INVENTORY OF THE
COCONUT PALM RESOURCES

KINGDOM OF TONGA

Draft Report to the
New Zealand Ministry of Foreign Affairs and Trade

Prepared by
L.E. Burrows and R. Douglass

Landcare Research NZ Limited
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Executive Summary

Landcare Research New Zealand Ltd was contracted to design, plan, and implement an inventory of the coconut timber resource of the Kingdom of Tonga. The inventory is a component of the Tonga Forestry Project managed by Landcare Research New Zealand Ltd as Management Service Agency (MSA) for the NZ Ministry of Foreign Affairs and Trade. Project implementation was a co-operative project between Landcare Research and the Forestry Division of the Ministry of Agriculture and Forestry.

The Tongan forestry project has had four main component parts in 1995/6: the coconut timber resource inventory; an economic evaluation of the plantation forests on 'Eua; a draft management plan for the 'Eua National Park; and a five year agro-forestry plan.

Main findings of the coconut resource inventory presented in this report are as follows:

Current density and distribution of coconut palms
- Mean coconut palm density for all main Island Groups is 91 stems/hectare, but ranges from 71.6 stems/hectare on Tongatapu to 135.6 stems/hectare on Ha'apai;
- the overall stem density of coconut palms in the inventory area has declined by 26.6% over the last 16 years;
- the decline in Tongatapu and Vava'u has been more than 35%; and
- the stem height-class distribution for all Island Groups surveyed is unbalanced, with the majority of stems being in the middle height-classes. Over 50% of stems are between 10 and 15 m tall, while only 5% of palms are <5 metres and 8% are >15 metres.

Deforestation and reforestation
- The decline in palm density has been happening for about 30 years but equates to a loss of some 72,500 palms/year, or 600 hectares/year, for the area surveyed 16 years ago;
- losses are due to clearance of mature palms for a variety of reasons, and absence of replacement plantings;
- most losses are at a very small scale (<0.1 hectares) and are probably due in the main to agricultural practises;
- annual losses attributable to utilisation for timber equate to <25% of all losses for the period of most active timber utilisation (1985-1995);
- replacement plantings have been at about 25,000 new palms per year for the last 15 years; and
- maintenance of the resource at current levels would require at least 100,000 new palms planted per year, equivalent to about 800 hectares of new coconut plantation.

Sustainability of the timber resource
- Utilisation of the coconut resource for timber production is not sustainable under current conditions;
- if strict legal harvesting controls were enforced the total recoverable senile timber volume for Tongatapu, Ha'apai, and Vava'u will not last beyond five years at present utilisation rates;
- if just timber production from palms is considered at the expense of nut-based products the resource could be managed to provide the current level of output for 40-50 years;
- to implement the latter option, timber utilisation controls would need to be relaxed, utilisation of currently waste stump wood investigated, and price to owners would need to be increased significantly to secure supply of a higher proportion of felled stems; and
- growth-rate and senility-rate of coconut palms in Tonga should be investigated. Such work could be integrated with other coconut studies currently under way by MAF Research, and would be important for fine-tuning results presented here.
Domestic consumption demands from the resource
- Local domestic consumption of coconut products, including fibre, food, drink and stock-
food, requires ~1.25 million palms nationally;
- each average household consumption can be satisfied by a plantation of 80-90 palms occupying 0.7 hectares, with 2 new palms planted/household/year; and
- new plantings over most of the last 15 years have not been sufficient to provide for future domestic consumption, although planting density has increased in the last three years.

Potential for copra production
- current potential production of copra could be as high as 10,000 - 15,000 tonnes/year, or 0.7 - 1.0 tonnes/household/year; and
- potential copra production is greatest at present due to the large proportion of palms in the most productive height-classes, but will decline to nothing over the next 20-30 years at current re-establishment rates.

Conclusions and Recommendations
- The substantial changes occurring within the coconut plantations of Tonga are only of concern if future national economic opportunities are being compromised;
- There is a need to assess the level of importance of coconut products in the future domestic and commercial production base of Tonga;
- Legal regulatory requirements aimed at maintaining coconut establishment levels and controlling utilisation for timber are not currently enforced. Farmers do not replant coconuts because, beyond those required for home supply, they see little value or future return from them;
- Existing legislation affecting the coconut resource should be reviewed in view of the above assessment and inventory results; and
- Because of the time scales involved and low returns coconut palms are never planted as a timber source. If rejuvenation of the plantations is desirable it will have to be based on the economics of other products than timber.

To help determine management and planning options predictions of future productivity from the resource is needed. Coconut population structure, density and distribution results from the inventory combined with existing nut production information can be used to model the productivity of the palm population under different establishment, production, and utilisation scenarios.
- Model future productivity of the coconut palm resource under different scenarios.

Institutional strengthening/training
- It is recommended that consideration be given to tertiary level training of at least one Forestry Division staff member in mensuration and analysis. This would strengthen in-house capability to monitor changes to the coconut plantations, if this task is confirmed as a Forestry Division role. It would also have valuable application in other areas of Forestry Division responsibility such as the plantation(s) and agro-forestry;
- Practical mensuration skills developed during the inventory should be maintained by the Forestry Division by regular application to forest resource monitoring exercises.
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1. Introduction

There is strong interest from Tongan agricultural and forestry sectors in the sustainability of the coconut palm resource. Due to the level of cut for timber production, clearances for cash crops, and waning of the coconut replanting scheme (CRS), concern has been expressed over the level of palm deforestation. The concerns can be summarised into four main issues:

- What is the current density and distribution of the coconut palm resource?
- What are the levels of deforestation and reforestation and how will they affect the future production of coconut products?
- What size is the remaining palm timber resource and can it provide a sustainable supply of sawn timber at present harvesting levels?
- Is the current resource adequate to supply other products for household consumption and copra production?

No recent quantitative data are available upon which to base planning and management decisions. Consequently the New Zealand Ministry of Foreign Affairs and Trade (MFAT) have funded an inventory of the resource aimed at addressing these issues (see Terms of Reference, Appendix I). This report presents the results of the inventory.

2. Background

Coconut palms (Tongan = niu) (Cocos nucifera) are ubiquitous throughout the Kingdom of Tonga where they are regarded as ‘the tree of life’. Their importance in Tongan life is reflected in Tongan mythology and products derived from coconut are used in a wide variety of ways both in the kitchen and elsewhere (van der Grijp 1991). Copra production has played a major role in the economy of Tonga for many years. More recently the economic importance of copra as an agricultural crop in Tonga has declined due to a reduction in world prices and land has been cleared of coconut stems to plant more light demanding crops such as squash, watermelon, peanuts, corn, and tomato (MAF 1994, MAF 1995).

The changed agricultural economic situation has affected the emphasis placed upon replanting of coconut to the extent that areas cleared of palms are often not replanted. At the same time as copra production has declined utilisation of coconut stemwood for sawn timber production has increased with a sawmill active in each of the main island groups. As a result of increasing clearances and reduced plantings the coconut population of Tonga is thought to be in significant decline.

The coconut resource has been estimated by number on several previous occasions (Doyle 1977, Gould et al 1982, Statistics Department 1985) with variable results. The count survey of Gould et al (1982) is the most reliable previous estimate as results are presented on a density basis and an estimate of error was included.

To quantify Tonga’s remaining coconut timber resource and to plan for a sustainable local timber supply it is vital to undertake an inventory of the distribution, number, size and volume of standing coconut stems throughout the Kingdom. The need for such a resource estimation has long been recognised and an imbalance of age-classes noted (NZ Ministry of Foreign Affairs 1977).
This inventory has surveyed the bulk of the main islands with coconut plantations in Tonga, and about half the total land area. Other islands with substantial coconut plantations not covered by the survey include; the eastern, western and island districts of Vava'u, Eua, and the Niuas. The omitted areas total about 22% of the area under coconuts (Statistics Department 1985).

3. Objectives

- Estimate the current density of palms by Island group and age-class;
- Quantify the proportion of the landscape without coconut palms, and along with seedling palm density figures, comment on levels of deforestation and reforestation;
- Estimate the volume of recoverable palm timber as a means of determining sustainable wood production; and
- Determine the coconut resource required to satisfy various local consumption demands and the potential for copra production.

An additional goal of the inventory was to aid development through practical experience of some forest mensuration skills within the Forestry Division. Such skills have application through all facets of Forestry Division functions.

4. Methods

To provide quantitative estimates of the coconut resource the inventory used fixed-area plots randomly located throughout the three main island groups of the Kingdom of Tonga. In each island group all land except towns, villages, and mangrove swamps was sampled. Areas covered by the inventory included all of Tongatapu, the five central islands of Ha'apai (Ha'ano, Foa, Lifuka, Uoleva, and 'Uiha), and the central and northern districts of Vava'u (Pangaimotu, Nafaufau, Holonga, and Le'matu'a).

The field inventory took place between October and December 1995, using three teams each of three field-workers from the Forestry Division of the Ministry of Agriculture and Forestry. The teams were constantly supported by two supervisors, one from the Forestry Division and one or other of the authors.

4.1 Land areas

Past estimates of the coconut resource have proven difficult to compare due to differences in land area definitions. For this inventory a number of key land area figures have been used.

- Total area of the inventory (digitised from 'api maps) 35,419 ha
- Net area of the inventory (minus area occupied by towns, villages, swamps and mangroves transcribed from 1990 aerial photos onto 'api maps and digitised) 31,077 ha
- 'Total cultivated acreage' (as used by Gould et al 1982) 35,347 ha
- All agricultural land in Tonga (MAF 1993) 48,000 ha
- Total land area of the Kingdom of Tonga (see Appendix 4) 74,700 ha

A precise description of methods employed and technical results are given in Appendices 2 and 3.
5. Major findings

5.1 Current density and distribution of the coconut palm resource

5.1.1 Approach

Mean stem density for each Island Group was estimated from counts made on inventory plots. Stems were also classified into height-classes corresponding to life-stage, or approximate age-class, for better understanding of the population structure. Knowledge of the age-class structure allows prediction of trends in supply of coconut products over time.

