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Evaluating the Benefits of Conserved Crop Germplasm in PNG

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Abstract

The objectives of the paper are twofold: to review valuation methods for plant genetic resources and to develop methods to estimate the past and potential future benefits, both domestic and international, of existing germplasm collections in Papua New Guinea (PNG). The analysis concentrates on PNG's more important plant subsistence food crops: banana, sweet potato, and taro together with aibika. The paper documents the movement of germplasm in the food crops both within PNG and to international collections. Curators of and breeders using PNG germplasm material are surveyed concerning the future usefulness of this material, and their responses are reported and evaluated. Benefits are valued in terms of the value of future breeding in these species.

1. Introduction

The greater commercialisation of public breeding, and the higher profile of private breeders supported by plant breeders' rights, has increasingly highlighted the value of genetic material used in plant breeding (Godden 1984, 1991). Questions have also been raised in countries maintaining existing plant germplasm collections as to the value of preserving their stocks of genetic material, and sources of future funding. Biologists have often encouraged the conservation of all or most material, arguing that it is potentially valuable (Evenson, Gollin and Santaniello 1998). However, funding constraints are making this extremely difficult, especially in countries like PNG.

An economic estimation of the benefits and the costs of conserving accessions in collections is required to determine optimal levels and sources of funding and the optimal economic organisation of germplasm collections. The costs of the collections can usually be estimated from existing and historical data. However, empirical estimations of the benefits have been fraught with difficulties, despite recent methodological developments.

In valuing PNG's crop plant germplasm collections, a stochastic dynamic programming model has been developed to determine the net benefit of maintaining existing collections held by the Department of Agriculture and Livestock (DAL) and the National Agricultural Research Institute (NARI) in PNG (Kennedy, Godden and Kambuou 1997; Godden, Kennedy and Kambuou 1997). To analyse the relative costs of maintaining PNG's existing field germplasm collections, a spreadsheet model has been created (Godden, Wicks, Kennedy and Kambuou 1998) and a solution derived for the problem of taro germplasm maintenance and breeding in PNG, given the best available current data (Kennedy *et al* 1997). Data was not available for estimating transition probabilities for the two state variables, number of accessions and crop yields. In this paper are reported initial attempts to obtain data on the benefits of germplasm collections in PNG through the elicitation of subjective probabilities.

The following discussion on improving analysis of the valuation of benefits of germplasm collections in PNG begins with a summary of the different sources of plant genetic resource values — in situ and ex situ. In section 3, methods of valuing genetic resources and collections are reviewed, along with relevant applications. A description on the movement of PNG germplasm to national and international collections and assessment of the benefits of PNG material in these collections is given in section 4. Finally, in section 5, survey results are presented on the elicitation of subjective probabilities relating to (i) the probability of maintaining existing collections (survey of curators) and (ii) potential yield gains from the maintenance of these collections (survey of breeders).

2. Values of plant genetic resources

Agriculturalists and environmentalists both seek to preserve plant genetic resources. Agriculturalists usually emphasise the potential value it may have in a breeding program and hence on farm production, and environmentalists seek to preserve genetic biodiversity of all species (Evenson *et al* 1998).

Various taxonomies have been used to explain the value of genetic resources (Table 1). Oldfield (1989) adopted a broad classification, distinguishing between direct values (consumptive use and productive use) and indirect values (non-consumptive use, option and existence). Evenson (1993) considered the ‘consumer good’ (existence) values and ‘producer good’ (use) values. Existence values were seen to be held by those who believe in the conservation of all genetic resources, for the sake of biodiversity and long-term sustainability (Evenson *et al* 1998). Utilitarians focused on use values whereby genetic resources are preserved for the benefits they provide to humans now and in the future. Evenson (1996a) also defined six biodiversity values but did not explicitly categorise them into types of values, instead discussing them in terms of value to different interest groups.

Swanson, Pearce and Cervigni (1994) divided values into non-use and use values of plant genetic resources and defined the following *use* values:

- *exploration value* for yield enhancement - the direct contribution to the value of products produced with plant genetic resources in the plant breeding industry for the purpose of enhancing yields of existing agricultural crops;
- *exploration value* for reduced variability - maintenance of a pool that may be explored for the ascertainment of traits that might contribute to the future stability of agricultural production);
- *portfolio or insurance value* - the value of avoiding output variability and providing for future sustainability through more stable systems of the diversity of plant genetic resources in current agricultural usage (across countries and across time); and
- *quasi-option value* - the value of maintaining potentially valuable traits in the event of environmental shifts. For example, if new bio-types of pests and pathogens are introduced, genetic resources not currently valued may increase in value (Evenson 1996a).

For the purposes of estimation, benefits of plant germplasm resources and collections are most commonly defined in terms of potential yield increases resulting from breeding programs i.e. the exploration value for yield enhancement. The following section focuses on the different approaches available in determining the genetic resource contributions to yield increases.

3. Valuation methods of genetic resource contributions to yield increases

Evenson (1996a), Evenson *et al* (1998) and Pearce and Cervigni (1994) classified the approaches to valuing plant genetic resources (Table 2), for which Pearce and Cervigni (1994) provided a comprehensive summary of the usefulness of these approaches. To date there is no broadly accepted terminology in the classification of genetic resource valuation methods. ‘Direct’ and ‘indirect’ methods are used to describe both major categories (Pearce and Cervigni 1994) and sub-categories (Evenson 1996a; Norris and Kramer 1990) of valuation techniques.

Table 1: Sources of genetic resource values

Oldfield (1989)	**Indirect Values**			**Direct Values**	
	Existence values	Option values	Non consumptive use value (environmental services)	Consumptive use (recreational)	Productive use (commercially harvested)

Evenson (1993)	**Consumer good (existence value)**	**Producer good (use value)**

Evenson (1996a)	**Conservationists, biologists**			**Agriculturalists**	**Bio-prospectors**
	Psychic green	Option value		Bio-support for agriculture Crop improvement Animal improvement	Bio-prospecting for pharmaceuticals and chemicals

Evenson *et al* (1998)	**Non-use existence values**	**Use Values**			
		Direct use		**Indirect use**	
		breeding	recreation	option	diversity

Swanson *et al* (1994)	**Non-use Values**	**Use Values**
	Intrinsic	Yield exploration Stability exploration Portfolio Quasi-option

Brown (1990)		Future non-consumptive use value	Direct productive value	Indirect productive value

Evenson (1996a) considered three methods for measuring the value of plant genetic resources: subjective, subjective probability and objective. Pearce and Cervigni (1994) based their categorisation on the attempt to capture non-use values and use values, mentioned in the previous section. Hence, Pearce and Cervigni (1994) did not include subjective probability methods, usually used to estimate a probability distribution rather than a point estimate.

3.1 Objective methods

Objective methods have been used in analysing the relationship between production characteristics, genetic resource collections and breeding activities (Evenson 1996a). Adopting Evenson's (1996a) classification system, objective methods can be broadly classified as either direct or indirect.

Indirect objective methods are considered indirect because they do not create a direct link between the size and evaluation state of plant genetic resource collections (Evenson 1996a). Preferences for the environmental good are revealed indirectly through the purchase of related marketed goods. Techniques are used for measuring the producer good value of genetic resources, requiring statistical regression to relate the measure of varietal improvement to factors expected to cause or produce varietal improvement (Evenson 1998).

Pearce and Cervigni (1994) separated indirect methods into hedonic pricing and household production functions. However, there is some confusion over the definition of 'production function'. Pearce and Cervigni (1994) grouped household production functions and hedonic pricing methods under production function approaches. Evenson (1996a) referred to a 'breeding production function' (Gollin and Evenson 1997), which does not appear to be a standard production function based on inputs such as labour and capital. The number of released varieties was explained in terms of the contribution of germplasm collection and international and national breeding activities to the flow of germplasm material. 'Activities' referred to the number of contributed landraces to released varieties. Evenson (1996a) then went on to classify the breeding production function as a direct objective method but later reclassified it as an hedonic approach (indirect method) (Evenson *et al* 1998).

