i.

Environmental services

Windbreaks and living fences/boundary plantings

Bamboos have a high modulus of elasticity (9,000–10,100 N/mm^2), which helps them bend but not break even in high winds. They are often used as a windbreak to protect cash crops. However, effective management of the clump is essential to maximize this benefit, as congested clumps present a more solid barrier and are far more likely to succumb to strong winds.

Many varieties of clumping bamboos make outstanding windbreaks using relatively little space (i.e., a single row). Their flexibility results in little turbulence on the leeward side of the wind direction, and they can be planted or maintained with whatever level of air permeability is desired for a given situation. *Bambusa oldhamii* makes an excellent tall, narrow windbreak and boundary planting. This species survived cyclonic winds with the least damage (bending and breakage) of seven species trialed in Fiji, but well replicated experiments have yet to be done. *Bambusa multiplex* is

Table 3. Species currently available from a variety of commercial nurseries in the Pacific

Bambusa chungii
Bambusa dissemulator
Bambusa distegia
Bambusa dolichomerithalla silverstripe
Bambusa dolichomerithalla "stripe"
Bambusa emeiensis
Bambusa glaucophylla
Bambusa heterostachya
Bambusa lako
Bambusa longispiculata
Bambusa luteostriata
Bambusa malingensis
Bambusa mutabilis
Bambusa multiplex Alphonse-Karr
Bambusa multiplex Silverstripe
Bambusa oliveriana
Bambusa rigida
Bambusa textilis
Bambusa textilis "gracilis"
Bambusa textilis "fasca"
Bambusa ventricosa
Bambusa vulgaris var *vittata*
Bambusa vulgaris cv "Wamin"
Borinda boliana
Borinda fungosa
Chusquea coronalis
Chusquea culeo
Chusqeua leibmannii
Chusquea pittierii
Dendrocalamus asper
Dendrocalamus asper cv "Hitam"
Dendrocalamus brandisii
Dendrocalamus jianshuiensis
Dendrocalamus membrenaceous
Dendrocalamus minor amoenus
Dendrocalamus sikkimensis
Dendrocalamus ynnanicus
Drepanostachyum khasianum
Drepanostachyum sengteeanum
Gigantochloa apus
Gigantochloa atroviolacea
Gigantochloa atter
Gigantochloa albociliata
Gigantochloa luteostriata
Gigantochloa pseudoarundinacea
Gigantochloa robusta
Guadua angustifolia
Guadua angustifolia bicolor
Himalayacalamus asper
Himalayacalamus falconeri
Himalayacalamus "Damarapa"
Himalayacalamus hookeriana
Melocalamus errectus
Melocanna baccifera
Otatea acuminata aztecorum
Otatea glauca
Oxytenanthera abyssinica
Schizostachyum brachycladum
Schizostachyum caudatum
Schizostachyum glaucifolium

widely planted in Fiji as a dense low screening hedge and windbreak.

Timber substitution

Bamboo can substitute for timber in many uses. Wood harvested from forested areas is often used for building/construction and paper and pulp industries and bamboo could substitute for a large proportion of this. Wood "hardness" and durability vary with the species and with environment and maintenance. Some bamboos are extremely "hard" and have been compared favourably to both oak and maple.

Watershed protection, soil erosion, bioremediation

Bamboos maintain a permanent canopy over the soil and are excellent at reducing soil erosion, while providing a source of wood for income-generating activities. A 3-year-old plantation reduced soil erosion by 75% at an INBAR project site in China, even before canopy closure. Bamboos are also often used to stabilize riverbanks. They can also be used to absorb excess nutrient and fertilizer runoff such as around piggeries/chicken sheds, septic tanks, and sugarcane fields.

Biodiversity

Bamboos are habitats for a number of endangered species, including the Giant Panda (China), Red Panda (China), Mountain Gorilla (Uganda/Rwanda), Lesser and Greater Bamboo Lemurs (Madagascar), and bamboo bats (China). Some species of bamboo are themselves under threat due to over harvesting (e.g., *Qiongzhuea tumidinoda* in China), while others are known only from single locations and could be threatened if the habitat comes under pressure.

Climate change/adaptation, carbon sequestration

Bamboo is one of the most productive and fastest growing plants on the planet. Below-ground bamboo biomass makes up 25–50% of the total stock. Carbon content comprises usually about 50% of the total biomass. Modeling by INBAR indicates that managed bamboo holds higher levels of carbon than equivalent tree plantations, and that bamboos sequester carbon more rapidly in the early years of plantation establishment. Besides higher biomass, bamboo has other advantages over wood as a carbon stock. Unlike other woody crops, bamboo offers the possibility of annual selective harvesting and removal of about 15–20% of the total stock without damaging the environment or productivity. Over 90% of bamboo carbon can be sequestered in durable products such as boards, panels, floors, furniture, buildings, cloth, paper, and activated charcoal. Bamboo also has potential as a source of bamboo biochar, a carbon product produced from plant matter under conditions of low oxygen, which releases gasses that can be used to produce fuels and for power generation. The biochar residue itself is very stable and does not decay to release carbon into the atmosphere as rapidly as other plant materials do, and can hold carbon in the soil for many decades. It is also reported to improve soil structure and fertility, and is available commercially for this purpose.

Ecotourism

People appreciate bamboo houses and bamboo resorts are becoming popular in many countries including Australia, India, and China. Bamboo forests are a unique environment rarely encountered by most people, and many bamboo eco-

tourism locations include well tended bamboo species collections.

Biofuels

Bamboo can be used to produce charcoal, which burns hotter and cleaner than timber charcoal. Bamboo is often used in China as the frameworks for biogas generators, and research is ongoing into its potential for producing second-generation ethanol-based biofuels.

