# PART4 : NATURAL AND CULTURAL HISTORY

This volume concludes with a brief review of selected work on taro by the author and others since 1990, after the work reported in Part 3. Some general trends are considered first, then specific historical themes related to the natural and cultural history of taro.

# Chapter Seventeen
# General Trends in Taro Research

Historically, research on taro has been scattered, discontinuous, and dependent on the efforts of isolated individuals or small teams. There is no international centre for research on taro, despite its status as an ancient and globally distributed food plant (Rao et al. 2010). Although traded internationally as a food product, taro has not become a large-scale commodity crop like corn, potato, rice, soybean, or wheat. Over much of its range, local use of taro has continued since antiquity without direct interference or support from public authorities or private companies. Nevertheless, modern transport has made it easy for cultivars (and associated pests or diseases) to move quickly and far, through personal exchange, local trade, long-distance trade, and agricultural research activities.

At present, the continuing spread of Taro Leaf Blight (TLB) (*Phytopthora colocasiae*; Figure 17.1) (Singh et al. 2012) may be the biggest driver of change in taro production, the spread of new cultivars between different regions of the world, and the composition of local cultivar assemblages. For historical research this is problematic, as the changes are happening far more quickly than our ability to record the characteristics and historical significance of many cultivars. Historical research is fundamental to understanding the practical value and potential of a cultivar, its dispersal history and present distribution, its conservation status (endangered or not), and its cultural value. Ideally, farmers and users will always have access to old and new cultivars, to allow adaptation to changing social and environmental conditions, and to enjoy continuity in the use of culturally significant varieties. Even when old cultivars can no longer be grown in one area, because of their disease susceptibility or for other reasons, they may be suitable for use in other areas, or may have important qualities for plant breeding.

Given the limited funds available for taro, globally, most agricultural research on the crop has been focused on local and immediate needs such as the collection, conservation, identification, and description of cultivars (cf. IPGRI 1999), testing for agronomic and food qualities, testing for resistance to diseases and pests, selecting improved cultivars for diverse conditions, and minimising the number of living plants that need to be kept in collections while maximising the diversity preserved (Quero-Garcia et al. 2004; Mace et al. 2010; Taylor et al. 2010). Living collections of taro are inherently labour-intensive and expensive to maintain, and *in vitro* conservation methods such as tissue culture require continuous support for the required laboratory facilities and technical staff. Ultimately, the conservation of genetic diversity in taro will depend on people wanting to use the plant. For this, more attention needs to be given to the maintenance, development and use of culinary knowledge concerning taro (Matthews 2004b). In recent years, researchers involved with taro have turned towards a more decentralised model of

**Figure 17.1**   Early (above left) and advanced (above right) symptoms of Taro Leaf Blight (TLB) caused by *Phytopthora colocasiae*, on taro cultivars being tested at the National Institute for Agricultural Research (NARI), Bubia, Papua New Guinea. Below: shade house built at Bubia to grow taro seedlings produced in experimental crosses (2010, with J. Waki).

conservation, breeding, and cultivar dissemination. This is aimed at — and requires — participation by local universities, agricultural research organisations, farmers, and consumers (Lebot et al. 2005; Singh et al. 2010; INEA 2011).

There has been no general effort to study the food uses of taro (Matthews 2004b, 2010), the diversity of production systems for taro (despite some early academic interest — see Spriggs 2012), or the diversity of social and cultural values associated with the crop (e.g., Caillon 2012, and others in the same volume). There has also been no general effort to study wild populations of taro, other wild species in the same genus, and the relationships between these wild relatives and cultivated taro. My own



**Figure 17.2**   Corms of different elite cultivars being prepared for a taste panel at the Lowlands Agricultural Experiment Station (LAES), Kerevat, Papua New Guinea. Qualities such as acridity, taste, aroma, and texture will be tested by several different people who are regular consumers of taro, and the results pooled to assess the quality of the cultivars for commercial production and general consumption (2010, with R. Moxon).

ethnobotanical surveys have been very limited in geographical scope, and have been focused on wild taro populations (as reported in this volume; Matthews, Takei and Kawahara 1992; Matthews and Naing 2005; Matthews 2006; Matthews et al. 2012). Such work is difficult to organise from outside each country where taro is grown and used, and the number of countries where such work could be carried out is huge, since the crop is global in distribution. My hope is that the present volume can serve as a starting point (despite many flaws, or perhaps because of them) for students and researchers in many different countries. Much new work can be done now through systematic use of information sources, translation tools, and social networks supported by the Internet, but even this will be a large undertaking, and the quality of information that can be obtained in this manner is highly variable.

Research on the natural and cultural history of taro can show us how the crop has traditionally been maintained *in situ*, reveal threats to populations of wild taro and wild relatives, and help us develop conservation strategies where these are most needed (cf. Hunter and Heywood 2011). Studies of the wild relatives are fundamental to understanding the domestication process, the genetic and geographical origins of the crop, and relationships with organisms that appear as pests and diseases in cultivated taro. It is likely that traits present in wild taro populations and in close wild relatives have been largely ignored ever since human attention became focussed — thousands of years ago — on the qualities of selected forms present in gardens and around settlements. By looking at wild populations and relatives, we may discover (or rediscover) useful qualities that cannot be imagined until they are seen – or tasted. The corms of wild taros in most countries are considered inedible, or poor for eating, unless they are known cultivars planted in wild locations (as reported here in Chapter Seven). If known or new techniques can be used to render inedible wild taros edible, then unexpected but favourable qualities of taste, texture, nutritional content, or processing potential might be revealed. In cultivar trials and breeding programmes, it is usually the expected and familiar qualities that are tested (Figure 17.2).