5.1.2 Palm resource in each main Island Group

Counts of standing palms estimated for the inventory area are given in Table 1. Using the overall measured estimate of stem density (91.0 st/ha) and applying it to the 'total cultivated acreage' of Gould et al (1982) the current resource for the area assessed in 1979 is ~3.2 million stems. This area will be used for the purposes of comparison in appropriate sections.

The total area of actual or potential coconut plantation for Tonga equates more closely to 'all agricultural land' (MAF 1993), therefore the total resource for all Tonga is ~4.35 million stems.

Table 1: Net surveyed area, stem density of coconut stems with trunks taller than 1 m, and total stem numbers for the area covered by the inventory. Total stems do not sum due to rounding errors.

<table>
<thead>
<tr>
<th>Island Group</th>
<th>Net surveyed area (ha)</th>
<th>Mean density (st/ha)</th>
<th>Total stems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td>22,655</td>
<td>71.6</td>
<td>1,622,100 (±7.5 %)</td>
</tr>
<tr>
<td>Ha'apai</td>
<td>3,678</td>
<td>135.6</td>
<td>498,700 (±8.0 %)</td>
</tr>
<tr>
<td>Vava'u</td>
<td>4,744</td>
<td>78.7</td>
<td>373,400 (±9.8 %)</td>
</tr>
<tr>
<td>Overall</td>
<td>31,077</td>
<td>91.0</td>
<td>2,828,000 (±5.8 %)</td>
</tr>
</tbody>
</table>

5.1.3 Seedling palm resource

The mean density of seedlings are given for the 3 main island groups in Table 2. Differences between seedling densities in each island group are wide, but overall mean density of retained seedlings is low. The majority of seedling palms are wildlings growing on untended 'api. Few replacements are presently being retained in Ha'apai or Vava'u, while about half of the mean seedling density is being retained in Tongatapu equating to 3.8 stems/ha for that area.
Table 2: Mean stem density (st/ha) seedlings (individuals with trunks shorter than 1 m but leaves taller than 2 m) for each of the main Island Groups in the Kingdom of Tonga. Seedling density is further divided into those retained as replacements by farmers, and self-sown wildlings. The number of 0.5 ha plots measured (n) and error (+%) are given.

<table>
<thead>
<tr>
<th>Island Group</th>
<th>Retained</th>
<th>Wildlings</th>
<th>Sum</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td>3.8 (+40.4%)</td>
<td>5.1 (+102.4%)</td>
<td>8.9 (+59.7%)</td>
<td>180</td>
</tr>
<tr>
<td>Ha'apai</td>
<td>0.5 (+160.9%)</td>
<td>24.2 (+41.0%)</td>
<td>24.6 (+40.1%)</td>
<td>99</td>
</tr>
<tr>
<td>Vava'u</td>
<td>1.3 (+99.2%)</td>
<td>12.2 (+55.9%)</td>
<td>13.0 (+53.3%)</td>
<td>75</td>
</tr>
<tr>
<td>Overall</td>
<td>2.4</td>
<td>11.9</td>
<td>14.2</td>
<td>354</td>
</tr>
</tbody>
</table>

5.1.4 Age, productivity and senility of palm resource

To overcome the lack of detailed information on age and growth-rate, previous surveys have used palm life-stage as the basis of classification. Gould et al (1982) used life-stages as the basis of their analysis. They also assumed a growth rate of approximately 1 foot/annum as evidenced by some of their life-stage descriptions and selection of '10 foot height classes' which 'roughly equates with 10 year age groups'. Such a generalised growth-rate is supported by Pursglove (1985) who suggests a longevity for coconuts of 80 to 100 years and an attainable height of 20 to 30 metres, and Piot & Tesson (1994) who surveyed farmers in Tonga about their coconut plantations and used 3 years per metre. The oldest coconut replanting scheme (CRS) stands of trees are known to be about 30 - 35 years old and around 10 metres tall (Tevita Faka'osi pers. comm.). Because of the difficulty associated with subjective determination of life-stage classes, and the lack of definitive information on growth-rate this survey has simply measured stem height and assumes an average height growth of ~0.30 metres per year and uses both height and life-classes. Such a simplification ensures comparability with previous studies.

Legislative requirements demand identification of senile palms as the only trees eligible for utilisation. These were noted in the field. Senile palms (tall palms with shortened leaves (<1.5 m), few or no nuts, and abruptly reduced stem diameter below the crown) comprised 2.3% of the total stem count and ranged from 10 - 22 m in height with a mean height of 14.2 metres. They make up 2.9% of the stems from 10 to 15 m and 10.6% of those >15 m, although most stems >15 m can be considered pre-senile (senescent) with reducing nut productivity.

5.1.5 Palm height distribution

The overall height-class distribution of mean stem density (stems/ha) shows a distinct gap in the upper and lower size-classes (Figure 1). All Island Groups assessed closely follow the same pattern. About 50% of all stems are found between 10 and 15 m, while less than 5% are shorter than 5 m and 8% are taller than 15 metres.

The unbalanced height-class distribution of coconut palms in Tonga has resulted from a number of causes. The peak of stem density in the middle height-classes coincides with the beginning of the CRS ~30 years ago, while the low rate of re-establishment in recent years reflects the lack of interest in copra production and the closing of the oil extraction mill.
For the current coconut tree population to be structured in a sustainable manner the height-class distribution would need to be much more evenly spread. By making allowance for some occasional losses (e.g. insect induced mortality, storm damage, fire, implement damage) the distribution should have higher seedling densities, and show a gradual reduction in stem density with increasing height.

The upper height-class gap is of immediate concern to the Tongan timber industry, while the lower height-class gap has implications for the future sustainability of the resource for all productive uses.
Figure 1: Height-class distribution of mean stem density of coconut palms for the total area surveyed in Tonga. All main island groups closely follow the same pattern. Seedling palms (<1 m trunk) are subdivided into retained (R) and wildlings (W). A theoretical evenly-distributed palm population required to satisfy all the needs of domestic consumption is delineated. The sum of stems below the line is 26 st/ha.
5.2 Levels of deforestation and reforestation

Since the previous most reliable estimate in 1979 (Gould et al 1982), the total coconut palm population for the 'total cultivated acreage' of 35,347 ha has reduced by 1.2 million palms or 26.6% (Table 3). This equates to a loss rate of 72,500 stems per year. Marked differences occur between Island Groups with the Vava'u palm population having reduced by 39.5%, Tongatapu by 36.0%, while Ha'apai has only reduced by 9.9%. The relatively large reduction in Vava'u may not truly reflect the overall Vava'u situation as the central and northern districts surveyed appeared to have suffered more recent clearances than the eastern and western districts, which were not surveyed. As well as the measured reduction over the past 16 years a reduction in planting has been occurring since a peak ~30 years ago (Figure 1).

Table 3: Comparison of total number of coconut palms by island group between 1979 and 1995. Results from both surveys have been presented as stem density and 'total cultivated acreage' from the 1979 survey has been used as the basis of comparison.

<table>
<thead>
<tr>
<th>Island Group</th>
<th>Total cultivated acreage</th>
<th>Palms per ha. 1979</th>
<th>Total Palms (millions) 1979</th>
<th>Palms per ha. 1995</th>
<th>Total Palms (millions) 1995</th>
<th>Difference %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td>19,268 ha</td>
<td>111.9 (±7.2%)</td>
<td>2.156</td>
<td>71.6 (±7.52%)</td>
<td>1.380</td>
<td>-36.0 %</td>
</tr>
<tr>
<td>Ha'apai</td>
<td>6,476 ha</td>
<td>150.5 (±7.8%)</td>
<td>0.975</td>
<td>135.6 (±7.99%)</td>
<td>0.878</td>
<td>-9.9 %</td>
</tr>
<tr>
<td>Vava'u</td>
<td>9,604 ha</td>
<td>130.2 (±10.9%)</td>
<td>1.250</td>
<td>78.7 (±9.75%)</td>
<td>0.756</td>
<td>-39.5 %</td>
</tr>
<tr>
<td>Overall</td>
<td>35,347 ha</td>
<td>124.0 (±5.1%)</td>
<td>4.383</td>
<td>91.0 (±5.79%)</td>
<td>3.217</td>
<td>-26.6 %</td>
</tr>
</tbody>
</table>

At standard plantation spacings the overall loss rate is equivalent to clearance of almost 600 ha/year or 9,600 ha over the 16 years. Almost two-thirds of the overall clearances have taken place in Tongatapu, about one third in Vava'u, and only a small proportion has been cleared in Ha'apai.

Extrapolation to 'all agricultural land' of 48,000 ha would suggest that deforestation may in fact be as high as 1.6 million palms and 800 ha/year for the country as a whole. As we have no estimation of the situation in 'Eua or the Niuas the previous figures have been used throughout the report.

5.2.1 Deforestation

Loss of palms can result from several possible causes such as, natural mortality (insect attack and storm damage), clearance for urban expansion, incidental and direct clearance resulting from agricultural practises, and felling for timber production.

We have seen no reports of increased incidence of disease or insect pest attack. Cyclone Issac caused extensive damage, including wind-throw of coconut palms in March 1982 (Woodroffe 1983). The islands worst hit by Cyclone Issac were the Ha'apai Group, which show the smallest reduction in palm numbers between Island Groups, suggesting storm damage does not have as great effect as other causes. The bulk of the clearance appears to have been at the hands of man.
Deforestation was assessed on the 1990 aerial photographs at a patch-size of 10 ha, and from the inventory at scales of the plot (1.8 ha) and sub-plot (0.1 ha). Large scale clearance of palms (>10 ha) made up 9% of the landscape in 1990, similar to the area occupied by towns and villages (Table 4).

The area formerly occupied by the ~1.2 million trees lost since 1979, at 1979 densities, should total about 9,700 ha or 27% of the 1979 inventory area. No increase in large-scale cleared land area was found between the 1990 photographs and the proportion of whole plots with no palms in this survey, suggesting wholesale clearance of large tracts is not the main cause of loss. Examples of recent large-scale clearances were observed during the survey particularly on Pangaimotu in Vava'u between the 1990 aerial photographs and the present situation. The proportion of sub-plots with 1 stem or less (<10 st/ha) was 10.6% showing only a slight increase at that level between 1990 and 1995. It seems probable that the clearances are being carried out at a very small scale with the main effect shown by the reduction in overall stem density rather than as wholesale clearance. Likely causes of losses at such a small scale include incidental agricultural practices such as burning and mechanical implement damage, and demand for household firewood. More detailed remote sensing analysis of aerial photograph coverage from 1990, and other years if necessary, at a much smaller scale than time permitted for this inventory may better clarify deforestation extent and location.

