Genetic Loss in Food Crops in the Pacific: Socio-Economic Causes and Policy Issues

Clement A. Tisdell

https://doi.org/10.33318/jpacs.2016.36(2)-2

ABSTRACT

Genetic diversity of traditional food crops is declining in the Pacific Islands. Background information on the evolution of the diversity of these crops is provided, socioeconomic reasons for this loss are outlined, the economic consequences of this loss are analysed, and the economic benefits and costs of conserving crop varieties is examined. The potential economic benefits foregone by failing to conserve a crop variety are shown to depend on the nature of the demand function for the crop's production. The economics associated with the conservation of crop diversity by in situ and ex situ methods are discussed.

Keywords: *Biodiversity loss, crop varieties, gene banks, genetic capital, food crops, food security, Pacific Islands, sustainable development.*

INTRODUCTION AND PURPOSE

Along with climate change, loss of biodiversity (particularly the disappearance of existing genetic resources) is a major threat to the long-term maintenance of human well-being. Because its effects are less visible than those of global warming (which itself is a powerful force for biodiversity loss), loss of genetic resources has received much less public attention than global warming. Nevertheless, its consequences on human well-being may eventually be similar to those of a slowly spreading cancer on its victim. The FAO has reported that in the 20th century 'some 75 percent of plant genetic diversity has been lost as farmers worldwide have left their multiple local varieties and landraces for genetically uniform, high-yielding varieties"(FAO, 2004, Box 5). There is also concern that human beings depend on very few plants and animal species for their food supply. It is estimated that '75 percent of the world's food is generated from only 12 plant and five animal species'(FAO, 2004, Box 5). Furthermore, the FAO reports that about 1,000 domestic animal breeds were lost in the last century and about a third of remaining breeds (of which there are believed to be about 1,335) are threatened with extinction (FAO, undated). Haussmann *et al.* (2004) also point out that 'agriculture today is characterized by a sharp reduction in the diversity of cultivated plants' and that there has been substantial reduction in the interspecific and intraspecific diversity of these plants.

The purpose of this paper is to examine the loss in genetic diversity of traditional food crops in the Pacific Islands. In doing so, it will consider the origins of crops and crop varieties in these islands, their importance globally and provide some information about the extent of the loss of crop varieties in the Pacific Islands. Also, it aims to identify the socio-economic causes of such losses and presents economic analyses of their potential consequences for human well-being. Moreover, policy measures and methods to conserve the variety of crops in the Pacific Islands are discussed and economic difficulties of assessing these are highlighted.

THE GLOBAL CONTRIBUTION OF THE PACIFIC ISLANDS TO FOOD CROPS AND THEIR VARIETIES

It is not well known that the Pacific Islands contain one of the earliest areas in which agriculture first began. Renfrew (2007, pp. 210-211) indicates that gardens for the supply of food were established in New Guinea around 9000 years ago, probably around 500 years or so after wheat was first grown in the Levant in the Near East. New Guinea is believed to be the second centre in the world where plant cultivation began. Plant cultivation in South Asia, the Americas and China came much later.

While there is some controversy about the exact time-period in which the cultivation of food plants began in New Guinea, strong archaeological evidence indicates that it is one of the earliest centres in the world where agriculture evolved in the Holocene period (Denham*, et al.*, 2003), and it did so independently of other centres where agriculture originated. Taro (*Colocasia esculenta*), bananas (*Musa* spp.), and yams, (*Dioscorea* spp.) have been identified as some of the significant species cultivated in ancient times in New Guinea (Denham*, et al.*, 2003; Fullagar*, et al.*, 2006). Table 1 provides a list of food crops cultivated mostly in Melanesia in ancient times and which subsequently, diffused to other Pacific Islands. This, however, is not a complete list of indigenous crops of the Pacific Islands. Furthermore, the origins and diffusion of these crops is complex as shown by Zerega *et al*. (2004) in relation to the origins and diffusion of breadfruit. As can be seen from Table 1, some differences in scientific opinion exist about where some of these crops were first cultivated and their origins.

TABLE 1: *A list of various food crops believed to have originated in the Pacific Islands (especially New Guinea) together with relevant comments.*

Species	Comments
Bananas and Plantains (*Musa* spp.)	It is believed the wild *Emusa* banana was first domesticated in New Guinea and then it dispersed to Southeast Asia (Denham, *et al.*, 2003, p. 193) and subsequently, to other islands in the Pacific as they were settled. On the other hand, Bynum and Bynum (2014, p. 160) state that it originated in Southeast Asia as a domesticate. Most banana domesticates are derived from *Emusa* bananas.
Breadfruit (*Artocarpus altilis*)	Breadfruit has its origins in the Pacific Islands with New Guinea, the Mariana Islands and Palau being the suggested source of species from which hundreds of varieties have been derived in the Pacific Islands. However, the origins and geographical diffusion of breadfruit in the Pacific Islands is complex (Zerega, *et al.*, 2004) Its cultivation also spread to Southeast Asia and Southern India. European colonists introduced breadfruit from the Pacific to the Caribbean to help feed slaves there (Rix and Davis, undated).
Coconut (*Cocos nucifera*)	It is "thought to have originated in the coastal areas of Southeast Asia and Melanesia. In prehistoric times, it spread naturally on ocean currents eastward to the tropical Pacific Islands and westward to India and all the way to East Africa. Around 4,500 years ago, voyaging Polynesians and Indo-Malayans introduced their preferred forms to the various Pacific Islands" (Library of the University of Hawaii at Manoa, 2012a)

