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The Flora and Vegetation of Pitcairn Island – its phytogeography and conservation

Naomi Kingston

Thesis submitted in fulfilment for the degree of Ph.D

to

University of Dublin, Trinity College

June 2001

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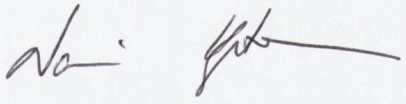

Naomi Kingston

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Abbreviations

Adv	Adventive
AFLP	Amplified fragment length polymorphism
BP	Before Present
bp	Base pairs
CBD	Convention on Biological Diversity
CCA	Canonical Correspondence Analysis
CR	Critically Endangered
Cul	Cultivated
DCA	Detrended Correspondence Analysis
DNA	Deoxyribonucleic acid
DSF	Direct Site Factor
End	Endemic
EN	Endangered
EX	Extinct
Ind	Indigenous
ISF	Diffuse Site Factor
ISSR	Inter-simple sequence repeats
IUCN	World Conservation Union
Kb	Kilobases
LAI	Leaf Area Index
LC	Linear combinations of variables
LOI	Loss on Ignition
LR	Low Risk
m.y.	million years
Nat	Naturalised
NMDS	Non-metric Multidimensional Scaling
PAR	Photosynthetically active radiation
pers. obs.	Personal observation
pers. com.	Personal communication
PIBE	Pitcairn Island Botanical Expedition 1997
PPFD	Photosynthetic Photon Flux Density
RAPD	Randomly amplified polymorphic DNA
RFLP	Restriction Fragment Length Polymorphisms
R:FR	Red to Far Red Ratio
sd	Standard Deviation
TCD	Trinity College Botanic Gardens
TSF	Total Site Factor
TWINSPAN	Two Way Indicator Species Analysis
UNEP	United Nations Environment Programme
UPGMA	Unweighted Pair Group Method with Arithmetic Mean
VU	Vulnerable
WA	Weighted average
WMIL	Wildlife Management International Limited

Summary

Good decisions cannot be made about the conservation of nature if we do not know what it is, where it is, and in what abundance. The aim of this thesis was to provide an integrated approach to the conservation of Pitcairn Island, so that educated conservation programmes could be developed in the future for the islands flora and vegetation. In order to achieve this, a step by step approach was taken for this simple island ecosystem, but one that could be expanded to suit larger and more diverse islands.

The first step was to gather baseline data on the flora and vegetation communities found on the island. This was done by carrying out a three month expedition to the island, during which species were mapped and collected, and the vegetation communities identified by means of quadrats and mapping. The flora consisted of 81 native species (including 11 endemic species), of which 30 were pteridophytes, and a further 250 introduced species. Non-native species were found right across the island, but native species dominated in the remoter valleys on the south of the island. The vegetation of was found to consist of 14 vegetation communities: 4 coastal, 6 woodland, 2 fernland and 2 scrub communities. Most of these vegetation types contained high numbers of non-native species, but in cases where there are a high number of native species, the dominant species was often an introduced taxon.

The next step involved determining the phytogeographic relationships of the flora, and this was done primarily by means of an extensive literature survey as well as contacting regional experts. The combination of plant taxa found in the Pitcairn group were most closely related to the taxa found in the Austral group of Islands to the west of Pitcairn, which were in turn derived from the flora of the South-east Polynesian biogeographic region of the Pacific. Species with a Pacific-wide distribution dominate the Pitcairn flora (21%), with Old World (20%), Worldwide (17%) and Endemic (17%) species also forming a large component of the flora, but no relationship was found between the Pitcairn flora and that of the Americas.

The third step involved the compilation of this data to make a conservation assessment of the flora and determine which species are in need of conservation, both in terms of Pitcairn Island, and in terms of their global distributions. This showed that 63% of the native flora was threatened on Pitcairn, while 22% was globally threatened. The threats to the flora were found to be not simply the loss of species, but also the loss of habitats and

genetic diversity within species. Estimation of the population size and distribution of species distinguished several species for which detailed population genetic assessments were beneficial in the development of conservation plans, and three of these species (two pteridophytes - *Angiopteris chauliodonta* and *Lastreopsis pacifica*, and one angiosperm - *Coprosma benefica*) were studied in more detail. For these species within and between population genetic variation measures were estimated by RAPD analysis. All six extant populations of the fern *Angiopteris chauliodonta* were studied, with most of the genetic variation being found within populations (57%) but with smaller populations not necessarily showing lower levels of variation than larger populations, although remote populations were less diverse. The total observed diversity in the species (H_T) was found to be 0.270, and thus not low in comparison to other rare species. In both *Coprosma benefica* and *Lastreopsis pacifica* only single populations exist, and so no between population comparisons could be made. In *Coprosma benefica* low levels of genetic variation were found in the remaining population of only 12 individuals ($H_T = 0.107$), but in *Lastreopsis pacifica* high levels of diversity were found ($H_T = 0.297$) in the population of 189 individuals.

Finally this knowledge of the distribution and conservation status of species and habitats were then combined to identify areas which could be successfully selected as reserve areas to conserve the largest number of rare species and native vegetation communities, without impinging on the activities and needs of the islanders. By employing the technique of complimentarity three potential reserve areas were identified, at Tautama, Big Ridge and Down Rope. This combination of reserves served to protect all of the native habitat types, 31 species threatened on Pitcairn, and all except two of the globally threatened species, both of which currently occur in highly degraded habitats, but could be translocated into the reserve areas.

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Chapter 1: General Introduction

1.1 Introduction to Oceanic Island Ecosystems

Island floras have been of scientific interest since European man began exploration of the oceans. Wallace in 1895 cited the importance of island floras in evolutionary and biogeographic studies, using Darwins work on the Galápagos islands, and his own work in South East Asia as examples. In a lecture to the British Association in 1866 Hooker drew attention to four characteristics of island floras: endemicity, impoverishment, dispersal and disharmony (Berry 1992). The age, position, and physiographic evolution of hotspot islands are simply and readily predictable, making them more attractive as model systems for the study of diversification (Paulay 1994).

Islands can be divided into two main types based on their formation and geological history. **Continental islands** are formed of continental rocks that have been separated from the main landmass by a rise in sea level or a geological shift, thus they retain relicts of the continental flora from when they were connected (eg New Caledonia, Ireland) (Mueller-Dombois & Fosberg 1998). **Oceanic islands** are ones which have never had connections to continental landmasses, but rather are products of volcanism or tectonic uplift, or of organic reef growth upon foundations formed by the first two processes (Mueller-Dombois & Fosberg 1998; Paulay 1994). They may grow through further volcanism, or subside, erode and disappear, and in a geological sense they tend to be transitory (Whittaker 1998). Oceanic islands may form in a linear chain as the plate moves over a stationary thermal plume (or 'hot-spot'; eg Hawaiian Islands, Austral-Cook chain), the islands may arise in isolation (eg St. Helena, Ascension Island) or the islands may form in a cluster (or 'archipelago') over an area of crustal weakness (eg Galápagos Islands, Western Canary Islands) (Whittaker 1998).

Two categories of oceanic island can be distinguished: high islands are active, dormant or extinct volcanoes, which are shaped by weathering and erosion; low islands or atolls are high islands that have subsided below sea level and have become covered by a carbonate cap. Due to changes in sea level or geological loading and flexure, atolls may become submerged (known as guyots) or emergent (known as makatea islands) (Menard 1964). These oceanic islands are essentially sterile when they arise and receive all of their biota through long-distance dispersal (Paulay 1994), with the species composition being a result of dispersal ability, age, remoteness, island size, speciation and adaptive radiation (Quammen 1996; Whittaker 1998). Thus the character of the terrestrial biota of oceanic islands is not dependent on the ocean, but on whatever source continent has ultimetely been responsible for providing the colonists (Cronk 1997). Not only do islands generally have fewer species than comparable mainland communities, but one or a few plant species are often overwhelmingly dominant in the island forests (Mueller-Dombois & Loope 1990).

Oceanic Island biotas provide excellent opportunities for biologists to study the dynamic processes of evolution and speciation (Aradhya *et al.* 1991). Island floras and faunas are of the greatest scientific interest for floristic and evolutionary studies, because of the nature of their situation and long isolation. They frequently include many endemics that have evolved in isolation and have limited distributions (Melville 1979).

1.1.1 Processes in island ecosystems

Dispersal and **migration** are distinct but complemetary processes: dispersal is the transport of propagules from one place to another; migration is the successful establishment of a species in a new area after dispersal (Tryon 1970). Migration cannot take place without dispersal, but dispersal may occur without migration. Dispersal from a source area will involve winds and currents as well as the direction, distance, size and environment of the target island (Tryon 1970). **Colonisation** differs from migration in that it involves the relatively lengthy persistence of an immigrant species on an island, especially where breeding and population increase are accomplished (MacArthur & Wilson 1967). Long distance migration involves the establishment of a new colony by dispersal to a geographically distant site (Tryon 1986). To determine if a migrant is likely to achieve successful colonisation it is necessary to be able to predict the longevity of the populations from a knowledge of basic demographic parameters (MacArthur & Wilson 1967).

Long distance plant dispersal can take place via ocean drift (hydrochory), air currents (anemochory) and animals (zoochory) (Ehrendorfer 1979). Zoochory can be subdivided into passive or epi-zoochory, where the propagule becomes adhered to the disperser, and active or endo-zoochory, where the propagules are eaten by the disperser (Ehrendorfer 1979). Ocean dispersed species are typically widespread strand plants (eg *Cocos nucifera*, *Pandanus* spp., some *Ipomoea* spp.), anemochorous species have tiny propagules that can be carried on air currents (eg pteridophyte, bryophyte & fungal spores, *Metrosideros* spp.), passive zoochorous species commonly have sticky or barbed fruits (eg *Bidens* spp., *Boerhavia* spp., *Pisonia* spp.) and active zoochorous species are usually berry fruited (eg *Ficus* spp., *Coprosma* spp., *Rubus* spp.) (Ehrendorfer 1979). Hydrochorous taxa must be capable of travelling long distances and in many cases survive prolonged periods of floating in salt water (Melville 1979). Rafting is a term applied to pieces of floating debris which may carry plant or animal propagules, plant parts or small animals across stretches of ocean (Carlquist 1965). The most important mode of arrival on Pacific high islands is internal transport in birds, in contrast to atolls, where the most important means of arrival is by flotation in seawater (Carlquist 1996).

All pteridophytes are anemochorous, and Tryon (1980) established that they are capable of being dispersed up to distances of about 1500km, and suggested that species with wider ecological amplitudes were more likely to migrate successfully to, and establish on,

oceanic islands. In addition the ecological differentiation of the life-cycle into physically separate coloniser gametophyte and persistent sporophyte phases enhances capacity for long-distance dispersal (Barrington 1993). The migration of a single spore of a homosporous fern species can result in the establishment of a new population in a distant locality, as the resulting bisexual gametophyte can undergo intragametophytic breeding (Kato 1993; Dassler & Farrar 2001). These resulting populations on isolated islands have the potential for speciation (Tryon 1986). If individuals of a species colonise a new area and remain isolated from the original population, they may eventually differentiate into a new taxon (Morrone & Crisci 1995). Brownsey (2001) argues that over 78% of the pteridophyte flora of New Zealand arose via long-distance dispersal.

Species which are hermaphrodite and self-compatible, and can produce offspring from a single founder individual will be very much better pre-adapted for island colonisation than dioecious or self-sterile species (Baker's Rule; Baker 1955). In some cases there is a breakdown of self-incompatibility or dioecy allowing succesful colonisation (eg monoecious *Coprosma* spp. in a typically dioecious genus) (Ehrendorfer 1979). There are examples however, where both male and female plants must have undergone successful dispersal (eg *Cocculus* spp. in Hawaii; *Pisonia umbellifera*) (Ehrendorfer 1979). Island floras, however, have high levels of dioecy or heterostyly, as these outcrossing species will have high levels of genetic variability, and thus be able to diversify into a wider range of available niches as would be found on oceanic islands (Richards 1997).

The **founder principle** pertains to the rare, random colonisation of a new area by dispersal of a small number of individuals of a species, containing only a small part of the genetic variation of the mother population, but sufficient to establish a breeding population (MacArthur & Wilson 1967; Rotondo *et al.* 1981). The founder principle suggests that propagules starting a new population will contain fewer alleles than the mother populations from which they originated (MacArthur & Wilson 1967), and thus represent a genetic bottleneck (Whittaker 1998). Founder populations will also be relatively homozygous due to inbreeding, and it seems that the escape from this homozygosity is an essential prerequisite for their subsequent radiation and diversification (Ehrendorfer 1979). Following colonisation a sustained low population number, with a low level of genetic variation, will increase the importance of chance alteration of allele frequencies known as **genetic drift** (Barrett & Kohn 1998). This can lead to a rapid shift to a new co-adapted combination of alleles contributing to the reproductive isolation from the original parent population (Whittaker 1998). Thus the founder principle may account for much of endemism found in Island populations (Rotondo *et al.* 1981).

There is debate over the relative importance of the founder event compared with the resulting genetic bottleneck, with some authors being more concerned with the consequences of reduction in genetic variation due to the colonising bottleneck

(MacArthur & Wilson 1967) than to differentiation produced by the founder effect (Berry 1992). However, both of these processes appear to be important in the rapid evolutionary divergence of mainland and island lineages (Whittaker 1998).

Comparisons of the frequency of heterozygosity in island as opposed to mainland populations was carried out by Frankham (1997), and found that for mammals, birds, reptiles, insects and plants there were significantly higher levels of genetic variation in mainland rather than island populations. In the same study animals capable of flight (insects, birds & bats) were shown to have less reduction in heterozygosity, while insular endemic species showed significantly reduced heterozygosity (Frankham 1997).

As a result of the chance nature of species arrival and establishment on oceanic islands, the resulting biota contains only a small proportion of the basic adaptive types found in surrounding source regions (MacArthur & Wilson 1967), with discrepancies in species and family representations (Quammen 1996). The island biotas are then described as **impoverished** as they contain less species per unit area than mainland populations (MacArthur & Wilson 1967), and **disharmonic** in that they tend to have a different balance of species compared to equivalent patches of the mainland (Whittaker 1998). This disharmony brings about adaptive radiation and high local endemism (Mueller-Dombois & Fosberg 1998).

The concept of the **taxon cycle** was first developed by Wilson in 1961 and demonstrates the idea that later-immigrating species alter the biotic environment, and thus have an important role in the further evolutionary change, niche shifts, or extinction of earlier colonists (Whittaker 1998). Community **succession** has been studied by monitoring the recolonisation of the island of Krakatau following its total sterilisation by volcanic activity in 1883 (Whittaker *et al.* 1989). 'A few blades of grass' were recorded in 1884, but coastal communities with hydrochorous species were the first to cover extensive areas (Whittaker *et al.* 1989). The development of the inland communities was more complex, but the pioneer community was comprised of wind-dispersed species, with zoochorous species arriving later, displacing the pioneer communities (Whittaker *et al.* 1989). It is widely thought, however, that equilibrium (or a climax community) has not yet been reached on Krakatau (Whittaker 1998). Equilibrium communities are rarely described in the literature, and may in fact be unusual on islands due to varying forms of environmental variability and disturbance (MacArthur & Wilson 1967).