3.1.1 Indirect objective methods - Production functions

The value of genetic resources has been measured indirectly through returns to research (e.g Azzam *et al* 1997). Based on the statistical association between the area planted to new varieties and productivity, returns to research literature has tended to value quantitative traits rather than qualitative traits. The number of breeding processes carried out before the new variety is released are not usually accounted for (Evenson 1996a). The total contribution of gene banks and plant breeding programs (in terms of public expenditures) to agricultural output has been well covered in the literature (e.g. Smale *et al* 1997). These studies do not attempt to isolate the factors of production involved in plant breeding.

To capture the specific contribution made by genetic resources to plant breeding and yield improvement, a number of studies have disaggregated the different components of advancements responsible for yield gains (Godden 1988; Godden and Brennan 1994; Gollin and Evenson 1998). The economic benefit of the new varieties is expressed as the product of the portion attributable

Table 2: Classifications of valuation methods for genetic resources

Evenson (1996a)	**Objective**				**Subjective**	**Subjective probability**
	Indirect		Direct		Contingent valuation	
	Hedonic specification	Returns to research	Breeding production function	Rent calculations		
	Qualitative and quantitative trait valuation	Quantitative trait valuation	eg Gollin and Evenson (1996)			

Evenson (1998)	**Hedonic approaches**			**Contingent valuation**		
	Hedonic pricing	Mapping genetic flows eg Gollin and Evenson (1997)		Willingness to pay	Willingness to pay for on-farm diversity	

Pearce and Cervigni (1994)	**Indirect**			**Direct**		
	Hedonics	Household production functions		Contingent valuation	Experimental	

Norris and Kramer (1990)				*Direct*	*Indirect*

to the introduction of new varieties and an appropriate shadow price (Pearce and Cervigni 1994). The value of the stages of the breeding process, and the value of the inputs involved in that process, are not disaggregated.

Pearce and Cervigni (1994) designed an analytical framework to estimate the value of plant genetic material (in terms of yield gains) in the breeding process. The production function included technical progress coefficients to capture the growth of breeding knowledge emobodied in labour and capital, a 'seed used' variable (i.e. variety or cultivar),[1] and a random variable representing climate, pests and other environments. Yields varied over time and space where time-increasing yields were assumed to result from either more efficient use of inputs or from changes in the variety variable. The variety variable was treated as the result of a production process that combined genetic material, labour and capital into improved varieties.

Given the lack of a producer market for genetic resources, Pearce and Cervigni (1994) suggested approximating the net value of genetic material by calculating the difference between the sum of discounted benefits of a given variety and the sum of discounted cost all other factors employed in breeding process. The cost of these factors included an appropriate rate of return on investment in human and financial capital.[2]

The complete genealogy of the released variety is usually very complex (Pearce and Cervigni 1994; Evenson 1996a). In order to estimate the value of the genetic resource, all the genetic steps which led to developing the released variety would need to be measured in terms of yield value added and cost of the particular cross. That is, costs and benefits at each stage of the breeding process —collection, evaluation, pre-breeding, and breeding— would need to be measured. Given the detailed information on actual breeding activities required, this type of analysis would be very data intensive and require an extensive database, such as the wheat database at CIMMYT.

Godden and Kambuou (1996) defined the value of germplasm collections as dependent on the future incorporation of the genetic material into commercial varieties via plant breeding. Hence, the future impact of plant genetic conservation on economic welfare was modelled to relate the effect of the conservation program to breeding benefits. Godden and Kambuou (1996) considered the size of a germplasm collection and the effectiveness of the germplasm conservation program in delivering benefits to practical plant breeding as major determinants of the impact on progress in plant breeding. The degree to which plant breeding may be benefited by germplasm conservation was seen to depend on the particular plant kind and the ease of breeding in that plant kind, the degree to which the genepool has been explored, the level of previous breeding effort (and therefore closeness to a theoretical "maximum" yield), the level of the current breeding effort, whether the plant kind is destined for subsistence or commercial agriculture, pressure of scourges and thus need for maintenance.

[1] Pearce and Cervigni (1994) used the term 'seed' to refer to an assemblage of genes ie variety. A seed refers to reproductive planting material.
[2] Pearce and Cervigni (1994) referred to financial capital and physical capital interchangeably.

3.1.2 Indirect objective method - Hedonic pricing

Traits contribute to the value of the variety through increasing yields or enabling higher yielding varieties to be planted in previously unsuitable environments (Evenson 1996b). Hedonic methods have been used to infer the value of individual traits or characteristics of a variety (Evenson 1996b, 1998; Gollin and Evenson 1990, 1998; Rao and Evenson 1998; Godden and Kambuou 1996; Smale *et al* 1997).

Godden *et al* (1996) depicted the value of a variety as the weighted value of that variety's characteristics. For example, if T traits t_i are economically valued where t_{ij} is the expression of trait i in variety j, and the marginal value of trait i is a_i—where a_i may be a function of variables such as the price of final product—then the value of a particular variety j may be defined as V_j:

$$V_j = \Sigma_i a_i.t_{ij}$$

The degree of improvement of some new variety k over existing variety j can be defined by the difference in value between varieties j and k:

$$V_k - V_j = \Sigma_i (a_i.t_{ik} - a_i.t_{ij}) = \Sigma_i a_i. (t_{ik} - t_{ij})$$

Evenson (1996b) measured the economic value of a rice variety explicitly by location. The hedonic specification included trait content indexes for each variety and a vector of economic as well as ecological conditions that influenced economic value and trait adoption.

3.1.3 Empirical studies using objective methods

Empirical work on the valuation of genetic resources and collections has focused on commercial crops, such as rice, wheat and maize, where detailed data sets are available (Godden and Brennan 1994; Evenson 1993, 1996b, 1998). Gollin and Evenson (1990) argued that the size of the germplasm collection influenced the amount of rare traits incorporated in modern rice varieties in India. They also reported that the use of landraces from international and national collections in rice varieties had a positive impact on rice yields.

A less data intensive approach was used by Evenson and Gollin (1997) to estimate the relationship between the stock of germplasm in international collections and the international flow of released plant varieties of rice. They attempted to estimate the value of an international rice germplasm collection in terms of its contribution to improvement and productivity growth of rice. Varietal releases were categorised by the pathway from origin to release. Varietal releases were found to be significantly related to the previous size of International Rice Research Institute (IRRI’s) landrace pool and the International Rice Germplasm Collection’s number of accessions. Tracking IRRI’s germplasm material was made possible by the availability of data from IRRI on the genetic makeup and movement of rice varieties. No official records exist on the movement of PNG material to other collections and their incorporation into new varieties. Documentation of the movement of germplasm has been the initial step in the valuing the benefits of PNG’s germplasm collections (Section 4).

Gollin, Smale and Skovmand (1998) developed a search model for traits of economic importance in ex situ collections of wheat genetic resources. They concluded that the underutilisation of wheat germplasm collections was related to the costs and time lags in the breeding process and did not imply that accessions had no value. Green (1997) discussed the potential value of the United Kingdom's statutory seed collections from a genetic resource perspective, in terms of the information provided on the varieties. No quantitative analysis was undertaken.

Attempts have been made to value rare and pharmaceutical plants. Phillips and Meilleur (1998) undertook a statistical survey on the usefulness and economic potential of rare plants in the USA. They identified commercial relatives of endangered species and considered the likelihood of wild germplasm being incorporated into crops. Mendelsohn and Balick (1995) estimated private and social values for undiscovered pharmaceuticals in tropical forests. A complete collection and screening of all tropical plant species was valued at US$3 to $4 billion to a private pharmaceutical company and around US$147 billion to society.

Limited research has been performed on the value of subsistence crop germplasm to farmers' yields. Literature on yield gains of subsistence crops has tended to focus on research station trial outcomes in terms of changes in levels of inputs. Yield improvement literature on bananas has focused on disease resistance and nematodes, breeding programs and strategies, pest and disease control, in vitro strategies, technological transfer and post harvest handling. Sweet potato researchers have assessed the impact of inputs on yield levels, such as levels of fertilisers and pesticides while taro research has concentrated on breeding programs for disease tolerance, agronomic issues and field trials.