Advantages and disadvantages of growing in polycultures

Bamboos are ideally suited to growth in polycultures and can be grown with many other tree and crop species. Some species, such as *Bambusa oldhamii*, are especially suited to boundary plantings and can increase existing food crop cultivation through providing protection and acting as windbreaks. However, lateral root spread can compete with cash crops grown close to windbreaks and annual root shearing may help reduce this. Bamboos can also provide raw materials for simple construction on the farm, including animal pens, sheds, agricultural implements, and support structures for yam, pumpkin, passion fruit and other climbing crops.

PROPAGATION AND PLANTING

Care should be taken to prepare and site a bamboo nursery appropriately. It should be level, in or near the plantation area, well drained but with easy access to irrigation, and ideally somewhat shaded and sheltered from wind. A deep, fertile sandy loam is ideal. Propagation is best done at the beginning of the growing season. Note that a propagule can only be considered successful once a new culm has grown from the original, and has rooted, which can take anything from a few months to a year. Always choose one or 2-year-old healthy culms as the propagule, because they are more vigorous than older culms.

There are eight main propagation methods.

Division

This involves digging up the clump and using an axe, spade, or heavy knife to divide the clump into several pieces. Experience in the Pacific indicates that for predictably greater success one should take "three generations" of culms as a propagule unit from the mother plant: A new generation with branches hardened off, its "parent," and its "grandparent." It is essential to trim back the branches partially before planting, thereby removing most of the leaves which would result in rapid water loss, while ensuring some remain for photosynthesis and water movement. Plant in a well prepared hole, including some bulky organic matter fertilizer and soil backfill.

Top: Container nursery with sun and wind protection. Middle: Nursery with plants propagated from offsets. Bottom: Nursery bed for plant propagation.

Offsets

One or two year old culms with rooted rhizomes attached are detached from the parent clump, severed to about 1–1.5 m tall or higher if there are no viable branch buds on the lower nodes, and planted in a nursery propagation bed or in large pots/polybags.

Culm cuttings

One or two-node sections of the culm, usually taken from the middle portion of the culm, are severed. Side branches and leaves are removed, leaving the strongest branchlet which is cut back to about 2–3 nodes. The culm cutting is then buried horizontally in soil directly in the field or preferably in a pot in the nursery where it can be more readily and regularly watered until after root development. Root-inducing chemicals may be useful with recalcitrant rooters.

Branch cuttings

A culm with primary branches that have swollen bases is selected and the branches severed. Branches are cut back to 2–6 internodes from the base and buried at an incline in a propagation bed so only the tip is sticking out. They are watered well, and a mulch of leaves or other shading material is applied on top. Branch cuttings take longer to reach useable size and culm cuttings are usually preferable.

Air-layering

This method ensures the cuttings are well rooted on the plant before severing. Transparent plastic sheet is tied below a healthy node, and a few handfuls of moist, well drained rooting material (e.g., coir fibre) is packed around the node. The sheet is wrapped round and tied at the top to make a watertight enclosure. Rooting usually takes a few months, after which the culm can be severed and the rooted node planted out. This method is only useful in areas of high humidity. Additionally, access is often limited to the lower parts of the plant, which is often not ideal propagating material.

Ground layering

This is a rarely-used method. The tip of a culm is cut off, and lateral branches cut back to one internode. It is then bent over and buried in the ground for its full length, ensuring the branches stick out sideways, whilst remaining attached to the parent plant at the rhizome. The basal part of the culm can be cut half way through if it does not bend easily.

Seeds

Bamboo seeds are rare and plants take a long time to reach harvestable size when propagated from them. Seeds are usually the size of grains of rice (depending on species) and can be sown in standard well drained seedbeds under shade. Once they have produced at least two very small shoots they can be transplanted into nursery beds. Seeds are often used to start tissue cultures.

Tissue culture

While tissue culture methods for bamboo have been developed and commercially practiced in recent years, the protocols are rarely made public. In vitro multiplication of tissues of mature bamboo exhibiting superior traits enables elite germplasm to be cloned. Tissue culture starting from germinated seedlings will usually not be true-to-type (i.e., possess all the desired qualities of the mother plant). Tissue culture protocols have now been developed for many priority tropical bamboo species, including species of *Bambusa* and *Dendrocalamus*, and others in the genera *Gigantochloa*, *Guadua*, and *Phyllostachys*. Plants may be produced either by direct multiplication or more often by somatic embryogenesis, usually from seed explants (with inherent genetic variability), although some species have been propagated from vegetative explants that maintain the characteristics of the parent.

Recommended outplanting techniques

Propagules should be planted out only when their root system is well developed and roots are about matchstick thickness. To outplant, water the propagules well before planting, dig a hole twice the size of the root ball, add organic fertilizer, backfill, and water in well. It is best to ensure there are no air pockets around the root ball and to avoid over-compacting the backfill.

The largest bamboos, such as those in the genus *Dendrocalamus* are spaced at 7 m × 7 m–10 m × 10 m, with slightly smaller bamboos spaced at 4 m × 4 m, 5 m × 5 m or larger spacings depending on ultimate size.

The recommended spacing in polycultures depends on the species being used (i.e., the mature or managed footprint), nature of soil and environment, and the size of companion crops, and other factors.

CULTIVATION

Variability of species

Classification of bamboos is difficult and there is often disagreement over the naming of new varieties. With the exception of ornamental bamboos, varietal differences are rarely of any importance to the eventual useability of the plants or culms. Plants derived from seeds of many species have been observed in Hawai'i to show considerable variability in wood and shoot quality.

Basic crop management

Watering

Bamboos need to be well watered during the establishment period to develop into healthy, luxuriant clumps: they may also require supplementary irrigation in lower rainfall areas. Mature bamboos require a great deal of water, but once es-

tablished do not require additional watering in humid and subhumid tropics.