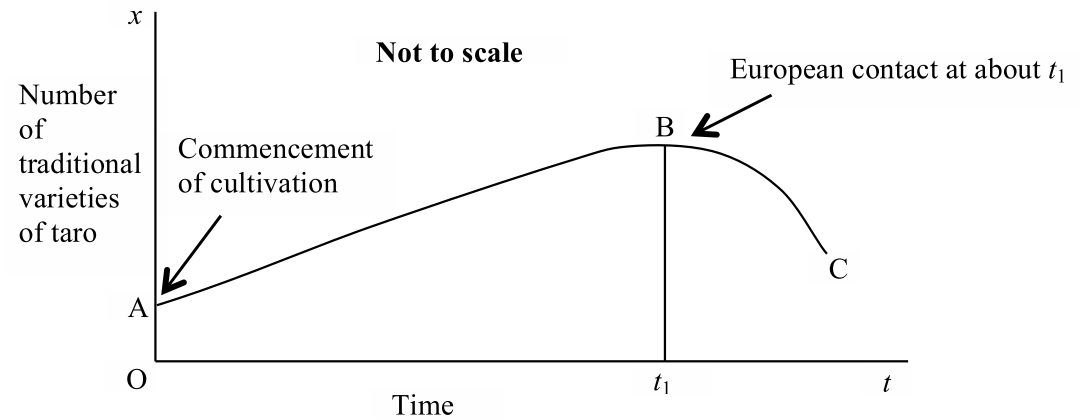
Sugar Cane (*Saccharum* spp.)	All six species of sugar cane are native to New Guinea and have been used by humans for over 8000 years. Today *Saccharum officinarum* is the species mostly grown for sugar production. The use of sugar cane initially spread from New Guinea to the north into Asia, then to the east in Pacific (Benson, 2012, pp. 98-102) and subsequently, more widely.
Taro (*Colocasia esculata*)	Although it had previously been hypothesized that taro cultivation first occurred in Asia, Fullager et al. (2006) have produced evidence that taro was most likely first cultivated in New Guinea and probably also in the Solomon Islands. Cultivation of several other aroid species has also originated in Melanesia.
Yams (*Dioscorea* spp.)	Fullager et al. (2006) have completed research indicating that New Guinea was the place where yams were originally domesticated. Their cultivation occurred subsequently in Southeast Asia and spread to other Pacific Islands. However, the origins and geographical diffusion of species of yams is more complicated than this (see, for example, Bynum and Bynum, 2014, pp. 42 -43; and Coursey, 1967).

As the cultivation of these crops spread in the Pacific, many local varieties were developed in order to make them better adapted to local ecological conditions, as has been exemplified by a case study of the breadfruit (Zerega, *et al.*, 2004). However, in recent times, many of these cultivated varieties have been lost as a result of changing socio-economic conditions and the stock of their wild relatives (for example, in New Guinea) is being eroded with the occurrence of economic growth and change. Most natural scientists believe that this narrowing of the genetic stock of these crops poses a serious threat to the sustainability of their contribution to food production. Threats to such sustainability are not only relevant to the Pacific Islands themselves, but also to other countries which rely on these crops for some of their agricultural production. For example, the preservation of the genetic capital for bananas and sugar cane could make a contribution to the sustainability of production from these crops in Australia.

Of course, some important food crops in the Pacific Islands were introduced from other parts of the world. The sweet potato (*Ipomoea batatas*) is an interesting and important example. It is reported that "Central America and Peru are generally accepted as possible centres of origin for this crop. Sweet potato cultivation in the eastern and central Pacific predates European contact by several hundred years, possibly occurring as early as 1000 CE [about 3000 years ago]" (Library of the University of Hawaii at Manoa, 2012b). It may have been introduced as the result of early contact of Polynesians with South America. It is now an important crop in the Pacific and in many other developing countries. A multitude of different varieties of sweet potatoes have been developed in the Pacific Islands.

Probably, the number of varieties of traditional cultivated crops in the Pacific increased over hundreds of years once agriculture commenced there, but following European contact and the greater integration of the Pacific Islands into the global economic system, the number of these varieties declined and in recent times, this loss appears to be happening at an accelerating rate. Taking, for example, taro (*Colocasia esculata*), this pattern might be like that shown hypothetically by curve ABC in Figure 1. The exact relationship is unknown because all the existing varieties of taro have not been fully documented, let alone many of the varieties which existed in the past.[1]

FIGURE 1: *The hypothetical relationship between the number of cultivated traditional varieties of taro available in the Pacific Islands and the efflux of time. Similar patterns probably apply to other crops which were cultivated before European contact, e.g. bananas.*



It is clear that increasing globalization since the beginnings of agriculture has played a major role in the global diversity of food crops both by addition and subtraction (see for example, Kiple, 2007; Kiple and Concée, 2000; and Murphy, 2007). However, the dominant trend in recent times has been to reduce global crop diversity (Haussmann*, et al.*, 2004).