Despite the obvious gaps in research, important historical insights have been gained through the efforts of many researchers and organisations since the late 1980s. Bioversity International (formerly the International Plant Genetic Resources Research Institute) has played a leading role in supporting conferences and the publication of research on taro (IPGRI 1999; Zhu et al. 2000; Guarino et al. 2004; Rao et al. 2010), and has encouraged ethnobotanical research on crops generally. This reflects a growing recognition that biodiversity, food security, and cultural diversity are interdependent (Pollock 2002; Maffi 2004; Nabhan 2009; Maffi and Woodley 2010). Previously, I noted that ethnobotany had the status of an orphan science (Matthews 1996), but this science (together with ethnobiology) has gained increasing recognition in recent years (Stepp et al. 2002; Ellen 2006; Fuller 2013). For those of us who identify with ethnobotany or ethnobiology, our academic homes are still mostly perched on the edges of other disciplines. Fortunately, common ground is not difficult to find, and the need to negotiate with other disciplines is probably a good thing. Ethnobotany is predominantly a field science, it is integrative in its practical and theoretical aspects, and its practitioners should be out in the world,

literally and metaphorically.

In the next chapter, I introduce some of the research that has been carried out since 1990, following the work reported in Part 3 of this volume.

# Chapter Eighteen
# Historical Themes

## 18.1 Cultivar Introductions and Food Preferences

In Part 2 of this volume I described three triploid varieties of taro that were and still are common in Māori communities of northern New Zealand. In Part 3, the possibility that two of these varieties (var. RR and var. GR) were historical introductions from China gained support in ribosomal DNA comparisons with the cool-adapted (temperate) cultivars of Japan, where many triploid cultivars are likely to have been introduced from China (over centuries or longer time periods). Ribosomal DNA analysis later proved very useful for distinguishing different cultivar groups in Japan (Matthews, Matsushita et al. 1992). Closely related cultivars within a cultivar group may have been introduced from outside Japan, but new cultivars in Japan are also known to have arisen through local mutation and selection. Ribosomal DNA patterns were constant within each of the main cultivar groups in Japan and were later surveyed in Japan, Taiwan, China, and northern Vietnam (Matsuda and Nawata 2002; Matsuda 2002). The triploid cultivar *Eguimo* is very similar (but not identical) with var. RR in phenotype and genotype (see Table 14.8, Figure 5.2), and cultivars with the same ribosomal DNA pattern as *Eguimo* have been found in northern and southern China and in northern Vietnam (Matsuda 2002).

The cultivation of taro has been a continuous tradition in New Zealand since long before the arrival of European and Chinese settlers, until the present. New cultivars continue to arrive, perhaps most often as undocumented introductions that follow modern immigration and food importation from the Pacific Islands (cf. Pollock 1992), Southeast Asia, and elsewhere. Plants have been grown from fresh corms imported from the Pacific Islands for markets in Auckland and elsewhere. Such introductions are mainly grown in home gardens, but some have also been adopted by botanical gardens and as ornamental plants. In New Zealand, a Cypriot immigrant family introduced the same cultivar of taro that I had previously seen growing in Cyprus, where taro is called *kolokasi* in the Greek language (Matthews 2006). I have also met Cypriot farmers in Australia who grow taro introduced from Cyprus; they sell the corms in Sydney where fresh taro from Queensland, Northern Territory, and the Pacific Islands can also be found. In 2009, I found *C. gigantea* (*bac hà* in Vietnamese; *hasu-imo* in Japanese, see Part 3, this volume) growing in Auckland, following its introduction by a member of the Vietnamese community (Figure 18.1). This may be the first record of *C. gigantea* in New Zealand. I have also seen *C. gigantea* flourishing in a suburban home garden in Sydney, Australia (c. 1994), and in 1997 found it growing in a community garden in Honolulu, Hawai'i (Matthews 1998), where Vietnamese immigrants often grow and use the plant (Nguyen

*Above*: Blades emerging in a small kitchen garden, alongside spring onion and other herbs used for making soup, North Shore, Auckland (2009). *Below*: Petioles peeled, cut, and cooked in soup (see central, long sections in mix), with wax gourd and other vegetables, as restaurant meal, Hanoi (2009). See also Figure 10.3.

**Figure 18.1** *C. gigantea* (Bl.) Hook. f. in New Zealand and Vietnam.

2005). The petioles (leaf stems) can be cooked in soup after peeling, and it may eventually become a useful vegetable in New Zealand.

In 1991, M. Morishita of the Osaka Agriculture and Forestry Research Center kindly provided me with virus-free meristem tip cultures of two Japanese cultivars of taro, *C. esculenta*, which I then carried to Auckland for propagation and dissemination to interested gardeners and researchers (see Appendix 23). My aim was to introduce cultivars already adapted to the cool, temperate climate of New Zealand. Later, I sent further cultivars to J. Scheffer at the New Zealand Institute for Crop and Food Research, Pukekohe. The Institute also obtained plants directly from commercial seed companies in Japan. The new introductions were all tested in Auckland, and better performing cultivars

**Figure 18.2** Production and use of taro leaves as a vegetable. *Above*: Large-scale cultivation of taro specifically for leaf production in southern Luzon, Philippines (2012, with M. Medecilo). *Below*: Leaves of a Japanese taro cultivar grown in South Auckland, and packaged for distribution throughout New Zealand. The leaves are kept fresh by cool storage and open wrapping in plastic (2011, courtesy New Zealand Kahoa Tauleva Trust).

were sent to further locations for trials (Scheffer et al. 1999; Bussell et al. 2004). Unexpectedly, Japanese cultivars have become a source of fresh leaves that are now grown in South Auckland (Figure 18.2) (Bussell and Triggs 2010), primarily for Pacific Islander communities that are unable to import fresh leaves from distant homelands. Coconut milk, an essential ingredient for Pacific Island cooking of taro leaves (as in the Philippines; see Matthews et al. 2012), is easily obtained as an imported, canned product. The common use of taro leaves with coconut milk in the Philippines and Pacific Islands may reflect a shared, ancestral cuisine, or independent discovery and appreciation of the taste and nutritional value of this combination.