An **endemic** taxon is one that is only found in a native state in a particular region (MacArthur & Wilson 1967). Endemicity is therefore relative based on the geographical area considered, for example a taxon which is shared between two given regions, but which occurs nowhere else is 'endemic' to both regions when considered together, but 'endemic' to neither when each area is considered separately (Rosen & Smith 1988). Endemics will however be adapted to the environment of the island on which they evolve

and may migrate readily to the other islands of an archipelago with similar environments (Tryon 1970). Island endemics fall into two categories; neo-endemics are forms that evolved *in-situ*, whereas palaeo-endemics are those which have become extinct elsewhere with a relict population being left (Cronk 1992). The presence of isolated endemic genera on islands is explained by the concept of palaeo-endemism (Cronk 1987), while neo-endemism explains the presence of closely related species on adjacent islands. Favarger & Contandriopoulos (1961) subdivide the concept of neo-endemism into three types: schizo-endemics, or those that arise through slow and progressive differentiation; patro-endemics, which are polyploid taxa that arise in the surrounding area from a narrowly distributed diploid ancestor; and apo-endemics, the opposite patro-endemics, where a narrowly distributed polyploid arises from a more widely distributed diploid taxon. Single island endemic species are generally found to have less genetic diversity then widespread species (Frankham 1997; Hamrick *et al.* 1991).

Speciation is a term used to describe the evolution of new species, and for islands can be differentiated into three main types; allopatric (or geographical speciation) when the speciation results from two populations being geographically separated, sympatric (or competitive speciation) when two populations occupy the same geographical range but become reproductively isolated due to behavioural and/or niche differences, and parapatric when there is an overlapping zone of hybridisation between the two species (Rosenzweig 1995; Whittaker 1998). Speciation in the island context is associated with long-distance migration, rather than through regional isolation or peripheral divergence (Tryon 1986). The founder effect and resulting genetic botttleneck cause rapid expansion of the population in the new site, and this rapid expansion can generate sufficient variability for rapid evolution (Barrett & Kohn 1991).

As gene flow with the source population would reduce the genetic isolation and reduce the likelihood of allopatric speciation, there is some evidence that insular endemism is positively correlated with the degree of geographic and thus genetic isolation (Tryon 1970). Differences between island populations and mainland ones are expected to be greater when the number of founders is smallest, when the population size differences are greatest, and the immigration rates are lowest (Frankham 1997). Similarly the degree of endemism decreases with rates of immigration to the island (Diamond 1984a), for example littoral habitats have low numbers of endemic species due to the high rates of immigration by the pantropical sea-dispersed species which occupy these habitats (Whittaker 1998).

Adaptive radiation is the multiplication of species (speciation) which occurs under the special circumstances that lead to the coexistence on single islands (or continents) of closely related but adatively very different species (MacArthur & Wilson 1967). Adaptive radiation is driven largely by sympatric speciation (Rosenzweig 1995). The most highly quoted example of adative radiation is that seen in Darwin's finches on the Galápagos

Islands where 13 extant species evolved from a single coloniser and radiated to fill all available niches (Whittaker 1998). Studies of adaptive radiations on islands indicate that both diversification and adaptive evolution are favoured by a low diversity of initial colonists, but thwarted in diverse biotas by the high degree of utilisation of niche space, and the presence of 'keystone' taxa (Paulay 1994). On the other hand the high proportion of endemic genera among Hawaiian insects and land snails may reflect their high population densities, hence low extinction rates, and the likelihood of many lines surviving to reach the level of endemic genera (Diamond 1984a). Post-colonisation adaptation probably plays little part in the origin of most island endemism; although natural selection affects island biotas just as much as continental ones, the main differentiation of island forms is usually the result of the chance characteristics of the original colonisers of each species (ie founder effects) (Berry 1992).

The rate of speciation and adaptive radiation is difficult to ascertain, but will vary between taxa and probably decline with time as the island accumulates species through colonisation and speciation (Whittaker 1998). Recently developed genetic analysis techniques which employ a 'molecular clock', through the assumption of a more or less constant rate of accumulation of mutations should allow the estimation of dates of lineage divergences (Avise 1994). Certain groups of species may be more successful at speciating and radiating then others, examples being finch-like birds in Hawaii and the Galápagos Islands, or plants from the family Compositae such as *Bidens* in Hawaii and the Pacific, and *Sonchus* in Macaronesia (Ehrendorfer 1979). Taxa which have the genetic plasticity to vary will be likely to do so in the oceanic island setting (Whittaker 1998). Possible plant breeding strategies favouring high speciation rates involve small effective population sizes and specialised mechanisms of pollen and/or propagule dispersal, features commonly found in the most rapidly speciating angiosperm families (Niklas *et al.* 1983). Widespread pteridophyte taxa will evolve more slowly than flowering plants, as the enormous evolutionary pressure exerted on angiosperms through their possession of flowers and fruits is virtually absent in ferns (Kramer 1993; Niklas *et al.* 1983).

Genetic divergence of a small population would be affected by the extent of genetic variation, the type of breeding system, the extent of genetic drift, the degree of phenotypic plasticity, the breath of ecological tolerance, the extent of gene flow from other populations and the stability of the environment (Tryon 1986). Intra-island speciation and radiation is restricted to islands large enough to allow effective segregation of populations within the island (Whittaker 1998).

Extinction refers to the disappearance of a species from the earth, but it is also routinely used to describe the disappearance of a species from a smaller area (Hunter 1995). It is a natural process which takes place due to species succession and compositional changes in vegetation (Spellerberg & Sawyer 1999). Four genetic factors that can contribute to higher extinction rates in island populations are: inbreeding depression, loss of genetic variation,

accumulations of mildly deleterious mutations and genetic adaptations to island environments (Frankham 1997). The reason for the susceptibility of island populations to extinction is controversial, but once the taxon's numbers have been depleted, the *coup de grâce* is usually delivered by stochastic factors, whether demographic, environmental, catastrophic or genetic (Rosenzweig 1995; Frankham 1997). Additionally island species have nowhere to migrate to if climatic or other factors alter the island habitats (Bramwell, pers comm. 2001). Recently extinction processess have been exacerbated through the activities of humans (Rosenzweig 1995). Since 1600, 171 species of bird have become extinct, with 155 of those becoming extinct from islands (Diamond 1984b in Quammen 1996). Similarly about three-quarters of all the animal species known to have become extinct since 1600 were island species (Jenkins 1992). In 1985 Gomez projected that 80% of known ferns would have disappeared in 20 years, due to the rate of tropical deforestation and the abundance of pteridophytes in tropical areas (Given & Jermy 1985; Gomez 1985). In a subsequent priority list for pteridophyte conservation Given and Jermy (1985) emphasise the need for regions to produce lists of endangered pteridophytes. Localised endemics and island floras are noted as being under high levels of threat and thus of particular importance (Given & Jermy 1985).

1.1.2 Threats to island ecosystems

Island biota and ecosystems are highly vulnerable to disturbances associated with human activities, the most serious of which are the introduction and release of grazing mammals and alien plants (Given 1981; Mueller-Dombois & Loope 1990; Paulay 1994; Wright & Lees 1996). Probably the greatest destructive force in island ecosystems is through the actions of man. This was noted by Wallace in 1895, when he discussed the destruction of St. Helena, following European discovery, due to goat trampling, forest clearance and the introduction of plant species. This anthropogenic destruction is also seen on other islands such as the Galápagos Islands (Schofield 1989), and Easter Island (Bahn & Flenley 1992). In a review of the threats to plant life, Lucas & Synge (1981) concluded that the greatest losses are likely on islands and refer to examples such as St. Helena, where the flora was largely devastated before botanical survey, and over half the known endemics are endangered. Island ecosystems are thus very vulnerable; an estimated 90% of all bird extinctions since 1800 having occurred on islands (Vitousek 1988; Birdlife International 2000). Currently one in three of all known threatened plant species are island endemics (Whittaker 1998).

Loope (in Vitousek, 1988), Cronk & Fuller (1995) and Cronk (1998) outlined some possible explanations for the observed patterns of susceptibilty of island ecosystems to biological invasions:

- species poverty; more vacant niche space
- reduced competitive ability due to repeated 'founder effects'

- disharmony of functional groups and relative lack of diversity
- small populations and low genetic variability; restrictive specialisation
- relative lack of adaptibility to change; loss of resistance to predators and disease
- loss of essential co-evolved and mutualist organisms
- relative lack of natural disturbance, especially fire, in the evolutionary history of many island biotas
- intensive exploitation by humans
- exaggeration of ecological release of alien species without their natural competitors

Simberloff (1998) suggested that the fragility of islands is partly due to structural characteristics of island communities, such as the absence of large groups of species, and the dominance of one or two species in most communities (ie disharmony). The evolutionary processes associated with isolation have meant that island species are especially vulnerable to competitors (Species Survival Commission/IUCN 2000a; Wright & Lees 1996).

Introduced species (both plant and animal), fires, pollution, tourism, mining, overfishing, destruction of aquatic resources, harbour and lagoon environments, and destruction of indigenous forest have been identified as the biggest environmental problems for Pacific Islands (Caldecott *et al.* 1996; Hamnett 1990; Heywood 1979; Soulé 1991; Wodzicki 1981; Wright & Lees 1996). These factors lead to genetic erosion through habitat destruction, degradation and fragmentation, overexploitation and changes in land use (Maxted *et al.* 1997). Climate change and climatic catastrophes also play a role in the destruction of island ecosystems (Caldecott *et al.* 1996; Maxted *et al.* 1997; Soulé 1991).

INTRODUCED SPECIES

The impacts of alien invasive species are immense, insidious and usually irreversible (Species Survival Commission/IUCN 2000a). Typically alien invasives are 'colonising' taxa that benefit from the reduced competition that follows habitat degradation (Species Survival Commission/IUCN 2000a). Introduced species threaten island biotas through habitat alteration and through interactions with native species (Paulay 1994).

Introduced species are typically plants that were introduced as a resource (eg timber trees), as an ornamental (eg *Lantana camara*), or accidentally (eg grasses introduced with crop seed or grain), and animals that were introduced by early settlers for food, pets or accidentally (eg rats, dogs, goats). Introduced species may become invasive and either crowd out native species with their monospecific stands (eg *Miconia calvescens* in Tahiti) or prey on them (eg an introduced snake (*Bioga irregularis*) in Guam has led to the extermination of the entire native bird fauna) (Paulay 1994). *Miconia calvescens* was also

found to act as a water pump, drying out the ground resulting in the death of tree ferns and understory pteridophytes (Given 1993). Invasion by *Lantana camara* is probably responsible for the extinction of at least one endemic plant species from the Galápagos islands (Mauchamp *et al.* 1998). In native forest (95% cover) in Hawaii, introduced species were found to comprise 67% of the seed in the seedbank, but only 1% of the seed rain (Drake 1998). Thus alien species tend to form persistent seed-banks, making them favourably placed to increase in abundance in the vegetation if the forest is disturbed (Drake 1998). In a study of 8 endangered species from the Galápagos islands, goats were considered to be the major threat in all cases (Mauchamp *et al.* 1998). In some cases, humans themselves act as the predatory threat to the native biota, notably in relation to large scale extinctions (in some cases up to 80%) of birds following the arrival of humans to Polynesian islands (Paulay 1994; Steadman 1997). Other threat factors such as environmental pollution and habitat destruction can provide conditions that favour introduced invasive speces (Species Survival Commission/IUCN 2000a).

LAND EROSION

Soil erosion is a complex problem, as not only does it produce sediments that can blanket other ecosystems, leading to water pollution problems, but it also degrades the productivity of the land from which the soil is eroded (Hunter 1995). Goat trampling and grazing can denude areas making them prone to erosion and landslides.

FIRES

Fires, which affect forest margins and lower slopes especially, were used in past to clear land in much of Polynesia and are a major factor in the destruction of native forest (Wodzicki 1981). Fires, probably mostly set by man, account for the large areas of Polynesian islands under fernlands and grass scrub (Fosberg 1991). Cleared areas will also be subject to erosion.

POLLUTION & OIL SPILLS

Pollution is a major problem for marine ecosystems which are affected by pesticide and fertiliser runoff, sewage and factory effluents, and are an issue on many Pacific islands such as Rarotonga and New Caledonia (Wodzicki 1981). Oil spills such as that which occurred in the Galápagos islands in January 2001 also pose a major threat to fragile island ecosystems (CNN 2001).

TOURISM

While tourism brings huge advantages to small and isolated communities, if not properly developed it can result in major ecological problems through pollution, the extra pressure exerted on natural resources and the collecting of reef coral and shells for souvenirs (Wodzicki 1981).

EXPLOITATION OF NATURAL RESOURCES

Deforestation by logging is practiced on a large scale in some of the larger island communities (eg Papua New Guinea, Fiji, New Caledonia and Samoa), or it may occur through climatic and natural factors (eg *Metrosideros sp.* dieback on the Hawaiian islands) (Mueller-Dombois & Fosberg 1998; Wodzicki 1981). Introduced species such as *Passiflora* spp. exacerbate the problem by hindering the natural regeneration of these forests (Wodzicki 1981). Similarly the resulting edge effects of habitat fragmentation worsen the problem (Lovejoy *et al.* 1986). The most obvious effects of mining on island ecosystems are seen in the devastation of phosphate mining on some makatea islands, such as Makatea and Nauru. However larger islands such as New Caledonia have suffered forest clearance and mining of soil, destroying the soil nutrient levels, causing erosion and subsequent pollution (Wodzicki 1981).

Other exploitation of natural resources is demonstrated by the problem of overfishing, especially with increased populations and with the introduction of canning industries to some island economies (eg Solomon Islands), and whaling (Hamnett 1990).

CLIMATIC THREATS

Environmental variability and sporadic environmental extremes are major hazards affecting typically benign island ecosystems (Stoddart & Walsh 1992). Vulcanicity, earthquakes, tsunamis, and cyclones can all be devastating but are episodic and spatially concentrated. Changes in sea level are more spatially widespread and occur over long periods, but can completely submerge or uncover islands, as well as causing shore erosion, disturbing the groundwater supply and consequently affecting the terrestrial vegetation and fauna (Stoddart & Walsh 1992). Variability from normal seasonal rainfall can have ecological consequences similar to sea level changes if linked to perturbations such as the El Niño phenomenon (Stoddart & Walsh 1992). In addition increased sea temperature brought about through global warming will increase the frequency of storms in the Pacific region (Emanuel 1987).

GENETIC EROSION

The reduction of species and populations, and resulting loss of genetic diversity means that plants will not be able to adapt to changing conditions quite so readily (Maxted *et al.* 1997). Inbreeding is thought in theory to increase chances of extinction of wild populations. However, it was only recently shown experimentally for butterflies that inbreeding leads to reduced reproductive success (Frankham & Ralls 1998). It has been suggested that random demographic and environmental events would drive small populations to extinction before genetic factors come into play (Lande 1988).

1.2 Conservation Biology

Conservation biology is the applied science of maintaining the earth's biological diversity (Hunter 1995). The field of conservation biology applies the principles of ecology, biogeography, population genetics, economics, sociology, anthropology, philosophy and other theoretically based disciplines to the maintenance of biological diversity throughout the world (Meffe & Carroll 1994). Biological diversity (biodiversity) means the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Species Survival Commission/IUCN 2000b).