Fertilization

Productivity will be greatly aided by the addition of generous amounts of organic or inorganic fertilizers. In commercial plantations, fertilisers are usually applied twice per year: just before the shoots emerge, and shortly before main culm extension (October/November in subtropical locations south of equator and May in subtropical regions in the northern Hemisphere). Liquid urea fertilizer is also applied to shoot-producing stands after shoot harvest. Application rates of well rotted manure are usually 15–25 kg per clump at each application. Bulky organic matter is preferred, as it helps maintain soil structure, but inorganic fertilizers can be applied. Rates will vary depending on soil and plant conditions.

Thinning/harvesting

Bamboos that are grown for ornamental purposes or for timber are managed differently from those grown specifically for shoots. For timber production it is best to begin thinning the clump in Year 2 (the winter or "dormant" period is best). Annual thinning keeps the clump as open as possible to allow culms to grow straight and to eliminate unnecessary work and damage when harvesting. Culms reach optimum functionality and use at 4 years old, and harvesting is then a process of selectively removing 4-year-old culms. It helps to score the culms in their year of emergence to enable dating later on. One common recommendation is to remove all culms 4–6 years and older, and also for the removal of any culms that would make future work more difficult or that are unusable due to form. The ultimate number of culms of a particular age kept in a clump is specific to each species, usage, and environment. A clean cut just above the node will avoid damage to the rhizome's buds and prevent a water pool from forming in the severed internode that can harbour mosquitoes.

When growing bamboos for shoots it is best to keep a limited number of healthy culms and harvest the shoots, usually 5–7 per clump per year, depending on clump size.

Left: Dense clump of *Dendrocalamus asper* in need of thinning, North Kona, Hawai'i. Right: Open stand of *Guadua angustifolia* in North Hilo, Hawai'i.

Each year, before the shoots start to grow, carefully dig out the soil from around the rhizomes to expose the buds to the sunlight—this will increase shoot production. At the same time, the rhizome system can be cleaned up a little, by removing inappropriately placed rhizomes, and entangled fibrous roots. Replace the soil and mulch with straw once the shoots start to grow, otherwise they may become bitter if exposed to sunlight. See e.g., Othman et al. (1995), see for further information about strategies for shoot production.

Species grown for ornamental uses may have attractive young culms, or develop unusual colorations with time. These can be managed to maximize their attractiveness, rather than their productivity. Clumps of species with attractive young culms can be maintained on a 3-year harvesting cycle to increase the proportions of young culms in the clump; those with colorations can be grown at wider spacings, and thinned more, to maximize sunlight penetration to the clump.

PESTS AND DISEASES

Susceptibility to pests/pathogens

No significant pests or diseases are reported in the Pacific, but many are found on bamboos in tropical and subtropical Asia. It is profoundly important to observe or implement strict quarantine procedures for importing bamboo plants in order to ensure the continuation of a pest- and pathogen-free bamboo population.

Diseases

Rusts (Ceratosphaerea), blights (*Sarcocladium*, *Coniothyrium*, *Fusarium*, *Acremonium*, *Pteroconium* spp amonst others), culm rots (*Fusarium* spp.), and witches brooms (*Balansia* spp, *Aciculosporium*, *Loculistroma* and *Epichloe* spp.) all affect bamboo plantations in tropical and subtropical Asia and could become problematic in the Pacific. Damping off and wilt (*Rhizoctonia* spp.) and a range of leaf blights and spots (such as *Bipolaris*, *Cochiobolus*, *Colletotrichum*, *Dactylaria*, *Curvularia* spp.) affect seedlings and young plants in nurseries.

Pests

Over 40 types of pest have been recorded from bamboos. Significant among these are defoliators such as locusts (*Ceracris*, *Phlaeoba*, *Heiroglyphus* spp.), leaf rollers (primarily *Algedonia* spp.), puss moths (*Besaia*, *Loudonta* spp.) and many others. Other pests include sap suckers such as stinkbugs (*Hippotiscus* spp.), coreid bugs (*Notobitus* spp.) and froghoppers (*Aphrophora* spp.), but populations usually remain low and damage is limited. Culm and shoot borers including bamboo shoot weevils, (*Cyrtotrachelus* and *Otidognathus* spp.) and shoot boring noctuids (*Oligia* spp.) can cause considerable economic damage because they feed on the growing shoot/culm and cause physical damage as it extends, resulting in malformed culms. Of the major genera, experience from growers indicates that *Bambusa* is more susceptible to scales and mealybugs than *Dendrocalamus* or *Gigantochloa*.

Powder post (*Lyctus* spp.) and long-horned beetles (*Niphona*, *Chlorophorus,* and *Ceresium* spp.), and shothole and ghoon borers (*Dinoderus* spp.) attack culms postharvest, while *Udonga* spp. suck the sap of bamboo seeds.

Preventing and treating problem pests and diseases.

Practicing proper management and harvesting, including the removal and burning of infected plant parts as soon are they are apparent, is usually the best way of keeping pest and disease problems to a manageable level. Spray treatments using proprietary pesticides and fungicides do exist, but are rarely used.

Non-chemical treatment methods include soil turning before winter, which is regularly practiced in China, but is of limited use in the South Pacific. Placing some freshly cut culms in a plantation for pest species to lay eggs in and then burning them is sometimes practiced. Destroying pests by hand is also recommended. Natural enemies of some pests do exist, but are not yet available commercially.

DISADVANTAGES

Some bamboos are very large and may not be suitable for small areas. However, growers have a wide range of species with different size and product combinations to choose from, and so should be able to find a suitable one for their plot. Good management can help keep a large bamboo on relatively small plot of land. It is important to select the right species for the site and intended purpose.

Poor management can result in harvesting culms that are not suitable for the intended purpose, and that don't have a market. Training in clump management and processing, should the grower wish to add value, is essential.

Bamboo often taps into new markets—e.g., bamboo clothing was unheard of 10 years ago. There can be resistance to unfamiliar products, and a good market strategy is essential. Bamboo wood is very "silica rich" and hard on edge tools.

Potential for invasiveness

It is strongly recommended that only clumping bamboos be planted in the Pacific. Clumping (sympodial) bamboos are rarely invasive, although *B. longispiculata, B. chungii,* and *B. vulgaris* var *vittata* have very open clumps and could be invasive if not managed appropriately.