In Japan, the leaf blades of taro are rarely recognised as a food. This can be stated with confidence as just a few local examples of such use were reported in a nation-wide survey of traditional foods, a survey that described in detail hundreds of recipes using corms or petioles (Rural Culture Association 1997). In Cyprus and Egypt, no part of the leaf is used, and in Cyprus the slimy mucilage produced by corms is strongly disliked. The sliminess is reduced by various preparation methods, before cooking, and by the addition of lemon juice during the cooking process (Matthews 2004b, 2006, 2010).

Culinary practices tend to follow long-established food preferences, and are associated with different vernacular names for taro, in many different languages. In theory, the full food potential of taro may be most easily developed in countries like Australia, New Zealand, and the USA, where diverse communities can share information and experiment with a range of imported and locally-grown cultivars. This will require cross-cultural dissemination of crop information, and careful translation of the vernacular names and recipes used by speakers of different languages.

The label on one bag of taro leaves sold in Christchurch, New Zealand (c. 2008) gave the following warning to new explorers, with good reason, but with no practical guidance (what is 'proper cooking' ?):

'Raw taro leaves to be properly cooked before consumption. Should never be eaten raw.'

For the uninitiated, avoiding taro is usually the first preference, unless curiosity or hunger overwhelm caution.

## 18.2 Archaeology and Taro

### 18.2.1 Ancient starch

In the late 1980s, Tom Loy (then at the Department of Prehistory, ANU) began looking at starch residues on stone tools from Kilu Cave, Solomon Islands (Loy et al 1992; Loy 1994). Modern plant reference samples for that study were provided by the ANU taro collection, and led to the tentative identification of starch and calcium oxalate raphides from taro, from wild or cultivated sources (no differentiation could be made). Since 1992, with varying degrees of confidence, taro starch has been reported in archaeological contexts in Papua New Guinea (Crowther 2005; Fullagar et al. 2006), Pitcairn Island (Horrocks and Weisler 2006), Fiji (Horrocks and Nunn 2007), New Caledonia (Horrocks

et al. 2008), New Zealand (Horrocks and Barber 2005), China (Lu 2006), and elsewhere. The identification of ancient taro starch granules is especially difficult, due to their small size, simple shape, and similarity to the immature or smaller starch granules of other plant species. The most reliable identifications may be those made when taro-like starch granules are found *en masse*, in groups or clusters, along with taro-like raphides.

Ancient starch, with or without identification, has been reported in a huge variety of cultural, temporal, and physical contexts (Torrence and Barton 2006; Shibutani 2009; Henry et al. 2011; Haslam et al. 2011), but the archaeological work has not been supported by detailed biochemical studies of ancient starch, detailed taxonomic studies of modern starch, or the use of advanced techniques in histology and microscopy. Collins and Copeland (2011) note the need for more research on starch taxonomy and diagenesis, and question previous identifications of 'cooked' starch in archaeological contexts. The recent archaeological discoveries of ancient starch in very diverse geomorphological contexts offers biology and ecology a new and unexpected direction for investigating the fate of energy and carbon captured by photosynthesis and stored in starch. Ancient starch is likely to be present in many natural sediments, possibly at such low densities that it remains unavailable to micro-organisms (Barton and Matthews 2006). Optimising and calibrating methods for the extraction of starch from sediments could lead to new ways of understanding energy flow in natural and agricultural ecosystems, a fundamental issue for soil science, ecology, and the modeling of global carbon cycles.

It is also conceivable that starch derived from agricultural sources (and milling sites in particular) has washed out into shallow estuaries and near-shore deposits formed by the outwash from river deltas. In such near-shore sediments, deposits of ancient starch could provide a widely-dispersed signature for the arrival of agriculture (or milling techniques) in large river catchments.

### 18.2.2 Carbonised residues, macro-remains and pollen

As part of a wider effort to develop archaeobotanical techniques, and to make use of the micro-residues that are often abundant in archaeological contexts, Jon Hather pioneered methods for characterising the starchy tissues of various root crops, including taro (Hather 1991). This approach has led to identification or tentative identification of taro starch in Sulawesi, Indonesia (Paz 2005) and Timor-Leste (Oliviera 2012). Under very dry conditions, taro tissues can also be preserved, though few instances of this are known. At Quseir al-Qadim, Egypt, several dry fragments of taro corm were found, and two were radiocarbon dated to AD 1050–1170 (van der Veen 2011). Taro pollen were first described in detail by Haberle (1995), who then found taro pollen in lake sediments dated to the early Holocene in northeastern Queensland (Haberle 2005). This is the area where wild taro now is most abundant in Australia (Figure 14.3). The taro pollen first appears in the sequence as other pollen records show the region becoming warmer and wetter. When more is known about the natural range, ecology, and diversity of wild taro populations in Southeast Asia and the Pacific, archaeologists and botanists might like to revisit the various techniques of archaeobotany and palaeobotany in order to learn whether or not wild and cultivated lineages of taro can be distinguished through

**Figure 18.3**  Low-level production of taro using simple methods of protection, in naturally wet habitats. *Above*: wild taro (a wild-type?) protected with bamboo fences, without cultivation, on a muddy riverbank next to village (Ba Be, northern Vietnam; 2012, with D. V. Nguyen). *Below*: taro planted inside enclosures made by excavating the bank at left, and rearranging loose boulders from the stream bed; lacking containment, the soil here is minimal (Mount Mayon, central Philippines; 2013, with M. Medecilo).

observation of intact tissues (macro-remains), starch, pollen, and seeds.