Parties to the Convention on Biological Diversity (CBD) are enjoined to develop effective and scientifically sound protocols and methodologies to conserve biological diversity, encompassing ecosystems, species and genetic diversity (Maxted *et al.* 1997). The World Conservation Union (IUCN) prepared a World Conservation Strategy in 1980, and cited it objectives:

- to maintain essential ecological processes and life-support systems
- to preserve genetic diversity
- to ensure the sustainable utilisation of species and ecosystems

Biological conservation has two theoretically founded aims, the preservation of members of the biota (individuals, populations, species) and the preservation of the functional ecological systems (Lambeck 1997; Udvardy 1975), and conservation programmes should be guided by the biology of the species or systems that they seek to preserve (Falk & Holsinger 1991). In addition, effective conservation management is impossible without knowledge of the biodiversity it seeks to conserve (Soulé 1991).

1.2.1 Species based conservation

Species become rare by several pathways, and the evolutionary and ecological consequences of rarity are diverse (Rabinowitz 1981). Three aspects of the situation of a species relate to its rarity, those being: geographic range, habitat specificity, and local population size (Rabinowitz 1981). Combinations of these factors result in 8 categories of abundance of which 7 describe some form of rarity (table 1.1) (Rabinowitz 1981). One of these categories can be applied to all species.

Table 1.1 - A typology of rare species based on three characteristics; geographic range, habitat specificity, and local population size (from Rabinowitz, 1981).

Geographic range		Large		Small	
Habitat specificity		**Wide**	**Narrow**	**Wide**	**Narrow**
Local Population Size	Large, dominant somewhere	Locally abundant over a large range in several habitats	Locally abundant over a large range in a specific habitat	Locally abundant in several habitats but restricted geographically	Locally abundant in a specific habitat but restricted geographically
	Small, non-dominant	Constantly sparse over a large range and in several habitats	Constantly sparse in a specific habitat but over a large range	Constantly sparse and geographically restricted in several habitats	Constantly sparse and geographically restricted in a specific habitat

Genetic diversity of a species occurs at four levels of organisation: among species, among populations, within populations and within individuals (Hunter 1995). The number, size and age of individuals all effect the genetic structure and dynamic of populations (Hartl & Clark 1997; Lande & Barrowclough 1987). The amount of genetic variation present is what facilitates adaptation to changes in the environment and thus evolution to occur (Hunter 1995; Lande & Barrowclough 1987). Low diversity in populations and species with restricted geographic ranges can leave the species at risk from inbreeding depression and thus susceptible to disease epidemics or environmental change (Huenneke 1991). Assessment of these demographic factors allows the evaluation of a populations breeding size, vulnerability to extirpation (Gilpin & Soulé 1986), or loss of genetic variation through inbreeding (Hartl & Clark 1997).

The goal of species conservation is to maintain the evolutionary potential of species by maintaining natural levels of diversity. This can only be done if the level of genetic variation of a species is known. Genetically effective management changes between species, and so for any plan to be drawn up there must also be a detailed knowledge of the species' natural history (e.g. ecology, breeding system, life-history). Any recovery or management plan drawn up without this information will be subject to error (Hamrick *et al.* 1991).

Partitioning of genetic diversity within and between populations is a major contribution towards evaluating population viability, as it allows assessment of the amount of gene flow in and among the populations, and the distinguishing of which populations are the most depauperate (genetically), fragmented, or closely related (Haig 1998). Reduction in population size will dramatically reduce the genetic diversity within the species, slowing recovery rates and making full evaluation of the consequences of the reduction difficult (Mauchamp *et al.* 1998). In addition reduced population sizes can result in breeding between close relatives leading to a reduction in fitness, known as **inbreeding depression** (Barrett & Kohn 1991). Similarly a loss of fitness due to hybridisation of rare species with closely related but more common species can lead to **outbreeding depression** (Barrett & Kohn 1991).

Population viability is affected by stochastic effects which can be categorised into 4 classes: demographic, environmental, and genetic uncertainty, as well as natural catastrophes (Shaffer 1987). Demographic stochasticity is uncertainty due to random or seasonal variation in reproductive success and survivorship at the individual level; environmental stochasticity refers to random variation in parameters that measure habitat quality, such as climate, nutrients, water and pollutants; genetic stochasticity is random variations in gene frequencies of a population due to genetic drift, bottlenecks, inbreeding and other effects; natural catastrophes are specific events such as droughts or cyclones that occur at random intervals (Hunter 1995).

The **minimum viable population** (MVP) of a species is the threshold number of individuals that will ensure that the population will persist in a viable state for a given interval of time (Gilpin & Soulé 1986). Some species are naturally rare and thus the size of the mimimum viable populations may be rather small and extremely dependent on the species (Soulé 1987). It can be helpful to estimate the Minimum Viable Populations (MVP) for survival of a species before effective recovery plans can be formulated (Whittaker 1998), but as the MVP is difficult to assess and varies between species due to differing habitat requirements and life strategies, viability assessments are complex, time consuming and often inaccurate. In theory in the assessment of the MVP for a species, the aim is to ensure that the population is large enough to ensure a 95% probability of persistence for 100 years (Whittaker 1998). To quickly assess the MVP it is necessary to look at several factors for the species under study (Menges 1991):

- Threats to in-situ populations
- Genetic variation across the species range and within populations
- Phenotypic plasticity and microhabitat requirements
- Viability of populations, and their life histories

The 'effective population size' could be added to this list, as the size of the breeding population is rarely equal to the total population size (Barrett & Kohn 1991).

One attempt to determine a standard from which to define the MVP for species was known as the 50-500 rule, and based solely on genetic grounds (Franklin, 1980, in Hunter 1995). An effective population size of 50 was thought to be the MVP that would avoid problems associated with inbreeding, while 500 individuals would ensure that the population retained enough genetic variability to evolve in step with changing environments (Frankel & Soulé 1981). Initially this rule was widely accepted, but was later disregarded on the basis that it assumed 'genetic uniformitarianism' (Frankel & Soulé 1981). It is now generally accepted that the MVP varies greatly across species and depending on the circumstances facing each population, and their ecological traits that impact the distribution of genetic variation (such as population size, degree of isolation,

pollination and seed dispersal mechanism) (Hamrick *et al.* 1991). Similarly, establishing the minimum viable populations sizes on genetic grounds alone is inadequate, as demographic factors are ultimately more likely to cause the extinction of a species (Holsinger & Gottlieb 1991; Lande 1988).

There has been much effort placed on developing models for estimation of minimum viable populations (see Soulé 1987), but these models tend to be over simplified and thus omit essential features of the biological problem at hand, especially in that they rarely can account for both genetic and demographic forces (Ewens *et al.* 1987).

Management of a particular species should incorporate details of the species ecology, especially its life history and demography, which may require larger populations than has been suggested on genetic grounds alone (Lande 1988). Good conservation policies must be based on the sound understanding of the biology of the particular species and of the factors mitigating against its natural survival (Rossetto *et al.* 1995). The primary conservation goal should be to establish self-sustaining populations whenever possible, if necessary using ecological manipulations to minimise inbreeding and maximise genetic variability within populations (Holsinger & Gottlieb 1991; Lande 1988).

METHODS IN SPECIES CONSERVATION

Ex-situ conservation is the conservation of species outside of their natural range, while *in-situ* aims to conserve species within their natural habitat. Therefore the two methods are complementary and reinforce one another (Brown & Briggs 1991). *Ex-situ* plant collections are generally held in botanic gardens or in long term storage facilities as seed or in tissue culture (Brown & Briggs 1991).

Propagation of endangered species in captivity can contribute significantly to global conservation efforts, but maintaining plants *ex-situ* is essentially implementing a safety first policy, and should not be seen as an excuse for avoiding the *in-situ* conservation of plants in their natural habitat (Synge 1979). The limited facilities available in botanic gardens will not be able to combat against random genetic drift and selection that is inevitable in artificial environments (Lande 1988), and for some taxa (eg humidity sensitive pteridophytes) it is very difficult to replicate the habitat conditions required by the species (Wagner 1995). As such *ex-situ* conservation should be carried out when it does not impinge on the funding available for managing biodiversity in the wild (Caldecott *et al.* 1996). *Ex-situ* conservation strategies require controlled breeding to combat against outbreeding depression (between distinct populations or species) and inbreeding depression (many plants can self-fertilise) (Barrett & Kohn 1991). *Ex-situ* collections can be used to increase numbers for reintroduction plans that will be used to enrich wild populations, to grow live plants from seed collections for study, and as a last resort against total extinction (Brown & Briggs 1991).

In-situ conservation strategies are ideal in that they conserve the species in its natural habitat and thus perpetuate the integrity of gene pools and of coevolutionary relationships (Millar & Libby 1991). Preservation of plants in their natural habitats should be regarded as the mainstay of plant species conservation, but it is a complex task and will primarily rely on the delimitation of preserve areas and thus tie in with habitat based conservation (Given 1994). This integrated species and habitat conservation is discussed with nature reserve selection in section 1.2.3.

Reintroduction is the deliberate establishment of individuals of a species into an area and/or habitat where it has become extirpated with the specific aim of establishing a self-sustaining population for conservation purposes (Maunder 1992). Where a single threatened population is vulnerable to extinction, the establishment of a second population at a similar site acts as an insurance against its extinction (Maunder 1992). This requires some knowledge of the species ecological requirements (Maunder 1992). *In-situ* conservation programmes should also aim to conserve the nearby pollinator populations and propagule disperser populations of the species (Karron 1991), as well as mutually evolved species.

As conservation is essentially a 'crisis discipline', with neither time nor economic resources on its side, it is necessary to prioritise species based on a measure of their value (charismatic ecologically or economically important), genetic distinctiveness and the degree of threat (Hunter 1995; Maguire 1987; Holsinger & Gottlieb 1991). With a large agenda and limited resources, conservation biologists have to be efficient strategists, and this often leads to the targeting of certain species to advance the overall goal of maintaining biodiversity (Hunter 1995). As the requirements of individual species are characteristics of the landscape in which they occur, an efficient means for meeting the needs of all species without studying each one individually has to be found (Lambeck 1997).

Flagship species are charismatic species that are commonly used in conservation strategies that seek the support and sympathies of the general public (Hunter 1995). Examples would be the use of the Giant Panda bear as a logo by the World Wide Fund for Nature (WWF). **Umbrella species** are species which have large home ranges, and thus by protecting enough habitat for their populations, adequate habitat for many other species will also be protected (Hunter 1995). Flagship species are often good candidates for umbrella species (Hunter 1995). However centering large reserves on umbrella species may lead to large gaps in the overall protection of biodiversity (Kerr 1997). **Indicator species** are species which have such a narrow ecological tolerance that the size and health of their populations is a good indication of the environmental conditions (Hunter 1995). Many birds, lichens and aquatic invertebrates are examples of indicator species. **Keystone species** are species that are of greater importance than would be predicted from their abundance (Hunter 1995; Simberloff 1998; Terborough 1986) - species that are at the

top trophic level. The recognition that some ecosystems have keystone species whose activities govern the well-being of many other species suggests an approach that may unite the best features of single-species and ecosystem management (Simberloff 1998). Soulé & Simberloff (1986) advocate an approach to the design of nature reserves that is based on keystone species instead of species diversity itself, as such high priority to multi-purpose (multi-species) reserves, save on cost and manpower.

Species based approaches to conservation have been criticised on the grounds that they do not provide whole-landscape solutions to conservation problems, and that they use up a disproportionate amount of conservation funding (Lambeck 1997). It has also been argued that single species based conservation management is not only expensive and inefficient, but is impossible because the species exists only as part of the ecosystem (Simberloff 1998).

1.2.2 Habitat based conservation

From a conservation standpoint, ecosystems have a critical strategic role because protecting a representative array of ecosystems will protect biodiversity at the species and genetic level to a significant extent (Hunter 1995). Some authors feel that the only way to deal with the challenge of conservation is to manage at least entire ecosystems, if not whole landscapes, by unified methods designed to save all of their inhabitants at one time (Simberloff 1998). Maintaining ecosystem diversity also requires maintaining the spatial arrangements in which the ecosystems occur (ie landscapes) (Hunter 1995). Thus the key feature is a focus on ecological processes rather than individual species (Simberloff 1998). More work needs to be done to find out what fraction of rare plants are rare because their habitats are rare or destroyed (Holsinger & Gottlieb 1991).

Habitat based conservation thus places a greater emphasis on the relationship between species diversity, species richness and landscape processes (Lambeck 1997). Plants are best conserved in their native habitats and thus the priority must be preservation of intact ecosystems, not only for the well-being of the plant species they contain, but also for the maintenance of the essential processes they support (Synge 1979).

Fragmentation is defined as the breaking apart of habitat, but does not necessarily imply loss of habitat (Fahrig 1998). Fragmentation has major implications in habitat conservation as it can result in large environmental changes to an ecosystem (Whittaker 1998). Table 1.2 lists some of the environmental changes, notably to habitat edges, that can occur following fragmentation.

Table 1.2 - Classes of edge related changes triggered by the process of forest fragmentation. The first-order effects may lead to second-order effects and, in turn, third-order effects (from Lovejoy *et al.*, 1986)

Class		Description of change
Abiotic		Temperature
		Relative humidity & water table
		Penetration of light
		Exposure to wind
Biological	First-order	Elevated tree mortality (standing dead trees)
		Treefalls on windward margins
		Leaf-fall
		Increased plant growth near margins & depressed bird populations near margins
		Crowding effects on refugee birds
	Second-order	Increased insect populations
	Third-order	Disturbance of forest interior species, but increased population of light-loving species
		Enhanced survival of insectivorous species at increased densities (except birds)

Selecting sites for conservation involves weighing multiple criteria such as size, representativeness, rarity, condition and feasability (Hunter 1995). Ecosystem processes are usually maintained even once a species has been lost from an ecosystem (Simberloff 1998), so while the ecosystem and landscape will remain, the species that comprise them may be reduced in diversity, and species lost.

Lambeck (1997) proposed a multi-species approach for conservation, in order to maintain the composition and configuration of habitats and meet the needs of the species present requiring conservation. This approach builds on the idea that there are 'focal' species whose compositional and spatial attributes must be present in the landscape for successful management regimes, and thus whose requirements encapsulate those of an array of additional species (Lambeck 1997). For example, the species most deleteriously affected by invasion of introduced species would be identified and used to define the level of weed control required (Lambeck 1997). This differs from approaches which use the 'keystone' species concept, in that a suite of taxa at risk are identified and management regimes appropriate to them are implemented, rather than regimes appropriate to the dominant, but not necessarily most threatened, taxa in the habitat (Lambeck 1997).

The Queensland National Parks and Wildlife Service has successfully employed a technique known as gap analysis, whereby once the vegetation communities of an area have been fully mapped, any vegetation communities that lie outside of protected areas, overlayed onto these maps, are identified and given high priority for conservation (Burley 1988). Gap analysis has also been used in Andean cloud forests to identify particular areas that should be put under some form of protective management (Burley 1988).

1.2.3 Integrated species and habitat conservation

Integrated species and habitat based conservation combines the need for measures of the number of species and their relative abundance in a sample (Vane-Wright *et al.* 1991). This involves the delimitation of three diversity measures; alpha diversity, or the species richness of a site; beta diversity, or the differentiation between communities along habitat gradients; gamma diversity, or the product of the alpha diversity of communities and the degree of beta differentiation among them (Whittaker 1972).