5.2.2 Utilisation for timber production

All the Tonga Timber Ltd sawmills in combination (previously Forestry Division, MAF) have cut on average 16,000 stems/year during their most prolific period (MAF Annual Reports 1993 - 1995, Tonga Timber Ltd pers comm). In Vava'u, where the reduction has been greatest, stems utilised by the sawmill have averaged only a few hundred per year. Yet the overall reduction for the whole country was 72,500 st/yr. Palm utilisation for timber production consumes a minor proportion of stem losses corresponding to between 20 - 25% of cleared palms since 1985 and probably less than 10% per annum before that when sawmill utilisation was lower.

5.2.3 Reforestation, the key to the future management of the resource

Even with considerable rate of clearance there would be little need for concern if replacement palms were planted. In recent times re-planting of coconut palms has been minimal. Over most of the last 15 years (i.e. stems less than 5 m tall, Figure 1) retention of replacement palms has averaged less than 0.8 st/ha/yr. In the last 3 years there has been a slight increase in re-establishment as it seems probable that landholders retain or replace palms for domestic consumption. This replanting has been at a rate of 25,000 per year for the net survey area. Although a mean 14.2 seedling palms/ha were found throughout the Kingdom, only 2.4 seedlings/ha had actually been planted or retained for productive purposes. Wildlings were normally found in high density clumps or thickets, on unworked 'api. Few will find their way into the productive palm population as they will be cleared or burned when the 'api is worked up again.

If there is future value to Tonga in a productive palm coconut population, and its present size is deemed suitable, then a massive replanting scheme will need to be developed. To maintain the current potential production level would require new plantings averaging ~3.3 st/ha (100,000 palms) throughout Tonga, requiring some 800 ha of new planting per year.

5.2.4 Summary

The Tongan palm population has been reduced by 1.2 million palms (26.6 %) for the area surveyed by Gould et al (1982) since 1979. The vast bulk of coconut palm clearances, which equates to a plantation area loss of 600 ha/year for the past 16 years, has been at a very small scale, most likely resulting from incidental agricultural damage. In recent years between 20 and 25% of felled palms have been utilised for timber production.
Reforestation has been minimal for most of the past 15 years. To maintain the palm population at current levels will require new plantings of ~100,000 palms per year indefinitely. Current establishment is ~25,000 palms per year.

5.3 Sustainability of sawn timber supply

5.3.1 Approach

To assess the potential resource of sawn timber it was necessary to estimate the total volume of wood in the standing plantations and make deductions for known losses. To that end, all stems within inventory plots were measured for height and diameter and their volume determined by application of a volume equation developed for the purpose (Appendix 2, Figure 3). Known losses due to unacceptable stem shape, stumps, top-logs, slab, and soft core have all been estimated and mean volume per hectare calculated. Volume estimates were then summed by the known agricultural area of each Island Group to give an accurate estimate for the country as a whole. A summary diagram of the timber resource from standing plantation to sawmill outturn is given in Figure 2 and vol/ha by height-class in Table 9.

Only senile stems are supposed to be utilised for timber production and total standing volume estimates have been made for them. The rate at which palms become senile and available for timber harvesting is unknown but assumed to be age-dependant. Further information on the rate of senility would be valuable when trying to estimate the sustainability of the resource.

5.3.2 Standing volume

Mean whole stem standing volume for all palms in all areas surveyed was 135 m³/ha, while volume for stems >10 m (old mature, senescent, and senile) was 72 m³/ha, and for senile stems only 2 m³/ha (Table 9). Due to much higher stem densities in Ha'apai, and slightly larger diameter, volume per ha there was about twice that for Tongatapu or Vava'u (Table 9).

Stump volume averaged 9 m³/ha but was also about twice as high in Ha'apai compared to Tongatapu or Vava'u due to greater stem density in most height classes (Table 9).

Sawlog volume was derived from the total stem volume for stems over 9.5 m tall. Minimum stem height for palms capable of producing a sawlog is derived by adding the mean stump height (1.2 m) the mean top-log length (5.3 m) and a minimum acceptable sawlog length of 3 m. By deducting the stump, the top-log, and curved or bowed stems from total stem volume the net sawlog volume is found (Table 9).

5.3.3 Conversion efficiency of producing wood from coconut palms

Conversion efficiency of coconut stems is poor despite regularity of size and shape, mainly due to small diameter (high surface to volume ratio) and the large proportion of soft core in each log. In Tonga, for every palm cut, average sawn timber outturn varies from 0.084 m³ or 16% recovery (Mean of figures presented in MAF Annual reports 1985 - 1990), to 0.166 m³ or 32% recovery (Tonga Timber Ltd Annual Report 1994). In other words 6 - 12 trees, or 9 - 17 sawlogs are required to produce 1 m³ of sawn timber. Such a recovery rate compares with 24% recorded for other localities (Sibayan et al. 1976). Variation in recovery % is simply affected by the amount of slab and soft core included as outturn. If the market will buy it, then it is worth cutting and it will be included in outturn volume. As the current sawing regime is operating at 32% recovery this figure was used when calculating potential recoverable volume (Tables 9 and 10).
The sawn timber included in the 32% recovered is 'dimension' - all sound planks, '1/4 or 1/2' - where a side or corner of the plank has some soft core, and long lengths of 'slab' - hard outer pieces, flat on one side but with 'bark' on the other. Short slab along with the soft core and sawdust or kerf, totalling 68% of sawmill input sawlog volume currently ends up as waste. No figures of relative proportions of each of the sawn timber types are available although indications from an Indonesian study suggest about equal amounts of each is probable (Sibayan et al. 1976).
Figure 2: Summary diagram of the recoverable coconut timber resource of Tonga.
The total stem-wood volume of all stems for the surveyed Island Groups of Tonga (135 m³/ha) with allowances for measurable losses is 550,000 m³. This is the potentially recoverable sawn timber, under current utilisation regimes, for all stems >10 m (Table 10).

5.3.4 Production potential from utilisable senile stems

The timber resource is further reduced when just senile stems are considered. Recoverable volumes for senile stems by Island Group are presented in Table 10. The total timber volume available from senile stems for the 31,077 ha of the net inventory area is 21,182 m³, or 32,717 m³ by extrapolation to 'all agricultural land'.

Saw milling of over-mature stems is entirely compatible with domestic nut consumption and copra production as long as nut-productive trees are not taken. Although only senile stems are allowed to be utilised for timber production, due to the low nut productivity of most stems >15 m tall, and quite a few 10 - 15 m, these stems could be utilised without seriously affecting nut production. If senescent stems (all stems >15 m) are considered for utilisation as well, then the sums of total recoverable timber volume are 67,226 m³ and 103,834 respectively for the same areas.

5.3.5 Current rate of utilisation

All the Tonga Timber Ltd sawmills (previously Forestry Division, MAF) in combination have cut on average 16,000 st/yr during their most prolific period (MAF Annual Reports 1985 - 1995), and a much lower number per annum before that. By far the greatest number of utilised stems originated in Tongatapu. In Vava'u, stems utilised by the sawmill have averaged only a few hundred per year, and in Ha'apai even less. The production of coconut timber from all sawmills operating in the Kingdom has averaged about 1600 m³/annum for the past 5 years, although indications are that production may have increased to about 2000 m³/annum over the last three years (TTL pers comms).

Sawlogs are cut between 3 and 4 m in length so depending on whole stem length 1, 2, or occasionally 3 sawlogs can be cut from one palm. On average 1.45 sawlogs are cut per palm.

5.3.6 Sustainability of the resource

With a total senile resource of 21,182 m³ from the area of the inventory, increased by 22% to include the balance of the coconut plantations for all Tonga, at the present rate of clearance with only 20 - 25% of felled palms being processed by sawmills, the current resource of senile palms will last for 3.6 years! That supply period would in practise be extended a little by allowing for a growth increment and presuming that some additional palms become senile. It would also require extraction of senile palms from all available locations throughout the Kingdom. Clearly the existing resource is not sustainable under current conditions.

If senescent palms are included in the resource available for milling then the period of availability would last for 11.3 years - still not sustainable.

A sustainable management regime could be put in place if; palms could only be felled for saw milling, all Islands with a significant coconut palm resource were progressively targeted, and senescent as well as senile palms were allowed to be cut. The total resource currently available could then be managed to provide a supply of logs for >40 years. In combination with a large increase in new planting now and continued into the future the apparent lower size-class gap could be spanned and a sustainable timber supply provided.
Under current utilisation conditions the source of coconut trunks for utilisation at the sawmill will dry up in about ten years. Before that, lack of availability of stands of regular sized stems will begin to affect harvesting efficiency. Unless other sources of raw material become available, the current saw milling and timber production infrastructure of Tonga will severely decline.

5.3.7 Potential utilisation of currently waste coconut wood.

Tonga Timber Ltd (TTL) is in the process of making better use of currently waste wood as fuel in a timber drying plant. Waste wood from the sawmill and top-logs from the field will be more efficiently utilised than at present.

An additional efficiency which needs investigation is utilisation of the wood volume in stumps. This represents a considerable volume of the most dense wood which is currently left to waste in the field. Due to their large diameter and small soft core, the volume of high density wood in stumps is equivalent to >20% of the total current volume production from the sawmills (Table 9). That amount of wood may be significant in light of the short current sustainable supply horizon. The short piece-length and very hard lignified wood may require that special systems be developed to aid utilisation. The available resource could be considerably increased if the problems associated with handling short lengths of extremely dense wood, along with marketing of small piece sizes (e.g. furniture components, carving blanks, parquet) can be overcome.

