April 2006
ver. 2.1

Metroxylon amicarum, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm)

Arecaceae (palm family)

Will McClatchey, Harley I. Manner, and Craig R. Elevitch

IN BRIEF

Distribution Southeast Asia, Melanesia, and some islands in Micronesia and Polynesia.

Size Depending on species, 9–33 m (30–108 ft).

Habitat Tropical lowland forest and freshwater swamps, usually found near sea level but can be found 1–700 m (3–2300 ft) with rainfall of 2000–5000 mm (80–200 in).

Vegetation Grow with a wide range of species found in lowland freshwater swamps and in traditional swidden gardens in lowland rain forests.

Soils Can grow on a wide variety of soils, including well drained, poor quality sand, clay, or ʻaʻā lava.

Growth rate The growth rate is rapid, exceeding 1.5 m (5 ft) per year in optimal conditions.

Main agroforestry uses Coastal protection, improved fallow, homegardens.

Main products Staple food, thatch.

Yields Under good conditions, *M. sagu* can yield 15–25 mt of air-dried starch per ha (6.7–11.1 t/ac) at the end of an 8-year growth cycle. Other species are somewhat less productive.

Intercropping Interplanting for its non-food products is practiced extensively on many Pacific islands.

Invasive potential It has little potential to become invasive.

M. warburgii **growing among breadfruit (*Artocarpus altilis*) and poumuli (*Flueggea flexuosa*) in American Samoa.**

INTRODUCTION

The genus *Metroxylon* is found from 17°S to 15–16°N latitude ranging from Thailand, peninsular Malaysia and Indonesia, to Micronesia, Fiji, and Samoa. The palms are generally found at low elevations in swamps. The genus is of significant economic importance in traditional societies and is of ever increasing importance in Malaysia, Indonesia, the Philippines, and Papua New Guinea. Because of their value, *Metroxylon* species have been moved from place to place by aboriginal peoples, with much of the present distribution probably due to multiple ancient introductions.

Metroxylon species stand between 9 and 33 m (30–108 ft) in height. Generally, the species tolerate salinity and prolonged flooding and acidic and wet soils. Observations of *M. warburgii* in Samoa suggest that the species does well in polycultural complexes.

Metroxylon palms are used throughout the Indo-Pacific region by lowland-, marsh-, and near-marsh-dwelling peoples. *Metroxylon* is of extreme importance to over a million people who use the palms as their primary dietary starch source. The palms are of secondary importance to thousands of other people who use them as a source of superior house thatch with limited use as a food supplement.

DISTRIBUTION

Native range

Metroxylon species are found in moist localities in tropical rainforests, moist upland rainforest, and freshwater swamps of Southeast Asia, Melanesia, and some high volcanic islands in Micronesia and Polynesia. They are also present on a few low islands and atolls of the Pacific, (e.g., Futuna and Nukuoro).

The natural habitat of *Metroxylon* is tropical lowland forest and freshwater swamps. The palms are often found growing in the freshwater margin at the back of mangrove swamps, extending inland as far as slow moving freshwater flows.

They are found in swamps from southern Thailand, peninsular Malaysia, Indonesia, and the Philippines through Pohnpei, Samoa, and Fiji. Distribution is extensive in New Guinea, but they are not found in swamps in Northern Australia. Much of the distribution outside of Melanesia is probably of ancient anthropogenic origin.

M. amicarum is native to the Caroline Islands (Federated States of Micronesia, states of Pohnpei and Chuuk), the Marshall Islands, and formerly in Guam and Palau.

M. paulcoxii is found in Western Samoa on 'Upolu and Savai'i islands.

M. sagu is believed to be endemic to Papua New Guinea, New Britain, and the Molucca Islands. Flach (1997) considers Papua New Guinea to be the center of diversity. *M. sagu* is present in Aimelik, Palau, at the old Japanese introduction station.

M. salomonense is endemic to the Solomon Islands including Bougainville Island (Papua New Guinea).

M. vitiense is endemic to Fiji on the islands of Viti Levu, Ovalau, and Vanua Levu.

M. warburgii is found in Futuna, Fiji, Rotuma, Solomon Islands, Vanuatu, Western Samoa, American Samoa, and possibly in Tahiti, Tokelau, and Tonga.

Current distribution

In Papua New Guinea and most Pacific islands, *Metroxylon* spp. are found mainly in wild stands. As it is difficult to distinguish between wild and feral, many so-called wild stands may stem from ancient plantations. Various species are grown throughout the tropics in experimental and commercial plantations.

M. amicarum in Pohnpei is found in freshwater wetlands, either coastal or moist upland rainforest. A few were reported by Stone (1970) to be planted in Guam. There is no local name for this species in Guam, suggesting that it is an introduced species there. *M. amicarum* is possibly an aboriginal introduction to Pohnpei from the Santa Cruz Islands as a cultivar of *M. warburgii* (McClatchey 1998, 2002).

M. paulcoxii is possibly an aboriginal introduction from the Santa Cruz Islands via Rotuma as a cultivar of *M. warburgii*.

M. sagu is by far the most important economic species and is now grown commercially in Malaysia, Indonesia, the Philippines, and New Guinea for production of sago starch and/or conversion to animal food or fuel ethanol. In many countries of SE Asia, except Irian Jaya, *M. sagu* is mainly found in semi-cultivated stands. Irian Jaya has about 6 million ha of *M. sagu*. The stands of good quality *M. sagu* can be quite large. Papua New Guinea has an estimated 1 million ha of wild and 20,000 ha (49,400 ac) of semi-cultivated *M. sagu*. *M. sagu* is also found in Guam, Palau, Nukuoro, Kosrae, and Jaluit, Marshall Islands (Fosberg et al. 1987), most likely the result of human introduction.

M. warburgii has been distributed from Northern Vanuatu and the Santa Cruz Islands to many other adjacent island groups, such as Banks, Tikopia, Anuta, and Rotuma, and a bit further to Fiji, Samoa, and Futuna. It is expected that further research will find that *M. warburgii* is a widely

Distribution of *Metroxylon* species.

dispersed and highly varied species.

BOTANICAL DESCRIPTION

Preferred scientific names

Metroxylon amicarum (H. Wendland) Beccari
M. paulcoxii McClatchey
M. sagu Rottboell
M. salomonense (Warburg) Beccari
M. vitiense (H. Wendland) H. Wendland ex Bentham & Hooker f.
M. warburgii (Heim) Beccari

Family

Arecaceae (palm family)

Subfamily

Calamoideae

Non-preferred scientific names

Many species of *Metroxylon* have previously been classified under the genera *Coelococcus* and *Sagus*.

M. amicarum *Sagus amicarum* Wendl., *Coelococcus amicarum* (Wendl.) Warb., *C. carolinensis* Dingl., *M. carolinense* (Dingl.) Becc., *M. amicarum* var. *commune* Becc., and *M. amicarum* var. *majus* Becc. are not preferred names (Fosberg et al. 1987).

M. paulcoxii No valid non-preferred scientific names known. *M. upoluense* is often used, although it is an invalid name.

M. sagu *Sagus inermis* Roxb. and *Sagus spinosus* Roxb. are not preferred names. In Rauwerdink's classification, *M. rumphii* and *M. squarrosum* are given as synonyms (Flach 1997).

M. salomonense *Coelococcus salomonensis* Warburg, Ber. and *Metroxylon bougainvillense* Beccari are not preferred names.