Most grove-forming (monopodial) bamboos can become serious pests if not properly managed and can be hard to contain once established. Examples include many of the

large *Phyllostachys* species (*P. pubescens, P. bambusoides*). The sympodial *Melocanna baccifera* has extremely long rhizome necks (up to 8 m) and can be highly invasive.

COMMERCIAL PRODUCTION

Postharvest handling and processing

Processing of bamboo is often divided into primary processing, such as preservation and basic splitting, and secondary processing, producing a finished article.

Preservation of bamboo is particularly important to extend its useful life and maintain quality. Bamboo culms are susceptible to insect and fungal attack and decay with time. These limit the useful lives of bamboo products and may reduce the quality of the raw material to the point that it is no longer usable.

Bamboos have traditionally been preserved by soaking in water for a few weeks and smoking. There are many modern methods of preserving bamboos that can be divided into two general categories; non-pressure methods and pressurised methods. Non-pressure methods allow the preservative, typically copper sulphate or borax, to penetrate the bamboo at a natural rate and are more suitable for small-scale processing, as they do not require complicated equipment. The two main non-pressure methods are soaking the bamboo in preservative and allowing the preservative to penetrate by capillary or wick action. Pressurised methods force the preservative (usually boric acid-based preservatives) into the bamboo. These methods are more rapid but require pressurised vessels and facilities that are more expensive to establish and run.

Bamboo shoots

Bamboo shoots may be consumed fresh on the day of harvest, in which case no postharvest handling is required beyond removing obviously damaged and below par shoots prior to sale.

In Hawai'i, fresh shoots are harvested and placed in cold water for rapid temperature reduction and stored at 4°C overnight. They are then trimmed and cleaned and packed in styrofoam boxes with an ice pack and are transported to market at 10–12°C. For storage, shoots can be peeled and boiled for 2–3 hours, continually refreshing the water. They are then cooled as rapidly as possible to 30°C or less and stored in jars in brine (salt content of 5–8% of the weight of the cooked shoots).

Commercially, shoots are mainly canned, an involved process involving drying the shoots, removing the sheaths, rinsing, dressing, classification according to shape, grading, weighing, placing in cans, sterilizing, adding water, adjusting the pH, cooling, heat preservation, inspection and packing.

Processing

Primary and secondary processing can be easily done at a community level and there are a huge range of types of products, from those produced in large quantities with low individual value (for example incense sticks, chopsticks, and bamboo mats) to those that involve more skill to produce,

A simple farm-scale pressurized treatment system in North Hilo, Hawai'i.

Invasive monopodial bamboo covering a hillside, Maui, Hawai'i.

such as handicrafts and furniture. Training in production techniques is usually essential, and it is often economical to train trainers from the community, so they can train others.

Some products suitable for community-level production include handicrafts (including musical instruments), household items such as baskets and trays, round pole furniture, split pole furniture, incense sticks, toothpicks, matchsticks, mat boards, roofing sheets, charcoal, charcoal briquettes, and simple structures.

New technologies that enable laminates to be produced with only hand machines have recently been developed, and this offers enormous possibilities for community based production of high value panelling, flooring and other boards. Pulp can be produced on a village level (as it was originally in China 1,000 years ago) but is not very economical and would only suit the production of niche-market papers. Bamboo toilet paper is now a leading seller in Australian supermarkets, and bamboo fibre is used for mass-produced paper cups. The technologies for producing certain products require significant capital investment and are not suitable for low investment situations, such as shoot canning and bamboo tar-oil production. Production of bamboo rayon products, particularly clothes, is presently very high-cost and the techniques are proprietary.

Housing

Many different construction systems exist for bamboo housing, from the wood-framed, bamboo lath-panelled simply erected houses of the Viviendas del Hogar de Cristo charity in Ecuador, through high-tech modular designs, to the modern upmarket round pole houses that are built in Hawai'i. All except the most basic require a concrete foundation, and they should all be erected by trained practitioners, although the techniques are not difficult to master. A simple bamboo-framed school building takes a few weeks to construct. The legal status of a bamboo structure depends on the laws in place in the territory in which it is built. An ISO standard for round-pole bamboo houses is available, but building codes for bamboo houses based upon it have not yet been developed in most countries.

Product quality standards

With the exception of two Colombian standards for the cultivation of *Guadua*, no standards exist for species that are grown in the Pacific. Standards do exist for a range of products in China, but they deal only with products made from *Phyllostachys pubescens*, which is a subtropical species rarely grown in the Pacific. They could be used as models to develop similar standards for other bamboo species in the countries of the South Pacific and include:

- Bamboo timber
- Bamboo mat plywood

Left: Fresh bamboo shoots sold at farmer's market in Kona, Hawai'i. Middle: *Nastus elatus* has a delicious edible shoot. Right: Ready-to-harvest shoots of *Dendrocalamus giganteus*.

Top left: A open structure built from framework covered with canvas, North Kona, Hawai'i. Top right: Conventional architecture with bamboo structure and trim, North Kona, Hawai'i. Bottom left: Many bamboos are both highly ornamental and very useful. *Otatea acuminata* makes a beautiful hedge to 4 m in height, while also providing usable canes and edible shoots, South Kohala, Hawai'i. Bottom middle: *Gigantochloa maxima*. Bottom right: Culms of *Dendrocalamus asper* 'Betung Hitam'.

- Bamboo chopsticks
- Bamboo flooring
- Structural bamboo and wood composite board
- Decorative bamboo veneered panel
- Plybamboo for bottom boards of trucks and buses, and for concrete formwork
- Laminated bamboo strips lumber
- Plybamboo for high value products such as doors and windows
- Strip plybamboo for bottom boards of trucks and buses
- Standard terminology for bamboo-based panels

INBAR's bamboo construction standard (ISO22156 Bamboo Structural Design) was approved by the International Standards Organisation in 2007. This covers all aspects of building with round-pole bamboos including structural design, beams, panels, trusses, reinforcement in concrete, and fire protection. It is now available for countries to adopt/adapt, providing a framework for developing national legislation.