Farm yield and production figures for subsistence crops are scarce, especially in developing countries. FAO provides PNG statistics on total production, area harvested and yields for banana, sweet potato and taro. However, there are no national production, area or yield figures regarding the different varieties of these species, restricting the use of objective methods.

3.2 Subjective methods

Subjective methods (which Pearce and Cervigni (1994) defined as direct approaches) are used to elicit preferences directly through survey and experimental techniques, such as contingent valuation methods. However, the complexities of the breeding processes have limited the effective application of subjective methods for valuing agricultural biodiversity (Evenson 1996a). Evenson *et al* (1998) suggested that contingent valuation is more suited to valuing 'consumer goods' than plant genetic resources which are usually classified as 'producer goods'. The average consumer would have little knowledge about germplasm collections, and hence would find it difficult to assign a value.

3.3 Subjective probability methods

While many studies have successfully documented the value of particular germplasm *ex post* and even estimated its value *ex post*, few have been able to determine this value *ex ante* (Godden and Kambuou 1996). The focus of the present study is to assess the value of PNG's germplasm collections and to estimate the *potential* benefits of conserving this material. Godden *et al* (1998) identified the need for probabilities in estimating the maintenance expenditure for the collections and deriving improved varieties from these collections.

The management of plant germplasm collections is an economic decision problem. For decision making the only valid probability approach is the subjective one where decision makers bear responsibility for their decisions and use their own strengths of conviction (Dillon 1971). Plant breeding is an uncertain process, and hence the value of germplasm in terms of future plant varieties that could be developed from it is similarly uncertain (Godden *et al* 1997). Subjective probabilities are beliefs held by individuals that reflect their degree of uncertainty about some idea or event (Bessler 1984). Compared to objective frequencies, subjective probabilities allow for incorporation of intuitive knowledge and recognition that the future may not be like the past (Dillon 1971). They are not restricted to situations where a series of observations are available and are appropriate to depict events that only occur once or have never occurred (Norris and Kramer 1990).

3.3.1 Constraints

Two conditions need to be met when eliciting subjective probabilities: coherence and compatibility (Norris and Kramer 1990).

1. Subjective probabilities should be coherent with the probability calculus whereby:
- The probability of a given event is between 0 and 1 inclusive;
- The sum of all probabilities of all possible mutually exclusive events equals 1; and
- If 2 events are mutually exclusive, then the probability that at least one of the events will occur is the sum of the individual probabilities.

2. Subjective probabilities should correspond with the assessor's judgement where all probabilities are consistent with all other beliefs held by the individual.

In regard to the second point, it is impossible to know whether the subjective probabilities truly reflect the respondent's judgement, especially if the decision makers have stakes in certain events (Karni and Safra 1995). Sources of bias can be classified as motivational or cognitive (Norris and Kramer 1990):

Motivational – conscious or subconscious adjusted responses according to perceived system of personal rewards/penalties for responses.[3]

Cognitive – relates to the way humans process information:
- *Representativeness* – where the likelihood of an event is evaluated according to its similarity to a larger population of events of which it is presumed to be an example (Norris and Kramer, 1990);
- *Availability or time/memory related* - more recent events may be seen to be more frequent than events from less recent events;
- *Anchoring and adjustment* - where different starting points yield different estimates;
- *Misconception of chance* – observation of an unexpectedly high number of chance outcomes creates a belief that the likelihood of an event not recently occurring is greater than it actually is; and
- *Psychic bias* - having a preference for some probabilities over another.

[3] To avoid this bias, scoring rules have been used where assessors maximise their expected scores if their stated beliefs are equal to their true beliefs (Norris and Kramer 1990).

3.3.2 Techniques for eliciting subjective probabilities

A subjective probability can be used to estimate either a point estimation (likelihood of a single event) or a probability distribution (whole range of possible outcomes). Norris and Kramer (1990) divided elicitation methods into direct and indirect methods.

Direct methods for eliciting subjective probabilities include questioning of respondents on the likelihood of an outcome to which they respond numerically. The responses can be represented graphically as a probability density function (PDF) or cumulative density function (CDF). In creating a PDF, probabilities are assigned to either a series of specific values to reflect their perceived likelihood of occurrence or to intervals. With intervals, the assessor estimates for each interval the probability that the true value or outcome lies within the interval. CDFs are made up of successive subdivisions. Assessors divide an interval into fractiles such that an event is equally likely to occur in any sub-interval. In the field, respondents have preferred the PDF method over the CDF method (Norris and Kramer 1990). In comparison, Hardaker *et al* (1997) recommends the use of CDFs, suggesting difficulties in ensuring the area under the PDF curve was equal to one. However, this could be overcome by the use of the counter method that provides respondents with counters adding up to one or 100%.

Indirect methods refer to probabilities inferred from preferences or choices between possible bets, decisions or alternatives (Norris and Kramer, 1990). Indirect methods are useful when the resulting probabilities are not clear to the assessor (Winkler 1967 in Norris and Kramer 1990). Methods used in agricultural economic studies include:

- *gamble method* - betting odds until assessor is indifferent between two offered bets;
- *weighting method* - assign weights to outcomes;
- *ranking method* - division of outcomes into intervals and ranking the intervals in terms of likelihood of occurring; and
- *visual counter methods* - use of visual tools such as counters to assign to the likelihood of a given outcome. The probability is the ratio of counters assigned to the interval to the total available.

There does not appear to be a superior technique. However, Norris and Kramer (1990) suggested that techniques could be evaluated according to their accuracy, reliability, acceptability and effectiveness. Accuracy is difficult to measure when the subjective probability is elicited for unique or rare events for which there are no objective probabilities. However reliability can be measured by checking for the same response at different times of questioning, with different techniques. Acceptability refers to the assessor's attitudes towards techniques (eg ease of using methods, confidence in their estimates, length of time required to make estimates). Finally, the effectiveness is a measure of predictive ability.

3.3.3 Empirical studies using subjective probabilities

Norris and Kramer (1990) provided a comprehensive summary of applications in agricultural economics of the elicitation of subjective probabilities. Of interest are a number of studies on eliciting subjective probabilities from farmers on potential yields of their crops. The visual counter method was well accepted by the assessors and considered to improve the predictive power of decision models.

There are few cases of subjective probability methods being used in valuing genetic resources. Evenson (1996b) adopted subjective probability estimates as a component of his priority-setting methods for rice biotechnology research and more broadly for rice research (Evenson, Dey and Hossain 1996). In determining the value of benefits from a rice biotechnology research program, Evenson (1996b) estimated the 'time to achievement' component through the elicitation of subjective probabilities and adopted hedonic trait valuation studies and existing data to estimate the 'units affected' and the 'benefits per unit affected'. The 'time to achievement' subjective probabilities were obtained from two estimates: length of time for a 25% probability of achievement (optimistic estimate) and 75% probability of achievement (conservative estimate). Evenson stressed the need for subjective probabilities to be elicited from scientists whom he claimed would have the necessary technical skills and objectivity.

In Evenson *et al* (1996), 'time to achievement weights' as well as the 'benefits per unit' were estimated by subjective probabilities. To obtain the benefits per unit, ratings of the current and potential research contribution of research techniques in research priority areas were elicited from scientists. Assuming funding remained unchanged, the group was then asked to estimate the number of years it would take to achieve 25% (optimistic estimate) and 75% (conservative estimate) of the difference between achievement to date and potential of research techniques in research priority areas.

Kennedy *et al* (1997) used a simple breakeven analysis in the case of the PNG taro collection. Lack of data prevented an empirical analysis, therefore best estimates were used to estimate the probability distributions. Results showed that even if the probability of future yield gains from retaining collections was low, quite small yield increases were sufficient to make retention of the collections economic. Stochastic dynamic programming analysis confirmed that retention of collections was likely to be economic in the case of taro.