M. vitiense *Coelococcus vitiensis* H. Wendl. ex Seem. and *Sagus vitiensis* H. Wendl. ex Seem. are not preferred names

M. warburgii *Coelococcus warburgii* Heim. *M. upoluense* is often used, although it is an invalid name.

Common names

M. amicarum

Caroline ivory nut, Caroline ivory nut palm, Polynesian ivory nut palm, Polynesian ivory palm (English)
oahs (Pohnpei)
oj (Marshall Islands)
rupang, *rúpwúng* (Chuuk)

M. paulcoxii

niu Lotuma (Western Samoa)

M. sagu

ambasao (Kwara'ae, Solomon Islands)

balau (Melanau, Sarawak)
chr aè saku (Cambodian)
lumbiya (Philippines)
pohon sagu, pohon rumbia (Bahasa Indonesia)
rumbia (Malaysia)
sago palm, true sago palm, sago (English)
sakhu (Thai)
sa:khu'u, *tônz* (Laos)
saksak (Pidgin English, Papua New Guinea)
sagu (Vietnamese)
tha-gu-bin (Myanmar)

M. salomonense

ao (San Cristobal)
atava, *endeve*, *karamava*, *katuva*, *karama*, *katua*, *karmo*, *nive* (Choiseul)
ato (Bougainville, Florida Islands)
ato, *hapiri*, *naota*, *natho*, *tete-na* (Santa Isabel)
ato, *rao*, *sao* (Guadalcanal)
atovo, *endeve*, *kinenda*, *nggoe*, *pina* (New Georgia)
kalovo (Savosavo)
lao, *rao*, *sao*, *wanda* (Malaita)
name (Shortland Islands)
nat (Russell Islands)
pina (Vella Lavella)

***M. paulcoxii*, 'Upolu, Samoa.** PHOTO: W. MCCLATCHEY

***M. amicarum*, Chuuk Atoll.** PHOTO: W. MCCLATCHEY

***M. sagu*, Aimelik, Palau.** PHOTO: W. MCCLATCHEY

***M. salomonense*, Kolobaqara, Solomon Islands.** PHOTO: W. MCCLATCHEY

***M. warburgii*, American Samoa.** PHOTO: W. MCCLATCHEY

***M. vitiense*, Nasavusavu, Vanua Levu, Fiji.** PHOTO: W. MCCLATCHEY

M. vitiense

songo, *songa*, *niu soria*, *seko* (near Nadi) (Fiji)

M. warburgii

enkul, *natakra*, *natalawa*, *natangura*, *netato*, *nindru ambih*, *notah*, *nuwauriet*, *sokora*, *tangula*, *tenebee*, *tsuku*, *wataghor* (Vanuatu)
lnkoko, *noeroe*, *lovnete*, *nete*, *nokwo*, *otovo*, *ole*, *oe*, *koko*, *laukoko* (Santa Cruz group)
niu Lotuma (Western Samoa)
ota (Anuta, Futuna, Rotuma, Tikopia)

Size

Note that for the leaf and petiole lengths the lower numbers apply to juvenile palms, while the higher numbers apply to mature palms.

M. amicarum reaches a height of 12–33 m (39–108 ft) tall, with a stem 30–36 cm (12–14 in) in diameter. Leaves 4–7 m (13–23 ft) long, petiole 1–3 m (3.3–10 ft) long.

M. paulcoxii is small to moderate size; petiole 1–3 m (3.3–10 ft) long, rachis 1.5–2.9 m (5–9.5 ft) long.

M. sagu reaches 15 m (49 ft) in height with bole diameter (without leaf sheaths) of 35–60 cm (14–24 in).

M. salomonense attains 8–20 m (26–66 ft) tall, with stems 25–55 cm (10–22 in) in diameter. Leaf petiole 1.3–7 m (4–23 ft) long, rachis 2.9–7.5 m (9.5–25 ft) long.

M. vitiense grows to 5–16 m (16–52 ft) tall, with stem 36–50 cm (14–20 in) diameter. Leaf petiole 1.8–8 m (6–26 ft) long, rachis 4–6 m (13–20 ft) long

M. warburgii reaches a height of less than 9 m (30 ft) when mature. Six to 9 m (20–30 ft) tall, with stem 31–43 cm diameter (12–17 in), leaves 0.3–1.5 m (1–5 ft) long

Flowers

The inflorescence is large, paniculate, and mainly terminal for most species. The palms are monoecious, having both male and female flowers on the same plant. Flowers differ little between species other than in length of the parts. The palms are monocarpic; i.e., they fruit and flower once and then die. An exception is *M. amicarum*, which flowers for a number of years (pleonanthic) instead of flowering once and dying. Flowers are borne on crowded spikes, spirally in pairs (of male and hermaphrodite, functional female) flowers.

Leaves

Like most palms, *Metroxylon* species have an erect crown of large, pinnate arching leaves. Leaves moderate to large, pinnate; petiole 0.33–7 m (1–23 ft) long, unarmed or armed with single to multiple spines 1–46 cm (0.4–18 in) long, occurring as clusters, combs, or upon collars of short lateral vascular bundles, sometimes with wide, thin, and papery flattened spines up to 50–60 cm (20–24 in) long and 1–2 cm (0.4–0.8 in) wide; rachis 2.3–7.7 m (7.5–25.3 ft) long, unarmed or armed like the petiole or much less so, particularly in leaves emerging higher on the stem, the surface often adorned with transverse spineless combs; leaflet number proportional to leaf length, usually 160–340, 72–203 cm (28–80 in) long and 4–17.8 cm (1.6–7 in) wide, with a single large, hard, sometimes yellow midrib, frequently glossy green above and dull-pale green below, unarmed or armed with short spines, 1–29 mm (0.04–1.14 in) long, along the margins and main vein.

Fruit

Mature fruits are globose, ovoid or pyriform, 1.5–8.3 cm (0.6–3.3 in) wide, and 2.3–10.6 cm (0.9–4.2 in) long. The epicarp is covered in 7–40 regular ordered, alternating vertical rows of green to golden yellow, to dark brown, to grey-margined, reflexed scales, with mid-fruit scales 4–19 mm (1.6–7.5 in) long.

M. amicarum

Fruit rounded to pyriform, (5.3)7.2–8.3(13) cm ((2.1)2.8–3.3(5.1) in) in diameter, 5.6–13 cm (1.7–5.1 in) long; epicarp covered in 26–38(40) rows of golden to chocolate brown and grey margined, reflexed scales, with mid-fruit scales 7–14 mm (2.7–5.4 in) long. *M. amicarum* seeds are disseminated by gravity or water. Fruits are often found on shores of the Caroline Islands, having been carried by ocean waves and currents from one island to another or one part of an island to another.

M. paulcoxii

Fruit obpyriform, 5.4–6 cm (2.1–2.4 in) in diameter, 6.5–7 cm (2.6–2.7 in) long, with emergent apical stigmatic remains; epicarp covered in 24–26 rows of green to golden yellow-brown to grey margined, reflexed scales, with the mid-fruit scales 13 mm (5.1 in) long.

M. salomonense

Fruit rounded, globular, 5.9–8 cm (2.3–3.1 in) in diameter, 5.2–7 cm (2.0–2.7 in) long; epicarp covered in 25–38 regular ordered alternating vertical rows of green to golden yellow, sometimes tinged with red, to brown, with grey margined, reflexed scales, with mid-fruit scales 11–19 mm (4.3–7.5 in) long.

***M. vitiense*, showing spines on leaf base and petiole, Viti Levu, Fiji.** PHOTO: W. MCCLATCHEY

M. sagu

Fruit depressed-globose to obconical, 3–5(7) cm (1.2–2(2.7) in) in diameter, covered with 18 vertical rows of rhomboid greenish-yellow scales. *M. sagu* produces both pollinated (seeded) and parthenocarpic (non-pollinated) fruit. Seeded fruits contain a stony (hard), white endosperm and brown testa. Parthenocarpic fruit are smaller and contain a spongy mesocarp. *M. sagu* fruits take about 24 months to mature.

M. vitiense

Fruit rounded to elliptic/ovular, 4.1–5.8 cm (1.6–2.3 in) wide, 4.9–6.4 cm (1.9–2.5 in) long; epicarp covered in 25–27 rows of green to golden yellow to dark brown to grey margined, reflexed scales, with mid-fruit scales 9–12 mm (3.5–4.7 in) long.