### 18.2.3 Structures associated with taro production

Much of the interest by archaeologists in taro arises from the fact that modern taro production is often associated with the construction of drainage systems (to remove water) or irrigation systems (to supply water). Remnants of larger systems are relatively easy to find, archaeologically, or may remain obvious in the landscape long after their abandonment (Barber 1989; Bayliss-Smith and Golson 1992; Bayliss-Smith 1996; Denham et al. 2003; Denham and Barton 2006; Spriggs 2012; numerous contributors in Spriggs et al. 2012). Ethnographically, there are also many situations where natural slopes, or natural stream or riverbanks, are used to plant and grow taro on a small scale, with or without modification of ground surfaces (cultivation, stone arrangements, or larger earthworks). Even if low-level production (cf. Smith 2001) was common in the past, in a particular area, it might leave few archaeological traces. For taro, low-level and dispersed production is more likely to have allowed cycles of breeding and selection to occur (through relaxed control of the plant life cycle), and is more likely to have provided suitable contexts for domestication, initially and in later periods, and assuming some degree of selection pressure and isolation from wild-type populations.

At present, it is not known when, where, or how a tropical wild-type taro was transformed into a high-yielding starchy crop. A wild-type plant with naturally favourable qualities as a leaf, shoot, or starch source, for food or fodder, could have become widespread as a useful plant, in low-level production systems, before being domesticated anywhere within the wider range thus created. Eventual transformation through selection may have been a prerequisite or primary motivation for investment in the construction of larger scale production systems. Wild-type taro is likely to have reached Australia and New Guinea long before human arrival through natural dispersal (cf. Denham et al. 2009; Hunt et al. 2013). Its presence in New Guinea has been considered consistent with suggestions that taro was domesticated at an early date in New Guinea (see Part 3 and Matthews 1991), but this wild-type did not necessarily have any role in agriculture and domestication of the crop (Matthews and Terauchi 1994: 257). Genetic relationships with cultivated and domesticated forms of taro, and with wild taros in Southeast Asia, are currently under investigation (Ahmed et al. 2013).

Depending on intended uses, as leaf vegetable or as starch source, taro may also be managed with or without the addition or enrichment of soil in a production system. On a riverbank at Ba Be, in northern Vietnam, patches of taro that are considered locally to be wild and self-propagating are encouraged to grow by placing light bamboo fences around them (Figure 18.3). The fences help keep the plants in place when the river rises during the wet season, and the plants are used as a source of leaves for food and pig fodder. In a stream bed on Mt Mayon, Philippines, taro was planted in simple enclosures of loose boulders which cannot hold a deep soil, suggesting that the plants were grown for leaves and/or stolons, not corms (Figure 18.3).

Archaeologically, evidence for low-level production systems like those seen at Ba Be and Mount Mayon might be preserved by changes in a river course. After excavation

and discovery many centuries later, it would be difficult to distinguish protection of self-propagating wild plants, planting without cultivation, or planting and cultivation, if evidence for enclosures and plants was found. Evidence for stone arrangements or fences might easily lead to the assumption that the ground enclosed was cultivated. Use of the plants as leaf vegetable, and not as starch source, would also be difficult to distinguish. Archaeological discovery of seeds in the mud might indicate that neither the leaves (with immature inflorescences enclosed) nor corms were harvested, leaving open the possibility that stolons were the main target for harvest (Such use was observed by the author in a nothern Luzon garden, in 2012). Alternatively, the plants might produce fruit and seeds soon after abandonment of a production system, before being covered with sediments.

Flowering and seed production by taro, in wild or cultivated environments, is highly dependent on the intended uses and harvesting methods. When allowed to flower, a single taro plant can produce thousands of seeds, and a large proportion of these may fall together with fruit in the vicinity of parent plants. The seeds do not float, and may be deposited in the near vicinity, even when there is some water flow on ground surfaces or in ditches. While surveying wild taro populations in Australia, Papua New Guinea, and Southeast Asia I have seen taro flowering and fruiting in many kinds of modified or loosely managed environments (Figure 9.3; Matthews and Naing 2005; Matthews et al. 2012; Hunt et al. 2013).

In recent decades, there has been some progress on the study of past and present taro production systems in the Pacific Islands (e.g. Hollyer et al. 1997; Spriggs et al. 2012), but relatively little work has been done in most regions of Asia or Africa. In Maputaland, South Africa, mixed cultivation of banana and taro in modified swamps (Grobler et al. 2004) may be of special interest for attempts to follow the movements of Austronesian-speaking peoples and their plants into Africa. In Cyprus and Egypt (Matthews 2006), I have observed taro production that is based on old Mediterranean or West Asian traditions of water management, though modern water shortages in the Mediterranean and West Asia will make it increasingly difficult to continue traditional methods of taro production in those regions. In Cyprus, taro now is mainly irrigated with water raised from underground sources, using mechanical pumps and deep pipe wells, rather than animal power and shallow hand-dug wells. In 1996, I learned from elderly informants that taro was also irrigated using channels from adjacent perennial rivers, earlier in the 20th century, before the rivers were dammed and the water diverted to distant areas for agricultural and urban uses. Archaeologists have long been interested in water management in the Mediterranean and West Asia, but mainly in relation to large-scale and extensive production of cereal crops and not the small-scale but intensive production of taro and other non-cereal crops.

Following fieldwork in Cyprus and northern Japan, I reviewed the use of storage systems to preserve taro corms as food and as planting material (Matthews 2002). These two uses can be associated with very different storage methods, since storage for consumption does not always require living shoots. When taro corms are stored for planting, in cooler regions, protection from cold is provided by the construction of various kinds of pit or covered mound. Structures designed specifically for storing taro

**Figure 18.4** Taro (Greek: *kolokasi*) harvest in progress at Agios Georgos, Paphos District, Cyprus. The settlement is named after St George, the patron saint of agriculture. Irrigation water is supplied by a permanent spring nearby. After drying, the leaves will be cut away from the corms now on the ground. Many of the standing plants display inflorescences that cannot develop further under winter conditions. In antiquity, the small port below the present settlement was used for trans-shipment of grain from Egypt to Italy; Egypt today is a large-scale producer of taro (Matthews 2006) (October 1996, with P. Croft).

may have been preserved archaeologically, but have not been reported. This aspect of taro production has received little or no attention by archaeologists working in the temperate regions of Eurasia, Africa, and New Zealand. In Japan, it is likely that many ancient pits identified in generic terms as 'storage pits' were in fact pits located close to hearths for warmth and designed to keep taro corms alive during winter, for planting in spring. In contrast, green vegetables stored for consumption can be kept in cold storage pits, away from hearths. Specialised pits and other structures used to store taro planting materials may be widely distributed in the northern temperate zone of Asia, and in higher altitude farming areas in Himalaya.