3.3.4 Techniques in current study

The principal future need is for good information on the likely future benefits of maintaining germplasm collections. The current study attempts to elicit subjective probabilities for yields and collection size in order to carry out a complete empirical analysis for the value of germplasm collections in PNG.

An indirect approach was adopted to elicit PDFs for predetermined intervals. In the case of PNG respondents, both the visual counter and the gamble method were attempted, with most preferring the visual counter technique. For breeders familiar with probability distributions, a direct approach was preferable.

4. Valuing the benefits of PNG germplasm material

As a preliminary step to determine both domestic and international benefits of PNG's germplasm collections, an attempt was made to track the movement of germplasm originating from PNG. Most of the information was obtained through direct correspondence and a questionnaire sent to likely international holders of PNG material (see Appendix A). Where possible, estimates were obtained of existing yield advances achieved by the use of PNG material in breeding programs and the potential importance of PNG material in current breeding. Given that only three respondents were successful in including PNG germplasm material in breeding programs, a second survey was carried out on the potential value of all material in germplasm collections of the relevant crops (see Appendix B). A subjective probabilities approach was adopted and for respondents in PNG a visual counter method was used.

4.1 Documentation of the movement of PNG germplasm

Tracking the movement of PNG germplasm to international collections provided a sample of breeders and curators of taro, banana and sweet potato. Geographical coverage was wide and the number of PNG accessions in individual collections ranged from 1 to 274. The material had been obtained either directly from the PNG collection, collection missions, international genebanks or from other researchers.

4.1.1 Taro

In PNG, taro germplasm is currently held at Bubia Agricultural Research Centre, Lae; Lowlands Agricultural Experiment Station, Keravat; Highlands Agricultural Experimental Station, Aiyura; Laloki Agricultural Research Station, Port Moresby; and Unitech, Lae (Kambuou 1995). The National collection at Bubia held 310 accessions in 1998.

Figure 1 illustrates the movement of taro material to Bubia Agricultural Research Centre from around PNG. A majority of the accessions were collected from Morobe, East New Britain and central provinces (Kalabus 1998). The working collection at Bubia Agricultural Research Centre also contains introduced varieties from the Pacific, Indonesia, Thailand. Figure 2 displays the transfer of overseas material to the Bubia working collection.

Figure 3 captures the movement of germplasm from PNG collections to international collections. The arrows indicate the direction of the transfer. So far, first and second round transfers have been documented i.e. material that has moved from the place of origin to a collection (first round) and transferred onwards (second round). The second row consists of first round recipients while the third row contains second round transfer recipients. The boxes contain information on the recipient and institution holding the material. Where information is available, the collector, number collected and date of the collection mission is given in the parentheses and the number of accessions held in a particular year is presented in square brackets. For example, [7:1986] is interpreted as ‘seven accessions of PNG taro were held in 1986 at the given institution’.

Taro germplasm originating from PNG has been collected and held in various collections in the Asia-Pacific region. No records of PNG taro germplasm in CGIAR genebanks have been located, although the International Institute for Tropical Agriculture (IITA) holds 100 land races and 60 old cultivars of taro (CGIAR 1998). The movement of PNG taro germplasm around the Pacific has been restricted by the outbreak of taro leaf blight. In Palau, fines were incurred for bringing in tissue cultured material from Fiji (Bishop 1998 pers. comm.).

The earliest known taro collection mission to PNG was undertaken by Professor Douglas Yen. The material from this collection mission has been distributed widely (see Figure 3). Several collection missions to PNG have been carried out by Japanese researchers but the material has not been used in breeding programs. The survival rate of the PNG material is unknown but it is assumed to be low given the difficulties in maintaining some tropical varieties in a temperate climate (Matthews 1998 pers. comm.).

4.1.2 Musa (banana and relatives)

The PNG national musa germplasm collection is currently held at Laloki Agricultural Research Station, Port Moresby (298 accessions in 1999) and duplicated at the Lowlands Agricultural Experiment Station, Keravat.

Musa germplasm material originating in PNG has been officially collected by international research and breeding programs since the 1960s, either directly from the research stations or from independent field work. The latest collection mission was carried out by PNG DAL, the International Plant Genetic Resources Institute (IPGRI) and the Queensland Department of Primary Industries (QDPI) in 1988-89.

Figure 4 captures the movement of musa germplasm from the PNG collections to international collections. The recipients of musa germplasm from PNG are divided into virus indexing centres (VICs), research institutes, breeding programs and in vitro genebanks. Where information is available, the name of the collector, number of accessions collected and date of the collection missions are given. For the research institutions, the nature of the research is also documented. Square brackets indicate the total amount of PNG germplasm accessions held in a particular year in a collection. The parentheses contain the number of accessions transferred between institutions. These are either displayed inside the boxes or by the arrows joining the donor and recipient boxes.

4.1.3 Sweet potato

In PNG, sweet potato germplasm is currently held at the Highlands Agricultural Experimental Station (HAES), Aiyura (1158 accessions) and the Lowlands Agricultural Experiment Station (LAES), Keravat (1062 accessions). Under the Secretariat for the Pacific Commission (SPC) and Pacific Regional Agricultural Program (PRAP), PNG sweet potato varieties are being evaluated, indexed and tissue cultured at LAES, Keravat. Around 77 PNG varieties have been sent to Samoa and Fiji. The collection at LAES also contains 73 accessions from overseas but many are not suited to conditions in PNG (see Figure 5).

Figure 6 describes the movement of sweet potato germplasm from the PNG collections to international collections. Given the substantial number of Japanese germplasm collection missions to PNG, the Japanese collections are documented separately in Figure 7. Where information is available, the collector, number of accessions collected and the date of the collection missions are given. Figure 6 reads the same as Figure 4.

The number of accessions donated by the International Potato Center (CIP) are given in parentheses. Second round recipients have not yet been contacted directly. It is possible that they hold PNG material from other sources, hence the total number of PNG accessions in their collections may be greater.

In Japan, the PNG material has been characterised and used as breeding materials in breeding programs. However, to date, no lines have been used in varieties released to farmers for cultivation. In Figure 7, the circles contain information on the collection missions and the boxes contain information on the institutions holding the material. The collection mission ‘circles’ state the mission leader, number of accessions collected, and year(s) of the missions. The numbers in the parentheses above the arrows give the number of accessions donated to the given institution. The square brackets inside the boxes contain the number of accessions in the given year.

4.2 Survey one

Valuation of PNG material in international collections commenced with questionnaires sent to known[4] and likely holders of PNG taro, sweet potato and musa germplasm. Out of the 25 respondents, 13 had taro collections, 11 had banana germplasm material, and 1 had sweet potato material. Of the 25 respondents 14 believed that they had no PNG germplasm material. Four recipients were unaware that they actually held material originating in PNG.

The constraints to obtaining PNG germplasm were varied. However, the lack of knowledge about the material and access to it were the most common responses (Table 3).

Table 3: Constraints in using PNG material

Constraints	Musa respondents	Sweet potato respondents	Taro respondents
Knowledge about material	2	1	3
Access	3	1	1
Phyto sanitary issues	1		2
Quality	2		
Low banana production	1		
Lack of funding	1		
No interest in material			1
Expense			1

Most of the recipients of PNG germplasm material were not using it in breeding programs. Only three respondents had breeding lines containing PNG material, all of whom were musa breeders (Table 4).

Table 4: International breeding lines containing PNG musa germplasm

Institution	Number of PNG varieties	% yield increase from new varieties containing PNG material	No. of varieties distributed to farmers
International	1	10-15	0
National 1	80	>15	6
National 2	94	5-10	0

4.3 Survey two

To gain quantitative data on the potential benefits of germplasm collections, a second questionnaire was designed to elicit subjective probabilities relating to potential yield and size of collections. It was assumed that 'yield' was the only desirable trait in crops. Respondents included both international and national curators and breeders of either musa, sweet potato or taro germplasm. Respondents were not required to have PNG material. Given the difficulty in making such estimates about future varieties (ie those not yet in the farmers' field), it was considered unreasonable to attempt to obtain estimates from

[4] International genebanks provided data on the request and transfer of PNG material from their international collections.

farmers. From 70 questionnaires, 27 completed surveys were received. A breakdown by location and type of collection is given in Table 5.