M. warburgii

Fruit obpyriform, (3.5)5.4–7 cm ((1.4)2.1–2.7 in) wide, (4.4)6.4–8.5 cm ((1.7)2.0–3.3 in) long, with emergent apical stigmatic remains; epicarp covered in 23–31 rows of green to golden yellow-brown, grey margined, reflexed scales, with mid-fruit scales 9–13 mm (3.5–5.1 in) long.

Bark

The bark of mature palms is gray, rough, and fissured in long plates or corky ridges. The stem is frequently surrounded by deteriorating, partially attached leaf-sheaths. The lower internodes frequently have suckers and/or sharp to blunted adventitious roots. On younger trees the bark is smoother and paler gray to brownish in color. The inner bark is light colored and bitter.

How to distinguish from similar species/look-a-likes

Metroxylon species may be confused with other palms, although not with any that are found in the native range. Palms in Samoa have often been incorrectly reported as *Metroxylon vitiense*, when only *M. warburgii* and *M. paulcoxii* have been reported in Samoa.

M. amicarum has inflorescences that are axillary; most of the other *Metroxylon* species are monocarpic (the terminal bud develops into a large inflorescence). *M. amicarum* palms are also the tallest, reaching 33 m (108 ft) or possibly taller.

M. sagu has 18 rows of scales on the fruit. The other *Metroxylon* species have between 24 and 40 rows of scales.

M. sagu commonly reproduces by suckers and rarely by seed, while the other species are not reported to reproduce by suckers and normally reproduce by seed. *M. sagu* is eas-

Young inflorescences cut from *M. salomonense*, Guadalcanal, Solomon Islands. PHOTO: W. MCCLATCHEY

Fruits maturing on *M. amicarum*. PHOTO: D. WARD

Developing inflorescence of *M. salomonense* over a period of 2 years and 4 months. The tree shown was planted in 1985 as a juvenile. From left to right: first-order branches forming (11 Dec 2000), flowers forming (6 Sept 2001), and fruit forming (26 Apr 2003). LEFT AND CENTER PHOTOS: E. BURSON, RIGHT PHOTO: R. BAKER

***M. amicarum* fruits, Nett, Pohnpei. Note the wide variation in shape from fruits collected from one stand of trees.** PHOTO: W. MCCLATCHEY

***M. amicarum* fruit.** PHOTO: R. BAKER

ily distinguished by the robust size of the inflorescence branches, which are massive compared with other species.

M. warburgii, along with *M. paulcoxii* and some *M. amicarum*, is easily recognized by its pear-shaped fruits. *M. warburgii* is found over a very wide range of islands and is unstudied throughout much of that range. It is very likely that the species is more variable than currently realized.

GENETICS

While *M. sagu* is mainly propagated vegetatively, the other species reproduce by seed. Of these, *M. amicarum* and some individuals of *M. warburgii* stand out because they do not die upon reaching a reproductive age, instead persisting to become quite tall.

Known varieties

The number of locally identified and named varieties of *M. sagu* is very large. In the Western Sepik basin of Papua New Guinea, Rauwerdink (1986) noted that local sago growers distinguished 20 local cultivars.

Varietal differences have been noted for a number of characteristics including degree of spininess; color of starch; width, length, and thickness of leaflets; number of years until inflorescence initiation, to name a few.

M. sagu has many selected varieties that are thornless and reach maturity in less than 6 years. Rauwerdink (1986) has reviewed the range of varieties and characteristics of preferred types.

Selected varieties are not known for the other species covered here.

Culturally important related species in the genus

All of the species are of major importance to local cultures, except for *M. vitiense*, when was of marginal importance in Fijian society except for a few communities where it was considered to be a source of superior thatch and edible heart of palm.

ASSOCIATED PLANT SPECIES

The less commercially important species are found both in lowland tropical freshwater swamps as well as in traditional swidden gardens in higher altitude lowland rain forests.

In Pohnpei, *M. amicarum* is an occasional component of the montane (upland) rainforest. Plants common to this rainforest are *Clinostigma*, *Glochidion*, *Myrsine*, *Elaeocarpus*, *Syzygium*, *Psychotria*, *Timonius*, *Astronidium*, *Cyathea* tree ferns, and many lianas (*Ipomoea*, *Merremia*, *Freycinetia*, *Hypserpa*, and *Pachygone*). *M. amicarum* is also found in freshwater swamps where common components are species of *Terminalia*, *Campnosperma*, *Barringtonia*, *Erythrina*, *Ficus*, *Hibiscus*, *Phragmites*, *Acrostichum*, and *Scirpodendron* (Mueller-Dombois and Fosberg 1998).

In Papua New Guinea freshwater swamps, *M. sagu* is found in association with *Campnosperma brevipetiolata*, *Terminalia brassii*, *Pandanus*, and several other species. (Mueller-Dombois and Fosberg, 1998).

In the Solomon Islands, *M. salomonense* forms a distinctive freshwater forest type (Mueller-Dombois and Fosberg 1998).

M. vitiense commonly grows in forests in swampy places (Smith 1979). Formerly, it was common near Navua, Viti Levu, but is now found in the more inaccessible swampy valleys.

In Samoa, *M. warburgii* is found in a number of villages on Upolu and Savai'i islands growing as a cultivated species in polycultural agroforests. Here *M. warburgii* has been found growing in traditional agroforests in association with *Citrus* spp., breadfruit (*Artocarpus altilis*), screwpine (*Pandanus* spp.), coconut (*Cocos nucifera*), and *Alocasia macrorhiza*, to name a few common cultivated species.

Massive inflorescence branches of *M. sagu*. PHOTO: W. MCCLATCHEY

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

The suitable climate for *Metroxylon* species is the humid tropical rainforest of SE Asia and the equatorial Pacific. The relative humidity should be at least 70%, but the plant can tolerate lower humidity for short periods without damage, and incidental light should be above 800 k/cm²/day (Flach 1997).

Metroxylon species do not tolerate water shortage well. In rainfall-dependent sago palm growing localities, rainfall should be uniform and ample. Flooding for prolonged periods and stagnant water are detrimental to growth.

As long as sufficient water is present, there does not seem to be an upper temperature limit for growth of sago. The palms cannot tolerate frost and grow more slowly in cooler climates such as Hawai'i or areas with seasonally cooler weather such as Florida and Queensland.

Metroxylon species can be found in areas where the rainfall is high throughout the year or where there is a summer maximum of rainfall. Soil moisture is probably more important than rainfall pattern or amount, if groundwater and surface water sources are adequate. Flach (1997) noted that if there are short dry spells, the water table should be at most 40–50 cm (16–20 in) below the soil surface.

Elevation range

1–700 m (3.3–2300 ft). Although certain *Metroxylon* species grow well in inland and upland areas, all *Metroxylon* palms growing away from lowland regions are the result of human cultivation.

Mean annual rainfall

2000–5000 mm (80–200 in)

Rainfall pattern

Metroxylon grows in areas with summer or winter peaks or uniform rainfall without pronounced dry spells.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

The plant does not tolerate drought (unless there is ample groundwater).

Mean annual temperature

25°C (77°F)

Mean maximum temperature of hottest month

Greater than 30°C (86°F)

Mean minimum temperature of coldest month

17°C (63°F)

Minimum temperature tolerated

17°C (63°F) (Flach 1997)

Soils

Metroxylon species can grow on a wide variety of soils. They can persist on well drained, poor quality materials including sand, clay, or ʻaʻā lava. The palms will grow in soil that is periodically inundated by salt water as long as fresh water flow is more prevalent.

Soil texture

They prefer medium and heavy soils.

Soil drainage

Metroxylon species grow best in soils with impeded drainage or with seasonal waterlogging. Waterlogging for long periods impedes growth and productivity.

Soil acidity

The palms thrive in acidic to neutral pH (4.0–7.4) soils. One reference indicates tolerance of very acid soils (Flach 1997).