5.4 Allocation of the resource to other products

5.4.1 Household consumption

There are about 100,000 people and 15,000 households averaging 6-7 people each in the Kingdom (MAF 1993). They derive many essential products for daily family sustenance such as weaving/roofing material, food, drink, and stock food from coconut palms. Although important uses are made of leaves, most products are dependant on fruit. Previous estimates of the per capita daily domestic consumption of coconuts range from 0.64 (The Coconut Review Committee 1982) to 3.3 (Piot and Tesson 1994).

The latter figure, derived from a very small sample, is clearly an over-estimate. Average production figures range from 25 to 32 nuts/palm/annum (The Coconut Review Committee 1982, MAF 1995). The more conservative figure has been used here. If the higher consumption figure is used and annual palm production of 25 nuts, with a human population of ~100,000, a national productive population of more than 4 million palms would be required to supply local demand. That is clearly not the case as a large proportion of the current nut production from 3.2 million trees (Table 3) currently falls to waste.

5.4.2 Resource requirements to satisfy household consumption

Using the 0.64 daily consumption figure would mean that ~1 million trees are needed to satisfy local consumption. The partitioning of consumption figures between humans and stock presented by Piot & Tesson (1994) makes sense at present but is likely to alter with variations in copra price. During times when copra price does not warrant harvesting it is likely that a much larger proportion of nut production ends up as stock food than when copra harvesting is active.

\[ \text{Total coconut} = 3,217,000 \]
By dividing the 1 million productive trees into home-supply plantations about 67 productive trees per household would be required. If such a standard plantation was evenly spread across all height (age) classes to provide a balanced sustainable resource, and with the addition of some replacement young trees and a few senescent palms with low nut production yet to be felled, an age-structure of ~2 trees planted per year per household for a sustainable plantation of 80 to 90 trees per household and a total national plantation of 1.25 million trees would provide the necessary resources.

If 1.25 million trees were evenly spread across all height classes for the coconut plantation area of the country as a whole (48,000 ha of agricultural land - MAF 1993), an overall density of about 26 stems/hectare is required to satisfy internal domestic consumption (Figure 1). Spaced at 9 x 9 m, as recommended by the CRS, each household plantation would occupy 0.7 ha or 10,500 ha nationally. The indicative domestic consumption line in Figure 1 has a total of 26 st/ha below the line and a slight gradient to allow for losses. If the proportion of land without coconuts increases then the density/ha on the remaining land would need to increase to compensate and the domestic consumption line in Figure 1 would move upwards. For Tongatapu and Vava'u 26 st/ha is about a third of the current total palm population, for Ha'apai 20%. The lower gap in the height-class distribution means that additional replanting over the near future may be required and maintained for some time just to satisfy domestic consumption requirements. Indications are that over the last few years new establishment has been carried out to a level necessary to provide subsistence production of nuts (Figure 1). The remainder of the resource above that threshold are available for other productive purposes.

5.4.3 Potential for copra production from the current resource

Substantial copra production from the current coconut palm population is feasible. As with the supply of wood products, and due to the unbalanced height-class, a peak of potential production will take place over the next few years with a steady decline to no surplus nuts for copra production in about 30 years. Excess nut production from two million palms not required for domestic consumption from the 'total cultivated acreage' currently equates to 50 million nuts per annum. About 5000 nuts are required to produce a tonne of copra (Coconut Review Committee 1982), so the current potential national copra production is 10,000 tonnes, or 0.7 tonnes per household. If 'all agricultural land' (48,000 ha) is harvestable then potential production for the country would be ~15,000 tonnes, or 1.0 tonnes per household.

5.4.4 Future copra production potential

Unless a substantial replanting scheme is implemented, in about 20 to 30 years time there will be a considerable reduction in the coconut tree population of Tonga. At that stage there will be no surplus production above domestic consumption which could be directed towards additional exportable products such as copra, even if a market existed. At that time Tonga may even experience a shortage of coconut products necessary for domestic consumption.

6. Conclusions

Tonga has very clear specific legislation designed to maintain coconut planting levels and control utilisation. The legal requirements are currently overlooked in the interest of pragmatism. Conditions existing when the legislation was enacted have been superseded and other crops have surpassed copra as the favoured crop of choice by farmers. The coconut palm resource of Tonga is presently balanced between a current capability for high productivity, and rapid decline to insignificance as a means of earning or mitigating overseas funds.
Tree crops by necessity have a long lead-in time and it takes a far-sighted long-term view of the country's future to see the importance that coconuts can play in that future. Tonga is at a cross-roads in its use of the 'tree of life'. As the productive cohort of palms grows through to senescent and senile age classes over the next 20 - 30 years, without replacement a rapid decline in overall stem density and potential productivity will ensue.

A decline in the palm population is not necessarily a problem. Only if significant future returns can be envisaged from coconut nut products is the imminent situation serious. It is probable that recognition by landholders of the number of palms necessary to provide for their own home consumption will guarantee maintenance of a subsistence resource. And for the growing number of Tongan households which don’t have an interest in a land-holding, that may mean importation of coconuts or coconut products from elsewhere within the Kingdom or overseas. Further clearance of palms may even improve the productivity of other crops.

Previous reports have spoken of the 'problem that Tonga faces of a large number of senile and senescent palms' (The Coconut Review Committee 1982). A similar situation existed throughout most coconut growing nations of the pacific (NZ Foreign Affairs 1977) and resulted in the widespread utilisation of what was seen as an almost infinite resource. Results from this survey show that the large resource of senile and senescent palms no longer exists in Tonga. Availability of senile palms for timber utilisation is now dependant on the rate at which palms become senile rather than an untapped resource which can be 'mined' indiscriminately.

Since the middle of this century comments have been made about the nonchalance with which Tongans treat 'the tree of life' (Koch 1955). The replanting scheme was begun in 1966 to help rectify an imbalance in the age distribution of the coconut population, and to improve the productivity of the resource through improved genetic material. Despite initial positive reports (The Coconut Review Committee 1982), planting subsidies, the ease with which coconuts fit with many other agricultural systems, along with legal establishment and harvesting requirements, all have given way to continuing clearance and degradation of the tree population as a whole.

Resolution of the coconut plantation issues facing Tonga are tied up in the likely future importance of export commodities based on copra. No landholder plants coconuts for timber production due to low returns and the long time periods involved. Any incentive for plantation restoration has to be driven by the combined economics of other coconut products. Utilisation of senile palms for the production of timber has a part to play by making best possible use of what would otherwise be a wasted resource, but it is the combined package of products which would need to be targeted rather than any one commodity if coconut palms are to again play a significant part in the health of the Tongan economy.

Only when it is clear that the palm resource can provide a useful future productive function will it be possible to make management and planning decisions to achieve the desired function. For example, if there is seen to be a major economic future in copra production then utilisation for timber would need to be strictly controlled to maximise the production of nuts. Alternatively, if copra is unlikely to again become a viable commodity and mitigation of expenditure on imported timber is seen to be most important then management for sustained timber supply should be the focus, at least until other sources of timber supply come on stream.

Although finite without substantial new plantings, the existing resource could be managed to supply timber for 40 - 50 years. With replanting, the resource could be made sustainable by relaxation of the demand that only senile stems may be sawn, combined with increased returns to the landholder for palms, which would secure a higher proportion of the resource for utilisation.
A major shortage of potential copra-based products could be partially overcome by focusing any new establishment on existing improved genetic stock from overseas. Improved stock has been demonstrated to begin bearing earlier and to be much higher producing than wild or selected stock (Persley 1992). Higher producing earlier-bearing palms would improve supply of all nut-based products but would probably be at the expense of timber as improved palms are shorter in stature and have a shorter life both of which would affect wood quality and volume.

In summary:

- All products derived from coconut palms in Tonga, other than for domestic consumption, are unsustainable in the medium to long term due to low levels of re-establishment, ongoing clearances and subsequent stem density reductions.

- Under the most strict utilisation controls the timber resource will last less than 5 years.

- If managed predominantly for timber production the resource could be made to last 40-50 years at current levels of cut.

- As a result of stem density losses timber production will be most affected in Vava'u and Tongatapu, and to a lesser extent in Ha'apai. Due to human population pressures and demands for raw materials such as construction timber, likely effects will first be felt in Tongatapu.

- Unless national re-establishment is maintained above ~30,000 planted seedlings/annum (~2 seedlings/household) nut production for domestic consumption will be threatened within about 30 years.

- To maintain the palm population of the inventory area at about 3.2 million, which would allow sustainable potential production of copra, and timber, at current levels would require establishment of at least 100,000 st/yr indefinitely.

- At CRS recommended stocking rates 100,000 palms would require ~800 ha/yr.

6.1 Coconut Plantation Strategic Planning

Whatever decisions are made regarding the future of the coconut resource, supply predictions for a range of products will need to be made. The results of the inventory presented in this report provide the raw data required to model the coconut palm population of Tonga and its products under different establishment, production and utilisation scenarios. Such modelling could be a valuable tool and used to determine the best national management options for the resource.

6.2 Institutional Training

Experience gained by staff of the Forestry Division during the inventory means that the Division has some of the mensuration skills required to monitor future fluctuations in the coconut palm population, and in other plantation and agro-forestry applications. Additional training of at least one Forestry Division staff member in mensuration and analysis to a tertiary level is required to strengthen skills in this area to a level capable of dealing with the range of applications that exist.

An initial task of in-house mensuration skills would be to complete the coverage of the inventory in the areas where substantial coconut resources are known to exist but were not covered in the time available for this survey. 'Eua, the remaining districts of Vava'u, and the Niuaus would be obvious targets. A ranked list of islands by area is included in Appendix 4.
7. Recommendations

- That Tonga needs to clarify the position and importance of coconut products in the future production base of the country, with the aim of establishing the relative values of potential copra production and timber;

- That population structure and density data presented in this report, along with existing productivity information be used to model the coconut palm population under different establishment, production, and utilisation scenarios as a means of determining management and planning options;

- That the growth rate of coconuts in Tonga be investigated to improve the management of the resource by better understanding the relationships between age, size, life-class, senility and productivity. Such an investigation should cover variations due to climate, cultivar, and soil fertility within the Kingdom and could be integrated with other coconut palm research currently being carried out by MAF Research;

- That tertiary training of a Forest Division staff member be pursued to strengthen institutional skills in mensuration and analysis;

- That possible utilisation of the coconut wood contained within stumps, and currently left to waste, be investigated;

- That to further refine the estimate of total coconut stems and wood volume, the coconut resource inventory be extended to a level where over 90% of the land area of Tonga has been surveyed. This would entail surveying the 14 largest islands. This inventory has covered 8 of them. Along with completing the remaining districts of Vava'u, the next 6 largest islands would need to be visited. They are listed in appendix 4; and

- That more robust testing of the volume equation developed in this report by carried out by accurate stem measurement of a large sample of felled trees from a variety of locations.