## 18.3 Mapping and Describing Wild Taro Populations

Since 1990, and following the discovery of wild taro populations in northern Australia and Papua New Guinea (Part 3, this volume), my main goal has been to map the distribution of wild taro populations in Asia and the Pacific and to learn as much as possible about their ethnobotany, ecology, and genetic diversity. This work began in southern Japan (Matthews Takei and Kawahara 1992), then continued in Indonesia

(fieldwork 1992 and 1996), Australia (fieldwork 1994), Myanmar (Matthews and Naing 2005), Taiwan, the Philippines (Matthews, Takei and Kawahara 2012), and Vietnam (fieldwork 2011, 2012). Utilisation of wild taro populations is remarkably widespread, the main uses being as a green vegetable (young leaf blades, cooked) for human consumption, and as a green fodder (entire upper plant, cooked) for domestic pigs. Wild pigs have a natural liking for the young shoots and leaves of cultivated taro, in the raw state, and farmers often need to protect taro gardens from wild pigs.

Our recent study of chloroplast DNA sequences in taro (*C. esculenta*) indicates considerable diversity within the species (Ahmed et al. 2013). Different wild populations may belong to quite different genetic lineages and have different palatability for humans and animals. Deliberate dispersal of relatively palatable forms of wild taro as a food and fodder plant is likely to have occurred over long periods of time. Relating ethnobotanical data to the new understanding of genetic diversity in taro is a major challenge that lies ahead, as the exploration, description, and genetic analysis of wild taro populations continues. In few situations is it easy, on first sight, to recognise a wild population as part of a wider natural distribution of wild-types. Based on early experiences in Australia, Papua New Guinea, and Indonesia, a short field guide for describing wild taro populations was prepared (Matthews 1997, and Appendix 22). In Taiwan, *C. formosana* Hayata is a wild species that appears very closely related to *C. esculenta*. It is regarded by local botanists as a natural part of the flora. The ethnobotany, ecology, and genetic diversity of this species have not been studied. My impression also is that *C. formosana* is a part of the natural island flora, though human modification of the island landscape, vegetation, and fauna are likely to have had secondary effects on the distribution and abundance of this plant (Figure 18.5).

In the 1980s, many examples of wild and cultivated taro were assembled in a living collection maintained in Canberra, but this could not be kept for long after the PhD research project concluded in 1990. A small number of plants were kept for a short time for use in a pilot study of cyanogenic glucosides in wild and cultivated taro and in *Alocasia* spp. (Bradbury et al. 1995). In late 1989, with FAO support, part of the collection was sent to National University of Malaysia at Bangi, Selangor, but the plants do not appear to have been kept there. Since 1990, samples from a taro DNA archive established in Canberra have been kept by the present author in Japan. The archive now also includes dry leaf samples obtained during fieldwork in Japan and Southeast Asia and stored with silica gel. Many of these DNA and leaf samples have been studied by Ahmed et al. (2013), and some have also been compared with African taro samples by Grimaldi (2013), in collaboration with the SeaLinks Project of the University of Oxford, UK.

Most of the stored DNA samples have become degraded as a result of changes in location, and failures in refrigeration, over many years. Fortunately, modern techniques of DNA analysis allow even severely degraded DNA to be analysed. Samples of wild taro growing at a single location at Hope Vale, in northern Queensland (see Chapter Fifteen) were chosen from the archive and analysed for genetic evidence of breeding. The variability of simple sequence repeats (SSRs, or microsatellite loci) provided the first genetic confirmation of breeding in a wild taro population (Hunt et al. 2013). Breeding

**Figure 18.5**   *C. formosana* Hayata on roadbank (at right) in Wulai district, northern Taiwan (2013, with K. C. Tsai).

by taro in Papua New Guinea was previously confirmed by observation of insect pollinators (Figure 15.1), fruiting and seed production (Figure 9.3), and a report of seedlings (Price et al. 2008) (see also Ivancic and Lebot 2000). Taro seedlings in northern Australia have not yet been reported, but are expected; the main period of flowering and fruiting is likely to be from the middle to late wet season, so seedlings might first appear in the late wet season or early dry season, in locations where wet ground is maintained throughout the wet season. Without wet ground, taro seeds cannot germinate, and the seedlings cannot survive. At room temperature on a wet substrate, fresh taro seeds planted in the laboratory typically germinate two weeks after planting, without any dormant phase (author's observation). In the field, after dispersal on to wet ground surfaces, it is likely that taro seeds germinate after a similar period.

In the 1980s, while conducting field surveys in Australia and Papua New Guinea, I became interested in various insect genera that have close co-evolutionary relationships with taro and other aroids (Part 3, this volume). Of special interest are the taro planthoppers (*Tarophagus* spp., Matthews 2003), taro grasshoppers (*Gesonula* spp., Rehn 1952, 1959; Amédégnato and Devriese 2008), and drosophilid flies in the genus *Colocasiomyia* (formerly *Drosophilella*) (Sultana et al. 2006). Earlier studies indicated great diversity and narrow host specificity among these flies (Carson and Okada 1982a, b; Toda and Okada 1983; Yafuso and Okada 1990), but it now appears that the pollinators

are not always restricted to one host plant species (Sultana et al. 2006, Takenaka et al. 2006). However, host switching by the flies is likely to have been influenced by human activities (for example, habitat modification, plant introduction, and transplantation) that lead to the juxtaposition of previously separate host plant taxa. In Okinawa, Japan, Miyake and Yafuso (2005) found that *Alocasia culcullata* (an exotic introduction of likely Chinese origin) is now pollinated by two *Colocasiomyia* species that are usually found on *Alocasia odora* (a plant that is generally considered native in Okinawa). It is possible that *Colocasiomyia* flies are involved in cross-pollination (hybridisation) among aroids generally. Further studies of insect pollinators will be important for understanding the natural and cultural history of taro and its wild relatives, and the possible role of hybridisation in the domestication history of taro.