Special soil tolerances

All of the species seem to tolerate salinity for short periods without apparent damage, with some populations growing in regular salt spray, periodic tidal flux, and at the edges of brackish mangrove swamps. Salinity should not exceed 10 S/m (equivalent to 1/8 the salt concentration of sea water) (Flach 1997).

Tolerances

Drought

Drought is detrimental to the growth and productivity of all *Metroxylon* species.

Full sun

The palms do best when there is an adequate amount of sunlight, which is needed to complete their life cycle. With sunlight, the trunks will elongate and begin to produce and store starch.

Shade

Trees grow well in moderately open forest canopies under up to 50% shade. Where growing in mixed stands, the palms can be shaded out by dense shade cast by taller dicotyledonous trees. *M. sagu* produces suckers even when shaded.

Fire

The palms do not tolerate fire.

Frost

The plants do not tolerate frost.

Waterlogging

Metroxylon species tolerate waterlogging, although *M. sagu* is not found where the groundwater depth is too deep. In permanently wet situations, *M. sagu* will develop pneumatophores (modified roots for gaseous exchange). In permanently wet or flooded localities many specimens will remain in the rosette stage and not complete their life cycle and reach maturation (Flach 1997). *M. sagu* is one of the few species that can be grown in swamps without extensively modifying the swamp habitat. However, even though modification is unnecessary, cultivation within the swamp habitat may have detrimental effects on the swamp ecosystem.

Salt spray

Salt spray as well as mild soil salinity are tolerated.

Wind

They are tolerant of windy conditions including bad storms and are rarely observed with sheared tops.

GROWTH AND DEVELOPMENT

Cultivated varieties in well established plantations (particularly of *M. sagu*) grow to a height of 12–18 m (40–60 ft) in 6–14 years. At maturity the trees convert stored stem starch into a large, terminal inflorescence; therefore, farmers watch for early development of the inflorescence as an indication of harvest time. At that time, hormones in the tree convert stored starch into simpler sugars for mobilization.

M. sagu undergoes four stages during its life cycle. Flach's (1997) model has an 11–12 year life cycle from seed to seed under optimum ecological conditions. These stages are:

1. Rosette stage of 45 months from seeding; during this period the plant forms a total of about 90 leaves. This is a period characterized by relatively little growth.
2. Bole formation stage of 54 months; during this period, the bole elongates to maximum height and produces one leaf per month. Plants during this stage have a total of a bout 24 leaves and 54 leaf scars on the bole and are producing a high amount of starch.
3. Inflorescence stage of 12 months. The plant forms two leaves per month, the rate of starch accumulation starts to decrease, and the starch moves from the lower to the upper bole. Palms are harvested for starch during this and the next period. In the semi-cultivated *M. sagu* stands of Papua New Guinea and Irian Jaya, local collectors say that for high production per unit time and area, starch should be harvested at flower initiation (Flach 1997).
4. Fruit ripening stage of 24 months.

Some varieties of *M. sagu* develop an inflorescence at 6–7 years. While this species forms dense stands in freshwater swamps, it produces its highest yield of starch and completes it life cycle when the soil is drier and not flooded.

***M. amicarum,* growing in broad, flat valley with numerous freshwater seeps and small streams, just above sea level. Kitti, Pohnpei.** PHOTO: W. MCCLATCHEY

Other *Metroxylon* species typically require 12–15 years to reach maturation but under ideal circumstances may flower in 10 years.

Growth rate

The growth rate is rapid. Assuming a life cycle of 12 years, growth to a height of 20 m (66 ft), and optimal ecological conditions, this gives a growth rate of 1.67 m/yr (5.5 ft/yr).

Flowering and fruiting

These palms are monocarpic, meaning they flower once, then die. *M. amicarum* is an exception; it flowers repeatedly over many years. Most of the time, *M. warburgii* flowers only once; however, some individuals exhibit growth that is between hapaxanthic and pleonanthic, with an extended but still terminal growth period with large leaves in the inflorescence.

Yields

In Papua New Guinea and Southeast Asia, *M. sagu* is harvested for its large starch grains. Barrau (1959) gave the average yield per trunk as 110–136 kg (242–299 lb) of starch, and up to 400 kg (880 lb) for sterile cultivars. Purseglove (1968) stated that in a New Guinea swamp forest there are about 60 palms per hectare (24 palms/ac) worth felling for their starch, yielding 7000 to 9000 kg (15,400–19,800 lb) of starch per year, with a water content of 35–40%.

In the subsistence economy of the Oriomo Papuans, 150–160 hours of work are required to produce enough sago starch for one person per year (1 kg [2.2 lb] air dried starch/day) (Ohtsuka 1983). In Salawati Island, West Irian, an average wild sago palm trunk weighing 1000 kg (2200 lb) yields 150 kg (330 lb) of dry starch (Flach 1997). Sarawak smallholders produce about 50,000 mt (55,000 t) of air-dried sago flour per year for export (Singapore Zoological Gardens Docents 2000).

Leaf production rates are uncertain. However, growers indicate that it is critical that at least three mature leaves be left when harvesting leaves for thatch, or else the palm is likely to die. Often palms harvested for thatch have impeded growth and the appearance of stress. As an indication of this stress, Haska (1995) noted that for *M. sagu* in West Java, average starch production "is only 55 kg/trunk" from palms grown for leaves, while it is "175 kg/trunk for the same variety grown for starch only."

Rooting habit

M. sagu has heavy aerial and spongy roots with a tough central vascular strand that penetrate only about 1 m (3.3 ft) deep into the soil (ARCBC 2004). It is likely that the rooting system is fairly shallow, similar to coconut's. In wet areas, the palm produces pneumatophores (roots which aid in respiration).

Reaction to competition

When growing in mixed forests, *Metroxylon* can be shaded out by faster growing species. It does not compete well against dicotyledonous trees (Flach 1997). However, it readily grows as a living fence on the sunny side of gardens and in agroforestry plantations of mixed, shorter stature trees and shrubs.

PROPAGATION

All *Metroxylon* species are propagated by seed. An exception to this is *M. sagu*, which for the most part is sterile, reproducing via vegetative suckers emerging from roots or lower trunks of parent plants. The species also reproduces by stolons, often meters in length. For more information on propagating *M. sagu*, see Schuiling and Jong 1996.

Propagation by seed

Seed collection

With the exception of *M. amicarum*, *Metroxylon* species reproduce only once, at the end of their life cycle. The flowering stage occurs at an age of 6–20 years. Seeds only germinate when fully mature (signified by large fruit size and the husk turning color from green to straw or brownish). Fruits take 24–36 months to reach maturity. Because of the height of the fruit at the apex of the palm, and the difficulty of assessing maturity, it's best to collect fruit immediately after it has fallen to the ground.

Seed processing

The seeds are large and can easily be cleaned of loose debris or soil after falling.

Seed storage

The seeds lose their viability rapidly when stored and do not tolerate dry conditions. Successful germination occurs within 1–2 months after maturity, and it is best to sow seeds immediately after harvest. Seeds may germinate while still attached to the infructescence (vivipary) and grow to heights of 0.9–1.2 m (3–4 ft) tall before breaking off and falling to the ground. This is particularly common in *M. warburgii*.

The short life span of the seeds and the long reproductive cycle means that *Metroxylon* is best maintained and conserved in field gene banks (Flach 1997). In a sago swamp, seeds germinate readily when they are laying on moist soils.

Pre-planting seed treatments

Flach (1997) noted that germination can be speeded up if the seed husk is removed and the covering over the embryo (operculum) is loosened. Care should be taken not to damage the embryo.

Growing area

Due to the large seed size and rapid early growth, *Metroxylon* is well suited for direct-seeding in the field, assuming conditions are consistently moist. Seedlings can also be germinated in a nursery and transplanted bareroot at a young age, or grown to a larger size in a container. Seedlings transplant well as long as roots are not bound.