SOCIO-ECONOMIC CAUSES OF THE GENETIC EROSION OF TRADITIONAL FOOD CROPS IN THE PACIFIC ISLANDS

There are several socio-economic reasons why many varieties of traditional food crops are being lost in the Pacific. Similar socio-economic causes are present elsewhere in the world. Their relative importance has not been investigated empirically as yet, and many of the socio-economic reasons for their decline have received little attention, particularly by natural scientists. Socio-economic reasons for this decline in Oceania include the following:

> *MARKET REQUIREMENTS.* Many economies in the Pacific have become increasingly market-oriented and some of their food production is exported to foreign markets. There is an economic incentive to grow varieties of crops (and species of crops) that transport and store well and which are most preferred by buyers. In some markets, standardized produce is preferred, for example, for supplies to supermarkets. Masibalavu et al. (2002) concluded (from a survey in Fiji) that there has been significant erosion in taro landraces in Fiji and that this is associated with increasing market demands and use of taro hybrid varieties by many farmers. A report prepared by the Government of PNG points out that semi-subsistence farmers there tend to grow crop species, cultivars and landraces that are preferred by consumers and which can be sold for cash and that this is resulting in genetic erosion (FAO, 2009, p.7). Similarly, the Fijian Government has pointed out that traditional varieties of food crops are now rarely seen in local markets (FAO, 2008, p. 13) and in some localities, only export varieties are being grown (FAO, 2008, p. 17).
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> *IMPROVED VARIETIES.* The development of new crop varieties which are more profitable to grow or give greater yields than existing ones usually result in the erosion of existing varieties. This has for example, been stressed by Haussmann *et al.* (2004). However, the new varieties may prove to be vulnerable to new plant diseases whereas some of the varieties which are lost may have possessed resistance to these diseases. Individual farmers have no economic incentive to save traditional crop varieties to cater for this possibility. This is because the event is uncertain, is likely to be distant in time, and they are likely to be unable to appropriate significant economic benefits from their conservation decision. It might also be noted that the development of improved varieties of crops tends to be a two-edged sword. It raises current economic returns, but it also accelerates the loss of crop diversity and in the long-term, this could endanger the sustainability of agricultural production (Haussmann*, et al.*, 2004; Tisdell, 2014).
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> *DECOUPLING OF THE PRODUCTION OF CROPS FROM LOCAL ECOGEOGRAPHIC CONDITIONS.* Many scientific advances in agriculture reduce the extent to which the growing of crops depends on local environmental conditions. For example, artificial fertilizers, pesticides,

irrigation and so on help to reduce this dependence. Therefore, crop varieties which were once the most productive in natural local conditions are often less productive than new varieties (improved varieties) which respond well to a package of human-regulated inputs (Tisdell, 2015, Chs. 5 and 8). In many parts of the world, such decoupling has resulted in global loss of livestock breeds (Tisdell, 2003). Furthermore, as is well known, the 'Green Revolution' has resulted in considerable erosion of crop varieties (Alauddin and Tisdell, 1991).

CROP SUBSTITUTION. In modern times, some new crops have been introduced to the Pacific. Their cultivation resulted in land that was once used for traditional crops being used for these new crops. As a result, several local crop varieties would have been lost. Furthermore, the extension of cultivation of particular crops has a similar effect. The commercial growing of sugar cane in Fiji for exports of sugar most likely displaced some varieties of traditional crops. In PNG, the growing of commercial crops for export, such as, palm oil, coffee and cocoa, has had similar effects. The extension of markets (for example, as a result of less restricted international trade) is a major influence on the loss of local varieties of food plants and is also a factor in the loss of local breeds of domesticated animals (Tisdell, 2003; Tisdell, 2015, Ch. 6). This is because market extension promotes regional specialization in production. As a result of market extension, some agricultural activities which once existed in a region and resulted in distinct varieties of crops or breeds of animals being conserved may cease being economical. They may be replaced by other economic activities. Consequently, a global loss in biodiversity occurs.

URBANIZATION/CENTRALIZATION OF POPULATIONS. Considerable migration has occurred from the more remote places to central places in Pacific Island states and territories. In some cases, this has resulted in reduced crop cultivation in remote areas and subsequent loss of local landraces. Similarly, with the spread of urban centres, agricultural land is lost and this could have a negative effect on the survival of some plant varieties. Furthermore, the lifestyles and demand for different types of food of urban residents differ from those of rural residents and this alters the pattern of demand for food.

CHANGED FOOD HABITS AND TASTES. Food habits and tastes can change over time as a result of cultural change, alterations in the structure of society (including a society's urbanization, and changes in the nature of work) and as a result of advertising. For example, demand for convenience foods is likely to increase in households where family members are involved in wage or salary employment in urban areas. Furthermore, as a result of globalization and increased international contact, the range of available foods (for example, the availability of foods which are popular abroad) can be expected to increase. All of these factors can result in a fall in the demand for traditional foods and consequently, reduce the extent of their cultivation. For example, globalization has resulted in an increase in the demand for cereals (including wheat and rice) in the Pacific Islands. Cereals are used to supply new types of food in the Pacific Islands, such as bread, wheat biscuits and so on. These trends are further reinforced by the presence of fast food developments in some places in parts of the Pacific, for example, the establishment of McDonalds outlets. Furthermore, migration has played a role in influencing food habits. For instance, the migration of Indians to Fiji has influenced the pattern of food consumption there.

INCREASING IMPORTANCE OF MONETARY TRANSACTIONS AND GREATER AVAILABILITY OF FOREIGN CURRENCY. Monetary exchange has increased in importance in the Pacific Islands, while subsistence living and barter have become less common. Hence, the market system is becoming more widespread and market extension is occurring. This facilitates loss of crop biodiversity (see point 4). In many Pacific Island nations and territories, the demand for processed food (much of which is imported) is driven by the growing importance of cash income and monetary exchange, as well as urbanization. The growth of the cash economy is facilitated by monetary remittances and by funds supplied by overseas aid. This phenomenon has resulted in some Pacific Island nations and territories being classified as MIRAB economies (Bertram, 2006; Bertram and Watters, 1985). Although this classification cannot be applied to all Pacific Island nations and territories (Tisdell, 2016) even in cases where the classification is inappropriate or barely appropriate (such as Papua New Guinea), the size of their monetary economies have grown in importance. When foreign funds flow into a Pacific Island nation as a result of overseas remittances, aid or the earning of foreign exchange as a result of exports, overseas funds become available to import food and other commodities. Dependence on local food supplies declines. While imports increase the range of foods available to Pacific Islanders, greater reliance on imports makes Pacific Islanders economically vulnerable to a decline in foreign aid, reduced overseas remittances, or a fall in export earnings.