## 18.4 Historical Linguistics and Phylogeography

Taro, along with other aroid crops (Matthews 1995), has a strong but not exclusive association with the spread of the Austronesian language family. Names for taro, or varieties of taro, in Māori (an Austronesian language) are noted in Appendix 9. Since taro is a staple crop in many Pacific islands, reconstructing names for taro and taro-related terms in hypothetical Austronesian proto-languages has been significant for discussions of Oceanic culture history (e.g. Pawley and Green 1973, 1985; Blust 1984–85; Ross 1988; Li 1994; Wolff 1994; Ross et al. 1998). Early Austronesian-speaking societies are believed to have known and used taro, but linguistic evidence does not positively indicate that taro was present in the proto-Austronesian vocabulary (Blust 1984–85, Bellwood 1997: 242). If Austro-Asiatic names for taro are accepted as cognates for the Austronesian names (as suggested by Blench 2012), then it may be necessary to consider the possibility of cross-family borrowing in either direction, depending on where, geographically, taro is likely to have had a longer association with people as a useful plant.

Few linguistic studies have focused solely on taro and taro-related terms: the only examples may be Portères (1960), Kikusawa (2000), and Blench (2012). There has been no published attempt to record and collate data on the names and related terms in all language families in the regions of Asia and the Pacific where taro is wild or has been long cultivated. How vernacular names for taro vary between the wild and cultivated forms is hardly known, and it is not easy, at present, to relate the emerging phylogeographical understanding of taro (and its close wild relatives) with the emergence, diversification, and spread of names and terms asociated with the plant. In Chapter Sixteen, two main directions of domestication were suggested, one leading to temperate adapted forms of taro and beginning in the Himalayan mountain region, and a second beginning in possibly multiple regions within the wet tropical zone extending from India and Southeast Asia to New Guinea. These are all key regions to begin analysing the names of taro, and the difficulty of the task is well illustrated by Blench (2012), who notes, for example, that Northeast India is a region of high lexical diversity in the names for taro, forming a complex of apparently unrelated terms. He suggests that this may reflect local transfers to taro of terms originally applied to wild aroids in the region.

Since cultivated taro, wild taro and closely related wild species are distributed from Himalaya to Vietnam, China, and Taiwan, lexical diversity and complexity in taro names and related terms is likely to exist over a much larger geographical range than that already indicated. Blench (2012) has surveyed languages in most regions where tropical cultivated taros are likely to have originated. The region where cool-adapted (temperate) cultivars of taro are likely to have originated, from Himalaya to the eastern mountain slopes in southern and central China, is only partially covered. No comparison has been made, so far, of Austronesian names and related terms for cultivated taro (*C. esculenta*) and wild taro (*C. formosana*, Figure 18.5) in Taiwan.

## 18.5  Theories of Origin, Domestication and Dispersal

Genetic diversity in taro has mainly been explored through studies of cultivars held in living research collections. Yoshino and his colleagues analysed isozyme variation and focused on relationships between triploid and diploid cultivars in Yunnan and Nepal. The results indicated that the triploid cultivars in Yunnan are most closely related to diploid cultivars in Yunnan, and that triploid cultivars in Nepal are most closely related to diploid cultivars in Nepal. The derivation of triploids via unreduced gamete production was also confirmed (cf. Chapter Fifteen). Tahara et al. (1999), Ochiai et al. (2001), and Yoshino (2002) concluded that since the triploids are derived from diploids, the diploid taros in Nepal and Yunnan must have differentiated as separate gene pools in each area, before the triploids arose (Figure 18.6). This implies that domestication began in breeding taro
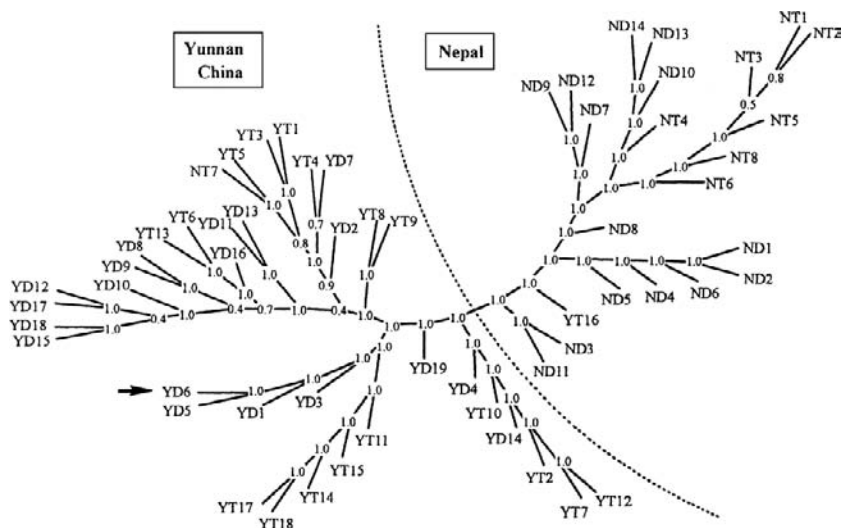


**Figure 18.6**  Consensus phylogenetic tree obtained after Wagner parsimony analysis of isozyme variation data of taro. Each labelled tip represents a single tested plant. D=diploid, T=triploid. Since no outgroup was known among the accessions, the tree is unrooted, though YD6 (arrowed) served as an outgroup for the purposes of calculation (from Yoshino 2002 and Tahara et al. 1999).

populations in the separate regions of Nepal (Himalaya) and Yunnan, China (near-Himalaya). The results are consistent with ethnobotanical observations (Xu et al. 2001) cytological surveys by Zhang and Zhang (1990, 2000), and the evidence for two principal routes of movement of cultivars into Japan, from Southeast Asia and mainland China (Matsuda 2002).