Germination

The seeds germinate best when exposed to a temperature of 30°C (86°F) and high humidity for prolonged periods (Ehara et al. 1998). Under such conditions, freshly harvested *Metroxylon* seeds have a high germination rate in 1–2 months. Such conditions can be achieved in a closed nursery, which heats up quickly in the sun. Artificial heat such as a climate-controlled cabinet or temperature-regulated bottom heat can also work. Prolonged exposure to temperatures above 38°C (100°F) can harm the seeds.

Media

A standard well drained nursery medium containing peat moss, coir, sand, etc., can be used, as long as the medium is free of pathogenic organisms.

Time to outplanting

Plants should be outplanted as soon as possible. Plants can have roots up to 30 cm (12 in) long and 2–3 eophils (first leaves) and still survive transplantation.

Approximate size at time of outplanting

Although it is best to outplant before the second eophil emerges, plants with several sub-mature leaves (1–2 m [3.3–6.6 ft] long) and a well developed root system have been successfully planted out.

Transplanting volunteer seedlings collected from under mature palms may be the easiest propagation method. This is a *M. warburgii* seedling collected in American Samoa. PHOTO: C. ELEVITCH

DISADVANTAGES

Metroxylon species, aside from *M. sagu*, are not very productive as starch plants. Their importance as a source of thatch is gradually decreasing as more durable man-made materials become available. Other minor products such as vegetable ivory are of limited economic importance. The spiny leaves may be considered a drawback, especially in urban environments. Expansion of the species into freshwater swamps may have serious ecological implications for the fauna and flora and is not recommended.

Potential for invasiveness

Metroxylon species are not considered to be an invasive.

Diseases and pests

The Pacific island species have few notable pests or diseases. The problems of diseases and pests are greater with intensive cultivation of *M. sagu*. In Sarawak, the main pests are the hispid beetle larvae (*Botronyopa grandis*) that feed on young tissue of the unopened spear at the central base of the crown; termites (*Coptotermes* spp.), which can be a pest on peat soils containing undecayed vegetative material; and red striped palm weevil larvae (*Rhynchophorus* spp.), which burrow into injured plant tissue (Gumbek and Jong 1991, cited by Flach 1997). Wild boars and monkeys may uproot newly planted suckers. Sudden drainage of a swamp can lead to a loss of leaves associated with a physiological disease (Flach 1997).

Other disadvantages or design considerations

More research information is needed on the fertility requirements of *Metroxylon* in order to raise yields above subsistence levels.

AGROFORESTRY/ENVIRONMENTAL PRACTICES

Soil stabilization

The root systems are able to trap silt.

Crop shade/overstory

In the Western Province of Papua New Guinea, farmers plant kava (*Piper methysticum*) in beds under a cover of *M. sagu* (Lebot 1991).

Improved fallow

Throughout the Pacific, *Metroxylon* species are planted or protected in fallow land.

Homegardens

Metroxylon species are frequently incorporated in mixed homegardens on many Pacific islands.

Living fences

Young palms, with their numerous spines, act as fences for pigs and deterrents to trespassers. As the palms mature and develop above-ground stems, new palms may be planted adjacent to the juveniles to maintain the spininess of the fence.

Boundary markers

The seeds are planted along rock walls and other property boundaries.

Windbreaks

Although *Metroxylon* species are not recommended for use as windbreaks, they are tolerant of windy conditions and are rarely observed with sheared tops.

Animal fodder

After removing most of the starch, the pith of *M. sagu* is fed to pigs in Papua New Guinea and many SE Asian countries. It is used as a basis for commercial animal feed in SE Asia.

Wildlife habitat

The palms provide nesting sites for birds.

Coastal protection

As the species is somewhat tolerant of salinity, it may offer some protection to low-lying coastal areas from extensive saltwater inundation by storm surges.

Ornamental

Considered to be a desirable ornamental plant in Pohnpei and other Pacific islands.

USES AND PRODUCTS

The various species of *Metroxylon* have important cultural values throughout many parts of the Pacific and SE Asia.

Top: Living fence of *M. warburgii* and pandanus in Samoa. Bottom: *M. warburgii* in a Samoan homegarden together with coconut, breadfruit, papaya, citrus, and other trees. PHOTOS: C. ELEVITCH

The two primary uses are for the production of edible starch and durable leaf thatch. Several secondary uses have also been recorded, but these are not comparable in economic importance to the primary uses. *M. sagu* is a staple food crop in the Sepik and Gulf provinces of lowland Papua New Guinea, where most of the sago grows in wild, uncultivated stands. Among the Asmat of Papua New Guinea, felling of the palm and harvesting of the sago starch is accompanied by ritual. In house construction, the leaves of sago are used for roof thatch and wall siding, and the wood is also used for floorboards and rafters. In the Solomon Islands, the thatch is known to last 5 years or longer. The decaying trunks of the sago palm are a source of sago palm beetle grubs (*Rhynchophorous ferrugineus/bilineatus*), an excellent source of protein. In the other parts of the Pacific, *M. warburgii* and *M. amicarum* are viewed as emergency food and are rarely or no longer eaten by people, although they are used for thatch and animal feed. Various parts of the plant are used for traditional medicines, toys, and other miscellaneous items.

PREPARING SAGO STARCH

1. Preparatory processing
   - Possible homage (monetary, spiritual, or familial) paid for access to a *Metroxylon* tree.
   - Selection of a tree containing usable starch.
   - Felling of the tree.
   - Possible transport of the log.
   - Splitting the tree open, lengthwise.
   - Removal of the pith.
2. Extraction of starch.
   - Crushing, threshing, and/or hand kneading of the pith to release the starch.
   - Washing and straining to extract the starch from the fibrous residue.
   - Collection of raw starch suspension in a settling container.
   - Decanting the water layer in order to collect the residual semi-solid pan of starch.
3. Storage of starch product.
   - Drying to form flour.
   - Cooking to form a bread or pudding.
   - Distribution of the dried/cooked end product.

(Barrau 1958, Henderson and Hancock 1988, McClatchey and Cox 1992).

Staple food

Metroxylon starch may be eaten as raw chunks of pith or as baked pieces of pith. Whole logs have been baked and taken as sea-provisions on long canoe voyages (Codrington 1891).

Each of the species is presently or has been formerly used as a source of edible starch, with the possible exception of *M. vitiense*. The most intensive use as a food source has been in the western Solomon Islands and Bougainville. Throughout the rest of the range of distribution, it was eaten as a famine food, although this is questionable in Fiji (Seemann 1865–1873) and in at least one culture in the eastern Solomon Islands (Woodford 1890).

Production and use of sago starch varies somewhat from location to location but can generally be summarized in the stages as indicated in the text box above.

Guppy's (1987) description of sago processing is typical:

"In the extraction and preparation of the sago, the natives of Bougainville Straits employ the following method. After the palm has been felled and all the pith removed, either by scooping it out or splitting the trunk, the pith is then torn up into small pieces and placed in a trough extemporized from the broad sheathing base of one of the branches of the felled tree. The trough is then tilted up and is kept filled with water, which running away at the lower end passes through a kind of strainer, made of a fold of the vegetable matting that invests the bases of the branches of the cocoa-nut tree, and is then received in another trough of similar material. The fibrous portion of the pith is thus left behind, and the sago is deposited as sediment in the lower trough. When this trough is full of sago, the superfluous water is poured off, and the whole is placed over a fire so as to get rid of the remaining moisture.... The sago is now fit for consumption, and is wrapped up in the leaves in the form of cylindrical packages 1½ to 2 feet in length."

As discussed above, production of sago from *M. paulcoxii* and *M. warburgii* is probably a recently introduced concept in Samoa. No one was observed producing starch from *M. paulcoxii*. Although starch production from *M. amicarum* is known, it is very rare, the trees being much too highly valued for thatch. Presently, many cultures have virtually abandoned the production of sago starch, in favor of other starch crops such as sweetpotato, taro, cassava (manihot), or imported rice.