REMITTANCES AND MIGRATION PATTERNS. Remittances to family members by migrants are likely to reduce economic incentives to undertake agricultural production in the Pacific Islands. There is evidence that in some jurisdiction, remittances are mainly used for consumption (Brown*, et al.*, 2013). In addition, the composition of the population in rural areas may be skewed towards the elderly (because younger family members tend to migrate). The elderly are less able to engage in agricultural production and this may further result in loss of varieties of traditional crops.

LOCAL SUPPLIES OF AGRICULTURAL PRODUCE ARE RESTRICTED BY TRANSPORT DIFFICULTIES. The territories of many Pacific Island nations are scattered, some parts are remote and are relatively inaccessible in relation to their central urban places. For example, transport between the outer islands of many Pacific states is costly and infrequent. This reduces their economic potential to supply food to the main urban centres in the Pacific Islands and increases the dependence of Pacific Island nations on imported food. In many cases, it is cheaper to import food from abroad rather than source it from remote areas in the Pacific Islands. There is also a further complication. As pointed out by the Government of PNG, most traditional types of food crops in the Pacific Islands are highly perishable and this limits the scope for their transport and storage. The PNG Government recommends that greater attention be given to the production of flour from root and tuber crops near their source of production in order to reduce this problem (FAO, 2009, p. 16). Also some crops such as bananas can be dried (desiccated).

Note that the price of food products does not reflect the environmental cost of their supply, for example, the extent to which their transport results in increased CO_2 emissions. For example, food which is transported over greater distances is likely to use a greater amount of fossil fuels and result in a higher level of CO_2 emissions than food supplied locally by farmers. This is why some social groups favour increased reliance on locally produced fresh food, for example, supplied in farmers' markets. However, it is not only the nature of food transportation that has consequences for CO_2 emissions. The use of artificial fertilizers can, for instance, add to these emissions. Furthermore, other environmental consequences of food production need to be considered. Even if consumers wanted to take these effects into account, they are hindered in doing so by lack of knowledge about the environmental consequences of their food purchasing decisions (see, for example, Tisdell, 2011, pp. 27-28). This limits the social economic value of market systems.

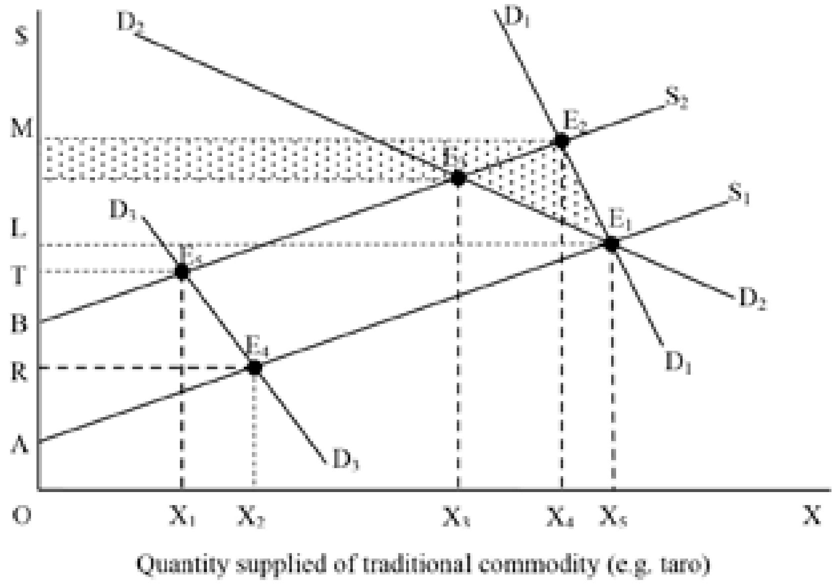
CONSEQUENCES FOR HUMAN WELFARE AND FOR ECONOMIC SUSTAINABILITY OF GENETIC EROSION IN FOOD CROPS

The economic consequences as well as the ecological and biological impacts of a reduction in the size of the genetic stock and of changes in that stock are poorly understood. Even the existence of many varieties of traditional crops in Pacific Island countries is unknown or poorly known. This problem has been pointed out by the government of PNG and also by that of Fiji (FAO, 2008, 2009). As a result, many varieties of traditional crops could be lost without the scientific community ever knowing that they once existed, let alone having knowledge of their attributes. Moreover, acute uncertainty exists about the attributes of the available crop varieties which will prove to be valuable in the future. For example, it is difficult to know what attributes of crop varieties may prove to be valuable in counteracting crop diseases or pests that could evolve in the future. Both the occurrence of future crop diseases and the attributes of crop varieties that may counteract their negative consequences are uncertain.

Now let us consider whether economics can provide any guidance on the possible benefits of conserving traditional crop varieties. What economic factors influence the extent of the economic loss suffered if, due to the occurrence of a disease (such as taro blight), the productivity of a favoured crop variety fails? In other words, what is the economic value of being able to avoid this loss by possibly making use of a genetic attribute of a traditional crop variety?