Product storage requirements and shelf life

Preservation treatments are essential, as bamboo deteriorates rapidly if not treated (lasting a few months up to a few years). Products made from properly treated bamboo can last for many decades. Canned bamboo shoots last for years, but fresh shoots last only a few days unless refrigerated in which case they can keep for several weeks.

Recommended labelling

Labelling of bamboo products must comply with national legislation of the importing (and sometimes the exporting) country. Many nations have specific labelling requirements for canned bamboo shoots for instance, and exporters must comply with the labelling requirements of the importing country.

SMALL SCALE PRODUCTION

The potential of bamboo to improve the quality of life for a family or a community is vast. Production involves a wide range of stages, each of which imparts added value and so many people can earn incomes from involvement in the production chain. Bamboo is light and easy to process, so it is easy for people to work at home in their spare time should they wish. Skilled practitioners can impart higher values to the products, especially if producing handicrafts, and skills enhancement will increase the economic sustainability of

There are many low- and high-tech joinery systems. Top left: Bamboo pole butt shaped and through-bolted. Top right: Bamboo Links™ joinery system connected with metal strap clamps and through-bolts. Bottom left: Model of stainless steel joinery fittings for connecting structural wall panel to floor structure. Bottom right: Simple metal plate pressed to shape and drilled to connect up to five bamboo poles with through-bolts.

Table 4. Advantages of bamboo

As a crop

Bamboo can be harvested annually and non-destructively	Clear-cutting of bamboo stands is highly detrimental, reduces yield in subsequent years, and increases environmental degradation.
Bamboo establishes rapidly after planting	The first harvest of culms usually comes 3–4 years after planting, but with careful management, bamboo shoots can be harvested from the third year.
Limited investment is required to establish a plantation	Bamboo propagules are easy to produce/cheap to purchase, and establish rapidly.
Bamboo plants yield for decades	Although yield may reduce slowly with time, the only major hindrance (of some species) comes with flowering and subsequent death, often after 50–60 years.
Bamboos respond exceptionally well to proper management	Unmanaged stands yield 1–2 MT/ha per annum, but proper management practices can increase yield by 10–20 times.
Bamboos can be grown on peripheral or non-cropping land	Growing bamboo need not interfere with food cropping, and represents real increases in food and livelihood security.
Bamboos can be intercropped	Shallow-rooted food or cash crops are ideal. Plantations of sympodial bamboos can be intercropped with rhizomatous crops such as ginger or turmeric up to about 3 years of age.
Growing bamboo builds on farmer's inherent plant cultivation skills	In this way it effectively enhances farmers capacity to absorb periodic shocks to income streams.

As a raw material

Bamboo processing already occurs in many societies	Processing and production of new products can build on existing skills and is more likely to be chosen as an option than an entirely new technology of which producers have no experience.
There are a multitude of different products that can be made from bamboo	This gives a wide range of options to producers and provides flexibility in case of market disruption to particular types of products.
Bamboo lends itself to community-based growing and processing	The range of different skills required to grow, process, and market bamboo and bamboo products are often available, or can be developed, within a community.
Many processing stages may be involved, depending on the product	This creates opportunities for value addition (and hence income generation) at each point of transfer of ownership of the semi-processed product, forming a chain of value addition from production to sale.
Producers can add value to bamboo even with limited technical knowledge/skills	Simple, easy-to-learn skills such as splitting and weaving can add value and increase incomes.
Products may require high or low levels of skill to produce, or a combination of both	Some products, such as handicrafts, are inherently skills-dependent while others require skilled or semi-skilled inputs only at some stages of processing, allowing people with many skill levels to be involved.
Bamboo processing is gender neutral	Almost all bamboo processing activities are equally suitable for men and women. In some communities, growing, and harvesting is seen traditionally as a man's work.
Bamboo can be processed at home and in spare time	Money earned in this way is genuine additional income.

As a saleable product

Semi-processed bamboo is as valuable a product as raw bamboo or a finished product	Processing imparts value to the bamboo and intermediate products can command good prices within the production-to-consumption chain.
Skilled inputs greatly increase the value of the commodity	Skilled processing activities, such as natural-dye colouring, fine splitting or intricate weaving add much value to the bamboo and can be treated as separate vocations in themselves. Less skills-dependent activities such as preservation also add value.
Bamboo products have high value and low value markets	The market may be low volume, high value, or high volume, low value, depending on the type of product. Combining production of both types in a community increases its ability to withstand market fluctuations.

the family/community. A wide range of products can be made that reach different market niches, so production can be adjusted should one market line start to fail.

A small nonelectric tool kit consisting of one or more handsaws, a heavy knife or machete for splitting, a smaller knife for fine work, and a chisel or two, plus drills or gimlets will enable production of a great many items and structures. When harvesting large culms a chain saw is helpful.

Bamboo is proven as a sustainable source of income for small scale producers, but success depends heavily on delivering a quality product that meets market demand. Understanding the market, knowing how to produce for it, and delivering on time and at the right price are essential skills for any potential bamboo entrepreneur.

Use in the Pacific

Bamboo has a range of benefits that make it excellent for developing small-scale productive enterprises. It is widely used throughout the Pacific for temporary building structures, rafts, harvesting poles, fishing rods, food and water containers, food tongs, and handicrafts. Bamboo species are most often harvested from the wild, such as secondary forests in Melanesia. In Hawai'i, wild bamboo stands are commonly harvested for fishing poles, edible shoots, and some construction applications, as well as for some craft work and kadomatsu. It is little used for food except to small extent by Southeast Asian immigrants. In the PNG highlands the shoots of *Neololeba atra* are sometimes consumed. *Nastus elatus* (New Guinea sweet shoot) is an outstanding edible shoot that can be eaten with minimal preparation.