Throughout SE Asia there are many traditional ways of preparing sago for consumption. (See Flach (1997) for many details about the starch, etc.). In Indonesia and many of the SE Asian countries, sago starch is produced commercially for use as food. In Cirebon, Indonesia, the starch is used in making noodles. The starch is also used in making white bread.

Sago pearls are made in West Malaysia and Sarawak. In West Malaysia the pearls are used in the preparation of three-palm pudding (sago pearls in coconut milk, and sugar from *Arenga pinnata*). In Sarawak the pearls are mixed with rice bran.

Fruit

Immature fruits (seeds) are occasionally reported as being eaten, particularly by children.

Nut/seed

In Chuuk, buttons were made from the hard, white, ivory like nut (endosperm) of *M. amicarum* during the Japanese mandate years. The nut is eaten by pigs in Chuuk and Pohnpei (Merlin et al. 1992, Merlin and Juvik 1996).

Leaf vegetable

The apical meristems or palm hearts are large and soft. The trees may be harvested prior to maturation exclusively for this purpose, with the meristem and several feet of the immature leaves being used. These palm hearts are used locally or are sold in local markets. They are eaten raw as a vegetable or cooked with other foods (now common in curries).

Secondary food products

Indirect traditional uses of *Metroxylon* include collection of mushrooms and beetle larvae that feed upon fallen trees. These are then eaten by local peoples. Naturally fallen palms may be checked periodically for growth of mushrooms and larvae, and in some areas palms are felled with the intention of collecting larvae or fungus at later times. The practice of intentionally felling *Metroxylon* to induce production of secondary products may represent one of the earliest forms of agriculture.

POHNPEI LORE

In Pohnpei, *M. amicarum* is the tallest of three native palms. Of those born of chiefly status (*Nanmwarki*), the maternal lineage, or "blood," is known as *Neinneinioahs Soupeidi*. The phrase is an honorific, with symbolic reference to this tall palm (Merlin et al. 1992). The implication is that the child will grow to be as tall, or as high in rank, as his forbears (as tall as an *M. amicarum* palm).

One legend says that before Pohnpei was vegetated, people lived in houses of rock without any roofs. A lady with magical powers visited the island and took pity on the people there. She then sent them the *oahs* plant, which the people used for thatching and other significant purposes (Elias 1998).

Top: The starch can be eaten raw. Bottom: The starch is usually harvested and refined into pure starch using a water process. Both photos: *M. warburgii*, American Samoa. PHOTOS: W. MCCLATCHEY

Appliances

The smooth inner surface of the sheaths also may be used as temporary containers or troughs for animal feed and as kneading boards for bread made from sago. *Metroxylon* leaflets may be used to line cooking pits. Woven leaflets are used as temporary baskets. Whole leaves are used to cover and protect dry-stored canoes (Feinberg 1988). The stiff, hard midribs may be used to make brooms, may serve as temporary sewing needles or pins, or may be used as thatch sheet skewers (Firth 1950). Guppy (1887) reported that gourd bottle-corks/stoppers are made from lightly rolled discs of sago leaves. The leaf sheaths are commonly covered externally with rough spines and/or rib-like protuberances. These rough sheaths have served as rasps in the preparation of sago and other food products that must be grated.

Toys

Bats, balls, and rafts are made by children from the leaf base.

Beverage/drink/tea

Starch of *M. sagu* is used in the manufacture of fructose syrup for non-alcoholic drinks. Perhaps the starch can also be used for making starch pearls similar to tapioca pearls used in fruit drinks.

Medicinal

The roots, young leaves, and stem cork of *M. amicarum* are used for traditional medicine in Pohnpei.

Timber

The wood (outer cortex) of *Metroxylon* stems is used as flooring and as planking for crossing short streams or swampy areas. The wood is not reported as being long lasting or durable, but is employed as a by-product by those who extract starch. Wood has also been used as house rafters (e.g., in Chuuk) and as wall material, although this is an infrequent usage. The woody leaf petioles of *M. sagu* are used to make walls, ceilings, and fences (Schuiling and Jong 1996).

Fuelwood

The bark can be used as a factory fuel.

Canoe/boat/raft making

The leaf rachis, without leaflets, may be used as a "raft" (Firth 1950). Children sometimes make surfboards from the petiole base (leaf sheath) that can be up to one meter wide.

Fiber/cordage

The fibrous outer layers of *M. sagu* leaf petioles are used for cordage and mat weaving (Schuiling and Jong 1996). Pith and leaf fibers have been studied for use in paper production (Kasim et al. 1995).

Fodder

The raw starch is used as pig feed on a local level. The starch has also been used on an industrial scale to feed pigs and chickens (Dunsmore and Ong 1970, Jalaludin et

Left: The leaf sheath covered with spiny ribs can be used as a grater in preparing sago starch. Right: *M. warburgii* with fronds pruned for thatch, Samoa. PHOTOS: C. ELEVITCH al. 1970, Müller 1977, Ong 1973, Springhall and Ross 1965).

Thatch/roofing/mats

Leaves are highly valued for thatch for roofs and house walls in many islands of the Pacific. In Pohnpei, roofs are called oahs, the Pohnpeian word for *M. amicarum*, as the leaves are used for thatch (Merlin et al. 1992).

The leaves are made into thatch in two different ways, with slight variations of these patterns in different cultures. Leaves may be woven into thatch sheets using the following procedure:

***M. warburgii* thatch, Rotuma.** PHOTO: W. MCCLATCHEY

1. Mature leaves are split down the middle of the rachis.
2. The halves of the leaf are woven and matched with the distal apex of one half attached to the proximal petiole base of the other, and vice versa.
3. The pair of leaves is allowed to dry in the sun, thus curing it into a dry thatch.
4. Drying may take from half a day to a week or more depending on the temperature and weather.

The thatch sheets may also be used green and allowed to dry on the house (Gardiner 1898). A slightly different weaving pattern is used for sets of leaves used to thatch the apex of the roof. Rather than using pairs of leaf halves, two entire leaves are woven facing one another, then one of the two leaves is split in half (down the rachis) leaving two leaf halves and one entire leaf all woven together. After weaving, the entire leaf is at the center of the thatching strip and the leaf halves are attached to each side. These unique apical thatch leaves are commonly called fakatafiti (or a cognate) throughout their usage in western Polynesia.

Alternatively, leaves may be manufactured into sewn thatch sheets through the following procedure:

1. Leaflets are removed from the rachis.
2. Each leaflet is folded over a supporting spine of wood (e.g., *Areca macrocalyx*), bamboo (e.g., *Bambusa* or *Schizostachyum* spp.), or rattan (*Calamus* spp.).
3. The leaflets are sewn or pinned to the spine using coconut sennit, thin lengths of split *Calamus*, or *Flagellaria* stems or other suitable materials.
4. The lengths of the leaflets may be trimmed to produce a uniform-size sheet or may be left in uneven lengths.
5. The resulting thatch sheets are dried in the sun as the woven sheets.

The thatch is applied in layers, with each sheet being tied to the rafters with coconut sennit or vines. Walls may also be constructed from the same thatch sheets.

In northern Vanuatu, where both *M. warburgii* and *M. salomonense* are present, thatch from each species is used for different constructions. *Metroxylon warburgii* sheets are used for roofing, whereas *M. salomonense* sheets are used for wall siding (Zona, pers. comm.). In Samoa, older informants indicated that the leaves of *M. paulcoxii* were not useful for thatch but that *M. warburgii* is considered to be a superior thatch. Younger Samoan informants did not seem to be aware of the difference between species and seemed to harvest the leaves indiscriminately.

The leaflets (basic thatch materials) of *M. amicarum* and *M. warburgii* contain highly modified and enlarged subhypodermal bundles of fibers. These fibers explain the enduring quality of thatch made from these species. As humans have selected these species, they have probably also selected for increased fiber production and have selectively planted cultivated trees with better leaf qualities.