Figure 2 throws some light on the matter. It is assumed that the occurrence of this new disease adds to the cost of supplying the food crop, X. Whereas the original supply curve might have been as shown by line $AS_{1,}$ after the occurrence of the crop disease, it might shift upwards to BS_2. If the demand for X is shown by D_1D_1, there is a considerable loss in consumers' surplus as a result of the occurrence of this disease. This loss is equivalent to the area of quadrilateral LE_1E_2M. On the other hand, the loss in consumers' surplus will be smaller if the demand for X is more elastic. For example, the demand curve marked D_2D_2 exhibits greater elasticity at point E_1 than does D_1D_1. In the latter case, the loss in consumers' surplus caused by the onset of the pestilence is smaller by an amount equivalent to the dotted area. In general, the loss in consumers' surplus tends to increase with the amount by which the cost of supplying commodity X rises once the pestilence occurs, and when the demand for the commodity is more inelastic, other things being held constant. The latter implies that consumers lack close substitutes for the focal commodity.

FIGURE 2: *Illustration of the adverse impact on the welfare of consumers of a new crop disease which fails to be controlled due to genetic erosion*

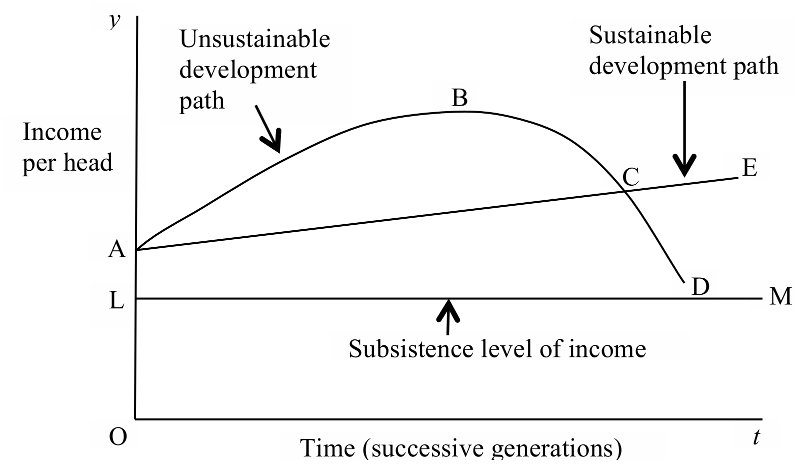


However, there is another important influence on the loss in the welfare of consumers that could result from genetic erosion in crops, and this could be more important than the elasticity of demand for a crop. It is the absolute level of demand for the crop. Other things being held constant, a loss of the type illustrated (consumers' surplus) in Figure 2 is larger, the higher the absolute demand for the commodity produced by the crop is. This can be seen from Figure 2. If, for example, the demand curve for X is as shown by line D_3D_3, the loss in consumers' surplus as a result of the pestilence is equivalent to the area of quadrilateral RE_4E_5T. This area is much smaller than when the demand curve is located at D_1D_1 or D_2D_2. Consequently, the economic benefit from having a strategy to avoid a negative effect on productivity of the occurrence of a disease in a traditional crop increases with the level of the absolute demand for the food produced by that crop and when the demand for it is more inelastic. Crops which are considered to be staples (such as bananas and taro in the Pacific Islands) are likely to satisfy these conditions. This would suggest that they should have a high priority for the preservation of the diversity of their germplasm. This should, as discussed later, have an influence on conservation strategies.

There are fears that the continuing loss of existing varieties of crops will eventually result in unsustainable economic development and the impoverishment of humankind (Tisdell, 2015). The fact of the matter is that the global human population relies on a narrow spectrum of food crops for its sustenance and traditional varieties of these food crops continue to be lost (Haussmann*, et al.*, 2004). Thus, the genetic diversity of most food crops is narrowing with the passage of time. It is, therefore, possible that diseases may adversely affect the productivity of several species of crops within a limited time-span. Unfortunately, the genetic resources that might have permitted humans to address this problem may already be lost by the time this food crisis emerges, if it does happen. This is a legitimate concern.

The problem can be illustrated by Figure 3. As a result of improved crop varieties and technological progress in agriculture, development path ABCD might be followed. Incomes per head rise at first but eventually decline as the genetic diversity of crops is lost. On the other hand, if measures are adopted to conserve the genetic diversity of crops, a development path like ACE might be followed. This is a sustainable development path. Path ABCD results in distant generations being poorer than they need be. Eventually, they could be worse off than current generations and their incomes might even fall to subsistence level, a level indicated by line LM in Figure 3 (Tisdell, 2011).

FIGURE 3: *Lack of conservation of genetic diversity of crops (for reasons given in Table 2) could result in the unsustainable development path ABCD whereas conservation of a greater diversity of crops might result in sustainable path ACE being followed.*



Of course, a continuing reduction in the varieties of individual food crops does not necessarily result in development path ABCD being followed, but it is a possibility that worries many scientists. If it is a possibility, what should be done about it? This depends on how much current generations care about future generations. If current generations are only concerned for the welfare basically of their children and grandchildren (as seems likely, see for example, Pearce, 1998, pp. 70-71), then an unsustainable economic development path may be chosen rather than a sustainable one. Consequently, there will be little public support for saving crop biodiversity, especially if this is costly to do. Moreover, this course of action is likely to be reinforced if (a) the likelihood of unsustainable economic development as a result of failing to conserve crop biodiversity is believed to be low or if (b) individuals are not inclined to believe that this is going to happen, unless they see concrete empirical evidence of it occurring. But, if one waits for this evidence, then, by the time it is obtained, it may be too late to reverse the downward trend. Therefore, the possibility of this type of unsustainable development path poses a challenge for rational decision-making.