Import replacement

Bamboo can be used to replace a wide range of imported goods including construction materials, charcoal, household items, and so on. Locally grown bamboo shoots can help reduce reliance on imported vegetables.

Table 5. Nutritional content of bamboo shoot (per 100 g)

Water	89–93 g
Fat	0.3–0.4 g
Fibre	0.5–0.77 g
Ca	81–96 mg
Fe	0.5–1.7 mg
Vitamin C	3.2–5.7 mg
Protein	1.3–2.3 g
Carbohydrates	4.2–6.1 g
Ash	0.8–1.3 g
P	42–59 mg
Vitamin B_1	0.07–0.14 mg
Glucose	1.8–4.1 g

In terms of agricultural uses, bamboo timber can be used for fences, water pipes, raised beds for vegetables, supports for earthen stairs, props for fruit trees, railings and pickets around decks, roofs over decks, trellises, and so on, thereby increasing agricultural productivity and sustainability, and reducing reliance on non-locally grown foods. In some cases, untreated bamboo can last over a decade in these uses, even weathering storms and constant sun exposure.

YIELDS

Expected range of yields

In trials at Colo-I-Suva, Viti Levu, Fiji, the best performing species has been *Bambusa oldhamii* growing to 12–14 m in height and 4–7 cm in culm diameter at 3 years after outplanting. *Bambusa textilis gracilis* also grew well, producing 60 stems at 3 years with a height of 9.8 m and culm diameter of 2.8 cm. *Bambusa malingensis* produced a high biomass, about 20–50 culms 7–10 m tall and 3–4 cm in diameter. This species develops large clumps with a sprawling habit and is not generally recommended except possibly for biomass production. In the warmer Samoan climate, *Dendrocalamus*

Simple garden structures made of bamboo poles, Hāmākua, Hawai'i.

Table 6. 2007 world import data (US$1,000) (INBAR, n.d.)

Product	Value
Bamboo shoots	233,000
Roundwood, charcoal of bamboo	38,890
Plywood of bamboo	287,050
Mats and screens of bamboo	144,608
Plaits and plaited products of bamboo	43,304
Bamboo paper products	89,553
Other fibre pulp of bamboo	18,570
Basketwork of bamboo	259,804
Bamboos for plaiting	90,784

asper has excelled, reaching heights of more than 30 m and outperforming *B. oldhamii*, which performs better at higher altitudes and is better suited to a subtropical climate.

Recommended planting density

Planting density is determined by maintenance practices in addition to species size in a given environment. For species-specific density recommendations, see Table 2.

MARKETS

Local markets

With the exception of minor uses in packaging and handicrafts, bamboo products are not known to be sold in local markets in the Pacific (in Fiji or Polynesia). In Hawai'i they are utilised on a small scale for building and for human consumption.

Export markets

No export market from Pacific islands is known to exist, but the potential is significant, with worldwide market in traded bamboo products at about US$2.5 billion.

The worldwide consumption of bamboo shoots is in excess of 2 million MT, mostly in Asia. The main potential export market for bamboo shoots is Japan. However, their preferred species is *Phyllostachys pubescens* (or moso), a monopodial type of subtropical bamboo with a rather unique flavor that may be not readily substituted for by any tropical bamboo. *Dendrocalamus latiflorus* shoots are popular in Taiwan, and large quantities are exported to Japan. *Dendrocalamus asper* shoots are a major canned export from Thailand to Japan. *Dendrocalamus giganteus* is favoured in Vietnam and Indochina. The greatest opportunities for exports of bamboo shoots from Pacific islands would be for fresh bamboo shoots to Asian communities on the U.S. mainland and to Asian countries with direct flight links and available cargo capacity.

Top: "Bamcat" measuring 4.8 m long has bamboo hulls that each weigh only 19 kg (crafted by Gary Young). Middle: Beer made with bamboo flavoring. Bottom: Rice flavoured with bamboo extract.

Specialty markets

Bamboo timber is an excellent substitute for wood produced from forest trees, and hence its greater use might take some utilization pressure off native forests. It is well suited to organic production systems and is highly suitable for Fair Trade certification. INBAR has just joined the Fair Trade movement to help enable more bamboo producers to obtain Fair Trade certification. No specific certification schemes yet exist for bamboo to enable its products to appeal to specialty markets, but such plans are under discussion and development. Forest Stewardship Council (FSC) certification has been extended to some bamboo forests in Colombia, but its beneficial impacts have yet to be demonstrated.

Branding

National or other brand identity is easy to develop, especially if the products from different nations are characteristic of those nations in some way. Bamboo can be combined with other agricultural products that are of special significance in particular nations, to produce highly recognizable national brands. The "Bamboo Bridge" brand, recently launched for products produced under INBAR's Global Marketing Initiative, is one such example.

Potential for Internet sales

Most natural bamboo products are lighter than their wood-based counterparts, and are cheaper to transport. Many bamboo companies throughout the world use the Internet to sell their wares.

EXAMPLE SUCCESSES

Matuaileoo Environment Trust Inc. (METI), Apia, Samoa

METI is a small environmental trust established in 2000 with an objective to "build capacity of grassroots communities towards self-reliance." One of METI's roles is National Coordinator of the Bamboo Crop Development Project. To start, a 0.4 ha mother plant bamboo plantation was established in Vailele in 2006, from which thousands of cuttings have been harvested for propagation. The species planted in the mother plant plantation are: B*ambusa balcooa*, *B. oldhamii*, *Dendrocalamus brandisii*, *D. asper*, *D. giganteus*, *D. latiflorus*, *Gigantochloa atter,* and *Guadua angustifolia*. METI also supports the activities of 16 farmers' cooperatives, ten of which have applied for grant funds to allow their members to set up small plots of bamboo intercropped with valuable tree species such as sandalwood.