Resin/gum/glue/latex

In Indonesia, the starch is used as an extender in plywood adhesives.

Body ornamentation/garlands

Metroxylon fruits, particularly those of *M. salomonense* and *M. amicarum*, have been (and are still) used as sources of vegetable ivory. Formerly European industries imported quantities of *Metroxylon* seeds, i.e., "ivory nuts," which were cut into buttons for clothing. The seeds, which are quite hard and ivory-like, are carved to produce cultural items of trade in local economies and for sale to tourists. The Solomon Islands presently exports *M. salomonense* seeds to Alaska, where they are carved and sold by traditional peoples in place of sea-mammal ivory. *Metroxylon amicarum* seeds carved and sold locally in the Federated States of Micronesia are also shipped to Japan. Some of

At Buma Village (North of Auki) in Malaita Province, Solomon Islands, leaves of *M. salomonense* are used in traditional houses for wall sidings and roof thatch. These materials are reputed to last for about 7 years. Other palms in this photo include coconut and betel nut. PHOTO: H. MANNER

***M. warburgii* thatch and walls, Rotuma.** PHOTO: W. MCCLATCHEY

these "ivory nuts" that were brought to Europe by sailors eventually became labeled as collections of "petrified apples" in the Berlin Museum herbarium. The vegetable ivory is distinguished from that of other palm seeds in that *Metroxylon* often has a greenish hue and a grain that is spiraled.

Ceremonial/religious importance

Among the Asmat of Papua New Guinea, a palm that is about to bear fruit is selected, then dressed with a woman's skirt of leaves. After a honorific recitation of brave deeds by the men, the palm is felled and attacked as an enemy. Holes are bored into the trunk. The sago palm beetle (*Rynchophorus ferrugineous/bilineatus*) then lays its eggs there, and 6 weeks later the grubs are harvested, carried triumphantly as a slain enemy to the village on a tray of sago leaves, and then consumed (Singapore Zoological Gardens Docents 2000).

Other

Other uses of *Metroxylon* that are either being studied or are presently in use include alternative uses (non-food) of sago starch and uses of by-products of sago production. Sago starch is a useful substrate for commercial fuel ethanol production (Haska 1995, Holmes and Newcombe 1980, Ishizaki and Tripetchkul 1995, Lee et al. 1987, Newcombe et al. 1980, 1982, Rhee et al. 1984).

By-products of commercial sago production include reclaimed fibers and waste pith used as fertilizer. Sago pith residue as a diluent and supplement to green manures has been studied (Bintoro 1995). This use is of particular economic interest, because *Metroxylon* frequently grows in swampy areas with poor soils. Suitable fertilizers developed from local inputs, such as pith residue, could provide efficient low cost agricultural improvements for the peoples who farm in and adjacent to commercial sago growing areas.

COMMERCIAL PRODUCTS

Starch

In contrast to other sources of starch, sago yields are exceptionally high. Under good conditions the range is from 15 to possibly 25 mt of air-dried starch/ha (6.7–11.1 t/ac) of *M. sagu* at the end of an 8-year growth cycle (Flach 1997). One source notes that this industry earns RM620/mt of air-dried starch (Flach 1997). *M. sagu* is considerably more productive for starch production compared with other *Metroxylon* species. Although the starch yields of other species have not been measured, the starch from each species (including *M. amicarum*) is similar in taste and consistency to that of *M. sagu*. It seems likely that because traditional selection in species other than *M. sagu* (and possibly some populations of *M. warburgii* in Vanuatu and Rotuma, Fiji) has probably focused on leaf qualities rather than starch, that starch production has not been maximized and therefore will be of lower quality and quantity.

Thatch

Thatch made of *Metroxylon* leaves is of considerable value to local peoples. On Guadalcanal in the Solomon Islands, sewn thatch sheets sell for SI$1.50 each, or about one third to one fifth of a day's wages. Thatch sheets of *M. amicarum* sell for US$0.50 to US$2.00 each in Pohnpei, with higher prices charged after storms and for large projects such as hotels. *Metroxylon* thatch lasts for up to 10 years, whereas the alternative thatches of coconut leaves, sugarcane leaves, and pandanus must be replaced every 1–4 years. Some well thatched *Metroxylon* roofs are said to have lasted as long as 50 years. The value of this thatch to traditional peoples cannot be underestimated.

The economic value of *Metroxylon* leaf was demonstrated following Cyclone Namu (May 1986) in the Solomon Islands, when for a long period many destroyed homes could not be rebuilt because of a lack of roofing and walling material (Henderson and Hancock 1988).

INTERPLANTING/FARM APPLICATIONS

For highest yields of starch, *M. sagu* should probably be grown as a monocrop, as few other plant food species do well in the peat swamp. Except for Papua New Guinea, there are few extensive stands of *Metroxylon* throughout the Pacific islands. As a food staple, sago is not a preferred starch in the Pacific. However, interplanting *Metroxylon* for its other products is practiced extensively on many Pacific islands.

Example 1

Location

Aopo Village, Savai'i Island, Samoa

Description

This is a backyard pig-foraging area and agroforest. The most prominent species found in this backyard kitchen garden was *M. warburgii*. The palms stand about 10 m (33 ft) in height and have large inflorescences, indicating maturity. Other trees in the vicinity are citrus species, coconut, etc.

Example 1: Pig-forage area and agroforest, Aopo Village, Savai'i Island, Samoa. PHOTO: H. MANNER

Example 2

Location

Taga Village, Savai'i Island, upland garden, and agroforest area.

Description

This area has young *M. warburgii* trees with old fronds trimmed off, standing about 4 m (13 ft) high in association with screwpine (*Pandanus* spp.), coconut, banana, breadfruit (*Artocarpus altilis*), and taro (*Alocasia macrorrhiza*).

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html.

GERMPLASM RESOURCES

Collections of most species are found at the Bogor Botanical Garden, Fairchild Botanical Garden, University of the South Pacific, Laucala campus, and the Lyon Arboretum, Honolulu.

Major collections of *M. sagu* varieties are held by the University of Malaysia, Sarawak, and the Ministry of Agriculture, Lae, Papua New Guinea.

Example 2. Top: Agroforestry system Taga Village, Savai'i Island, Samoa. Bottom: Older *M. warburgii* trees at Tafua-tai, Savai'i Island, Samoa, spaced about 8 m (26 ft) apart. PHOTOS: H. MANNER

BIBLIOGRAPHY

(☛ indicates recommended reading)

ARCBC. 2004. ASEAN's 100 Most Precious Plants. ASEAN Regional Centre for Biodiversity Conservation (ARCBC). <http://www.arcbc.org/arcbcweb/ASEAN_Precious_plants/edible/Metroxylon_sagu.htm>.

Barrau, J. 1959. The sago palm and other food plants of marsh dwellers on the South Pacific Islands. Economic Botany 13: 151–162.

Becarri, O. 1918. Asiatic palms—Lepidocaryeae. Annals Royal Botanical Garden, Calcutta 12: 156–195.

Ehara, H., C. Komada, and O. Morita. 1998. Germination characteristics of sago palm seeds and spine emergence in seedlings produced from spineless palm seeds. Principes 42(4): 212–217.

Ehara, H., H. Naito, C. Mizota, and P. Ala. 2003. Distribution, growth environment and utilization of *Metroxylon* palms in Vanuatu. Sago Palm 10: 64–72.

Elias, P. 1998. *Metroxylon amicarum*. <http://www.comfsm.fm/~dleeling/botany/1998/vhp/metroxyl.htm>.

☛ Flach, M. 1997. Sago Palm: *Metroxylon sagu* Rottb. Promoting the Conservation and Use of Underutilized and Neglected Crops 13. Institute of Plant Genetics and Crop Plant Research (Gatersleben) and International Plant Genetics Resources Institute (Rome, Italy). <http://www.ipgri.cgiar.org/publications/pdf/238.pdf>.