METHODS OF CONSERVING VARIETIES OF TRADITIONAL FOOD CROPS IN THE PACIFIC ISLANDS AND ECONOMIC ISSUES

A number of different techniques exist for conserving a wide range of varieties of crops. These broadly include the following:

In situ. Farmers can conserve traditional varieties themselves in their own fields, and the wild relatives of cultivated crops can be conserved in protected areas.

Ex situ[2]. There are two basic techniques for *ex situ* conservation:

Cultivation on state experimental farms (for example, at Koronivia Research Station in Fiji) and in botanical gardens.

In vitro conservation. This involves the preservation of seeds or tissues of plants. Types of *in vitro* conservation of germplasm vary. For example, cold storage with replanting of germplasm at various intervals to obtain new seeds or tissue is practised in PNG. The Secretariat of the Pacific Community, has a conservation facility in Suva which involves deep-freezing of germplasm, cryo-preservation. This may reduce the frequency with which replanting is needed to sustain the germplasm.

All of these methods involve costs and none guarantee that the germplasm to be preserved will in fact be conserved. Farmers will not conserve traditional varieties, unless this is the most economic choice from their point of view[3]. They may have to be sufficiently subsidized if it is intended to conserve some varieties of crops *in situ*. Field cultivation *ex situ* also is not without problems. It usually depends on the maintenance of state funding. Furthermore, *ex situ* fields where some varieties are grown may experience different environmental conditions to those in their place of origin and may not survive. Furthermore, cross-fertilization with other varieties can occur where samples of the crop varieties are grown *ex situ* in fields. In addition, costs usually result in a small population of each variety being planted in conservation fields. This increases the vulnerability of this population to environmental disasters.

In vitro conservation also involves biological, social and economic hurdles. There is a possibility that germplasm may lose its fertility in storage. In many cases, periodic replanting and subsequent replacement is needed to keep germplasm viable. Consequently, similar problems can occur to those that arise for *ex situ* cultivation in fields. Most of the traditional food crops in the Pacific Islands reproduce vegetatively rather than by seed and this adds to the difficulties of *in vitro* conservation. It is also possible for the equipment used in *in vitro* fertilization to fail.

According to Rao and Hodgkin (2002, p. 12), "Even under optimum conditions, accessions held [under] *ex situ* storage [*in vitro*] will need to be regenerated after a number of years. The genetic diversity of conserved material must be preserved during germplasm regeneration and this is more complex and difficult in the case of out-crossing species than inbreeders (Porceddu and Jenkins, 1982)". However, the fact that many traditional Pacific Island crops reproduce vegetatively should reduce the outcrossing problem. On the other hand, storing their tissues *in vitro* is more challenging than storing seeds of species which can be propagated from those seeds.

Because many of the traditional food crops utilized in Oceania reproduce vegetatively, not only is conserving their diversity challenging, but it is also of high importance from a sustainability point of view. For example, Bynum and Bynum (2014, p. 605) point out that "the fact that [cultured varieties] of bananas are clones means that they are especially susceptible to pests and disease, a real worry in the modern world".

A further problem is that available funding (from governments and aid donors) for *ex situ* crop conservation projects may be slashed or may cease altogether after a gene bank is established. This can result in the abandonment of gene banks and the loss of the genetic diversity which was entrusted to them for conservation. Ragone (2006, Slide 30) reports that four of the seven Pacific breadfruit collections which were started in the Pacific Islands were abandoned by 2006. These were the collections in Kosrae (FSM), Pohnpei (FSM), Samoa and the Solomon Islands.

Although the conservation of crop diversity involves considerable costs, as far as I know, there have been no recent estimates of the cost of *ex situ* conservation in the Pacific Islands. The PNG Government, however, has stated:

> *"Conservation and maintenance of these germplasm collections in field gene-banks are very expensive. A study undertaken by the PNG Department of Agriculture & Livestock (DAL) and the Agriculture Economics Department of the University of Sydney through funding from the Australian Centre for International Agriculture Research (ACIAR) in 1998 revealed that it was costing PNG around K183,000 annually to maintain four national germplasm collections of banana, sweet potato, cassava, aibika and taro in field gene-banks". (FAO, 2009, p.16)*

These estimates were made over 20 years ago. No up-to-date estimates for the cost of conserving the genetic diversity of crops in the Pacific Islands as a whole appear to be available. Moreover, it seems that no cost-effectiveness analysis has been done. Given that a target is to conserve a particular quantity and mixture of genetic diversity, this type of analysis would consider the relative cost of achieving that goal by adopting alternative conservation methods. While this would be a difficult task, it ought to be attempted.

The economic benefit-side of cost-benefit estimation is also difficult to assess. The economic analysis given in the previous section seems to provide some guidance. It suggests that priority should be given to conserving the genetic diversity of staple food crops. On the whole, it seems that this has happened in the Pacific Islands. Nevertheless, the past only provides a limited guide to the future. Crops which are in demand as staples for food supply may not continue in high demand in the future. Tastes do change. Furthermore, the possibility cannot be ignored that some local food crops that are little used now might become more important as a source of food supply in the future. The PNG government points out that "There are no formal arrangements in place in collecting and conserving [these] under-utilized crop species" in PNG (FAO, 2009, p. 12). This also appears to be the case in other Pacific Island states and territories.

A further issue, which has economic implications, is how many gene banks should be established in the Pacific Islands and where. To what extent should the gene bank collections be centralized within countries and in the Pacific Islands as a whole? While centralization may reduce the cost of *ex situ* conservation, the biological effectiveness of it could be reduced. There is also the question of the extent to which *ex situ* conservation of germplasm should be duplicated at different sites. While duplication will add to the cost of conservation, it is likely to reduce the risk of germplasm being irretrievably lost due to unfortunate events.