In surveys focused on cultivars in Southeast Asia and the Pacific Islands, Lebot and his colleagues have shown that the diversity of taro in remote Oceania is very narrow relative to that found in Melanesia and Southeast Asia, where two distinct gene pools can be seen (Kreike et al. 2004; Lebot et al. 2010). The observed decline in cultivar diversity, within one species, from west to east in the Pacific, mirrors a general, species-level decline in pre-European crop introductions from west to east (Matthews 2007; Whistler 2009). Since wild and cultivated taros may breed with each other, it is of interest to know where the eastern limit of the natural range of taro is located. In an analysis of genetic variation in wild and cultivated taros on islands in the Vanuatu group, AFLP data suggested close similarity between cultivars and most wild taros (Caillon et al. 2006). Despite the observed production of fruit and seed by wild taros, and the observation of birds (potential dispersal agents) eating taro fruit, the presence or absence of natural wild populations of taro in Vanuatu remains uncertain. The eastern limit of the natural range of taro may lay further to the west. Lebot et al. (2010) analysed isoenzymes (representing the nuclear genome) in a very large survey of 2,081 cultivars from seven countries in Southeast Asia and Oceania. The two cultivar gene pools are very tightly clustered, and lie close to each other, while the few wild plants studied are distant and scattered (Figure 18.7). This suggests that the two cultivar gene pools, in aggregate, represent a small part of the overall diversity that exists in wild taro populations.

A study of chloroplast genome variation in taro is currently in progress (Ahmed et al. 2012, 2013). The initial results suggest that chloroplast genome diversity in taro is large, when wild plants are included in the comparison. This is consistent with the nuclear genome data (zymotype analysis) summarised above.

In Figure 9.2 (also shown in Matthews 1991), I indicated the global distribution of taro in cultivation, likely natural range of wild taro, and the distributions of other *Colocasia* species for which distribution data were available (*C. affinis, C. fallax, C. gigantea)*. These other species provided a geographical reference point for the natural origin of *C. esculenta* as a natural species, and two schemes regarding the evolution, dispersal and domestication of taro were proposed. In the first scheme (Figure 16.1), the selection and dispersal of taro by humans began with starchy wild-types that evolved and dispersed naturally within a range restricted to mainland Southeast Asia. This single-origin scheme followed the suggestion by Hotta (1983) that root crops developed where species hibernated naturally in response to either seasonal dry periods or seasonal cold periods (see also Hutterer 1983; an alternative view in Hather 1996; Hotta 2002). It was thus assumed that starch was a target for the initial selection, use, dispersal, and cultivation of wild forms.

In the second scheme (Figure 16.3), selection and dispersal of taro by humans began with non-starchy wild-types of wide natural occurrence, in tropical and warm temperate
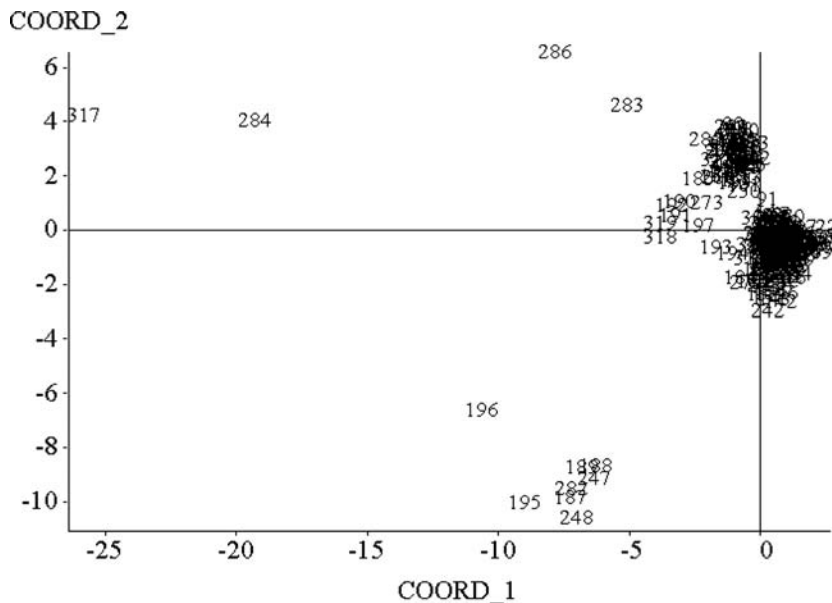
**Figure 18.7**   Principal components analysis of isozyme variation (zymotypes) in 2081 cultivars
from seven countries in Southeast Asia and Oceania (from Lebot et al. 2010).