The most inclusive way to achieve successful integrated habitat and species conservation involves the designation of nature reserve areas. There is a large body of literature and an unresolved debate relating to the best methods for reserve selection and design, and the percieved purpose of the reserve (Diamond 1975; Simberloff & Abele 1976; Given 1994; Kerr 1997; Mittermeier 1998; Simberloff 1998). Given (1994) outlines the various considerations for designating protected areas:

- size and shape - large enough to ensure the survival of all species types and the maintenance of ecological processes; compact with biologically meaningful boundaries and contiguous natural communities.
- edge effects, buffer zones and core areas - low edge to core ratio; attention to habitat restoration between reserve areas; adequate buffer zone delimitation with monitored traditional agriculture.
- representativeness - include 'hotspots of endemism' and 'hotspots of biodiversity'; encompass year-round habitat requirements for represented species
- local traditional, cultural and economic factors - employ local staff and managers; ensure direct benefit to the local community; incorporate tradiational husbandry and management if possible; provide adequate compensation when necessary.
- management - adequate training of local managers; allow for manipulative management if necessary.

Pressey *et al* (1994) add efficiency, flexibility and irreplaceability to this list of considerations. Efficiency in that the selected reserves should complement each other, flexibility relating to the large number of potential options for constructing representative reserve networks and irreplaceability as an recognition that certain sites are essential to the reserve network.

In the past reserve selection has been opportunistic and *ad hoc*, and as such has rarely achieved representativeness or efficiency (Pressey *et al* 1994). Recently researchers into reserve selection have developed computer generated models, which utilise an iterative approach to select the most appropriate areas for species and habitat protection most efficiently. Reserve selection is therefore carried out in a stepwise manner based on how well the new site complements the existing reserves, and avoiding any unnecessary

duplication (Pressey *et al* 1994). This concept of **complementarity** was developed to identify the optimally efficient, single-site sequences of priority areas (Vane-Wright *et al.* 1991), and offers the advantages of flexibility, efficiency and explicitness over other methods (Margules *et al.* 1994). In practical terms this involves two basic rounds of analysis; first, recognition of global priority areas by taxic diversity techniques; secondly within any such area, analysis without taxic weighting, to identify a network of reserves to contain all local taxa and ecosystems (Vane-Wright *et al.* 1991). Recently advocates of complementarity have suggested that using indicator species based complementarity for reserve selection reaches a compromise between maximising non-target species gains and minimising land-use requirements (Rebelo 1994; Reyers *et al.* 2000).

The identification of so called 'hotspots of diversity', or areas which are particularly rich in species are increasingly being delineated to help set priorities for conservation (Reid 1998). Similar techniques can also be used to identify 'hot spots of endemism' or hotspots of endangerment' (Reid 1998).

1.2.4 Island conservation

The protection of the unique biological features of island ecosystems presents a considerable challenge not only ecologically, but also because of the fragmented nature of the resource, scattered across all parts of the globe and all political systems (Whittaker 1998). In terms of plant biodiversity, the islands of the world make a disproportionate contribution for their land area and are suffering disproportionate pressure in terms of maintenance of that biodiversity (Whittaker 1998). Oceanic islands can serve as model systems for addressing fundamental questions about biodiversity and conservation: which areas are most likely to develop high species diversity and endemicity, and what makes a particular species or biota vulnerable to extinction (Paulay 1994).

Priorities for conserving wild plant species include the following (from WWF & IUCN 1989, in Caldecott 1996):

- Rare and endangered species
- Economically important species
- Species needed for restoring or rehabilitating ecosystems
- Keystone species whose loss would cause other extinctions
- Taxonomically isolated species with a high degree of uniqueness and scientific interest

Initial conservation actions should aim to remove or reduce the factors which threaten the species or habitat, and then to take steps towards species and habitat improvement and protection. Steps to reduce the effects of biological invasions and protect some of the native biological diversity on isolated oceanic islands involve (Vitousek 1988):

- the identification of taxa most likely to threaten native ecosystem and concentration of control efforts on these species
- selection of critical habitat areas from which most or all species of aliens are excluded
- protection of areas from further habitat destruction

Biological control is the term given to pest control not by chemical means but by the introduction into the environment of an organism that targets the pest species without affecting other non-target species (Whittaker 1998). It is vital that screening and testing are undertaken, however, as in some cases the introduced control agent becomes a pest itself (Gould 1993). In addition biological control is not always very successful, with only 50% out of 70 control programmes in Hawaii being successful (Cronk & Fuller 1995; Whittaker 1998). The commonly quoted example of biological control gone wrong is that which caused the extinction of 7 species of snail (*Partula* sp.) on the island of Moorea in French Polynesia. *Achantina fulica* had become an agricultural pest on the island following its introduction for food in 1967. *Euglandina sp.*, a carnivorous snail, was introduced as a control measure in 1977, but rather than attack the *Achatina fulica*, it had by 1988 caused the extinction of all 7 of the endemic *Partula sp.* (Gould 1993).

Successful eradications and some control programmes can significantly improve the likely success of re-introductions of native species, and thereby provide opportunities to reverse earlier losses of native biological diversity (Species Survival Commission/IUCN 2000a).

One of the most successful species recovery programmes to be undertaken in the Pacific is that of the Kakerori (*Pomarea dimidiata*), an endemic bird from Rarotonga. The species was thought to have become extinct in the early 1980's due to predation by rats (*Rattus* spp.), until 29 individuals were found in 1989 (Wright & Lees 1996). Since then due to an intensive recovery program involving habitat protection, predator control, public awareness and monitoring, the population number has increased to 100 individuals, and the population has survived two seasons of adverse conditions which could have rendered the species extinct if the recovery program was not in place (E. Saul pers comm. 2000; Robertson *et al.* 1994).

SUSTAINABLE DEVELOPMENT OF ISLAND ECOSYSTEMS

As islands present very specialised environments (Hess 1990), solutions to the ecological and developmental problems of islands require solutions that are tailored to the islands and not simply exported from the continents (Whittaker 1998). As well as major environmental problems (section 1.1.2), island communities face major social problems such as rural depopulation and the movement of young people to either the islands urban centres, or mainland communities (eg more Cook Islanders live in Auckland, New Zealand than on the Cook Islands) (Hamnett 1990). Conservation programmes are

unlikely to be a success unless the local human community is fully involved and supportive of such actions (S. Waldren, in press). Conservation activities should be implemented in tandem with development of agricultural services to relieve the need to exploit the environment of species under threat, and also with community development programmes to ensure that local people are involved at all stages of the project (see table 1.3) (Caldecott *et al.* 1996).

Table 1.3 - Sustainable development options for small islands should aim at increasing self-reliance, and can be categorised under six basic headings (from Hess, 1990)

Categories	Examples
Resource preservation	Conservation zones, multiple-use options, control of hunting
Resource restoration	Replanting, reintroductions, alien herbivore removal
Resource enhancement	Freshwater re-use, sea-water desalination
Sustainable resource development	Small-scale diversified, closely managed forms of resource-based enterprises (agriculture, fisheries, tourism)
Provision of human services	Alternative energy generation sources and distribution systems, waste disposal
Non-resource-dependent development	Financial services (tax havens), light industries processing imported materials, rental of fishing rights

1.3 Biogeography

Biogeography is the study of the geographical distributions of organisms and of the factors which affect geographical distributions (Rosen & Smith 1988; Spellerberg & Sawyer 1999). Biogeographic research was the key to developing the theory of evolution and is important today in the fields of conservation and biodiversity, in that we cannot make good decisions about the conservation of nature if we do not know what is there and where it is (Spellerberg & Sawyer 1999).

Biogeography can be divided into historical and ecological biogeography, where historical biogeography aims to reconstruct the sequences of origin, dispersal and extinction in terms of geological events, while ecological biogeography tries to account for the distribution of extant species (Myers & Giller 1988). These two main areas of biogeography are not mutually exclusive and overlap considerably (Rosen 1988). Phytogeography refers to the biogeography of plants and zoogeography refers to the biogeography of animals (Spellerberg & Sawyer 1999).

Morron and Crisci (1995) outline the 5 basic historical biogeographic methods as: dispersalism, phylogenetic biogeography, panbiogeography, cladistic biogeography and parsimony analysis of endemicity. Over the last decade historical biogeographers have been divided into two camps, those that support dispersal biogeography and those who argue for vicariance biogeography (Rosen & Smith 1988). Dispersalism derives from the traditional concepts of centre of origin and dispersal, while vicariance deals with the appearance of new species as a result of a biogeographical barrier (Rosen & Smith 1988). Traditionally dispersalism has been a descriptive biogeographic method, while other methods have employed compatibility, cladistic and phylogenetic techniques (Humphries & Parenti 1999; Morrone & Crisci 1995).

Phylogenetic biogeography applies rules of progression and deviation to elucidate the history of the geographical distribution of a group (Morrone & Crisci 1995). Panbiogeography involves plotting distributions of different taxa onto maps, connecting the distributions together, and looking for generalised tracks among taxa (Morrone & Crisci 1995) and as such it emphasises the importance of the spatial dimension in understanding evolutionary patterns and processes (Craw *et al.* 1999). Cladistic biogeography assumes a correspondence between taxonomic relationships and area relationships, and uses different taxa which show similar distributions to obtain general area cladograms (Humphries & Parenti 1999; Morrone & Crisci 1995). Panbiogeography and cladistic biogeography fall under the category of vicariance biogeography (Spellerberg & Sawyer 1999). Parsimony analysis of endemicity classifies areas by their shared taxa according to the most parsimonious solution (Morrone & Crisci 1995; Rosen & Smith 1988). Most recent studies have acknowledged that the various methods are not mutually exclusive, but should be integrated into a single biogeographic approach to resolve the problem under study (Morrone & Crisci 1995; Spellerberg & Sawyer 1999). The geographical and taxonomic processes discussed in section 1.2.1 provide a framework

within which many of the ideas of biogeography can be seen to be complementary rather than opposing theories (Whittaker 1998).

1.3.1 Island biogeography

While many scientists had speculated on the paucity of remote island biotas and the reasons for this (Carlquist 1965; Darlington 1965), island biogeography theory was first tested quantitatively by MacArthur and Wilson (MacArthur & Wilson 1967). They suggested that islands illustrated a dynamic equilibrium model, based on the idea that the number of taxa was determined by the rates of immigration and extinction, so species number remained constant, but species composition changed. They also looked at the effects of isolation, island size, competition and the role of chains of islands providing colonisation 'stepping stones', resulting in fringing archipelagos having higher species richness than oceanic islands.

The 'equilibrium theory of island biogeography' (ETIB) sought to explain diversity in terms of species-area relationships, showing that increased island size accounted for an increased number of species on larger islands, and that increased distance from the principal source resulted in a reduced number of species (MacArthur & Wilson 1967). The model accounted for the impoverishment and disharmony of distant insular biotas (MacArthur & Wilson 1967).

The authors were aware of the limitations of using area rather then habitat diversity in their analysis (MacArthur & Wilson 1967; Whittaker 1998). However, as reliable habitat information was unavailable they used area instead, as in many cases area allows a large enough sample of habitats (Brown 1988; MacArthur & Wilson 1967). In fact one of the examples used in the formulation of the theory (the numbers of bird species on Aegean Islands) showed that the availability of habitats accounted for the greatest part of the variation with little residual distance or area effect (MacArthur & Wilson 1967). The bird recolonisation of Krakatau (see section 1.2.1) was used in the formulation of the ETIB and appeared consistent, but the plant data was found to be a poor fit to the theory (MacArthur & Wilson 1967). More recently it has been decided that the island has not yet reached equilibrium and that that a more complex successional model is what is actually needed to account for the Krakatau data (Whittaker 1998).

Criticisms of the theory have included that it ignores habitat and treats species as interchangeable units, that it assumes ecological systems are in equilibrium when in reality equilibrium may never occur, and that it ignores successional effects and the role of environmental change (a review of the theorys' main criticisms is in Whittaker 1998). One of the major debates surrounding the ETIB was whether it could be used in the design of nature reserves - i.e. whether one large nature reserve would be better then several small nature reserves (Diamond, 1975; Simberloff & Abele, 1976; the debate is reviewed in Quammen 1996).

1.4 Site Description

The Pitcairn Islands are located in the South Pacific ocean, just south of the Tropic of Capricorn, and about half way between New Zealand and South America (25°4'S 130°06'W; see figure 1.1). The group is made up of four Islands; Pitcairn, a relatively young, high volcanic island; Henderson, an uplifted atoll, the uplift caused by the eruption of Pitcairn; and two atolls, Ducie and Oeno. The group is extremely remote, being seperated from both New Zealand and South America by over 4500km, from Easter Island, the nearest neighbour to the east, by 1570km and from the Gambier Islands to the west by 450km.

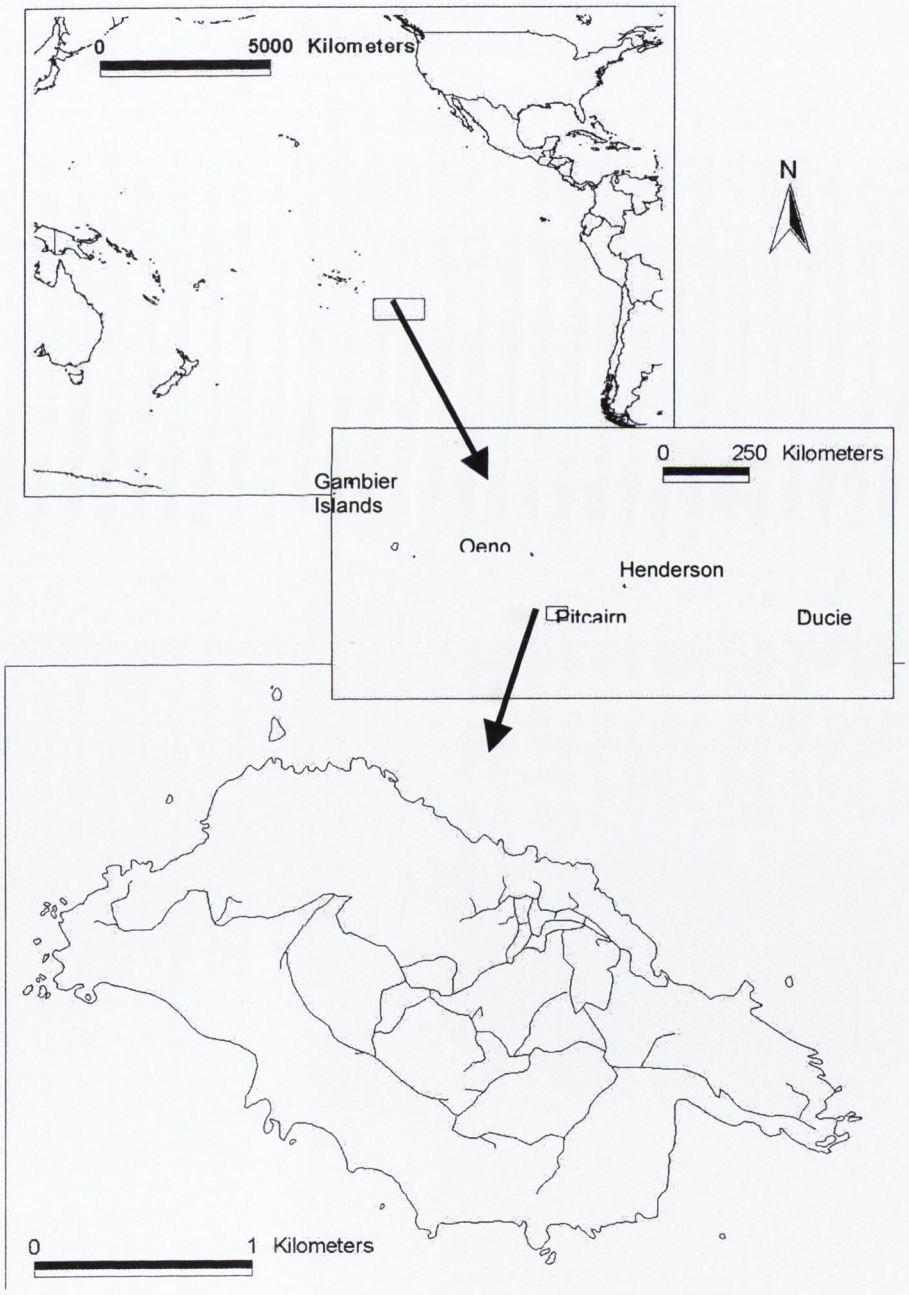


Figure 1.1 - The location of Pitcairn Island. The top map shows the islands location in terms of the Pacific, the central map shows the Pitcairn group of islands and some nearby island groups, and the third map shows Pitcairn Island itself (roads are marked on the map).