Another issue is the extent to which the crop germplasm of one country should be conserved in another country. Although in some cases, conservation of the germplasm of a less developed country in another country could be more effective in ensuring its conservation, many donor countries worry that they will lose control of the property rights in their germplasm. This can be a contentious political issue. Clearly, there are still many economic as well as other issues to be resolved in rationally determining the best strategies for conserving the germplasm for the wide range of varieties of crops which are present in the Pacific Islands.

CONCLUDING REMARKS

The Pacific Islands (particularly Melanesia, especially New Guinea) are the ancient source of many important crops. Some (for example, bananas and taro) were already cultivated in the Pacific about 10,000 years ago. New Guinea has the distinction of being one of the first places on earth where agriculture began. Following the origins of agriculture in New Guinea, Pacific Islanders developed a huge variety of food crops over hundreds of years as they extended their settlement of the Pacific Islands. As a result, the Pacific Islands are a rich source of germplasm which can be utilized to sustain and improve food production. This stock of germplasm consists both of natural capital and heritage capital, but unfortunately, it is now diminishing following European contact and colonization of the Pacific Islands.

With greater economic globalization and the extension of market and monetary systems (as well as a result of advances in agricultural technology and science), loss in genetic diversity (as in other parts of the world) is continuing at a rapid rate. Some of the important socio-economic and related causes of this loss of genetic diversity in food crops in the Pacific Islands were identified. There is a risk that this continuing loss will eventually reduce human well-being and result in unsustainable economic development.

Economic circumstances were identified, which would magnify the reduction in the economic welfare of consumers, if genetic loss increases the cost of supplying food provided by traditional crops. The basic theory indicates that this loss is likely to be greatest for staple food crops, that is, those for which the absolute demand is large. This loss is also higher the more inelastic the demand is for such crops, but this is of secondary importance.

There is a paucity of economic analysis of alternative strategies to conserve crop biodiversity[4]. Little analysis has been done of the cost of conserving the biodiversity of food crops in the Pacific and virtually no cost-effectiveness analysis has been attempted. This paper has identified several of the cost-effectiveness issues which need consideration.

It seems that policies to conserve the germplasm of food crops in the Pacific have focused on staple food crops. Although the focus appears to be appropriate on the basis of the economic theory outlined here, this preference also needs to be qualified. This is because food crops which are staples now may not always remain so. Minor indigenous food crops may prove to be in considerable demand in the future and so efforts to conserve their germplasm may prove to be economically valuable especially when the precautionary principle is taken into account (see, for example, Tisdell, 2010). Determining the economic value of conserving crop diversity is, therefore, a continuing but important challenge.[5]

ENDNOTES

1 *It would be useful to be able to quantify the loss of genetic variability in food crops in the Pacific, but there are inadequate available data to do this.*

2 *The Commission on Genetic Resources for Food and Agriculture (2010, p.58) in the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture states there were (at the time this report was prepared) 2,500 botanic gardens worldwide holding 80,000 plant species and 1,750 individual gene banks globally storing 7.4 million accessions of which 25-30 per cent (1.9 – 2.2 million) are distinct, that is, not duplicates. It also points out that gene bank holdings are being increasingly concentrated in fewer countries.*

3 *The International Treaty on Plant and Genetic Resources for Food and Agriculture (ITPGRFA) was intended in part, to provide a means for providing economic incentives to farmers to undertake crop variety conservation. However, it has proven to be weak or ineffective in promoting this purpose (Brush, 2007; Tisdell, 2015, Ch. 10).*

4 *It is disappointing to find that the Commission on Genetic Resources for Food and Agriculture (2010) gives no attention to the economics of conserving plant genetic resources and procedures for doing this, for instance, in gene banks.*

5 *I wish to thank two anonymous reviewers for the helpful comments in an earlier draft of this article and those who commented on a presentation of it in a seminar in the Faculty of Economics and Business in Suva at the University of the South Pacific.*

REFERENCES

Alauddin, M, and CA Tisdell (1991), *The 'Green Revolution' and Economic Development: The Process and its Impact in Bangladesh*. London: Macmillan.

Benson, W (2012), *Kingdom of Plants: A Journey Through Their Evolution*. London: Collins.

Bertram, G (2006), Introduction: The MIRAB economy in the twenty-first century. *Asia Pacific Viewpoint,* 47(1), 1-13.

Bertram, G, and RF Watters (1985), The MIRAB economy in South Pacific microstates. *Pacific Viewpoint,* 26(2), 497-519.

Brown, RPC, J Connell, and EV Jimenez-Soto (2013). Migrants' remittances, poverty and social protection in the South Pacific: Fiji and Tonga. *Population, Space and Place* psp1765. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/psp.1765/pdf. doi:DOI: 10.1002/psp.1765

Brush, SB (2007), 'Farmers' rights and protection of traditional agricultural knowledge. *World Development,* 35(9), 1499-1514.

Bynum, H, and W Bynum (2014), *Remarkable Plants that Shape our World*. London: Thames and Hudson in association with The Royal Botanic Gardens, Kew.

Commission and Genetic Resources for Food and Agriculture (2010), *Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Rome: FAO.

Coursey, D (1967), *Yams: An Account of the Nature, Origins, Cultivation and Utilisation of the Dioscoreaceae*. London: Longmans.

Denham, TP, SG Haberle, C Lentfer, R Fullagar, J Field, M Therin*, et al.* (2003), Origins of agriculture at Kuk Swamp in the Highlands of New Guinea. *Science,* 301(189), 189-193.