Table 5: Survey respondents

	International		PNG	
Collections	Curator	Breeder	Curator	Breeder
Taro (field)	4	1	4	1
Taro (tissue culture)	2			
Musa (field)	2	1	1	
Sweet potato (field)	2	3	2	1
Sweet potato (tissue culture)			1	
Aibika (field)			2	

To reduce bias, estimates of subjective probability distributions, rather than point estimates, were collected from a number of respondents (Evenson, *et al* 1996). In many studies of this nature, considerable time is spent in explaining and training respondents in the concept of subjective probabilities. In the present study, the international curators and breeders were situated worldwide, necessitating a written questionnaire, distributed by email, fax and mail. The questionnaire contained brief explanatory notes on the concepts of probability. Unfortunately, a number of respondents identified only the most likely outcome for maintaining the collection rather than providing a probability distribution. In PNG, the elicitation of subjective probabilities from curators and breeders was carried out face-to-face, using the visual counter technique. The latter method proved much more successful in obtaining complete probability distributions than the written survey.

4.3.1 Curator survey

The size of the respondents' collections ranged from 20 to 1200 accessions. The accessions were maintained for the purposes of biodiversity, breeding programs, research and multiplication.

Curators were asked about the likelihood of maintaining their current collections at different levels of expenditure over the next 10 years. As expected, most respondents suggested that with reduced expenditure, the probability of maintaining the collections decreased. Three respondents did not believe that they could maintain the current number of accessions in the collection without loss, even at current levels of expenditure.

Curators were then asked to consider relating different levels of expenditure to the likelihood of maintaining collections of varying sizes. In many instances, only the most likely occurrence was identified rather than a probability distribution. On average, it was considered more likely that a reduction in expenditure would lead to a proportional reduction in the size of the collection (see Figure 8). However, three respondents thought that it was more likely that a 25% reduction in expenditure would lead to an even greater reduction in the size of the collection (25-50% rather than a 1-25% loss of material). The latter cases were all field collections. In contrast, with a 50% reduction in expenditure, 5 respondents still believed that they could maintain their collections with minimal losses (1-25% reduction in material).

Respondents were asked about the types of activities and resources that would be affected if expenditure was reduced. Losses in the quantity of labour and deferring of capital items ranked the highest. Other affected activities included research, maintenance, multiplication and isolation of field material. Reduction in the quantities of insecticides, herbicides, fertilisers and hand tools were mentioned under ‘other resources’.

In terms of the most valuable characteristics of accessions, ‘pest and disease resistance’ rated the highest followed by ‘potential yield and ‘drought resistance’. Other characteristics of importance included palatability, cold tolerance and root quality traits. Given the outbreak of the taro leaf blight in the Pacific, and the prevalence of banana and sweet potato diseases, the response was as expected.

In considering the accessions that have been or are likely to be requested by a breeding program, curators were asked to think about dividing up their germplasm collection into sub-collections where the first sub-collection S1 comprised the first 25% of the accessions they would discard i.e. those least likely to contribute to increasing yield; sub-collection S2 comprised the next 25% of accessions they would discard; sub-collection S3 comprised the “second-best” 25% of accessions; and sub-collection S4 comprised the best 25% of accessions. Four respondents believed that material from all four sub-collections had been requested while five respondents felt that only the top 25% (S4) accessions had been distributed. In terms of likely requests, those respondents who believed that only their best material has been requested in the past, were more optimistic that less valued material (S2, S3 and S4) would be requested in the future.

4.3.2 Breeder survey

The number of accessions in breeding collections ranged from 40 to 500 and material came from diverse sources. Three collections contained over 80% of internationally obtained material, two collections had over 70% from national collections, and three breeders had collected over 80% of their material on collection missions.

For a majority of breeders, yield potential characteristics were the most important traits followed by quality and pest and disease resistance. Quality of material was also given the highest ranking by three respondents. While ‘pest and disease resistance’ ranked very highly by curators, it was not given a top ranking by any of the breeders.

Similarly to the curator questionnaire, breeders were asked to imagine dividing up their own germplasm working collection into sub-collections. Respondents were then asked to assess the likelihood of achieving a range of yield gains on research stations and farms in the next 10 years, with an ever decreasing size in their working collection (where S1, the worst accessions, would be discarded first). The responses were not uniform. Four respondents thought that a reduction in the size of their collections would reduce the chances of yield gains, while two breeders believed that discarding less valuable material increased their chances of achieving yield gains. It was expected by 85% of the respondents that yield gains would remain the same or increase, under any change in the size of the working collection. One respondent believed that they could achieve maximum yield gains irrespective of the size of the collection. In comparing research and farm outcomes, the shape of the distributions remained the same but at lower yield gains for on farm.

A similar set of questions was asked in regard to potential yields and a reduction in the size of the national germplasm collection. For most breeders, the most likely outcome was for yields to remain the same at most sizes of the collection, particularly for the whole collection. Four respondents believed that once the collection was reduced to the top 25% accessions, the yield gains would most likely be over 10%. In contrast, one breeder expected that yields would decrease with any reduction in the size of the national collection. Compared to the working collection outcomes, the changes in the size of the national collection increased the likelihood of reduced yield gains.

Breeders were then asked to consider the effect on potential yields if the national collection was lost and accessions were only obtained from international collections. Similar to the questions on their working and national collections, breeders were asked to state the probability of achieving a range of yield gains against a decrease in the size of the international collection. Again the results were varied. An increasing number of respondents believed that yields would be more likely to decrease with a reduction in the size of international collections, especially on farms. However, for some respondents, the smaller the collection, the increased likelihood of achieving above 10% yield gains.

In comparing the requests for material in the past with the likelihood of requests in the future, most respondents said the number of expected requests would either be about the same or more. On average, the chances of achieving 10% yield gains from random accessions requested from other collections doubled when the number of accessions increased from 100 to 200. With 50 accessions, the possibility of increased yields ranged between 0 and 30%.

Finally, respondents were asked to indicate the probability of increasing yields by 10% at three levels of expenditure (see Table 6). Most breeders believed that at ever decreasing levels of expenditure the chances of increased yields would fall. Three breeders believed that with an expenditure cut to 80% of the current level, there would be no likelihood of achieving a 10% yield gain. One breeder believed it was just as likely to achieve a 10% yield gain at the three levels of expenditure.

Table 6: Subjective probability in achieving a 10% yield gain

Respondents	20% increase in current expenditure	Current expenditure	20% decrease in current expenditure
1	45	35	20
2	36	35	29
3	46	27	27
4	74	26	0
5	50	50	0
6	100	0	0
7	33.3	33.3	33.3

4.3.3 Some individual responses

From the seven completed breeder surveys, only three provided complete probability distributions. Despite the small sample size, the distributions are graphed and some preliminary comments made. The three distributions are different for the working collection and national responses but for the impact of the availability of accessions from the international collection, the distributions are similar (see Figure 9 and 10). The most likely impact on breeders' yield gains, for all sizes of the international collection, is clearly for yields to remain the same.

Breeders provided information on the their origin of their material. It was expected that if a high proportion of material had come from a national or international collection then by reducing the number of accessions in that collection, potential yield gains from the breeders working collection would consequently fall. This was not evident from any of the three responses.

5. Conclusion

This paper is part of a larger project evaluating the maintenance of crop plant germplasm collections in PNG: aibika, banana, sweet potato and taro. The research reported in this paper focused on obtaining data for use in a dynamic programming model of the benefits of maintaining crop plant germplasm collections. Curators of germplasm collections were surveyed concerning the probability of maintaining collections at different levels of funding. Plant breeders were surveyed regarding expected future yield increases arising from different sizes of germplasm collections. Because of the global spread of collections and curators, written questionnaires were relied on to obtain information.