Pitcairn Island is very small, being only 4x2 km², and with the highest point at 347m. As the island is of volcanic origin its terrain is very rugged, with the soil being derived from volcanic ashes, and the underlying rock types formed of consolidated ash (Twyford 1958). Four different volcanic episodes account for varying ash substrates across the island (Carter 1967; Spencer 1995). The island is not protected by a fringing reef, causing the coast to be surrounded by cliffs with very few small boulder beaches. On the south of the island these cliffs and steep slopes reach almost to the highest point at 347m.

From the highest point in the south west across to the north east, the terrain is more gradually sloping, and the cliffs below Adamstown are much lower (c. 50m; plate 1.1), and lower again at St. Pauls Point (c.20m; plate 1.2). The only area with low coastal cliffs (c.30m) on the south of the island is at Tautama. A flat area known as Aute Valley covers a considerable portion of the south east corner of the island, at an altitude of approximately 180m. Tedside is used as general name for the area to the west and north-west of Big Ridge and Garnets Ridge, although it is actually comprised of several small valleys. It slopes from High point right down to a beach, which is also occasionally used as a harbour and may have be the location of the main Polynesian occupation.

Overall only about 10% of the island is flat land, an area of about 550 hectares, the remainder being at a 20-45 degree angle, and much steeper in some of the remoter valleys. Another 160 hectares are on slopes suitable for some cultivation, although the plots on such slopes are subject to erosion. Figure 1.2 shows the topography of the island, and the localities of any placenames used in the text of this thesis.

1.4.1 Geology

The Pitcairn Island group has a complex tectonic history with Oeno, Henderson and Ducie forming progressively at a 'hotspot', now south of the Easter Island plate, c.16m.y., 13m.y. and 8m.y. before present respectively (Spencer 1989). In all three cases the cessation of volcanism was followed by subsidence and the development of a carbonate cap. Pitcairn formed more recently (c.0.75-1m.y. BP) at a separate 'hotspot', but through the process of lithospheric flexure, the activity caused the uplift of Henderson island. Basaltic lava dating shows that the high islands of the Gambier group (5.2-7.2m.y) and the Tuamotu island of Mururoa (6.5-8.4m.y.), to the west, formed at the same 'hotspot' as Pitcairn (Spencer 1989). Farther east from Pitcairn along the same 'hotspot' alignment there are over 20 underwater volcanic edifices (seamounts), the shallowest of which is only 60m below sea level (Binard *et al.* 1992). Pitcairn is migrating along this alignment at a rate of 12.7(+/-5.5)cm per year (Duncan & Clague 1985). The young geological age of Pitcairn may account for the lack of fringing reef, a feature commonly associated with volcanic islands in south-east Pacific.

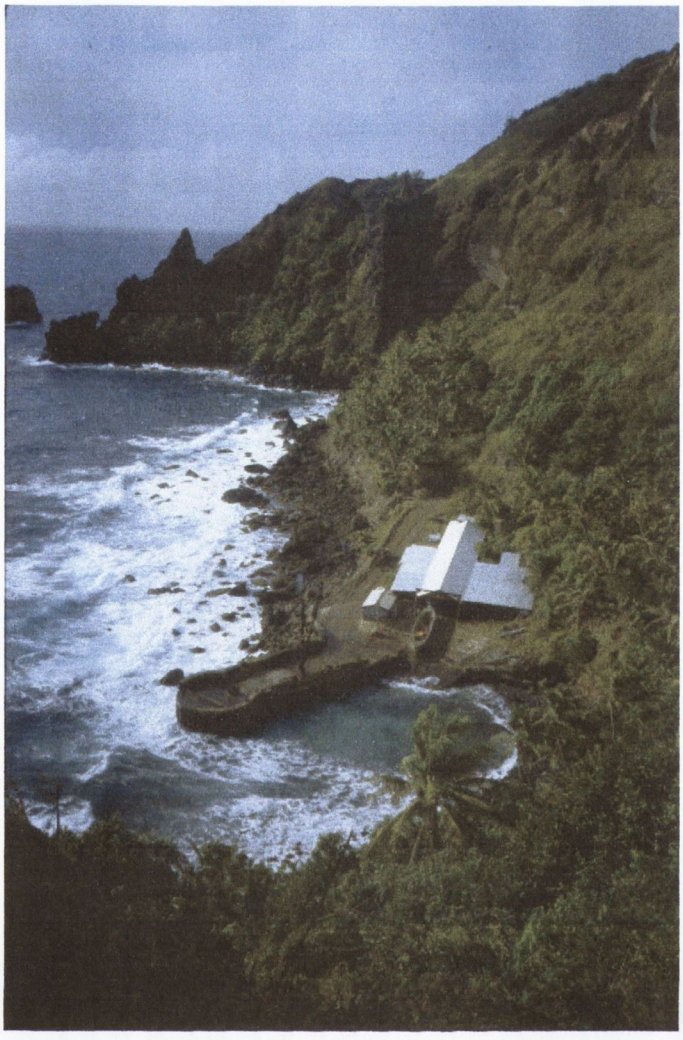


Plate 1.1 - Overlooking the main landing point at Bounty Bay from Adamstown, on the north-east of the island.

Plate 1.2 - Cliffs from Down Rope across to St. Pauls Point, showing typical steep cliffs from the south of the island. Note the lack of a protective fringing reef.

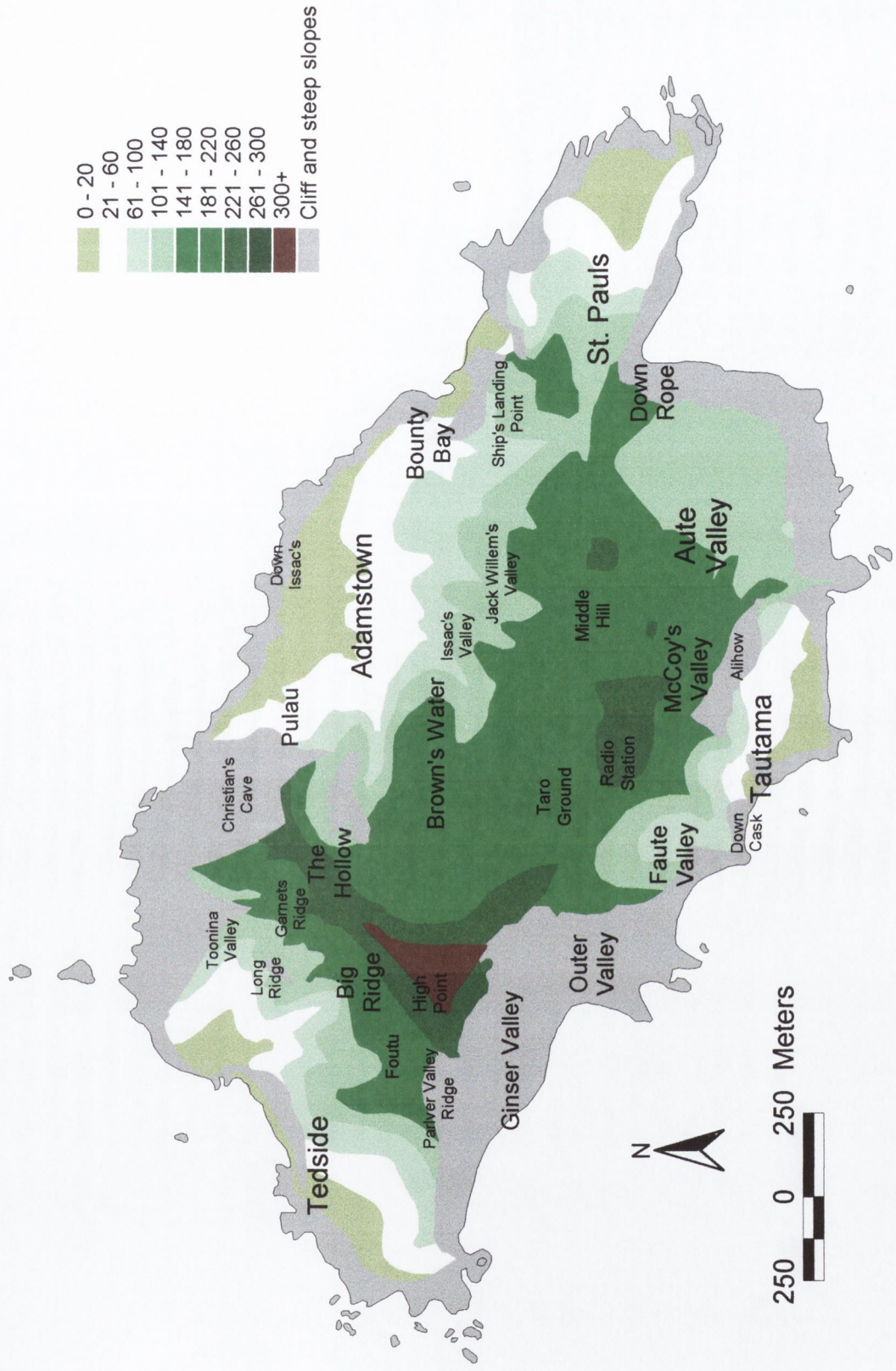


Figure 1.2 - Map of Pitcairn to show the location of any placenames used in the text of this thesis. Colours indicate the topography of the island.

Twyford (1958) carried out a detailed soil survey of the island, and identified three main soil suites; the Pulau suite, Adamstown suite and Taro Ground suite. The Pulau suite of soils were derived from tuffs, ashes and tuff agglomerates, the Adamstown suite from basaltic lavas, and the Taro Ground suite from iron-rich basaltic lavas and agglomerates. All of the soils were deep and fertile, but with major erosion in parts, and Twyford (1958) warned about the potential problems associated with erosion due to inappropriate land use and goat damage.

1.4.2 Climate

The climate of Pitcairn is sub-tropical. Mean annual rainfall is about 1716 mm, but with considerable annual variation. Mean temperatures range in summer from 17-28°C, and in winter from 13-23°C, with winter being wetter and windier (Spencer, 1995; Pitcairn Island Miscellany). There are no permanent springs on the island, but during wet periods streams run down the centres of several valleys. As for the rest of this region of the south Pacific, the trade winds blow from the south east, and Pitcairn is affected by complex climatic patterns which affect the whole of the Pacific region.

Sea currents in the south Pacific circle in an anti-clockwise direction, running west along the equator, south past New Zealand, east in the very south and north along the west coast of South America (Whittaker 1998). Pitcairn lies in the centre of this area and so recieves warm currents predominately from the north.

Pitcairn, like other oceanic high islands, has a leeward and a windward side, with the leeward side being generally drier. This effect is caused by the southeast trade winds which move towards the intertropical convergence zone (ITCZ; moving seasonally, but almost coincident with the equator). As the trade winds blow over the ocean to the ITCZ, they pick up moisture from its surface. This atmospheric moisture is carried to the intervening islands, where it is precipitated as oreographic rainfall on the windward side (Mueller-Dombois & Fosberg 1998). The higher the island the more rainfall is received, and the larger the discrepancy between high and low altitude rainfall. This explains the considerable annual variation in rainfall and the year round supply of rainfall found on Pitcairn. This rainfall pattern is interrupted during the cyclone season when heavy rains fall on both the leeward and the windward sides of the high islands. Cyclones form in the subequatorial tropics, when ocean temperatures are very warm, and move towards the subtropics in an eastward direction. As such they have pathways across the Pacific, along which the islands are the worst affected. The western Pacific region is the worst affected by cyclones, but paths also lie across the Cook, Austral and Society Islands. The Pitcairn Group are out of the line of cyclones, but are occasionally hit by them (Gothesson, 1997; Pitcairn Islanders, pers comm), and in 1997 cyclone Ursula passed only 400km south of Pitcairn Island (University of Hawaii 2001).

The El Niño is another complex climatic pattern that has a dramatic effect on the Pacific region. During El Niño, the trade winds relax in the central and western Pacific leading to a depression of the thermocline in the eastern Pacific, and an elevation of the thermocline in the west (Tropical Atmosphere-Ocean (TAO) Project 1995). This reduces the efficiency of upwelling to cool the suface and cut off the supply of nutrient-rich thermocline water to the euphotic zone. The result is a rise in sea surface temperature and a weakening of easterly tradewinds. Rainfall follows the warm water eastward, with associated flooding in Peru and drought in Indonesia and Australia. The eastward displacement of the atmospheric heat source overlaying the warmest water results in large changes in the global atmospheric circulation, which in turn force changes in weather in regions far removed from the tropical Pacific (Tropical Atmosphere-Ocean (TAO) Project 1995). La Niña is characterized by unusually cold ocean temperatures in the Equatorial Pacific, compared to El Niño, which is characterized by unusually warm ocean temperatures in the Equatorial Pacific (Tropical Atmosphere-Ocean (TAO) Project 1995).

Climatic change is having a serious effect on Pacific island ecosystems, and there is evidence of increased sea surface temperatures causing increasingly frequent and destructive tropical cyclones in the Pacific region (Emanuel 1987; Hope 1996).

1.4.3 Climatic history of Pitcairn

The climate of the Pitcairn group has not been static since its formation. It is possible to tentatively reconstruct the climatic history from the literature, although only from information for nearby island groups, as no quantitative studies have been carried out in the Pitcairn group. Glacial times were generally windier and stormier than in interglacial times, and there have been 10 interglacial cycles in the last 1 million years, or since the formation of Pitcairn island (Spencer 1989). As glaciation also alters sea levels, climatic changes correspond strongly to sea level changes.

While local sea level changes are usually attributed to glacial meltwater, the actual causes can be much more complex, including tectonic deformation, compression, gliding, elastic rebound, faulting, folding and tilting (Pirazzoli 1996). Former sea levels can be estimated from erosional indicators, emerged and submerged reef structures and marine zonation (Pirazzoli 1996; Pirazzoli & Montaggioni 1988), reef cores (Bard *et al.* 1996), and mathematical models (Clark *et al.* 1978).

Sea levels during the Pleistocene glaciations (between 1.77-0.01 m.y. BP) probably had a maximum drop of 130-150m below current sea levels (Menard 1964; Spencer 1989; Whittaker 1998). As a result of the lowered sea levels, islands in the Pacific such as Pitcairn would have been much higher and thus wetter on the windward sides during the Pleistocene (Nunn 1999). However, as there is evidence that the tradewind system was weakened during these glaciations, the islands leeward sides would have been much drier (Nunn 1999). During the last interglacial (128-111,000 BP) sea levels were 2-6m

higher then during the current interglacial (Nunn 1999), and thus many Pacific atolls may have been submerged. At the height of the last glaciation c.18,000BP sea levels were between 75-110m lower than present day levels (Bard *et al.* 1996; Clark *et al.* 1978). The Bølling-Allerød warm period (c.13-11,000BP) and subsequent rapid melting caused a sea level jump and resultant cooling event, known as the Younger Dryas climatic reversal (Bard *et al.* 1996; Nunn 1999; Whittaker 1998).