FAO (2004). What is Agrobiodiversity? *Building on Gender, Agrobiodiversity and Local Knowledge*. Gender and Development Service, Sustainable Development Department Retrieved from http://www.fao.org/docrep/007/y5609e/y5609e01.htm

FAO (2008), *Country Report on the State of Plant Genetic Resources for Food and Agriculture: Republic of Fiji*. Rome: FAO.

FAO (2009), *Country Report on the State of Plant Genetic Resources for Food and Agriculture: Papua New Guinea*. Rome: FAO.

FAO (undated). Food Security and the Environment. Retrieved from http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fwww.fao.org%2Fworldfoodsummit%2Fenglish%2Ffsheets%2Fenvironment.pdf&ei=ocswU56UCIifkAWr3YHwBQ&usg=AFQjCNFslMSYNGJU5O2hs8j-Wi85p0o-Fdw&sig2=W2000eZyj6emp2AS2ywYVg&bvm=bv.63587204,d.dGI

Fullagar, R, J Field, TP Denham, and C Lentfer (2006), Early and mid Holocene tool-use and processing of taro (*Colocasia esculenta*), yam (*Dioscorea* sp) and other plants at the Kuk Swamp in the highlands of Papua New Guinea. *Journal of Archaelogical Science,* 33, 595-614.

Haussmann, BIG, HK Parzies, T Presterl, Z Sušić, and T Miedaner (2004), Plant genetic resources in crop improvements. *Plant Genetic Resources,* 2(1), 3-21.

Kiple, KF (2007), *A Movable Feast: Two Millennia of Food Globalization*. Cambridge, UK: Cambridge University Press.

Kiple, KF, and K Concée (2000), *The Cambridge World History of Food*. Cambridge and New York: Cambridge University Press.

Library of the University of Hawaii at Manoa (2012a), Coconut (*Cocos nucifera*). Manoa Traditional Pacific Island Crops. Retrieved 17 February, 2014, from http://libweb.hawaii.edu/libdept/scitech/agnic/coconut.html

Library of the University of Hawaii at Manoa (2012b), Sweet Potato (*Ipomoea batatas*). Manoa Traditional Pacific Island Crops. Retrieved 17 February, 2014, from http://libweb.hawaii.edu/libdept/scitech/agnic/sweetpotato.html

Masibalavu, VT, D Hunter, M Taylor, and P Mathur (2002), Survey to determine the extent of genetic erosion of taro landraces in Fiji. Retrieved 11 March, 2014, from http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&sqi=2&ved=0CCgQFjAA&url=http%3A%2F%2Fwww.spc.int%2Ftarogen%2FDocuments%2FMisc_Publications%2FFIJIinsitu.pdf&ei=RFIeU7i_MaS1iQfdvoGwCQ&usg=AFQjCNEpFGtVZqRjwNd1VKD7pWTP_laLvA&sig2=g16gBC495n5j_JGuTOuczw&bvm=bv.62788935,d.dGI

Murphy, DJ (2007), *People, Genes and Plants*. Oxford and New York: Oxford University Press.

Pearce, DW (1998), *Economics and Environment: Essays on Ecological Economics and Sustainable Development*. Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Porceddu, E, and G Jenkins (1982), *Seed Regeneration in Cross Pollinated Species*. Rotterdam: A.A. Balkeme.

Ragone, D (2006). Conserving traditional varieties of economic plants: breadfruit, a case study. *Agroforestry.net*. Retrieved from http://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC4QFjAA&url=http%3A%2F%2Fwww.agroforestry.net%2Fevents%2Fafwksp2006%2Fpres%2FRagone_Conserving_Trad_Varieties_script.pdf&ei=E4UmU4LaCabmiAent4CADA&usg=AFQjCNEYH4QB-mDo5cV8as3wkbzMf5BQQw&sig2=kojKIouF4p-BgFALQPZy1Q&bvm=bv.62922401,d.aGc

Rao, VR, and T Hodgkin (2002), Genetic diversity and conservation and utilization of plant genetic resources. *Plant Cell, Tissue and Organ Culture,* 68, 1-19.

Renfrew, C (2007), *Prehistory: The Making of the Human Mind*. London: Weidenfeld and Nicolson.

Rix, M, and S Davis (undated), *Artocarpus altilis* (breadfruit). London Kew. Retrieved 14 February, 2014, from http://www.kew.org/plants-fungi/Artocarpus-altilis.htm

Tisdell, CA (2003), Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. *Ecological Economics,* 45(3), 365-376.

Tisdell, CA (2010), The precautionary principle revisited: its interpretations and their conservation consequences. *Singapore Economic Review,* 55, 335-352.

Tisdell, CA (2011), Core issues in the economics of biodiversity conservation. *Annals of the New York Academy of Sciences, Ecological Economics Reviews* 1219(1), 99-112. R. Costanza, Karin Limburger and Ida Kubiszewski, Eds.

Tisdell, CA (2014), Ecosystem functions and genetic diversity: TEEB raises challenges for the economics discipline. *Economic Analysis and Policy,* (44), 14-20. Available at http://dx.doi.org/10.1016/j.eap.2014.02.004.

Tisdell, CA (2015), *Sustaining Biodiversity and Ecosystem Functions: Economic Issues*. Cheltenham, UK and Northampton, MA, USA: Edward Elgar.

Tisdell, CA (2016), Models of the international economic dependence of Pacific microstates: a critical review with important implications for international policies and relations. *Journal of Self-Governance and Management Economics,* 4(2), 7-27.

Zerega, NJC, D Ragone, and TJ Motley (2004), Complex origins of breadfruit (*Artocarpus altilis*, Moraceae): implications for human migrations in Oceania. *American Journal of Botany,* 91(5), 760-766.