zones, respectively. In this case, it was suggested that starchiness increased in multiple areas of domestication after breeding and selection in early farming systems. More specifically, domestication may have begun in early swidden systems or nursery plantings (Matthews 1995). Such loosely controlled places provide obvious opportunities for breeding among cultivar assemblages in warmer climatic regions. Offspring growing from seed in fallow gardens or in nurseries might eventually be incorporated into active gardens, or provide planting materials for active gardens. Since proposing these contrasting theories, new evidence has become available regarding the diversity and distribution of wild *Colocasia* species, the economic uses of wild taro, and the ecological requirements for breeding populations of taro. Caillon et al. (2006) have reported the breeding of taro in populations apparently derived from cultigens, in Vanuatu, and the subsequent propagation of seeds by local farmers who had lost their vegetative planting materials. Botanical exploration in Southeast Asia and southern China has dramatically increased the number of known wild species of taro (cf. Hay 1996; Hsu et al. 2000; Long and Liu 2001; Yin et al. 2004; Ara and Hassan 2005; Cai et al. 2006; Yin 2006; Long and Li 2008; Li and Boyce 2010; Gogoi and Bosah 2013; Matthews and Nguyen 2014) (see *C. yunnanensis*, Figure 18.8, for example). This in turn suggests a huge expansion in the range of unexplored territory in which further wild species of *Colocasia* are likely to be found, from mainland and island Southeast Asia, to western Himalaya and southern or central China. Within the expanded region of reported diversity, further unreported species are likely to exist in remote mountain valleys, at elevations similar to

**Figure 18.8**  *C. yunnanensis* Long and Cai at approx. 2000 m above sea
level, near Sapa, northern Vietnam (2012, with D. V. Nguyen)

those where many recent discoveries were made (c. 400–4,000 m a.s.l.). At such
elevations, there are still many areas that cannot be reached by road and that remain to
be explored. Leaving aside all uncertainties, I will now consider the diversity and
distribution of wild *Colocasia* species in relation to the theories of origin, domestication
and dispersal discussed earlier.

   The evolutionary origin of taro (*C. esculenta*) was previously thought to be in the
vicinity of northeastern India, where the greatest diversity of other wild *Colocasia*
species was known (Figure 9.2), and thus where a common ancestor may have been
located. Now it is known that wild *Colocasia* species are spread over a much larger area,
and mainly in mountains, throughout the northern monsoon region of Asia (Figure 16.2).
The obvious diversification of *Colocasia* species in montane regions of Asia may reflect

a long natural history of evolution in response to tectonic uplift and climate change, over millions of years. The evolutionary origin of taro must be sought over this larger area, and the lower montane zone may be the most likely area to look, given the eventual spread of taro into tropical lowland regions.

## 18.6 Looking Back and Looking to the Future

Previous chapters in this book have presented very local to very broad images of the natural and cultural history of taro, all as part of an attempt to look back in time at the origins and dispersal of the crop. The great diversity of wild and cultivated forms of taro is still largely unmapped and undescribed, along with the diversity of cultural practices and meanings associated with the plant. The natural and cultural history of taro must be explored on foot, through swamps, along rivers, over mountains, into kitchens, and into the fields of farmers. Such work cannot be accomplished without guides, interpreters, hospitality, and the kindness of strangers. In my own experience on this trail, the appreciation of plants has been a unifying language for building new relationships with many different people. Perhaps it has always been this way, in the journeys and encounters that carried our ancestors, and taro, around the world.

As an ethnobotanist and crop historian, I am always asking how we can learn about the past of taro, especially in situations where the trail is most difficult to follow: looking back towards the distant past, and in societies where interactions between the plant and people are most complex. More by good fortune than good planning, my own journey began in places where the natural and cultural history of taro is relatively simple, in historical terms, in New Zealand and northern Australia. In Papua New Guinea — a more complex environment — I focused on wild populations of taro, which might represent progenitors for cultivated taro, or descendants, or a mixture of both, thanks to the clonal and sexual nature of the plant. As a species, taro has always been a reticulate, mobile, and evolving network, and it may have been tangled with a reticulate, mobile, and evolving network of human communities since long before the emergence of agriculture. Despite all the historical complexity, the division of cultivated taro into tropical and temperate forms is clear. This points to potential value in the future: the diversity that already exists in cultivated taro can be used as part of human adaptation to changes in climate (warmer, colder, or less stable) and crop production.

As we learn more about the natural and cultural history of taro, we can learn more about its potentials for future utilisation and enjoyment — as a wild and cultivated food or fodder plant, source of medicine, ornamental plant, and as a plant with different practical and cultural value in each area where it is grown and used. The potential of taro as a source of food security in China was stated in dramatic but realistic terms in the mid-16th century, by Shengzheng Huang (Huang 2012: 50–51):

> '..taro can help the country get through famine caused by a bad year for agriculture. Nowadays people seldom heed this advice. The latter generations have abandoned their senses, and it is too late when floods, droughts, storms, insects, frost and hailstorms hit.

People starve to death and their bodies litter the streets. Having the knowledge and ignoring it, and thus leading to annihilation, is the ultimate crime for a ruler. This advice should always be remembered.'

In Chapter Seventeen I noted a recent and understandable focus on issues of immediate practical concern for the production of taro in different countries and regions. Fundamental historical understanding of the crop will make it easier to imagine a wider range of goals for practical development of the crop. Whimsical development also has serious value, as flower growers and breeders know, and is a path that favours serendipity in learning about the plant. Any gardener, school teacher, or cook can participate in the development of taro by growing the plant, enjoying its ornamental qualities and food value, and telling others what he or she has learned.

If adaptation to climate change becomes our primary goal because of global warming, cooling, or instability (Taylor 2009), then we should consider how to use existing kinds of taro effectively, and how to develop new kinds of taro suitable for diverse combinations of water supply, temperature, humidity, soil fertility, growing season, day-length, total hours of sun, cropping system, culinary value, nutritional value, and disease resistance or tolerance. All of these factors, and more, are significant whenever an attempt is made to preserve or improve the plants that we live with.

We know how to feed the world: bring our present and future resources into balance with our present and future demands (Smil 2004; Tudge 2007). Since the world is always changing, 'sustainability' must be a dynamic balance, one in which we are constantly adapting to new challenges. We can do this on our own terms, or we can do this, less wisely, on terms imposed by the limits and uncertainties that we face. In all likelihood, we will only partly succeed in avoiding future food disasters, no matter how well we understand ourselves and the world. Our ignorance is unlimited. That is the magic and tragedy of science, and human knowledge generally. There is always more to learn.