The end of the Younger Dryas about 10,000 BP marked the beginning of the Holocene period (Nunn 1999). Rapid warming occurred again after about 6,000BP at which time sea levels were about 4m below current levels (Pirazzoli 1996). A postglacial high stand has been recorded for many Pacific islands during the period between 5000-1500BP (Pirazzoli & Montaggioni 1988). There is much debate as to the maximum height attained above current sea levels, with ranges varying from 1.7m (Pirazzoli & Montaggioni 1988) to 4m (Stoddart, 1969; measured for Rangiroa atoll) and up to 10m (Spencer, 1989; measured for Henderson Island). Subsequent sea level drops in the late Holocene exposed many of the atolls currently known, their comparatively recent surface exposure accounting for the low number of species occurring on them (Nunn 1990).

The so called 'Little Climatic Optimum' which occurred from about 1200-650BP was the major period for the expansion of Polynesian culture across the Pacific (Nunn 1990). It was a period of favourable conditions with persistent trade winds, clear skies and few storms, and temperatures of 0.5-1^{0}C above today. Sea levels may have been up to 0.9m above present levels (Nunn 1998). This climatic optimum was followed by the 'Little Ice Age', a period with increased precipitation that may have affected vegetation that may have become accustomed to the drier climate (Nunn 1990). Sea levels at this stage were approximately 0.9m lower than today (Nunn 1998). In the last 90 years a sea level rise has again been in progress (Nunn, 1990; recorded in the Cook and Solomon Islands), coupled with a warming of 0.4-0.5^{0}C of the Earths' surface (Jones *et al.* 1986).

1.4.4 Settlement history

Pitcairn was settled by Polynesians, probably from Mangareva in the Gambier (Buck 1938), from about the 10th century, at a time when world climates were warmer and calmer seas allowed easy exploration of the Pacific by Polynesian settlers (Irwin 1992). Polynesians sailed with the currents (in a south-eastern direction), and then back with the prevailing wind if no land was found in a certain time period (Irwin 1992). There was certainly trade between the Polynesian islands once they were settled, as timber and tools from Pitcairn have been found elsewhere in Polynesia, including Easter island (Bahn & Flenley 1992). Similarly pearl shells from the Tuamotus and Gambier islands have been found on Pitcairn Island (Irwin 1992; Weisler 1995). Contact was lost between Pitcairn and the more westerly Polynesian islands in about the 14th century, when the 'Little Ice Age' caused less climatic stability (Nunn 1990). The populations of the more isolated

islands declined and in some cases (eg Pitcairn and Henderson Islands) died out soon after this (Buck 1938; Weisler 1995). The populations on small, remote islands such as Pitcairn and Henderson may have never been permanent, but used as stop off points for long journeys or quarries for obsidian and pearl shells (Irwin 1992).

Pitcairn Island was re-discovered on July 2nd, 1767, by Carteret for Britain, but was charted wrongly. This is probably the reason why the Bounty Mutineers sought out the island as their new home and hideaway, and relocated to it in 1790 (Bahn & Flenley 1992; Gothesson 1997). The story of the 'Mutiny on the Bounty' is one of the most famous in seafaring lore. The Bounty was charged by King George III to sail to Tahiti and collect Breadfruit plants which were to be brought to the West Indies as a source of food for the slaves. Having spent longer then was original planned in Tahiti, the seamen were not keen to go back to Britain and mutinied in 1789. Bligh and his supporters were cast adrift and Fletcher Christian, reputed to be the ringleader of the mutineers, returned with the rest of the men to Tahiti. At Tahiti they took women and some native men and went to Tubuai to set up a colony. This was unsuccessful and so after only a few months they went to sea again, aiming for the Solomon Islands, but instead finding Pitcairn Island (Nicolson 1966; Ross 1964).

The initial settlers were made up of 9 mutineers, 6 Polynesian men and 13 Polynesian women. Following an initial quiet period, problems developed between the men on the island with disputes over land and women, the result of which was a period of unrest and murder. This meant that just 10 years after landing on the island only one man, John Adams, was left with 10 women and 23 children who had been born on the island (Nicolson 1966). During this time an interesting culture had been developing on the Island, with a mixture of Polynesian and European influences. The Pitcairnese creole language, still spoken on the Island, had begun to develop, although it was later to incorporate words learnt from American whalers and others who settled on the island (Kallgard 1991; Ross 1964). Food and cooking methods were predominantly Polynesian while the homes were built like European dwellings from local wood such as Taypau (*Homalium taypau*), Miro (*Thespesia populnea*) and Huliandah (*Cerbera manghas*). Tools were similarly a mixture of those taken from the Bounty ship and from Polynesia by the women. The Aute plant (*Broussonettia papyrifera*) was found also by the women and so they were able to make the traditional Polynesian Tapa cloth. Fishing was done from the rocks until in 1795 the first canoe was built, although it was built in a European style, without an outrigger (Nicolson 1966).

In 1856, due to overpopulation, the 194 islanders were evacuated to set up a colony on Norfolk Island, which had been abandoned as a penal colony. However, in 1859 2 families returned, followed in 1864 by another 4 families, increasing the islands population to 43 (Nicolson 1966). It was from this group that the present population of Pitcairn is now largely descended. Even still, indeed, very close links are kept between

the families on Norfolk and Pitcairn Island. In 1887 the Pitcairn islanders converted to Seventh Day Adventism wherin they have remained to this day (Nicolson 1966). Now over one third of the native born Pitcairners live away from the Island, with most of them in New Zealand.

Contact with the outside world is by daily radio link to New Zealand and by satellite telephone and fax. Supplies arrive by ship from New Zealand every 4-5 months, and a small co-op shop keeps surplus goods. Access to the island is extremely difficult as large ships or yachts cannot dock in the small harbour. All supplies to the island have to be offloaded into longboats at sea and transported into Bounty Bay. There is no air-strip, but plans are underway to construct a runway on the flat part of the island. From their first contact with British Admiralty in 1814, the island has been under British Rule as an Overseas Dependent Territory.

Currently Pitcairn is the only inhabited island in the island group, with a population of about 50. Oeno is used by the islanders for holidays, and Henderson is visited once or twice a year to harvest *Thespesia populnea* and *Cordia subcordata* to be used for carvings. Due to its remoteness Ducie is rarely visited by the islanders, but the 'World Discoverer' cruise liners visit Ducie, Henderson and Pitcairn enroute between Easter Island and Tahiti.

1.4.5 Current conservation status of Pitcairn group

The only conservation assessment of the Pitcairn island group flora to have been carried out was based on fieldwork undertaken in 1991 (Waldren *et al* 1995b). Following from these recommendations Henderson Island became a World Heritage Site and Oeno and Ducie islands have been identified as potential Ramsar sites.

For Pitcairn, Waldren *et al.* (1995b) estimated the native flora to consist of 66 species of which 53% were either threatened or insufficiently known. In the assessment they categorise 36 species using using the IUCN criteria (IUCN 1994; discussed in detail in section 5.1.2), 3 they listed as critically endangered, 4 endangered, 7 vulnerable, 1 as low risk, but they categorised 21 as being data deficient. The main conclusions of their analysis, however, pointed to the urgent need for a full and detailed floristic and vegetation survey to be carried out of the island so that meaningful conservation recommendations could be developed. They also recommended the appointment and financing of a Conservation Officer for the island group, and this position came into effect in 1997. In 1999 the Conservation Officer, J. Warren, attended a training course in the Royal Botanic Gardens, Kew funded by the UK Darwin Initiative, and on return to the island set up a nursery for native and crop plants.

1.5 Aims of study

The aim of this project was to provide an integrated approach to the conservation of Pitcairn Island. In order to achieve this, several steps had to be taken. The first was to gather baseline data on the flora (Chapter 2) and vegetation communities (Chapter 3) of the island. The next step involved determining the phytogeographic relationships of the flora and the global distributions of individual species (Chapter 4). This information could then be compiled to make a conservation assessment of the flora and determine which species are in need of conservation, both in terms of Pitcairn Island, and in terms of their global distribution (Chapter 5). Estimation of the population size and distribution of species distinguished several species for which detailed population genetic assessments would be beneficial in the development of conservation plans, and three of these species are dealt with in more detail (Chapter 5). This knowledge of the distribution and conservation status of species and habitats were then combined to identify areas which could be successfully selected as reserve areas to conserve the largest number of rare species and native vegetation communities, without impinging on the activities and needs of the islanders.

Spellerberg (1999) noted that good decisions cannot be made about the conservation of nature if we do not know what it is and where it is. This project sets out to define for Pitcairn what is there, and where it is, and in what abundance, so that educated conservation programmes can be developed in the future for the islands flora and vegetation.

Chapter 2 : Flora of Pitcairn Island

2.1 Introduction

The flora of an area describes the plants found in that area. The flora provides the raw material from which the vegetation communities in the area are formed (dealt with in chapter 4). Compiling floristic lists is important as it provides the baseline data from which any other study or use of plants can proceed (Prance 1998). Floras are necessary for the rapid assessment of biological diversity, in addition to providing much useful data for conservation planning (Prance 1998). Biodiversity surveys also allow assessment of the effects of human modifications on the environment, and enable adequate management to combat the effects of such modifications to be initiated (Haila & Margules 1996).

The term 'biodiversity hotspot' was coined by Myers in the late 1980's when identifying regions as conservation priorities based on the large numbers of endemic species contained in small areas and threatened with extinction (Reid 1998). The term is now applied to any area that ranks high in terms of species richness or endemism (Reid 1998). Determining areas that qualify as 'hotspots' begins with inventorying and mapping species distributions, as the most elementary practical needs are to know where the biodiversity is and of what it consists (Haila 1996). Mittermeier *et al.* (1998) include Polynesia as one of the world biodiversity 'hotspots'.

2.1.1 Previous floristic studies

The first publication on the botany of Pitcairn was not made for over 60 years after the discovery of the island in 1767. In 1831 W.J. Hooker and G. A. Arnott published a list with the names of 13 plants, mainly crops, that had been collected by G. T. Lay and A. Collie in 1825, as part of Captain Beechey's voyage on HMS *Blossom* (St. John 1987). Hugh Cuming visited in December 1827 while on a voyage around the Pacific islands, and collected 27 plants (including 6 crop species), these specimens now reside in Kew (St. John 1940), with some duplicates recently found at TCD. In 1829, J.A. Moerenhout visited Pitcairn and listed 15 crop plants, and in the following year A. Matthews visited with H.M.S. *Seringapatam* and collected 45 plants, including the first major collection of indigenous species (16 in total) (Gothesson 1997).

The next major collection was carried out by F.D. Bennett, a zoologist on a world voyage to study whales, in 1834. He spent a week on the island and collected 25 plants, including the first specimen of *Peperomia pitcairnensis*. His specimens were deposited in Berlin, and were destroyed during the 2nd World War (St. John 1987). In 1898 the islander Rosalind Young collected 35 plants for Captain Torlesse of the HMS *Royalist* which were identified by J.H. Maiden in Sydney, where the collection is now preserved (St. John 1987).

In 1922 the Whitney Expedition of the American Museum of Natural History visited Pitcairn, and one of the scientists, E.H. Quayle, collected plants. The specimens were sent

to the Bishop Museum, Hawaii, and written up in the three volume Flora of Polynesia (Brown & Brown 1931; Brown 1931, 1935). The collections made by the Whitney South Seas Expedition were those studied by Ernst Mayr, and formed the basis of his landmark theories into neo-Darwinian species evolution (Berry 1992).

Between 1931 and 1935 another islander, Harriet Ross, made a collection of 50 species and sent the collection to L. Cranwell at the Auckland Museum. This list was forwarded to H. St. John at the Bishop Museum (Gothesson 1997; St. John 1987). A collection of 286 numbers was made by Captain Jackson between 1933 and 1940, and was deposited in Liverpool Museum. In 1982 W.R Sykes examined some of the collection in Christchurch Herbarium (Gothesson 1997).

In 1934, two botanists, H. St. John and F.R. Fosberg, collected as part of the Mangarevan Expedition of the Bishop Museum. They collected 200 specimens, and made sight records of many more. They did, however, only spend two and a half days on the island, and therefore did not get to visit many of the remoter valleys. These collections were published by various people, with Copeland mentioning the ferns in 1938 and St. John listing the collections in 1987. Later in 1934, the ornithologist J. H. Chapin visited the island with a scientific expedition organised by the American Museum of Natural History, and collected plant specimens which are deposited in the New York Botanical Garden (Gothesson 1997).

In 1955 a soil survey of the island was carried out by I. T. Twyford who also made a botanical collection of 85 plants, now housed in Suva, Fiji (Twyford 1958). The ornithologist G. R. Williams collected a further 28 plants in 1956, housed in the Dominion Museum in Wellington (Gothesson 1997). In 1957 W.H Lintott, a student at the time, collected 170 specimens for W.R. Philipson from the University of Canterbury (W.H. Lintott pers com., 1998). Only the fern collections were published by Brownlie (1961) and St. John (1987), and the specimens were moved to Christchurch Herbarium in 1988. G. Paulay and T. Spencer collected 36 species as part of the Smithsonian Expedition to Henderson Island in 1987 (Fosberg *et al.* 1989). In addition an unmounted and undetermined collection of pteridophytes made by Randall and Collier was found in the herbarium of British Museum. They had visited the island as part of the Westward Expedition in 1971, although no record of their plant collections had been made.

In 1991-1992 J. Florence, S. Waldren and A. Chepstow-Lusty from the Sir Peter Scott Memorial Expedition to Henderson Island, collected on Pitcairn for one week. They collected about 100 specimens and noted the need for a complete floristic and vegetation survey to be carried out urgently (Florence *et al.* 1995, Waldren 1995a). Waldren et al. (1995b) carried out a conservation assessment of the Pitcairn flora, but as their analysis was based on limited distribution and ecological information many species were listed as data deficient.

2.1.2 Aims

The aim of this chapter is to compile a comprehensive inventory of the flora of Pitcairn Island, in order that more detailed analyses of the flora and vegetation can be successfully undertaken. In addition, by means of distribution maps, 'hot spots' of diversity can be identified, as well as areas most likely to have high numbers of invasive species.

2.2 Materials and Methods

2.2.1 Collections

Plant collections (vascular and non-vascular) were made on Pitcairn during July-September 1997, during the Pitcairn Islands Botanical Expedition (PIBE) with the aid of other expedition members, members of the Wildlife Management International (WMIL) rat eradication team, and Pitcairn Islanders. These included herbarium collections of the island's native and naturalised plants, or plants of uncertain identity, and seeds and spores of the native plants and some ornamentals. Where possible more than one collection was made for each species so that variability within species could be accounted for. Adequate collections were made so that duplicates could be distributed to other herbaria.

Herbarium samples were collected and pressed in the field, using standard lattice plant presses and sheets of newspaper. They were then air dried while still in the presses and the sheets of newspaper changed regularly. On return to Ireland the specimens were identified by comparison with voucher specimens held in Trinity College, Kew and British Museum Herbaria, or sent away to experts for appraisal.