In its long-term development goals the Government of Samoa has encouraged bamboo crop development, in particular as a substitute for timber in view of Samoa's dwindling forestry resources (as witnessed by a tripling of the value of annual timber imports over the period of 1995–2005 from 6 to 18 million tala). METI's involvement was the result of its close relationship with farmers' cooperatives, which were interested in starting innovative agricultural income-generating projects with a potential for being economically viable and strengthening the Samoan farmers' self-reliance and resilience to climate change.

The primary initial objective of the project is to increase the total area planted in bamboo in Samoa. Once a large enough supply is available, a local bamboo industry can become feasible. Some merchants and architects also feel confident that local sales of bamboo poles as substitutes for imported timber will expand once the Samoa Building Code has been revised and allows for bamboo to be used in home construction.

In addition to bamboo and sandalwood, METI is also growing *asi toa* (*Syzygium inophylloides*) and *poumuli* (*Flueggea flexuosa*) for timber together with bamboo. *Calliandra surinamensis* is being used as a companion tree for sandalwood, which is hemiparasitic and requires a host plant. As some of these tree species (e.g., *poumuli* and *Calliandra*) are good honey bee forage, funding is being sought to allow farmers

A number of species are being trialed at at the METI mother plant plantation established in 2006 at Vailele, Samoa. Left: *Bambusa oldhamii*. Middle: *Dedrocalamus asper.* Right: Simple structure made from bamboo and eleven low-tech metal fittings.

to cultivate five honey bee hives on each 0.4 ha planting as an additional income generating venture.

Whispering Winds Bamboo Cooperative, Inc., Kīpahulu, Hāna, Maui, Hawai'i

Whispering Winds began growing timber bamboo in 2003 as a cash crop. Factors that influenced their decision to grow bamboo included demand for locally grown timber and a favourable price structure for timber-grade bamboo in the marketplace. They are currently the largest timber bamboo plantation on Maui island. They grow thirteen clumping timber species. Processing includes harvesting, drying, and some treatment for rot and insects.

Top: Bamboo interplanted with fruit trees at Whispering Winds Bamboo Cooperative, Maui. Bottom: Transplanting bamboo plants.

Whispering Winds also sells nursery stock for over 20 species of bamboo landscape nursery plants for privacy hedges, windbreaks, edible shoots, and timber. For the landscaping market, species were selected for a range of heights (4.5–18 m) and utility as well as drought tolerance, aesthetics, and rarity. In addition to a standard selection of 20 species, another 40 species can be grown on contract.

Both the plantation and nursery are certified USDA organic and Demeter-certified Biodynamic, which strengthens their products' perceived value in the marketplace. They advertise in newspapers, landscape journals, and at a number of public agriculture-related events. They also hold frequent open houses and workshops. Much of their business comes via word-of-mouth.

Developing the market for structural bamboo is the biggest challenge for the timber bamboo portion of Whispering Winds Bamboo business. In order to get approval to use bamboo as a structural component in coded buildings, each species from a particular location must go through an extensive and costly certification process through the International Code Council (ICC) to establish baseline strength factors. In addition to strength factors of the bamboo species, the joinery also needs to be ICC certified. Until certifications are obtained, bamboo can only be used for structures that do not require building permits, such as small outbuildings, animal pens, fences, gates, trim, and visual screens.

ECONOMICS

Competition with China, India, or other nations who already have bamboo resources, culture, and industrial technology is not likely to prove economically viable for most Pacific islands.

If niche markets can be identified for which well controlled, value-added products can be identified, perhaps relatively small-scale production and processing can be economically viable. Fifteen years ago marine plywood showed the possibility of such a niche market. Current research would be needed to know if this is still the case.

Even for local markets with little or no shipping costs, locally grown and processed bamboo products might cost more than imported. Marketing studies would be needed to define potential products with viable markets.

FURTHER RESEARCH

Potential for crop improvement

Bamboo hybridization has been conducted in China for over 35 years, but it is a long process and the economic benefits are not clear. Some hybrids are now being grown commercially in China. However, selection of elites from seedling-derived populations for large-scale vegetative propagation and planting is often practiced and can help ensure increased yields.

Improving potential for family or community farming

Growing and processing bamboo can bring a range of benefits to farmers and small communities. There have been a handful of attempts to develop bamboo in the Pacific, but they have been hampered by a lack of grassroots interest, and not just limited to bamboo but encompassing forest resources in general. If bamboo is to help provide livelihoods, it is clearly essential to have an effective stepwise strategy of awareness-raising and resource and skills development that builds on existing practices and interests, perhaps developing a demonstration project to show the potential of bamboo. Government involvement and support will be essential. Bamboo sectors have been developed in parts of the world where before there was only subsistence use of bamboo, such as currently in the South Pacific.

Genetic resources

Genetic resources in the Pacific Islands include METI plantings on ʻUpolu, Samoa and Bamboo Association of Fiji plantings at Pacific Harbour and Colo-I-Suva. The largest collection of bamboo genetic resources in the region is held by Bamboo Australia, Belli Park, Queensland. Numerous species have been introduced into Hawaiʻi and are available through commercial nurseries.

Bamboo sector development in the Pacific

National evaluations of the bamboo production-to-consumption systems are a first and essential step in the development of national bamboo sectors, and enable effective decision making regarding all aspects of improving the supply and value chains, from resource development, nature, location and magnitude, to policy changes and the development/improvement of institutional support systems for producers.

Structural certification

Structural testing data is not easily accessed for many species. Existing data from around the world should be collected, evaluated, and made easily accessible. A survey of joinery systems and associated testing should be included.

CITED REFERENCES AND FURTHER READING

Clayton, W.D, K.T. Harman, and H. Williamson. 2008. GrassBase—The Online World Grass Flora. http://www.kew.org/data/grasses-db.

Dart, D. 1999. The Bamboo Handbook. Bamboo Australia.

Dransfield, S., and E.A. Widjaja (eds.). 1995. Plant Resources of South East Asia No 7. Bamboos. Backhuys Publishers, Leiden, Netherlands.