Fosberg, F. R., Sachet, M-H., and Oliver, R. 1987. A geographical checklist of the Micronesian Monocotyledonae. Micronesica 20(1 & 2): 19–129.

Jones, D.L. 1995. Palms Throughout the World. Smithsonian Institution Press, Washington, D.C.

☛ Kainuma, K., M. Okazaki, Y. Toyoda, and J. Cecil. (eds.). 2002. New Frontiers of Sago Palm Studies. Proceedings of the International Symposium on SAGO (SAGO 2001), October 15–17, 2001, Tsukuba International Congress Center, Tsukuba, Japan. Frontiers Science Series 37. Universal Academic Press, Tokyo, Japan.

Lebot, V. 1991. Kava (*Piper methysticum* Forst. f.): the Polynesian dispersal of an oceanian plant. pp. 169–201. In: Cox, P.A. and S.A. Banack. Islands, Plants and Polynesians: An Introduction to Polynesian Ethnobotany. Dioscorides Press, Portland, Oregon.

Marcus, J., and K. Banks. 1999. A practical guide to germinating palm seeds. Principes 43: 56–59.

McClatchey, W. 1996. A revision of the genus *Metroxylon* section Coelococcus (Arecaceae). Ph.D. Dissertation, University of Florida, Gainesville, Florida.

McClatchey, W. 1998. Phylogenetic analysis of morphological characters of *Metroxylon* Section Coelococcus (Palmae) and resulting implications for studies of other Calamoideae genera. pp. 285–306. In: Henderson, A. Evolution, Variation, and Classification of Palms. Memoirs of the New York Botanical Garden.

McClatchey, W. 1998. A new species of the genus *Metroxylon* (Arecaceae) from Western Samoa. Novon 8: 252–258.

McClatchey, W. 2002. Biogeographical Observation of *Metroxylon* Section Coelococcus. pp. 119–126. In: K. Kainuma, Okazaki, Toyoda, and Cecil, op. cit.

McClatchey, W., and P. A. Cox. 1992. Use of the sago palm *Metroxylon warburgii* in the Polynesian island, Rotuma. Economic Botany 46: 305–309.

Merlin, M., Jano, D., Raynor, W., Keene, T., Juvik, J., and Sebastian, B. 1992. Tuhke en Pohnpei. Plants of Pohnpei. East West Center, Honolulu.

Merlin, M., and J. Juvik. 1996. Ira me Neeniier non Chuuk. Plants and their Environments in Chuuk. East West Center, Honolulu.

Mueller-Dombois, D., and F. R. Fosberg. 1998. Vegetation of the Tropical Pacific Islands. Springer Verlag, New York.

Ohtsuka, R. 1983. Oriomo Papuans: Ecology of Sago-Eaters in Lowland Papua. University of Tokyo Press.

Pursglove, J.W. 1968. Tropical Crops. Monocotyledons. Longman Group, Ltd., London.

Rauwerdink, J.B. 1986. An essay on *Metroxylon*, the sago palm. Principes 30(4): 165–180.

Schuiling, D.L. 1996. *Metroxylon* Rottboell. pp. 116–120. In: Flach, M. and F. Rumawas (eds.). Plant Resources of South-East Asia No. 9. Plants yielding non-seed carbohydrates. Prosea Foundation, Bogor, Indonesia.

Schuiling, D.L., and F.S. Jong. 1996. *Metroxylon sagu* Rottboell. pp. 121–126. In: Flach, M. and F. Rumawas (eds.). Plant Resources of South-East Asia No. 9. Plants yielding non-seed carbohydrates. Prosea Foundation, Bogor, Indonesia.

Singapore Zoological Gardens Docents. 2000. Rainforest gifts. Sago and sago grubs. <http://www.szgdocent.org/ff/f-sago.htm>.

Smith, A.C. 1979. Flora Vitiensis Nova. A New Flora of Fiji (Spermatophytes Only). Volume 1. Pacific Tropical Botanical Garden, Lāwa‘i, Kaua‘i, Hawai‘i.

Stone, B.C. 1970. The flora of Guam. Micronesica 6: 1–659.

Thaman, R.R. 1993. Appendix. One hundred Pacific Island agroforestry trees. pp. 216–266. In: Clarke, W.C. and R.R. Thaman. Agroforestry in the Pacific Islands: Systems for Sustainability. United Nations University Press, Tokyo.

Thaman, R.R., C.R. Elevitch, and K.M. Wilkinson. 2000. Multipurpose trees for agroforestry in the Pacific Islands. In: Elevitch, C.R. and K.M. Wilkinson. Agroforestry Guides for Pacific Islands. Permanent Agriculture Resources, Hōlualoa, Hawai‘i.

Uhl, N.W., and J. Dransfield. 1987. Genera Palmarum. The L.H. Bailey Hortorium and The International Palm Society, Allen Press, Lawrence, Kansas.

USDA. 1988. Wetland regions and indicator categories. In: U.S. Fish and Wildlife Service. National list of vascular plant species that occur in wetlands. U.S. Fish and Wildlife Service Biological Report 88 (24). <http://plants.usda.gov/wetinfo.html>.

USDA. No date. Plant profile for *Metroxylon amicarum*. Wetlands Indicator Status: *Metroxylon amicarum* (H.A. Wendl.) Becc. <http://plants.udsa.gov/cgi_bin/plant_profile.cgi?symbol=MEAM4>.

Walter, A., and C. Sam. 2002. Fruits of Oceania. ACIAR Monograph 85. Australian Centre for International Agricultural Research, Canberra, Australia.

Whitmore, T.C. 1966. Guide to the Forests of the British Solomon Islands. Forestry Department, British Solomon Islands Protectorate Government.

Yen, D.E. 1991. Polynesian cultigens and cultivars: The questions of origin. pp. 67–95. In: Cox, P.A., and S.A. Banack. Islands, Plants and Polynesians: An Introduction to Polynesian Ethnobotany. Dioscorides Press, Portland, Oregon.

Traditional Tree Initiative—Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Metroxylon amicarum, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm)

Authors: Will McClatchey[1], Harley I. Manner[2], and Craig R. Elevitch[3]

1. University of Hawai‘i at Manoa, Botany Department, St. John 405, 3190 Maile Way, Honolulu, Hawaii 96822, USA; Tel:808-956-6704; Fax: 808-956-3923; Web: <http://www.botany.hawaii.edu/faculty/mcclatchey/>.
2. University of Guam, College of Arts and Sciences, UOG Station, Mangilao, Guam 96923, USA; Tel: 671-735-2874; Fax: 671-734-5255; E-mail: hmanner@uog9.uog.edu
3. Permanent Agriculture Resources, PO Box 428, Holualoa, HI 96725 USA; Tel: 808-324-4427; Fax: 808-324-4129; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>.

Acknowledgments: The authors and publisher thank Ray Baker, Hiro Ehara, Dale Evans, and Bill Raynor for their input. Photo contributions from Ray Baker, Eleanore Burson, and Deborah Ward are greatly appreciated.

Recommended citation: McClatchey, W., H.I. Manner, and C.R. Elevitch. 2006. *Metroxylon amicarum*, *M. paulcoxii*, *M. sagu*, *M. salomonense*, *M. vitiense*, and *M. warburgii* (sago palm), ver. 2.1. In: Elevitch, C.R. (ed.). Species Profiles for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Hōlualoa, Hawai‘i. <http://www.traditionaltree.org>.

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; SPC/GTZ Pacific-German Regional Forestry Project; USDA Natural Resources Conservation Service (USDA NRCS); State of Hawai‘i Department of Land & Natural Resources Division of Forestry & Wildlife; and the USDA Forest Service Forest Lands Enhancement 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 2002-47001-01327.

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; E-mail: par@agroforestry.net; Web: <http://www.agroforestry.net>. This institution is an equal opportunity provider.