Seeds and spores were collected and cleaned, and stored in envelopes for transport back to Ireland. When sampling we endeavoured to collect from several populations, and for some species from all populations (e.g. *Angiopteris chauliodonta*), and we collected from several individuals in each population. Sampling was random and covered the whole population, accounting for any topographical differences (Huenneke 1991). Brown & Marshall (1995) and Brown & Briggs (1991) suggest collecting from at least 50 individuals (absolute minimum 10) in 50 populations. This was not possible on Pitcairn, as most populations contained substantially less than 50 individuals and less than 50 populations occur for most species on the island. However, sampling guidelines were followed where possible, by collecting from several different fruits on each tree, to maximise diversity, and representing each source plant equally in the collection (Brown & Briggs 1991; Brown & Marshall 1995). In some cases collections from each plant were collected separately as suggested by Brown & Briggs (1991), which allows genotypes to be stored separately for future research. Also, while collecting from populations, and especially from individuals, care was taken not to collect more than one fifth of the seed present, in order not to affect small population viability (Martin 1998). In most cases substantially less was collected. For seed bank storage it is suggested that 1000 seeds are collected, and since most of the collections were less than this, it may be necessary to increase this amount from *ex-situ* populations now in cultivation. This is the method recommended by Brown and Briggs (1991). Other collections made were tissue samples for DNA analysis, spirit collections of flowers and pollen collections.

Ethnographic information was compiled both from speaking with the islanders, from botanical and historical publications about the island, and from dictionaries of the Pitcairnese Language (Gothesson 1997; Kallgard 1991; Nicolson 1966; Ross 1964; St. John 1987).

2.2.2 Distribution mapping

A topographical map of the island was divided into a 250m^2 grid, and within each of these grid squares species presence or absence was recorded while in the field (figure 2.1). Simply taking presence or absence data, as opposed to percentage cover data, does not detract from the quality of the analysis (Moore & Chapman 1986), and may be the best method, as the data lend themselves readily to rigorous methods of analysis, independent of any other evidence (Rosen & Smith 1988). This technique was used primarily to give information about the spread of invasive species across the island (as in Fleischmann, 1997), but also to give information about 'hotspots' of high native diversity (as in Heads, 1997). This was done by the construction of contour diagrams or 'isomores' for the number or type of species present in each grid square (Kent & Coker 1992).

In addition maps of the locations of individuals, or populations of rare and endangered species were drawn up. This allows individuals to be pinpointed on the island and also allows population monitoring. These maps were charted for 61 native species in total, including all of the endemic species. A system of trails cut for the rat eradication project facilitated ease of movement across the island. As the positions of these trails were marked on the map carried in the field, they also facilitated the identification of where in the field species were found in terms of the grid systems and for more detailed mapping. All maps were compiled using ArcView GIS ver. 3.1.

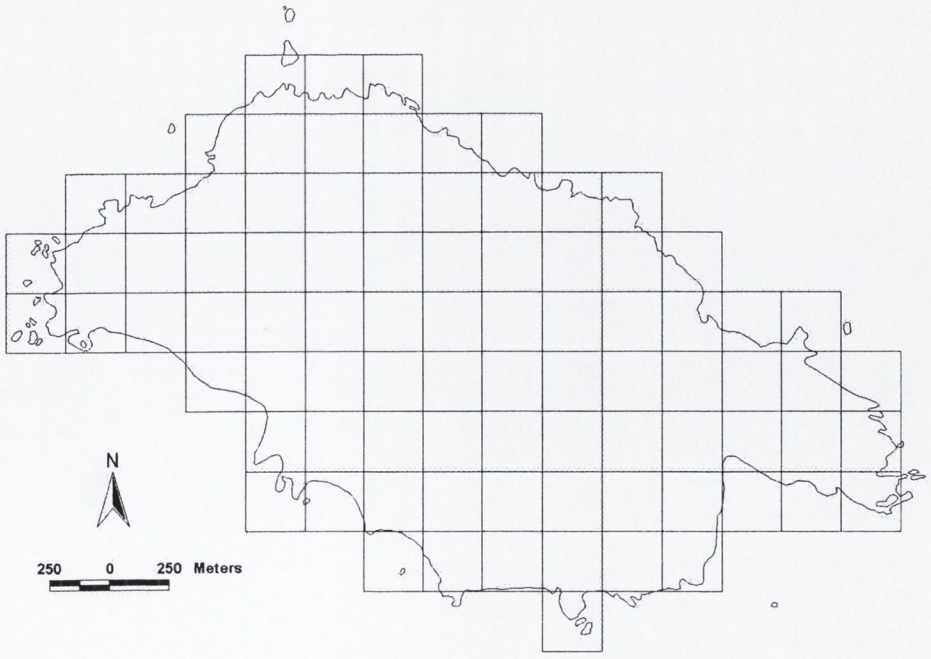


Figure 2.1 - Map to show Pitcairn Island overlain with the 250m^2 grid used during the floristic survey. Columns were labelled A-O and rows 1-10.

2.3 Results

2.3.1 Floristic survey

Ethnographic information collected included traditional names and uses of the plants, as well as when they were thought to be introduced to the island, and by whom. This information has been compiled in a database and for use by the islanders. It is important that this kind of information is collected and preserved as it could easily become lost as the island becomes modernised.

Table 2.1 - Collections made during the Pitcairn Island Botanical Expedition (PIBE 1997).

	Pitcairn	Henderson	Oeno	Total
Vascular plants	292	14	1	307
Bryophytes	53	2		55
Lichens	27	2		29
Fungi	33	10		43
Seed/Spores	91	26		11
Tissue samples	225	96		321
Spirit		6		6
Pollen	12			12
Total	733	156	1	890

Collections and field observations have shown the flora of Pitcairn to consist of 81 native species and 250 introduced species of vascular plant, this includes 9 endemic species (table 2.1 & 2.2). A further 2 endemics are now considered extinct: *Abutilon pitcairnense* as it has not been collected since 1934, and *Myrsine* aff. *niauensis* as it has not been collected since 1898, despite careful searches for both. Thus 13.6% of the total native flora is endemic.

Introduced species are listed in Appendix 1. Non-native species were divided into 4 categories, species that were introduced during the period of Polynesian habitation (Pol), species in cultivation on the island (Cul), species that have escaped from cultivation and naturalised on the island (Nat) and adventive species that have been accidentally introduced to the island and become established (Adv). Cultivated species made up the largest category with 139 species, 42 species were adventive, 35 naturalised and 34 were of Polynesia introduction. For many of the cultivated species, several varieties or cultivars were present on the island. In many cases it was difficult to determine if species were of Polynesian introduction, native or of later introduction, and so species listed by Whistler (1991) as being of Polynesian introduction to south-eastern Polynesia were assumed to be of Polynesian introduction. As Pitcairn Island was relatively briefly occupied by Polynesians some of these species may be of later introduction.

The numbers of bryophytes, lichens and fungi have not yet been determined, although 29 different bryophytes have been identified to genus level, and in some cases to species level, from the Pitcairn samples (see Appendix 2).

Table 2.2 - Floristic diversity of Pitcairn Island

	No. of species	% of total flora
Indigenous vascular plants	81	24.47%
Vascular cryptograms	30	9.06%
Angiosperms	51	15.41%
Endemic vascular plants	11*	3.32%
Vascular cryptograms	2	0.60%
Angiosperms	9*	2.72%
Introduced vascular plants	250	75.53%
Adventive	42	12.69%
Cultivated	139	41.99%
Naturalised	35	10.57%
Polynesian	34	10.27%

* - 2 extinct

The 11 plants endemic to Pitcairn are as follows:

Abutilon pitcairnense (Malvaceae)
Angiopteris chauliodonta (Marattiaceae)
Coprosma benefica (Rubiaceae)
Ctenitis cumingii (Aspidiaceae)
Glochidion comitum (Euphorbiaceae)
Glochidion pitcairnense (Euphorbiaceae)
Haloragis sp. (Haloragaceae)
Homalium taypau (Flacourtiaceae)
Myrsine aff. *niauensis* (Myrsinaceae)
Peperomia pitcairnensis (Peperomiaceae)
Peperomia sp. (Peperomiaceae)

In all, 12 new records were found of species that can be assumed to be native to Pitcairn island. Some of the new records have not yet been fully identified. In addition several old records were refound of species that had not been collected in over 100 years and were assumed to have been extinct, notably *Osteomeles anthyllidifolia* and the endemic *Peperomia pitcairnensis* (previously collected by Bennett in 1834 but the specimen was destroyed; see section 2.1.2). Similarly there was confusion in the literature as to whether *Psydrax odoratum* had been collected on Pitcairn Island itself, and this expedition confirmed its presence. The new records are as follows:

Lycopodium cernuum (Lycopodiaceae)
Ophioglossum nudicaule (Ophioglossaceae)
Ophioglossum reticulatum (Ophioglossaceae)
Trichomanes tahitense (Hymenophyllaceae)
Lastreopsis cf. *pacifica* (Aspidiaceae)
Peperomia sp. (Peperomiaceae)
Hibiscus australense (Malvaceae)
Pilea sancti-johannis (Urticaceae)
Samolus repens (Primulaceae)
Caesalpinia major (Leguminosae)
Haloragis sp. (Haloragaceae)
Ipomoea littoralis (Convolvulaceae)

Plate 2.1 – *Pilea sancti-johannis,* a new record for Pitcairn Island found during PIBE 1997. This species is also found in the Gambier Islands.

Plate 2.2 – *Hibiscus australense,* a new record for Pitcairn Island found during PIBE 1997. This species is also found in the Austral Islands.

2.3.2 Mapping analysis

Each native species was mapped, if possible to the individual level, but more often to the population level. Where species were widespread, their presence/absence within the 250m^2 grid was used. The grid system can also be used to map the distribution of any of the species recorded for the island. Thus species which have potential to become invasive can also be monitored as they colonise new areas of the island.

Grid data were also used to identify general trends in the flora from across the island. The total species number (both native and non-native) for each grid square is presented in figure 2.2, while the total percentage native species for each square is presented in figure 2.3. Several coastal squares show low numbers, but this may be because some of these areas were largely cliff and so were either species poor or under-recorded. In general the trend shows more species in the gardens and planted areas, and more native species in the remote valleys.

In addition the maps of individual species can be combined to identify 'hotspots' of native plant diversity to be pinpointed for conservation and protection as nature reserves. This will be discussed further in Chapter 5.

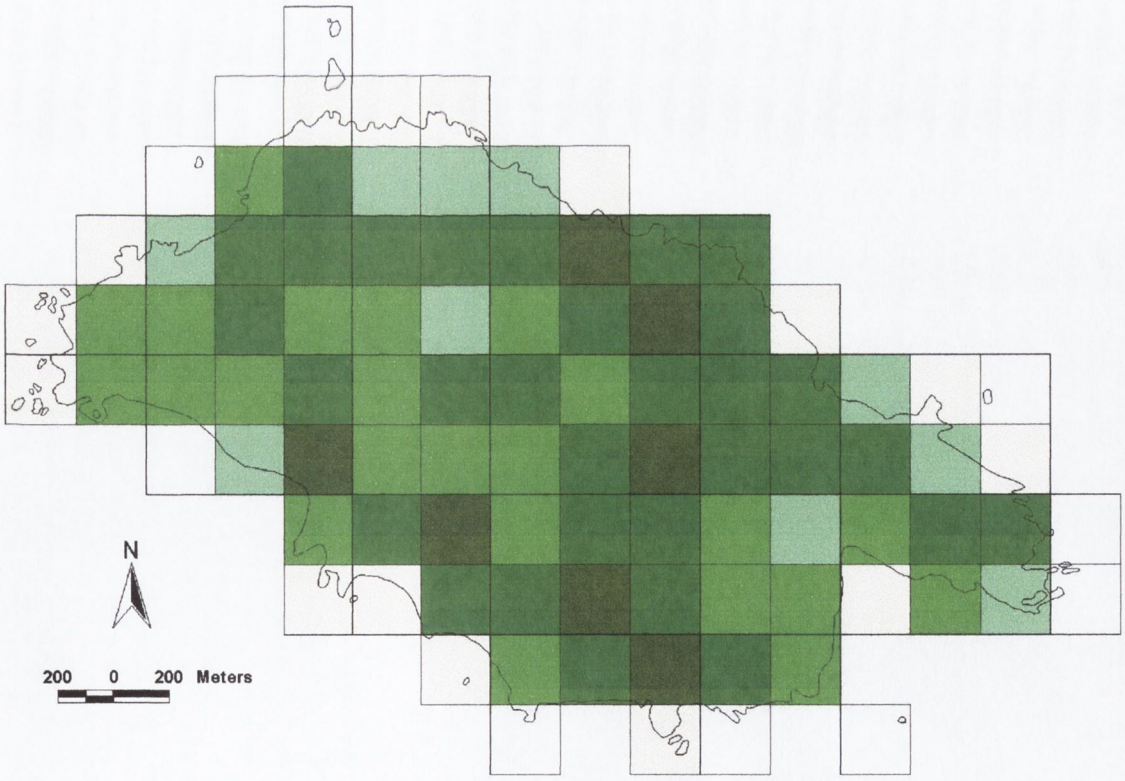


Figure 2.2 – Total species (both native and non-native) in each grid square for Pitcairn Island. 1-10 = ; 11-30 = ; 31-44 = ; 45-57 = ; 58-71 =

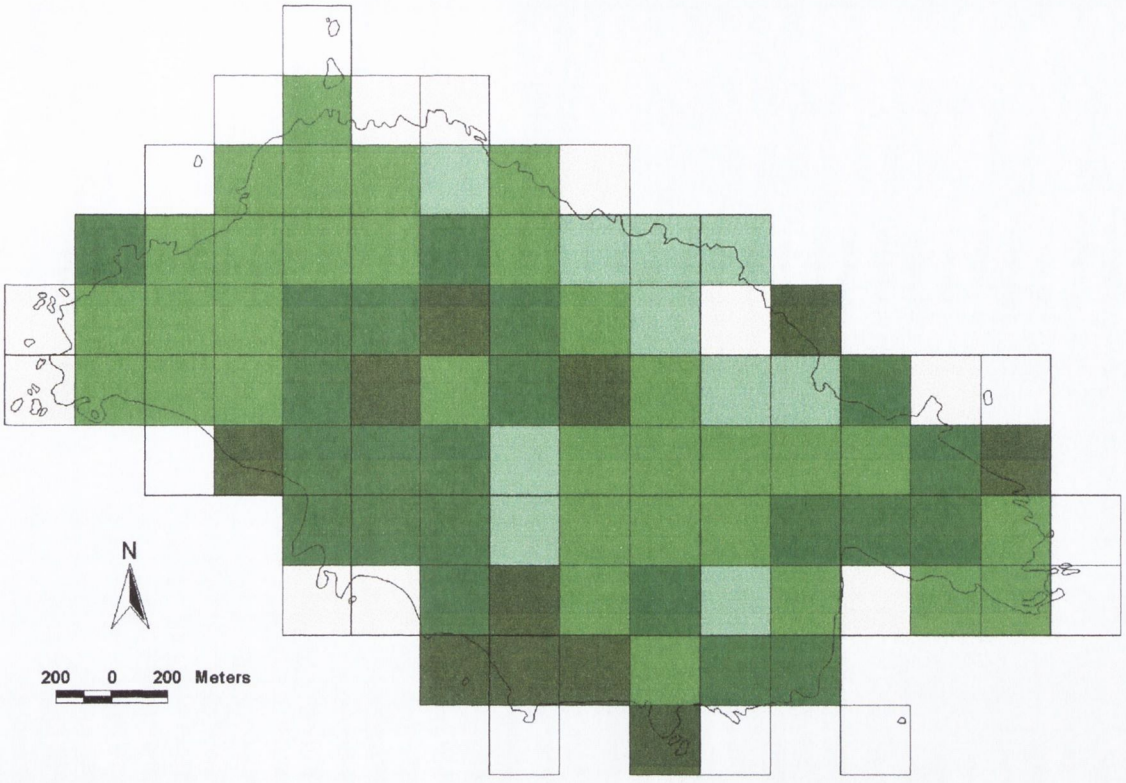


Figure 2.3 - Percentage native species in each grid square from across Pitcairn Island. 1-8 = ; 9-30 = ; 31-46 = ; 47-64 = ; 65-100 =

2.3.3 Flora of Pitcairn Island

A flora of the native plants Pitcairn Island is presented below, listed alphabetically by family (dicotyledons, followed by monocotyledons and then pteridophytes), then by genus and species. For each species a brief description of the habit, habitat and distribution is included. Where synonyms have been used for Pitcairn collections in other publications, these synonyms are listed along with the publication in which it was presented. Where a local Pitcairnese name is known for a species it is included, with the source of the name in square brackets. The 1997 collection numbers refer to herbarium voucher specimens collected only, with collection numbers for seed, spore or tissue collections not being listed. The information on the ecology and distribution of the species on Pitcairn Islands is based on observations made in 1997, unless otherwise stated. Worldwide distribution of species is based on information from a number of sources listed in section 4.2.6.