The use of the visual counter method for PNG respondents proved to be a successful technique in eliciting subjective probability data. To obtain complete probability distributions for input into the dynamic programming model, a greater sample of complete responses is still required, especially from international breeders and curators. Ways of obtaining this information while still relying on written questionnaires are currently being explored.

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Figure 1: Movement of PNG taro germplasm to the National Germplasm Collection Bubia ARC, 1985-1995

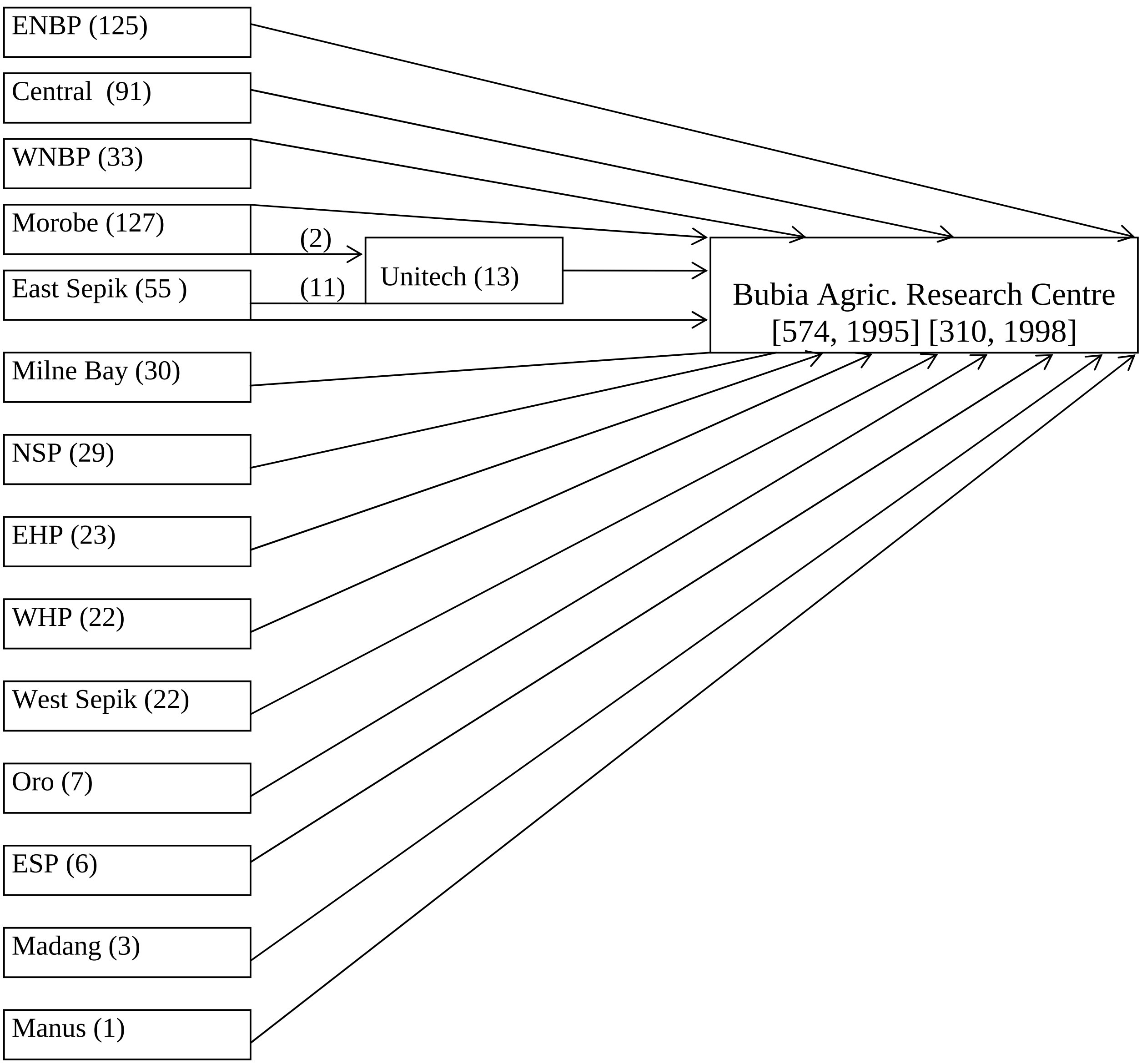
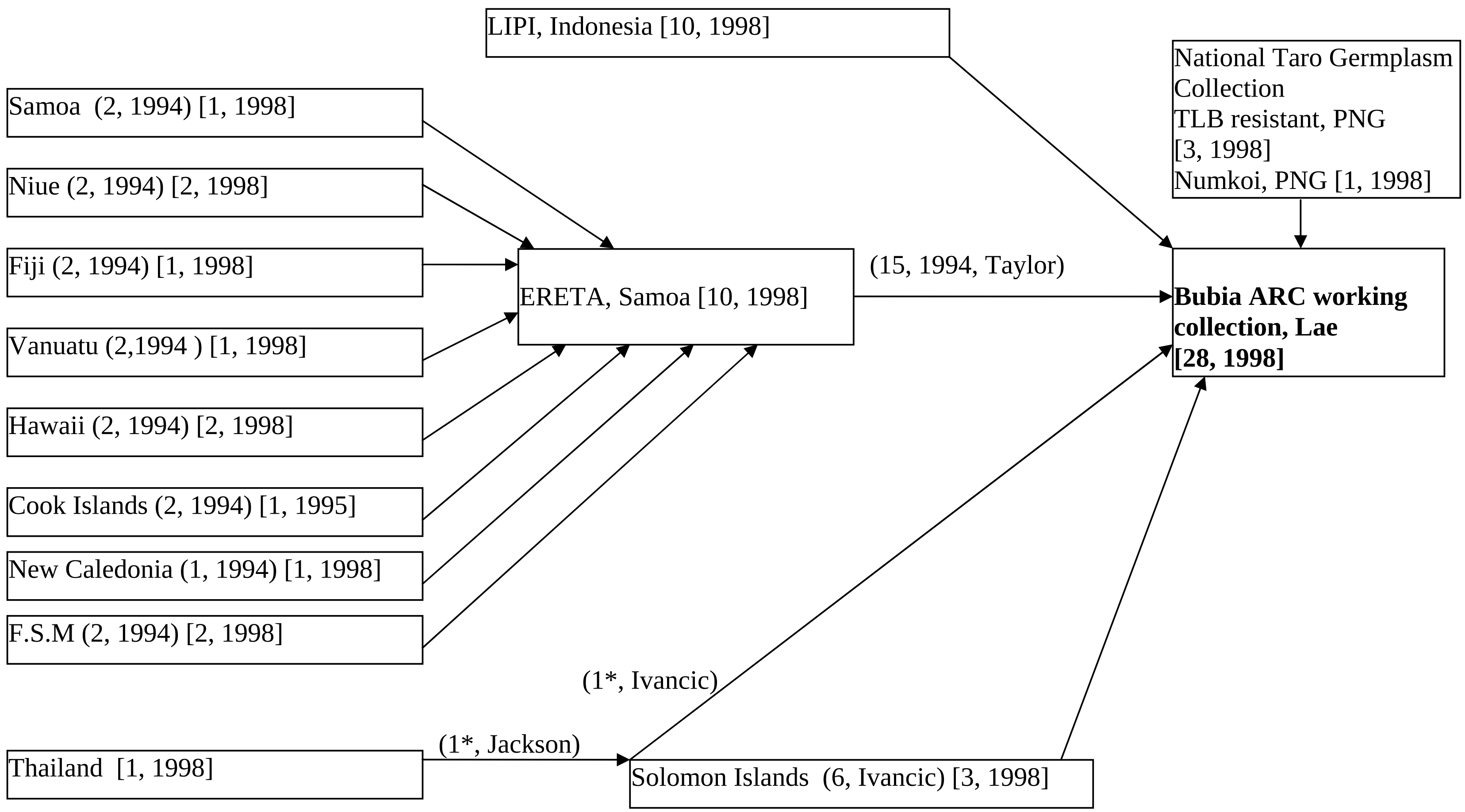
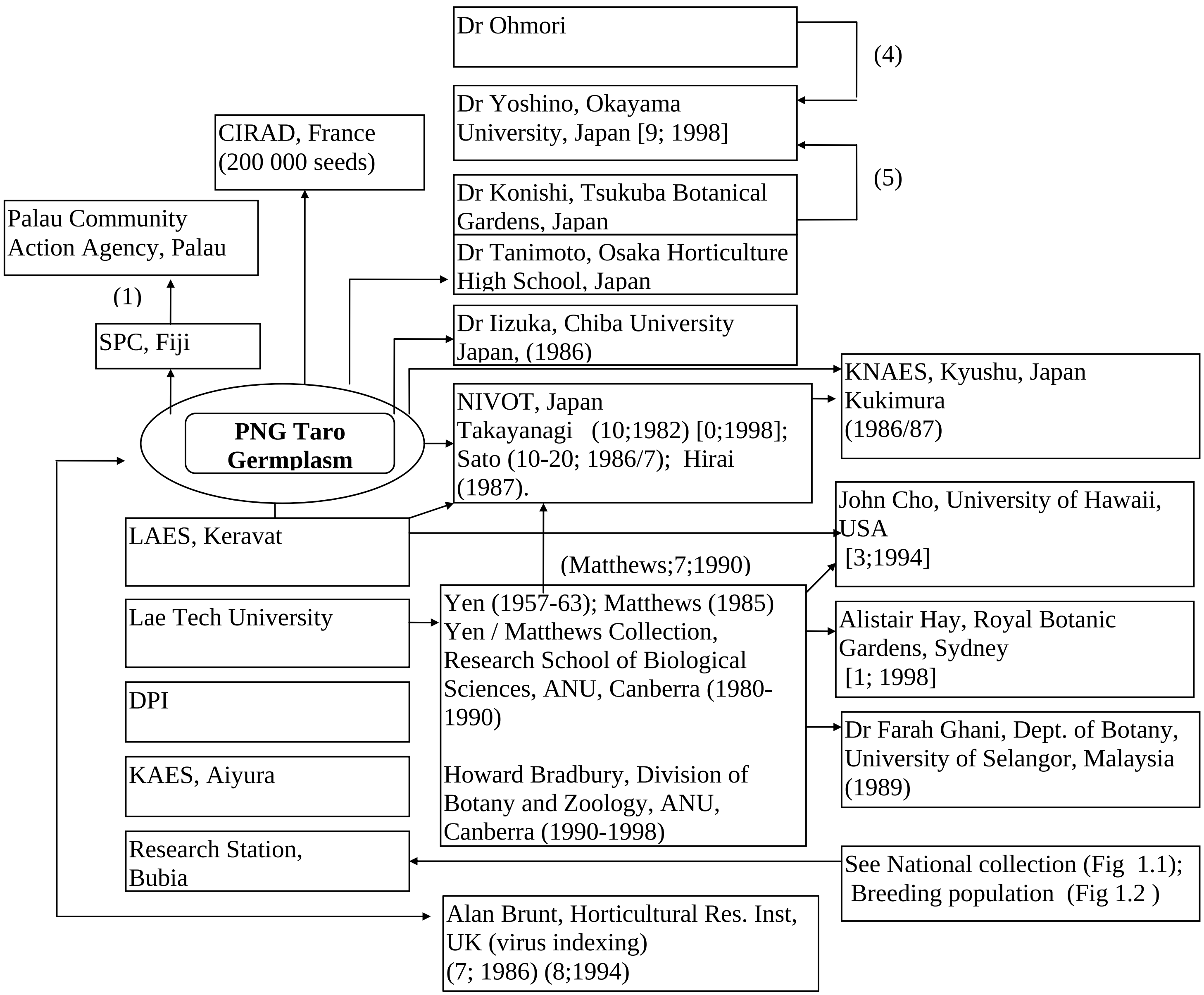