8. Acknowledgements

The authors wish to acknowledge the help provided by many people in compiling this report. Early discussions with Rob Allen, Russel Coker, Dave Leslie, and Tevita Faka’osi were seminal in clarifying the objectives of the survey. Rob Allen and Dave Leslie also gave valuable critical review of earlier drafts.

The inventory could not have been completed without the full support, experience, and guidance of the Head of Forestry Division, Tevita Faka’osi, and his staff. Lolomana’a Filiiai was the Tongan counterpart from the Forestry Division who maintained excellent logistical support for the field-teams who reliably measured the trees and collected the wealth of data. The field team-leaders were - Vunipola Latu, Graham Mala’efo’ou, and Simione Matapa. Team members were - ‘Isileli Kamaloni, Sione ‘Alateni, Spencer Hefa, Sione Lafo’ou, Sione Nau, Taupaki, and Koniseti Vaipulu. Chiharu Tajima, a Japanese volunteer, also helped with the fieldwork.
Dr Uilou Samani and Malakai Vaka of the Ministry of Lands Survey and Natural Resources were particularly helpful with access to their resources. Dr Samani gave permission and space to use the aerial photographic coverage and Malakai Vaka provided copies of island by island 'api maps which formed the basis of the field survey, as well as other useful mapping details. MAF District officers, particularly Vae'a 'Anitoni in Ha'apai, and Mana'ia Halafihi in Vava'u provided valuable assistance with local transport, drivers and guides. Forestry Division District Officers Leody Vainikolo and Sunia Napa'a also provided assistance in their Districts.

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The huge task of computer data-entry of the mountain of data collected was cheerfully carried out by Ngairu Bruerton (Landcare Research Ltd), and Richard Barker (Landcare Research Ltd biometrician) was often pestered for statistical advice which had considerable bearing on the development of methods and calculation of results.

9. References


Foale, M.A. 1987: Coconut germplasm in the South Pacific Islands. ACIAR Technical Reports Series No. 4, Australian Centre for International Agricultural Research, Canberra. 23p.


Appendix 1: Terms of Reference for the Coconut Resource Inventory

Terms of Reference

There is strong interest by the Forestry Division in the sustainability of current cut levels of coconut timber, particularly on Tongatapu, and results in the need for a Coconut Resource Inventory. There is also a much wider range of interests in the coconut resource, and any inventory of the resource would also need to take account of these requirements (e.g., copra production). A major concern is the level of coconut palm deforestation. To meet the range of requirements the consultant would need to:

Design, carry out, and report on a Coconut Resource Inventory that primarily provides volume information necessary to determine the sustainability of current and potential levels of cut for sawn timber, but also provides information about the coconut resource for the range of other uses and requirements.

1. To carry out a needs assessment for the inventory as a way of defining a problem statement. This is critical to defining the objectives.
   • review previous surveys of the resource which may form useful baseline information.
   • consider the requirements for knowledge about the distribution and quantity of various coconut cultivars
   • assess the need to understand the structure (size/life stage) of the coconut resource
   • determine the extent and tenure of the area to be covered
   • consider links to other information (e.g., villager attitudes, by gender, to the resource, growth rate site relationships, planting levels) relevant to sustainability of the coconut timber resource

2. To set achievable objectives for the inventory based upon the range of requirements determined above.
   • these should be explicit in their links to management of the coconut resource.

3. Define the field sampling procedure and analytical approach taking account of previous inventories.
   • develop a time framework, logistical requirements, and budget for carrying out the inventory (i.e., objectives 4 and 5 below)
   • specify a sampling strategy in terms of stratification (e.g., coconut density, 'api), sampling unit(s), and measurements (aerial imagery and field work) to be made to meet precision level required.
   • consider the types of analyses appropriate for the inventory data
   • assess method in field.

4. Carry out the field sampling, in combination with Tongan staff.
   • selection and instruction of field teams
5. Analysis of resource data (aerials and plot) and compilation of report presenting results.
   - The end product will be a report describing the resource for the area sampled in terms of the
     objectives defined.
   - Documentation will be completed for a computer database developed, and copies deposited
     with MAF.
   - Oral presentation of key findings to Tongan counterparts and NGO's, including identification
     of Tongan skill training required.

All stages of the Terms of Reference were completed. A needs assessment for the inventory in the
form of a planning report was completed (Burrows & Douglass 1995) and specific achievable
objectives defined.
Appendix 2: Inventory methods and detailed results

The methods developed have taken into consideration the range of variation in palm populations, topography, palm density, and cultivation intensity observed during the pre-inventory reconnaissance by the authors through Tongatapu, Vava'u, Ha'apai, and 'Eua during September 1995.

2.1 Methods

2.1.1 Stratification of the survey area

Initial stratification of the land area covered by the survey was carried out using high resolution 1:10000 scale colour aerial photographs taken in 1990. Coconut palms were readily identified on the photographs and they were used to classify the boundaries of towns and villages, areas of mangroves and swamps, and to delineate areas which have been cleared of coconut plantations. Large gaps in the plantation cover are visible from the air in parts of the Kingdom, and so areas of over 10 hectares with less than 10 coconut stems/ha were delineated (Table 4).

Table 4: Total land area, approximate areas of towns and villages, and of areas without coconuts for the area surveyed. Percentages are given in brackets. Areas without coconuts (swamps, mangroves, and areas where trees have been cleared) and towns were analysed from 1990 aerial photography, transcribed onto maps and digitised. Areas cleared of coconuts were defined as being over 10 ha with less than 10 stems/ha but were included as part of the net survey area.

<table>
<thead>
<tr>
<th>Island</th>
<th>Total area (ha)</th>
<th>Towns/Village areas (ha)</th>
<th>Mangroves/swamp (ha)</th>
<th>Net survey area (ha)</th>
<th>Cleared of coconuts (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td>26,050</td>
<td>2,748 (10.5)</td>
<td>647 (2.5)</td>
<td>22,655 (87.0)</td>
<td>2,520 (11.1)</td>
</tr>
<tr>
<td>Vava'u (central and Pangaimotu districts)</td>
<td>5,305</td>
<td>463 (8.7)</td>
<td>98 (1.8)</td>
<td>4,744 (89.4)</td>
<td>209 (4.4)</td>
</tr>
<tr>
<td>Ha'apai (Ha'ano, Foa, Lifuka, 'Uaha, and Uoleva)</td>
<td>4,064</td>
<td>363 (8.9)</td>
<td>23 (0.6)</td>
<td>3,678 (90.5)</td>
<td>85 (2.3)</td>
</tr>
<tr>
<td>Totals</td>
<td>35,419</td>
<td>3,574 (10.1)</td>
<td>768 (2.2)</td>
<td>31,077 (87.7)</td>
<td>2,814 (9.1)</td>
</tr>
</tbody>
</table>

2.1.2 Coconut Palm Cultivars

Recognition of various cultivars was considered as part of the terms of reference and needs assessment for the inventory. At least 11 varieties of coconut have been recognised in Tonga (Yuncker 1959). All are derivatives of 'Tonga tall' (Moata'ane Vatuvei pers comm. - Vaini Research Station), although at least 1, 'niu leka', is very slow growing and has been treated as a 'dwarf' variety by some authors (Foale 1987). Differentiation of varieties is based on nut or leaf colour or shape and no reference has been made to stem characteristics. No differences in stem character, size, or quality are recognised in the sawmill. In addition to 'Tonga tall', garden specimens of 'Malayan dwarf' exist in Tonga. The few 'improved selections' planted under the CRS were all from selected motherpalms of Tonga tall varieties (Coconut Review Committee 1982), no new germplasm has yet resulted in plantation plantings of dwarf x tall hybrids in Tonga.
Dwarf coconut stems ('niu leka') were encountered on very few occasions. Less than 0.1% of stems were classified as ‘niu leka’, so their effect on final results for the survey are considered insignificant as far as density and volume calculations are concerned. Although rare it was interesting to note that 70% of ‘niu leka’ recorded on plots occurred in Vava’u.

2.1.3 Field survey

For the purposes of comparison the field survey followed the methods employed during the count survey of 1979/80 (Gould et al. 1982) but with some important modifications. The differences were; all land tenures were surveyed, improvements were made in the randomness of the plot locations, and stem measurements were taken for all stems to better estimate volume.

Random sample starting points were selected by use of a grid laid over the ‘api ‘uta boundary map of each island group. About 200 plot sites were selected in Tongatapu with the expectation that some would fall in areas were plots would not be measured (towns, mangroves etc). The sample size was chosen based on the mean stem density results of the 1979/80 count survey. An expected proportional limit of error of ±10% was chosen as close to the error on the previous survey and a sensible goal. Sampling plot density was doubled for Vava’u where variability was expected to be higher, and continued on Ha’apai where extra available time between ferries allowed. As a result an overall plot density of approximately 1 plot per 88 hectares was achieved (Table 5).

Table 5:  Plot numbers, surveyed areas and plot densities for the inventory.

<table>
<thead>
<tr>
<th>Island groups</th>
<th>Number of plots</th>
<th>Net surveyed area</th>
<th>Plot density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td>180</td>
<td>22,655 ha</td>
<td>126 ha/plot</td>
</tr>
<tr>
<td>Ha’apai</td>
<td>99</td>
<td>3,678 ha</td>
<td>37 ha/plot</td>
</tr>
<tr>
<td>Vava’u</td>
<td>75</td>
<td>4,744 ha</td>
<td>63 ha/plot</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>354</strong></td>
<td><strong>31,077 ha</strong></td>
<td><strong>88 ha/plot</strong></td>
</tr>
</tbody>
</table>

For plot starting points falling within a standard ‘api ‘uta the plot began at a random range and bearing from a roadside corner of that ‘api (see appendix 1 - Field manual). For larger land-holdings (Government land, estates etc), range and bearing from a distinguishable geographic feature (e.g. a road junction) were determined in the office and located by distance measure and compass in the field.