Dunkelberg, K. 1985. IL-31 Bambus-Bamboo. Institute for Lightweight Structures, University of Stuttgart.

Farrelly, D. 1984. The Book of Bamboo. Sierra Club Books, San Francisco.

Frith, O.B. 2008. Mainstreaming Pro-Poor Livelihood Opportunities with Bamboo. INBAR, Beijing.

Hidalgo-Lopez, O. 2003. Bamboo: The Gift of the Gods. 2003. Oscar Hidalgo-Lopez, Bogota.

INBAR. No date. INBAR Database on Bamboo and Rattan Trade. http://www.inbar.int/trade/main.asp

Janssen, J.J.A. 2000. Designing and building with bamboo. INBAR, Beijing.

Liese, W. 1985. Bamboos—Biology, Silvics, properties, utilization. Schriftenreihe der GTZ, Nr. 180. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Liese, W., and S. Kumar. 2003. Bamboo Preservation Compendium. INBAR, Beijing.

Little, E.L., and R.G. Skolmen. 1989. Common Forest Trees of Hawaii (Native and Introduced). Agriculture Handbook no. 679. Forest Service, U.S. Dept. of Agriculture.

Mohanan, C. 2002. Diseases of Bamboos in Asia—An Illustrated Manual. INBAR, New Delhi.

Morán Ubidia, J.A. 2003. Traditional Bamboo Preservation Methods in Latin America. INBAR, Beijing.

Ohrnberger, D. (ed.). 1999. The Bamboos of the World: Annotated nomenclature and literature of the species and the higher and lower taxa. Elsevier, Amsterdam.

Othman, A.R., A.L. Mohmod, W. Liese, and N. Haron. 1995. Planting and Utilization of Bamboo in Peninsular Malaysia. Research Pamphlet No. 118. Forest Research Institute Malaysia (FRIM), Kuala Lumpur.

Pacific Island Ecosystems at Risk (PIER). 2010. *Bambusa* spp. http://www.hear.org/Pier/species/bambusa_spp.htm [accessed January 30, 2010]

Paudel, S., D. Greenberg, and R. Henrikson. 2007. Visionary Bamboo Designs for Ecological Living. INBAR, Beijing.

Ramanuja Rao, I.V., A. Kumar, S. Reza, and B. Motukuri. 2009. A Pathway Out of Poverty—Bamboo incense sticks

production as a livelihood option for rural women in Tripura, India. INBAR, Beijing and CIBART, Delhi.

Ramanuja Rao, I.V., B. Motukuri, S. Karpe. 2009. Breaking Barriers and Creating Capital—Sustainable Development with Bamboo in the Konkan Region, Maharashtra, India. INBAR (Beijing) and CIBART (Delhi).

Rao, A.N., V.R. Rao, and J.T. Williams. (eds.). 1998. Priority species of bamboo and rattan. IPGRI, Selangor and INBAR, Beijing.

SCCS Consortium. 2009. http://www.geos.ed.ac.uk/sccs/biochar/productionsources.html [accessed March, 10 2010]

Wang, H.J., R.V. Varma, and T.S. Xu. 1996. Insect pests of bamboo in Asia—An illustrated manual. INBAR, New Delhi.

Zamora, A.B. 2003. Micropropagation of bamboo. INBAR, Beijing.

Zhang, Q.S., S.X. Jiang, and Y.Y. Tang. 2003. Industrial utilisation of Bamboo. INBAR, Beijing.

Zhaohua, Z., and E. Yang. 2004. Impact Assessment of Bamboo Shoot on Poverty Reduction in Linan, China. INBAR, Beijing.

Zhu, Z.H., and E.L.Y. Yang. 2004. Impact Assessment of Bamboo Shoot on Poverty Reduction in Linan, China. INBAR, Beijing.

Specialty Crops for Pacific Island Agroforestry (http://agroforestry.net/scps)

Farm and Forestry Production and Marketing Profile for Bamboo (various species)

Authors: Andrew Benton, Manager, Networking and Partnership Unit, International Network for Bamboo and Rattan (INBAR), 8, Futong Dong Da Jie, Wangjing, Chaoyang District, PO Box 100102-86, Beijing 100102, P. R. China; Tel: +86-10-64706161 ext. 316, Fax: +86-10-64702166; Email: andrew@inbar.int; Web site: http://www.inbar.int

Dr. Lex Thomson, FACT Team Leader (EU-Facilitating Agricultural Commodity Trade Project), SPC Private Mail Bag, Suva, Fiji; Tel: +679 3378295 or 679 3370733 ext. 295; Email: LexT@spc.int

Peter Berg and Susan Ruskin, Quindembo Bamboo Nursery, Kamuela, Hawaii 96743; Tel: 808-885-4968; Web site: http://bamboonursery.com

Recommended citation: Benton, A., L. Thomson, P. Berg, and S. Ruskin. 2011 (revised). Farm and Forestry Production and Marketing Profile for Bamboo (various species). In: Elevitch, C.R. (ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. http://agroforestry.net/scps

Co-production reference: International Network for Bamboo and Rattan (INBAR) Working Paper 61

Version history: July 2010, February 2011

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai'i 96725, USA; Tel: 808-324-4427; Fax: 808-324-4129; Email: par@agroforestry.net; Web: http://www.agroforestry.net. This institution is an equal opportunity provider.

Acknowledgments: Many thanks to Norm Bezona, Nick Bertulis, Durnford Dart, Rich von Wellsheim, Li Yanxia, and Lou Yiping for their input. The editor thanks Kim Higbie, John Mood, Leimana Pelton, Virginia Small, and Rich von Wellsheim for their ground-breaking work with bamboo in Hawai'i and for their advice and support. Photos from Alvis Upitis and Matuaileoo Environment Trust Inc. (METI) are greatly appreciated.

Sponsors: Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2007-47001-03798.