Figure 2: Movement of introduced taro germplasm to the Bubia ARC working collection



( ) - date and original number transferred
[ ] - remaining number in Bubia collection in 1998

Figure 3: Distribution of Papua New Guinea's Taro Germplasm



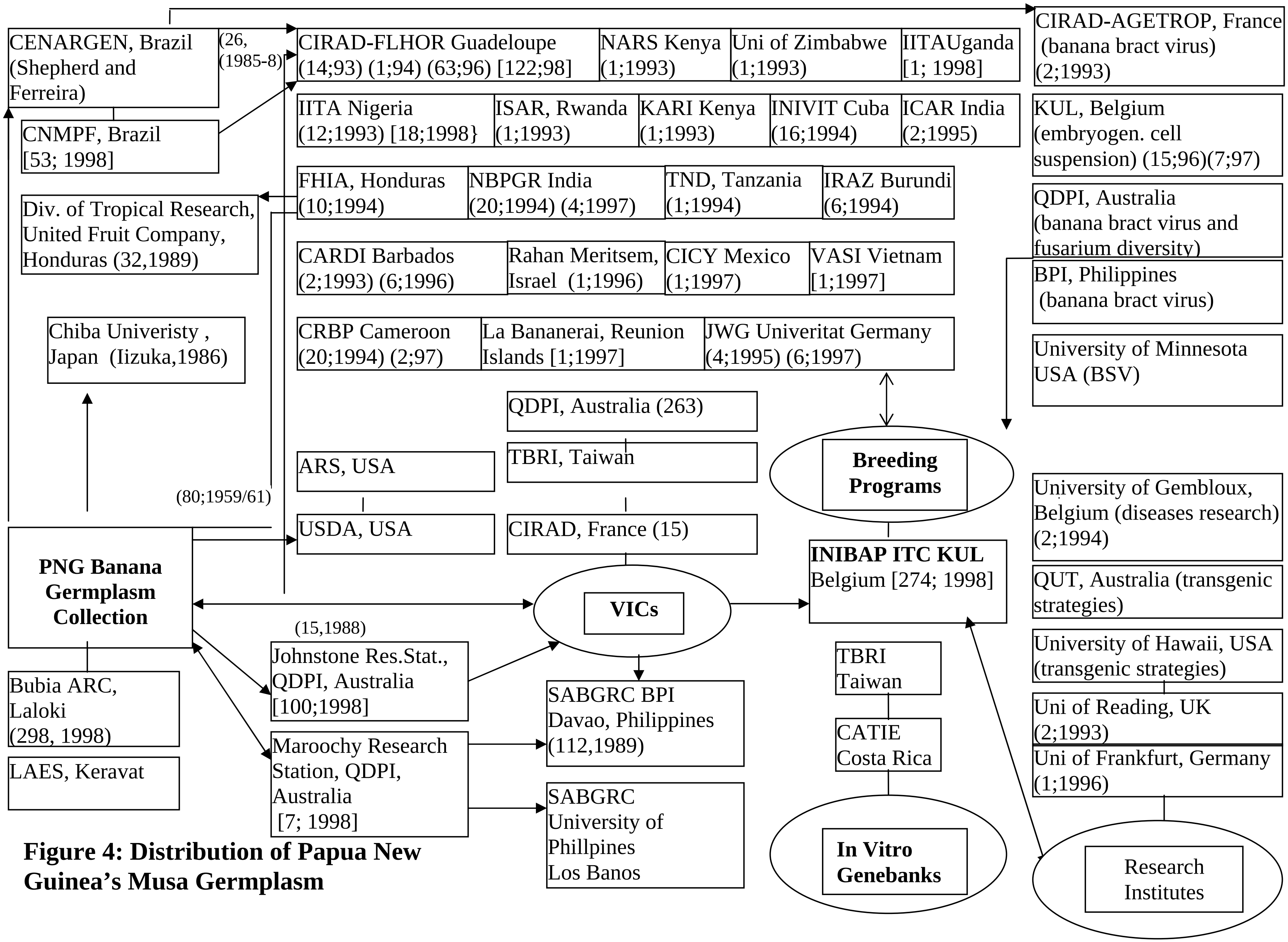
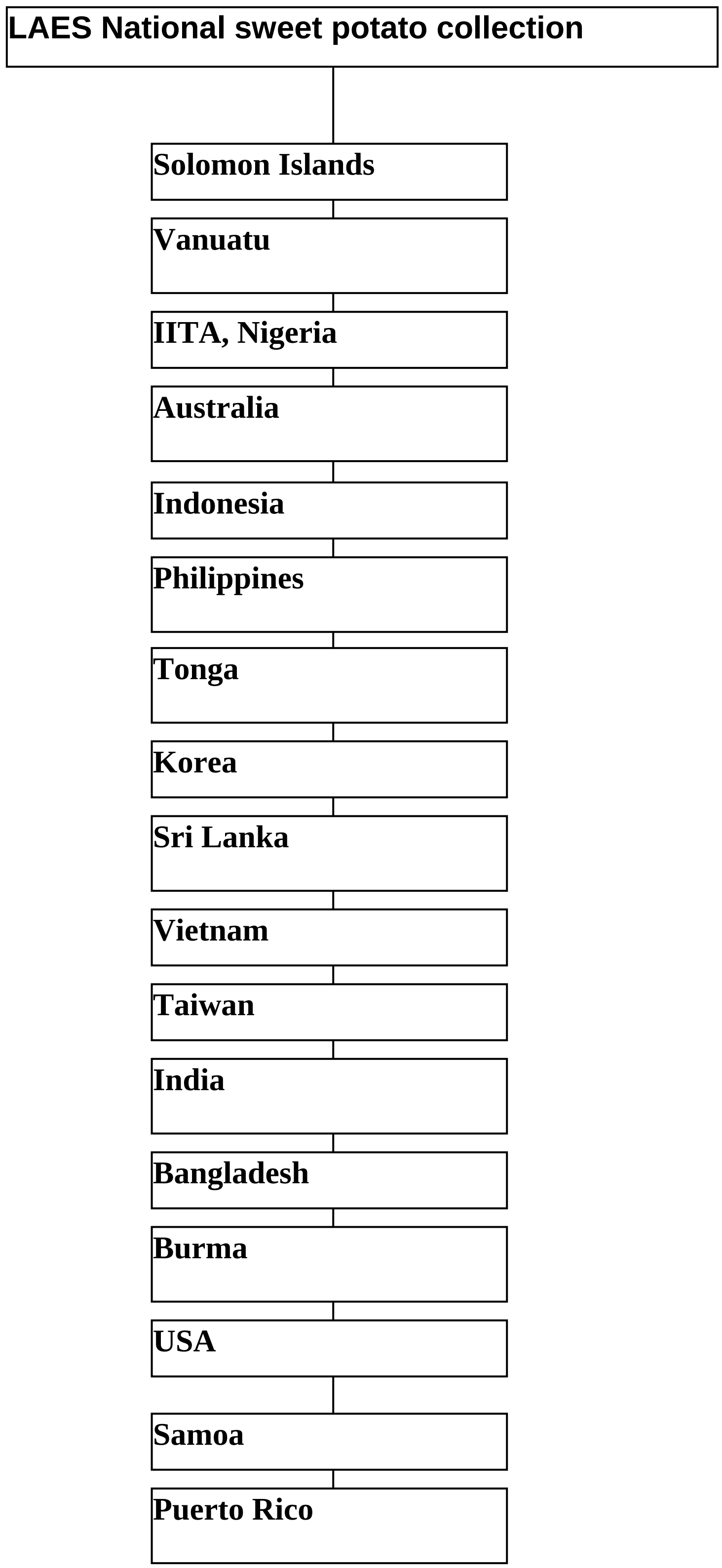


Figure 4: Distribution of Papua New Guinea's Musa Germplasm

Figure 5: Movement of Sweet potato germplasm to the LAES National Collection



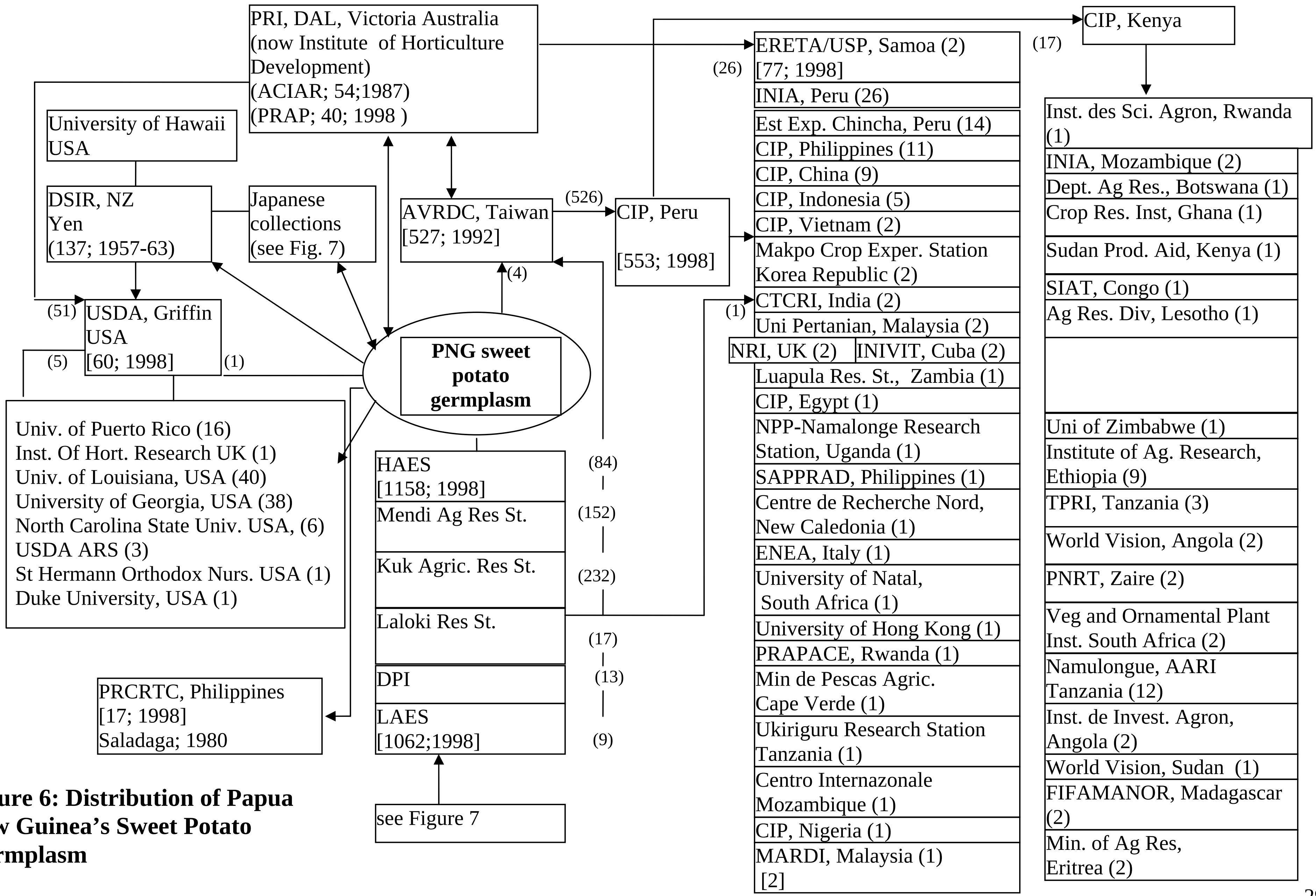


Figure 6: Distribution of Papua New Guinea's Sweet Potato Germplasm

Figure 7: Distribution of PNG's Sweet Potato Germplasm Material to Japan