Each plot comprised a set of five systematically located fixed area 50m x 20m belt transects alternating at 40 m intervals either side of a baseline running north-south (Appendix 2 - Field manual). Total plot area was 0.5 ha. Plot transects are always recommended to run across changes in stand characteristics (Goulding & Lawrence 1992). Most coconut plantations in Tonga are orientated generally north-south as recommended by the Coconut Replanting Scheme (The Coconut Review Committee 1982) and so transects were run magnetic east-west. Within the transects all coconut palms were counted, measured, and assessed for; form, variety, and senility.

Stem measurements included both total height and diameter for palms with trunks taller than 1 m. Stem diameter was taken at 1 metre as that is near the top of stem buttressing and close to the height at which loggers cut trees. For established/rooted palms with a stem less than 1 m tall and leaves greater than 2 m tall (seedlings) individuals were tallied. Seedlings were further subdivided into; retained - those that have been planted, or selected as replacements from wild stock by farmers, and wildlings - those that have self-seeded but not thinned to a final crop.
Stem length and diameter were used in a generalised volume equation to estimate total volume. Stem dimensions were measured on a selection of recently felled palms and the accurately measured volumes used to test appropriate volume equations. Recently felled stems were measured for, stump height, diameter at 1 m intervals along the length of the stem, and top-log length. Wood volume was estimated using the volume equation developed from the accurately measured stems. Future developments in the handling and extraction of logs and a planned coconut waste-wood fired drying kiln (at least in Tongatapu) means that total log extraction may soon be practised so volume of stumps and top-logs was estimated for each stem. Stump volume has been taken as the downward projection of the diameter as measured at 1 metre for mean stump height determined from the accurately measured stems.

Many stems exhibit damage to the lower stem such as; fire scars, climbing foot-holds, mechanical implement damage and machete cuts. Unless extreme, such damage does not appear to degrade logs or reduce millable volume as the damage is normally contained within slabwood and cut to waste when sawing.

Stem form was assessed in 3 classes - straight, bowed, and curved (IBPGR 1992). Curved stems straighten again below or above the curve sufficiently to extract a minimum 3 m log, while bowed stems are curved throughout their length and have no straight 3 m or longer section. Allowance for loss of extractable wood due to bow or curve has been made. Recovered sawn timber volume was estimated from outturn levels at Tonga Timber Limited sawmills and data from MAF Annual Reports.

2.1.4 Relationship between tree height, age and life-class.

To overcome the lack of detailed information on age and growth-rate, previous surveys have used palm life-stage as the basis of classification. Life-stage classes were based on tree productivity, green nut counts and an estimate of the time period until availability for saw milling (Gould et al. 1982). All these factors are themselves variable. Although Gould et al (1982) used life-stages as the basis of their analysis they also assumed a growth rate of approximately 1 foot/annum as evidenced by some of their life-stage descriptions and selection of '10 foot height classes' which 'roughly equates with 10 year age groups'. Such a generalised growth-rate is supported by Pursglove (1985) who suggests a longevity for coconuts of 80 to 100 years and an attainable height of 20 to 30 metres, and Piot & Tesson (1994) who surveyed farmers in Tonga about their coconut plantations and used 3 years per metre. The oldest coconut replanting scheme (CRS) stands of trees are known to be about 30 - 35 years old and around 10 metres tall (Tevita Faka'osi pers communities.). Because of the difficulty associated with subjective determination of life-stage classes, and the lack of definitive information on growth-rate this survey has simply measured stem height and assumes an average height growth of ~0.30 metres per year and uses both height and life-classes. Such a simplification may mean that height-class distributions are biased, particularly in the upper height-classes where growth can be expected to be waning with age, but does ensure comparability with previous studies.

Legislative requirements demand identification of senile palms as the only trees eligible for utilisation. These were noted in the field. Senile palms are normally tall, have shortened leaves (<5 ft), low productivity with few or no nuts, and abruptly reduced stem diameter below the crown (Coconut Review Committee 1982). Approximate comparative classes between the earlier surveys using life-stage descriptions and tree heights are given in Table 6. Results in this report have often been presented by height class corresponding to life-stage for the sake of comparison with previous surveys.
Table 6: Comparable classes of life-stage descriptions (Gould et al. 1982) and tree heights according to Piot & Tesson (1994), and from this survey, for coconut palms in Tonga. Stem height growth is assumed to be approximately 0.3 metres per year.

<table>
<thead>
<tr>
<th>Life-stages</th>
<th>Years to Saw milling</th>
<th>Stem height (m)</th>
<th>Approximate age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senile palms</td>
<td>1 - 6</td>
<td>&gt; 15</td>
<td>&gt; 45</td>
</tr>
<tr>
<td>Senescent palms</td>
<td>6 - 10</td>
<td>&gt; 15</td>
<td>&gt; 45</td>
</tr>
<tr>
<td>Old mature palms</td>
<td>11 - 15</td>
<td>10 - 15</td>
<td>30 - 45</td>
</tr>
<tr>
<td>Mature palms</td>
<td>&gt; 16</td>
<td>5 - 10</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Young mature palms</td>
<td>-</td>
<td>3 - 5</td>
<td>9 - 15</td>
</tr>
<tr>
<td>Immature palms</td>
<td>-</td>
<td>&lt; 3</td>
<td>&lt; 9</td>
</tr>
</tbody>
</table>

2.1.5 Error Estimation.

Throughout this report error is given as probable limit of error - PLE% (Goulding & Lawrence 1992). It is the Standard Error of the sample at the 95% probability level, multiplied by t (Student’s "t"), and expressed as a percentage of the mean. Error in the volume estimations is made at a plot level and makes no allowance for cumulative error resulting from the volume equation.

2.2 Detailed Results

2.2.1 Stratification of the survey area.

Areas for the different land-use classes assessed from aerial photographs are given in Table 4. Approximately 10% of total land area is taken by towns and villages, and 2% by swamps and mangroves. About 9% have no coconuts due to steep slopes (mainly in Vava’u), permanent pasture, or clearances.

In total 180, 99, and 75 0.5 hectare plots were measured on Tongatatapu, Ha’apai and Vava’u respectively, and 16,110 stems >1 m tall were measured. Plot density for the whole survey was 1 plot per 88 hectares (Table 5), giving a 0.6% sample.

2.2.2 Stem size, density and form.

The tallest individual coconut palm stem measured in plots was 26 m, but only 17 stems out of >16,000 stems exceeded 20 m. Diameter at 1 m averaged 32.3 cm and ranged from 18.1 to 59.1 cm. The majority of large diameter stems were found in Ha’apai where mean diameter was slightly higher than average (33.1 cm). Mean diameter in Vava’u was slightly lower than average (31.2 cm). As expected with palms there was a slight increase in diameter with increasing height due to sustained cell expansion over time (Rich et al. 1986). Mean diameter of stems 5, 10, 15, and 20 m tall were 31.2, 32.0, 32.8, and 33.6 cm respectively.

The density of stems by shape or form for each island group is given in Table 7. Proportions of stems in the different form classes; straight, curved, and bowed are similar across island groups. Bowed stems are considered to have no logs straight enough for the sawmill to handle and so will be omitted from the any sawlog volume calculations. The curve in curved stems most commonly occurs just above the buttress.
As observed in the field about 1.5 m of the stem is usually taken by the curve before straightening again, and so a 1.5 m section of stem will be deducted from the volume calculations for those stems.

Table 7: The proportion of straight, curved, and bowed stems encountered during the survey. Form classifications follow IBPGR (1992). Total number of all stems assessed on randomly located plots are presented by form class, along with their percentages in brackets.

<table>
<thead>
<tr>
<th></th>
<th>Tongatapu</th>
<th>Ha'apai</th>
<th>Vava'u</th>
<th>Total Stems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight</td>
<td>4,467 (69.3)</td>
<td>4,281 (63.8)</td>
<td>1,596 (54.0)</td>
<td>10,344 (64.2)</td>
</tr>
<tr>
<td>Curved</td>
<td>1,484 (23.0)</td>
<td>2,251 (33.5)</td>
<td>1,257 (42.6)</td>
<td>4,992 (31.0)</td>
</tr>
<tr>
<td>Bowed</td>
<td>492 (7.6)</td>
<td>182 (2.7)</td>
<td>100 (3.4)</td>
<td>774 (4.8)</td>
</tr>
<tr>
<td>Totals</td>
<td>6,443</td>
<td>6,714</td>
<td>2,953</td>
<td>16,110</td>
</tr>
</tbody>
</table>

2.2.3 Wood volume

Log selection for sawlogs consists of the lower stem above the buttress where it is straight and up to a height which still contains hard lignified wood (Richolson & Swarup 1977). Recovered log lengths total about 3 to 7 m per palm (Kaveinga Fa'anunu pers comm.). The remaining stem buttress or stump, and top-log with leaves are left in the field as waste.

2.2.4 Stem Volume Equation

Data from accurately measured felled trees from both Tongatapu and Vava'u were utilised to characterise the coconut stem profile. Forty-seven recently felled trees, and some short trees (~2 m), were measured at 1 m intervals along the stem. Top and bottom diameter measurements of each 1 m section were used to estimate actual stem volume. Section volumes were summed for each stem to provide an accurate estimate of whole stem volume including the stump.

Subsequent regression analysis of the relationship between basal area and stem height to predict the accurate volume estimate, provided a suitable volume equation (Figure 3). The equation takes the common logarithmic form for volume equations (Husch et al 1972) of:

\[ \log V = a + b \log (BA \times H) \]

where

- \( V \) = total stem volume (m\(^3\))
- \( BA \) = Basal area of the stem as measured at 1 m
- \( H \) = Height of the stem from ground to the base of the leaves
- \( a, b \) = constants given in Figure 2.

This equation has been used to estimate the volume of all stems in the sample. A robust test of the equation would be useful and would require the measurement of several hundred stems which was not possible in this exercise. Collection of such a data-set would be in the interests and within the capability of the logging crews from Tonga Timber Ltd.
2.2.5 Stumps and top-logs

Harvesting at times leaves stumps as tall as 1.7 m but averaged 1.2 m (Table 8). Often the purpose of such a high cut is to overcome a butt-sweep or curved trunk just above the buttress to provide straight logs for the mill.

The volume of stumps is included in the total stem volume as estimated by the volume equation and has been calculated separately from diameter measurements (Table 9). Because of the consistency in stem diameter, stump volume is strongly dependant on stem density.

**Table 8:** Some coconut stem dimensions as measured on a number of logging sites in Vava'u and Tongatapu. Small end diameter was measured around the clear stem immediately below the lowest fronds, stump height was measured from ground level to the top of freshly cut remaining stumps, and top-log length was the length of the residual log measured from the base of the leafy crown to a point estimated by the logging crew where approximately 50% of the cross-sectional area of the log consisted of hard lignified wood and was not taken to the sawmill for utilisation. Mean top-log volume was calculated from the above measurements.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>s.d.</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stump Height</td>
<td>1.2 m</td>
<td>(0.26)</td>
</tr>
<tr>
<td>2.</td>
<td>Small end diameter (SED)</td>
<td>19.1 cm</td>
<td>(4.5)</td>
</tr>
<tr>
<td>3.</td>
<td>Diameter at SED less 5 m.</td>
<td>22.4</td>
<td>(1.6)</td>
</tr>
<tr>
<td>4.</td>
<td>Top-log length</td>
<td>5.3 m</td>
<td>(0.98)</td>
</tr>
<tr>
<td>5.</td>
<td>Top-log Volume</td>
<td>0.18 m³</td>
<td></td>
</tr>
</tbody>
</table>

Logging crews leave the soft top-log of the stem to waste above a cut-off level where approximately 50% of the cross-sectional area of the trunk contains hard lignified wood. Measurement of top-log lengths was made at a number of recent logging locations in Tongatapu and Vava'u. The mean top-log length was 5.3 m (Table 8) and was independent of tree height. Mean top-log volume from the measured stems was 0.18 m³ (Table 8). This was comparable with the 0.14 m³ measured in a Philippine coconut harvesting study where mean top-log lengths averaged 4.2 m (Sibayan et al. 1976).

2.2.6 Form

Proportions of stems by form class are presented in Table 7. Volume estimates for straight stems (S) have been included in entirety, curved (C) have had 1.5 metres deducted from the stem to approximate the volume loss due to cutting out a section of the stem either side of a bend. The mean volume of a 1.5 m section of the lower part of the stem as measured on 41 felled trees on logging sites was 0.092 m³. Bowed stems (B) stems have been omitted from the volume tables as by definition they do not contain a straight log which could be utilised at the sawmill. They have been included in the tables as waste where appropriate.

2.2.7 Volume estimates

Mean whole stem volume for all areas surveyed was 135 m³/ha, while volume for stems >10 m (old mature, senescent, and senile) was 72 m³/ha. The density of stems >10 m tall was 53 st/ha and the total sawlog length for stems >10 m tall gave a mean 1.45 sawlogs/stem. Due to much higher stem densities in Ha'apai, and slightly larger diameter, volume/ha there was about twice that for Tongatapu or Vava'u (Table 9).
Stump volume averaged 9 m³/ha but was also about twice the volume in Ha‘apai compared to Tongatapu or Vava‘u due to greater stem density in all height classes except <3 m (Table 9).

Sawlog volume is derived from the total stem volume for stems over 9.5 m tall. That minimum height is derived by adding the mean stump height (1.2 m) the mean top-log length (5.3 m) and a minimum acceptable sawlog length of 3 m. By deducting the stump, the top-log, and curved or bowed stems from total stem volume the net sawlog volume is found (Table 9).

Sawlog volume is further reduced to recoverable volume and senile recoverable volumes in Table 10. The sum of total available senile volume for the 31,077 ha of national coconut plantation covered by this inventory is 21,182 m³. The total recoverable volume for all stems >15 m is 67,226 m³.

**Table 9:** Mean coconut wood volume (m³/ha) for each island group by height-class. Total stem volume includes the whole volume of all size and shape stems from base to leaves. Stump volume is the volume of the cylinder contained by the diameter at 1 m and a mean length of 1.2 m. Sawlog volume is considered for the 10 - 15 (old mature) and >15 m (senile/senescent) classes, although stems down to 9.5 m were included. Sawlog volume is the volume remaining from the total stem volume after deductions are made for stump, top-log, bowed and curved stems. Senile volume is the mean proportion of sawlog volume noted as senile in the field, 2.9% of stems 10 - 15 m and 10.6% of stems >15 m.

<table>
<thead>
<tr>
<th></th>
<th>&lt;3m</th>
<th>3.1-5m</th>
<th>5.1-10m</th>
<th>10-15m</th>
<th>&gt;15m</th>
<th>Total (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tongatapu</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total stem vol.</td>
<td>1.13</td>
<td>3.36</td>
<td>38.57</td>
<td>54.13</td>
<td>9.26</td>
<td>106.46 (±9.69%)</td>
</tr>
<tr>
<td>Stump vol.</td>
<td>0.20</td>
<td>0.35</td>
<td>2.79</td>
<td>3.09</td>
<td>0.45</td>
<td>6.88 (±8.84%)</td>
</tr>
<tr>
<td>Sawlog vol.</td>
<td>-</td>
<td>-</td>
<td>10.29</td>
<td>39.84</td>
<td>7.08</td>
<td>57.22 (±12.94%)</td>
</tr>
<tr>
<td>Senile vol.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.16</td>
<td>0.75</td>
<td>1.91</td>
</tr>
<tr>
<td><strong>Ha‘apai</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total stem vol.</td>
<td>1.20</td>
<td>8.92</td>
<td>94.01</td>
<td>93.68</td>
<td>7.52</td>
<td>205.33 (±8.34%)</td>
</tr>
<tr>
<td>Stump vol.</td>
<td>0.19</td>
<td>0.99</td>
<td>7.18</td>
<td>5.49</td>
<td>0.36</td>
<td>14.21 (±8.83%)</td>
</tr>
<tr>
<td>Sawlog vol.</td>
<td>-</td>
<td>-</td>
<td>23.56</td>
<td>73.58</td>
<td>6.06</td>
<td>103.21 (±10.49%)</td>
</tr>
<tr>
<td>Senile vol.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.13</td>
<td>0.64</td>
<td>2.77</td>
</tr>
<tr>
<td><strong>Vava‘u</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total stem vol.</td>
<td>0.76</td>
<td>5.56</td>
<td>46.52</td>
<td>48.66</td>
<td>9.17</td>
<td>110.66 (±10.44%)</td>
</tr>
<tr>
<td>Stump vol.</td>
<td>0.15</td>
<td>0.60</td>
<td>3.35</td>
<td>2.74</td>
<td>0.42</td>
<td>7.26 (±10.45%)</td>
</tr>
<tr>
<td>Sawlog vol.</td>
<td>-</td>
<td>-</td>
<td>11.48</td>
<td>37.36</td>
<td>6.92</td>
<td>44.28 (±13.23%)</td>
</tr>
<tr>
<td>Senile vol.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>0.73</td>
<td>1.81</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total stem vol.</td>
<td>1.07</td>
<td>5.38</td>
<td>55.76</td>
<td>64.04</td>
<td>8.75</td>
<td>135.00 (±)</td>
</tr>
<tr>
<td>Stump vol.</td>
<td>0.18</td>
<td>0.58</td>
<td>4.14</td>
<td>3.54</td>
<td>0.42</td>
<td>9.01 (±)</td>
</tr>
<tr>
<td>Sawlog vol.</td>
<td>-</td>
<td>-</td>
<td>14.26</td>
<td>48.75</td>
<td>6.76</td>
<td>69.77 (±)</td>
</tr>
<tr>
<td>Senile vol.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.41</td>
<td>0.72</td>
<td>2.13</td>
</tr>
</tbody>
</table>
Table 10: The sum of total potentially recoverable wood volume and senile wood volume (m³) within all stems 10 - 15 m (old mature) and >15 m (senile/senescent) by island group for the Kingdom of Tonga. Recoverable wood volume is 32% of mill input sawlog volume. Land areas used are given in Table 2 and comprise about 75% of the coconut plantation area of Tonga.

<table>
<thead>
<tr>
<th></th>
<th>10 - 15 m</th>
<th>&gt;15 m</th>
<th>Total (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongatapu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total recoverable vol.</td>
<td>288,824</td>
<td>51,327</td>
<td>340,151</td>
</tr>
<tr>
<td>Senile recoverable vol.</td>
<td>8,409</td>
<td>5,437</td>
<td>13,846</td>
</tr>
<tr>
<td>Ha’apai</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total recoverable vol.</td>
<td>86,601</td>
<td>7,132</td>
<td>93,733</td>
</tr>
<tr>
<td>Senile recoverable vol.</td>
<td>2,507</td>
<td>753</td>
<td>3,260</td>
</tr>
<tr>
<td>Vava’u</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total recoverable vol.</td>
<td>56,715</td>
<td>10,505</td>
<td>67,220</td>
</tr>
<tr>
<td>Senile recoverable vol.</td>
<td>1,640</td>
<td>1,108</td>
<td>2,748</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total recoverable vol.</td>
<td>484,801</td>
<td>67,226</td>
<td>552,027</td>
</tr>
<tr>
<td>Senile recoverable vol.</td>
<td>14,022</td>
<td>7,160</td>
<td>21,182</td>
</tr>
</tbody>
</table>

2.2.8 Data summary

Data entry and summary of field plot-sheets was carried out at Landcare Research, Lincoln. A copy of the raw data in both hard and electronic versions will be lodged with Forestry Division, MAF, Nuku’alofa and another retained at Landcare Research, Lincoln, New Zealand.
Figure 3: A stem volume equation for coconut palms in Tonga. This equation was used to estimate stem volume for all palms measured in the sample. BA = Basal area at 1 m, Ht = total stem height.

Coconut Volume Equation

Rank 3 Eqn 34 Iny=a+blnx

$r^2=0.947607136$ DF Adj $r^2=0.945225643$ FitStdErr=0.0483902204 Fstat=813.895598

a=-0.53635382

b=0.64916858

Cylindrical volume ($\pi r^2 h$) of stem
Appendix 3: Field Manual

A description of the field methodology, measurements to be taken, personnel, timetable and equipment requirements necessary for the inventory is appended.
Field Instructions

Methods follow standard forest inventory procedures with fixed-area plots established at random locations throughout the selected survey areas. Teams of 3 people will be needed to locate and measure the plots. A team leader will record the data and ensure accuracy and 2 measurers will measure the stems.

1. Inventory area

The areas selected include all Tongatapu, 2 districts in Vava’u (Pangaimotu and Holonga), and 2 districts in Ha’apai (Lifuka and Foa). Random plot locations are marked on ‘api boundary maps and a list of ‘api starting points have been selected.

2. Number of plots

150 plot sites have been randomly selected to be measured on Tongatapu, 40 on the selected districts in Ha’apai, and 60 on the selected districts in Vava’u.

Variance in coconut density will be tested during the survey to check final plot numbers required to satisfy the accuracy requirements. 20% additional plot sites have been selected in each area to be used if target accuracy is not achieved with the lesser number of plots. Plot density will be higher in Vava’u than for Tongatapu or Ha’apai as coconut distribution and size are more variable.

3. Plot location and layout

In the field all starting points will begin as closely as possible to an origin at the eastern or western-most corner of the nominally selected ‘api on the boundary nearest to the main access track or road. Plots will be associated with a particular ‘api name but will more often than not cover parts of 2 or more adjacent ‘api.

Having found the starting point the plot origin will be located at a random distance and on a random bearing away from the track or road. From the ‘api corner select a random compass bearing within the 180 degree arc away from the nearest roadway. Random number tables are attached to each team clipboard for this purpose (Table 1). Then select a random distance in 10 m steps between 10 and 50 m from the clipboard random tables and proceed to the plot origin. Cross off the random numbers as they are used on the tables.

Note the ‘api number, bearing and distance on the first plot-sheet along with any other notes regarding plot location. When selecting the starting point corner of the ‘api, in the morning select the eastern-most corner that lies nearest to a road, and in the afternoon select the western-most corner. This is to ensure that no possible consistant bias in the plantation layout on the ground will affect the results. From the plot origin defined in the morning the plot will lie to the west, and from the afternoon corner to the east (Figure 1).

Plots should not include land on main roads or main access ways, which are surveyed out of ‘api areas, but dividing tracks along ‘api boundaries should be included. If a surveyed road is encountered, proceed across the road along the same bearing for the width of the road, and complete the plot or subplot on the other side.
4. Plot design

A plot will consist of a set of five systematically arranged 50 m x 20 m belt transects, or subplots (Figure 2). Each subplot will lie alternately to the magnetic east or west of a central axis which runs north-south.

At this point the team leader should record the heading information on the plot sheet (Table 2);

a. Island/District  
b. ‘api number  
c. team members  
d. slope  
e. date  
f. starting range and bearing.

From the located plot origin (Figure 2) lay out a 50 m tape along a compass bearing to the west (am) or east (pm). This is the first subplot centre line. Where a subplot is on sloping ground measure the slope using the clinometer and record on the plot sheet. Sweep a 10 m swath on either side of the subplot centre line and include all palms with at least half their diameter within 10 m of this centre line. Check measure to marginal stems to confirm whether the half of the base of the stem is in or out. A 20 m tape is included with the team equipment for this purpose.

After measuring all coconut stems on the first subplot, then from the finishing end of the 50 m tape, and the 1st subplot, go magnetic north or south, away from the nearest road, for 40 m using the long tape measure. This is part of the north-south central axis of the plot. Lay out another subplot centre line to the other side of the axis from the first subplot and again along an east or west bearing. A separate plot sheet will be recorded for each subplot, slope and subplot number (A, B, C, D, or E) will be unique. Initial start bearing and distance do not need to be recorded on subsequent sheets.

The 3rd, 4th and 5th subplots will each be located 40 m on along the axis and alternately east or west of the main plot axis (Figure 2). The total area included in one plot comprising a set of 5 sub-plots is 0.5 ha and the whole cluster will cover an area of 1.8 ha.

5. Plot Measurements

Within each subplot accurate measurement and recording of stem size is essential to achieve worthwhile results from the whole survey.

a. Height

Height of stems will be estimated by eye by at least 2 team members and agreed upon, recorded, and then measured using a clinometer (PM5/360) to 0.1 m. When team ability to accurately judge height has been proven (estimated heights will be tested against measured heights during the survey), height of each fifth stem only will be measured, all others will be estimated. Total height will be measured from ground level, including the buttressed base, up to the base of the crown immediately below the leaves and nuts. A lookup table for converting from the clinometer’s % of base distance to height is attached to each clip-board Table 1).

b. Diameter

Diameter measurements will be taken at a standard height of 1m above ground using a diameter tape and measured to 0.1 cm. The height above ground can be checked using the linear measure on the back of the diameter tape. If a stem is growing on a slope, measure the 1 m from the side of the stem, rather than uphill or down. Diameters must be accurately measured with the tape wrapped tightly at right-angles to the axis of the stem.
One metre has been selected because it is generally close to the top of any buttressing, it is also about the height at which felling operations have been observed to cut stumps.

Take care to avoid measuring over damaged parts of the stem caused by cut footsteps, fire, or mechanical implements. Where damage occurs at 1 m measure the diameter as close as possible above or below it. Make sure a shifted diameter is typical of the 1 m diameter, below 1 m a variable sized buttress develops, above it stem diameter tapers only gradually.

c. Form

The form or shape of the stem affects the available length of log which can be utilised. Four commonly occurring standard shapes are recognised (Figure 3), but we will record the 3 which most affect saw-wood volume. These are; erect (Straight), Bowed, and Curved. Each stem is to have the appropriate box on the plot sheet (S, B, C) ticked for each stem.

Curved stems are common and will most often occur as butt-swept stems with little production loss using current logging methods. Bent stems are bent throughout their length and would be difficult to cut a straight 4 m log from anywhere along their length.

d. Varieties

In the variety column on the plot sheet record a D for dwarf if they occur, otherwise all stems will be treated as the one variety - ‘Tonga tall’. Because of the little hybrid influence on the coconut population as a whole, variety differentiation in the field other than for dwarfs is not required.

e. Seedlings

A tally will be made of all permanently established coconut seedlings over the whole plot. Any seedling coconut with leaves taller than 2 m and a stem height of less than 1 m will be tallied on the plot sheet in 2 classes; those planted or retained as replacements by land holders, and wildlings which have self-seeded.

f. Senile and senescent palms (small leaves and few nuts)

Tall coconuts which have leaves less than 1.5 m, few or no nuts and often with a sharply narrowed stem below the leaves are considered senile or senescent. Stems in this condition should be marked with an asterisk in the first column on the plotsheet.

6. Personnel and their tasks

Team Leader:
The team leader will be responsible for all team survey equipment and the accuracy of the team's measurements. He will normally be the person who ensures that the plot is correctly located using maps and 'api lists, and will record measurements on the provided plotsheets. He will help to estimate height, form and variety. Each day he will ensure his team has their necessary equipment, maps and plot list. After each day's fieldwork he will check over his team's plot sheets for omissions making sure there are 5 subplot sheets per plot, and pass them to the supervisor or counterpart.

Measurers 1 and 2:
They will use the compass and tapes to lay out each subplot, check measure whether stems are in the plot or out, and estimate and then measure the stem heights and diameters. One will take an end of the 20 m tape to a stem, while the other will take the other end of the tape, note the base length which gives a clear view of the stem, and use the clinometer to measure the height. The first measurer will measure the stem diameter and both will call out results for the team leader to record. They will call out the stem form class and variety for each stem and a running tally of seedlings in each subplot as it is traversed.
7. Equipment

Each field team will require the following equipment on a daily basis:
- 1 clipboard
- plot-sheets
- random number tables of distances and bearings
- pens/pencils
- 1 clinometer
- 1 compass
- 1 50m linear tape
- 1 20m linear tape
- 2 diameter tapes
- local 'api map(s) with 'api numbers
- daybag
- bush knife

8. Transport

Vehicle transport will be arranged by Forestry Division. Where possible several teams should work within as small an area as possible to make vehicle shifts most efficient. Teams will often be able to walk between plots.
Figure 1: Plot layout for field survey

Surveyed road or main access.

Random distance between 10-50 m

Random bearing within 180° of road.

Morning start point

Random distance & bearing
Figure 2.

Subplot E

Subplot D

Subplot C

Subplot B

Plotted origin

Random distance between 10 - 50 m

Random bearing within 180° of road

Road or Main Access
### Random Bearing From Api Corner (degrees magnetic) vs Random Starting Distance Between 10 & 50 m ($x(h)$)

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### Tree Heights Lookup Table for use with Suunto Clinometer

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Coconut Resource Inventory 1995

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Tally of Seedling Palms < 1m: Retained: Wildlings:

Notes:
Appendix 4: Area of the main islands in Tonga

Table 11: The 20 largest islands in the Kingdom of Tonga are listed along with their approximate total land area. Areas were digitised from the Atlas of Pacific (NZ Government. Printer 1986). Their island group is listed and those surveyed in this exercise noted.

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<tr>
<td>2 Vava'u</td>
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<td>4 Tofua</td>
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* The total land area of Tonga is variously quoted as 68,800 ha (Swaney 1994), 69,671 ha (Pacific Island Yearbook 1989), 72,000 ha (FAO in MAF 1993), and 74,700 (New Zealand Government Printer 1986).
Appendix 5: Database structure of raw coconut inventory data.

The coconut inventory database consists of data for each palm stored in fields outlined below and has been archived as both delimited ASCII text files and Paradox database files. A total of 16109 coconut palms were measured in 354 plots.

Hard copies of the field data sheets and electronic copy of the database files will be held by Forestry Division, MAF, Tonga and Landcare Research NZ Ltd, Lincoln, New Zealand.

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A  alphanumeric field
N  numeric field
*  key sort field