Key to the publications used:

Brn (Brown 1935)
B&B (Brown & Brown 1931)
Ble (Brownlie 1961)
Cop (Copeland 1938)
Fl (Florence *et al.* 1995)
Fos (Fosberg *et al.* 1989)
F&S (Fosberg & Sachet 1967)
G (Gothesson 1997)
StJ (St. John 1987)
Twy (Twyford 1958)

DICOTYLEDONAE

Aizoaceae

Sesuvium portulacastrum (L.) L. (Ind)

Pitcairnese name: Green rock weed [Twy]

Succulent, prostrate, trailing herb with white or pink flowers. Common and widespread on coastal cliffs and rocky shoes except in the extreme north (figure 2.4). Pantropical on beaches, rocky shores and cliffs.

1997 collections: J. Starmer 97-069

Other collections: Fosberg 11,340; Fosberg & R. Clark 11,294; Florence 10772.

Apiaceae

Apium prostratum Labill. (Ind)

Synonyms: *Apium australe* Thouars [StJ; Fos]

Pitcairnese name: Wild parsley [StJ]; Rock parsley [Twy]

Fleshy, prostrate or erect, herb with white flowers In umbels. Common and widespread on cliffs and among boulders and scree in coastal areas on the south and south west (figure 2.4). Distributed in coastal regions of the southern hemisphere.

1997 collections: J. Starmer 97-058; S. Waldren & N. Kingston 97-090; S. Waldren 97-635

Other collections: Young s.n.; St. John 15,020, 15,000 (as *A. australe*); Fosberg & R. Clark 11,292, 11,280 (as *A. australe*); Fosberg 11,533 (as *A. australe*); Florence 10777, 11017.

Apocynaceae

Alyxia scandens Roem. & Schult. (Ind)

Erect or scandent shrub to 4m, with verticillate, entire, fragrant leaves in threes at nodes; produces milky latex when cut. Rare on remote cliffs in shrub communities with *Bidens mathewsii* and *Metrosideros collina* (figure 2.4). Distributed from Fiji across the high islands of Polynesia to Pitcairn. The taxonomy of *Alyxia* is in need of revision (D. Middleton pers com 2000, to S.W.), but this seems very distinct from *A. fosbergii* of Henderson Island.

1997 collections: Starmer & Bingelli 97-172; P. Marriott 97-235; S. Waldren 97-240, 97-529

Other collections: Young 24

Cerbera manghas L. (Ind)

Synonyms: *Cerbera odollum* Gaertn. [Twy]

Pitcairnese name: Oleander [StJ]; Huliandah [C. Warren]

Evergreen shrub or tree up to 12m, with milky sap; leaves entire, oblong and spirally arranged at the ends of branches; white fragrant flowers found in terminal cymes. Found across the island, but most frequent in the western half around Tedside, where it regenerates freely, in woodland and on steep slopes (figure 2.4). The timber was formerly used by the Islanders for joists and house piling. This species is distributed from the Seychelles, across Asia and Australia to Polynesia.

1997 collections: S. Waldren 97-102

Other collections: Florence 11028; Young s.n. (as *C. odollum*)

Asteraceae

Bidens mathewsii Sherff (End)

Pitcairnese name: Ailihau [StJ; C. Warren; B. Christian]

Shrub to 1m high, with fragrant yellow capitula; leaves oblong with serrate margins. Locally frequent on cliffs, rock faces and steep slopes on the southern side of the island, notably at Tautama and Down Rope (figure 2.4). Found both in herbaceous communities, with *Haloragis* sp. and ferns, and under *Homalium taypau* woodland. Endemic to Pitcairn, but related to other species in *Bidens* sect. *Campylotheca* found also in the Marquesan and Hawaiian islands, Henderson, Oeno and Marotiri rocks.

1997 collections: N. Kingston 97-016; S. Waldren 97-532; 97-535; 97-670

Other collections: Mathews 110 (holotype); St. John 15,003; Fosberg & R. Clark 11,276; Brooke in Florence 11110; Florence 11015.

Boraginaceae

Argusia argentea L. f. (Ind)

Synonyms: *Tournefortia argentea* (L. f.) H. Heine

Pitcairnese name: Cabbage tree [StJ; Pitcairn Islanders]

Shrub or tree to 10m tall, pubescent, with pale bark; oblong, entire, leaves alternate but clustered at branch tips; flowers also at branch tips, numerous, white and fragrant. One tree seen at Bounty Bay, presumably the same one as seen by Florence in 1991 (figure 2.4). Common in the Pacific and probably rare on Pitcairn due to a lack of suitable habitat.

Other collections: Whitney Expedition; Ross 31; Fosberg 11,344; Florence 10799

Brassicaceae

Lepidium bidentatum Montin (Ind)

Synonyms: *Lepidium bidentoides* F.Br. & E.Br. var. *pitcairnense* F.Br. [Brn]

Erect herb, with fleshy spathulate, light green leaves, and white flowers in terminal racemes. Found only on eroded slopes at St. Pauls in 1997, but as it occurs typically on coastal rock and cliffs, it may be more widespread in inaccessible areas (figure 2.5). Distributed from Fiji across through Polynesia to Pitcairn, but most widespread on atolls.

1997 collections: S. Waldren & N. Kingston 97-138

Other collections: Quayle; St. John 15,001

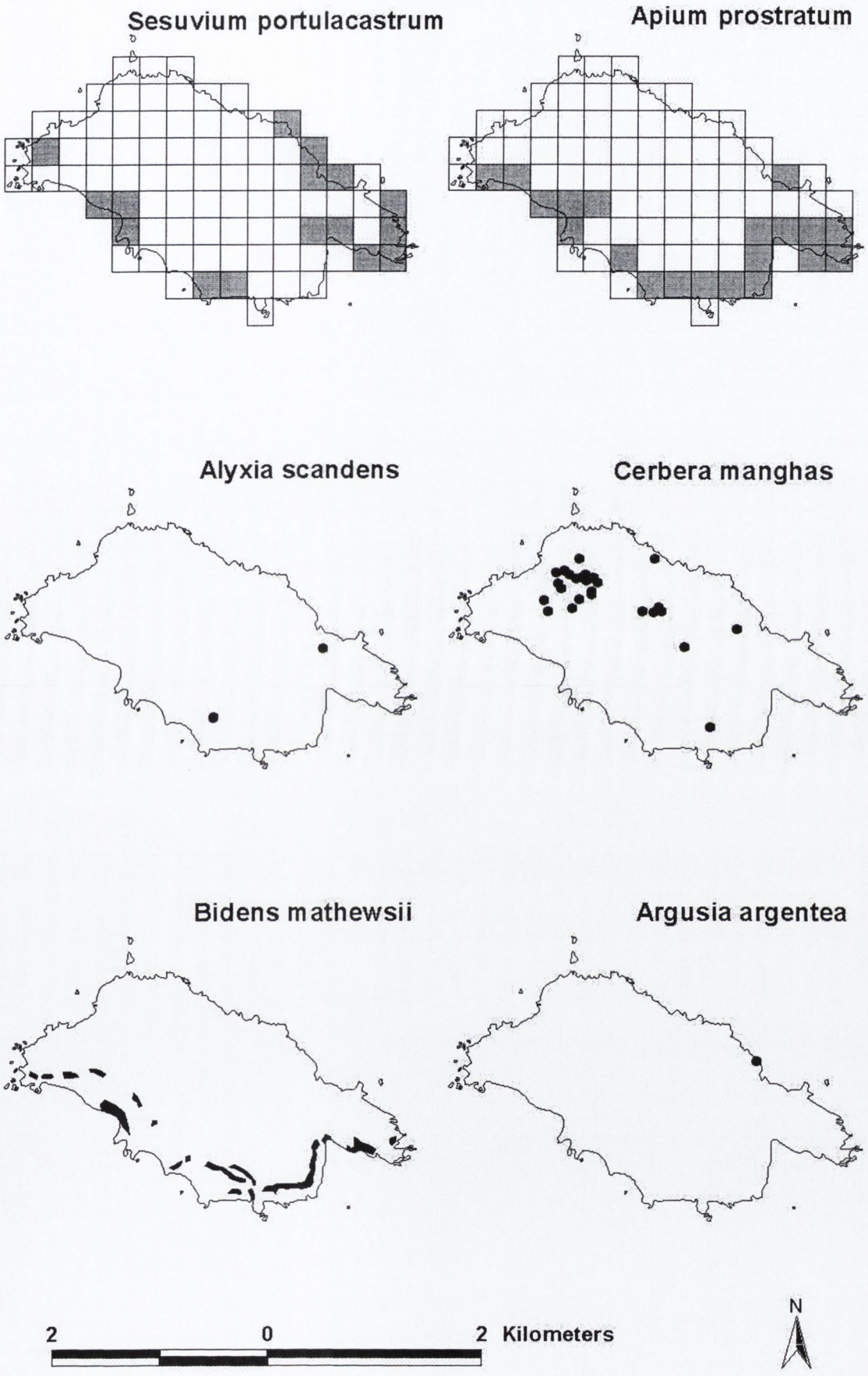


Figure 2.4 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Capparidaceae

Capparis cordifolia Lam. (Ind)

Synonyms: *Capparis sandwichiana* DC [Brn]

Prostrate shrub, with fleshy, opposite, ovate leaves and white flowers. Only collected once from Pitcairn by the Whitney Expedition in 1922. This is a widely distributed strand species, found from Asia through to Polynesia and Micronesia.

Other collections: Quayle

Convolvulaceae

Ipomoea macrantha Roem. & Schult. (Ind)

Pitcairnese name: Moon-flower

Climbing or prostrate vine, with milky latex; leaves simple, alternate; funnel-shaped flowers that open in the evening are white but fade to pink by mid-morning. Rare in coastal grassy scrub, and around the boat house at Bounty Bay, which is the only site from which it has been collected (figure 2.5). A sight record made with binoculars from cliffs at Tedside requires confirmation (S. Waldren 1997). Pantropical species of littoral habitats.

1997 collections: S. Waldren & N. Kingston 97-606

Other collections: Fosberg 11,333; Florence 10785

Ipomoea littoralis Blume (Ind)

Climbing or prostrate vine with twining stems; leaves mid to light green, slightly succulent; funnel-shaped corolla pale mauve with much darker purple throat, slightly two lipped. Found only from one station below Down Rope, at the edge of a *Pandanus tectorius* grove on a slope above the sea (figure 2.5); first record for the Pitcairn Group in 1997. Species has a pantropical distribution on littoral habitats.

1997 collections: S. Waldren 97-634

Ipomoea pes-caprae L. (Ind)

Synonyms: *Ipomoea brasiliensis* (L.) Sweet [StJ]

Pitcairnese name: Pa'hu'e [StJ]

Trailing vine with alternate, ovate leaves; flowers in cymes, pink to reddish purple with darker centre. Collected once by Fosberg in 1934 from Bounty Bay. Pantropical littoral species, probably ephemeral on Pitcairn.

Other collections: Fosberg 11,334 (as *I. brasiliensis* in StJ)

Euphorbiaceae

Chamaesyce sparrmannii (Boiss.) Hurus. (Ind)

Synonyms: *Euphorbia pitcairnensis* F. Brown [Brn]; *E. ramosissima* Hooker & Arnott [StJ]

Prostrate, trailing sub-shrub; leaves simple, opposite, rounded; flowers in cymes, white, inconspicuous. Commonly covered with insect egg cases (egg sample 97-66; emerged adults sample 97-115). Very local on coastal cliffs, and stony beach fronts. Distributed

mainly on the south of the island, and only in the north when sheltered (figure 2.5). Restricted to the Pitcairn Group and the Marotiri Rocks to the south east of Rapa.

1997 collections: S. Waldren 97-092; S. Waldren 97-185

Other collections: Matthews; Quayle (as *Euphorbia pitcairnensis* in Brn); St. John 15,007 (as *E. ramosissima*); Fosberg & R. Clark 11,279 (as *E. ramosissima*); Florence 10797

Glochidion pitcairnense (F.Br.) H.St.John (Ind)

Pitcairnese name: Mahaami; Mahame [StJ]

Small tree or shrub to about 6m tall, totally glabrous, with grey-brown bark; leaves bullate, variable in size; flowers yellowish green, small, from axils of leaves; fruits bright red contained in green, deeply lobed capsules. Found in a diverse array of habitats, from *Lantana camara* scrub and roadsides, to native and mixed woodland, but never in monospecific *Syzygium jambos* woodland. Often found in disturbed woodland communities. Widespread but local across the island, common in some areas around Pulau and St. Pauls, but rare in the extreme southern and western valleys, or at very high altitudes (figure 2.5). In the past was extensively exploited for construction. Found only on Pitcairn and Henderson Island.

1997 collections: S. Waldren & N. Kingston 97-050; S. Waldren & N. Kingston 97-051; S. Waldren & N. Kingston 97-052; S. Waldren 97-061; P. Bingelli 97-086; S. Waldren & N. Kingston 97-144, 97-236, 97-265; S. Waldren 97-338; S. Waldren & N. Kingston 97-584; S. Waldren 97-641

Other collections:. St. John 14,983; Fosberg & B. Christian 11,237; Florence & Waldren 11047; Florence 10736

Glochidion comitum Florence (End)

Similar to the previous species in general habit and habitat, but commonly pubescent with a pubescent ovary, and less lobed capsule. Apparently not found in 1997 despite careful searching although see note below.

Other collections: Florence 10728; Florence & Chepstow-Lusty 10730

Note - 1997 collection numbers 97-050, 97-051,97-052 ,97-086, 97-144, 97-236, 97-265, 97-584 were all putatively collected as *Glochidion comitum* as they showed pubescence in the field. However J. Florence determined all of the specimens to be *G. pitcairnense*, and so no *G. comitum* was collected in 1997. However, seed taken from glabrous specimens on Pitcairn and brought into cultivation in TCD have yielded pubescent progeny. Gene sequencing of samples collected on Pitcairn have shown that the pubescent and glabrous forms can be distinguished at the genetic level (U. Bradley, pers comm 2001).

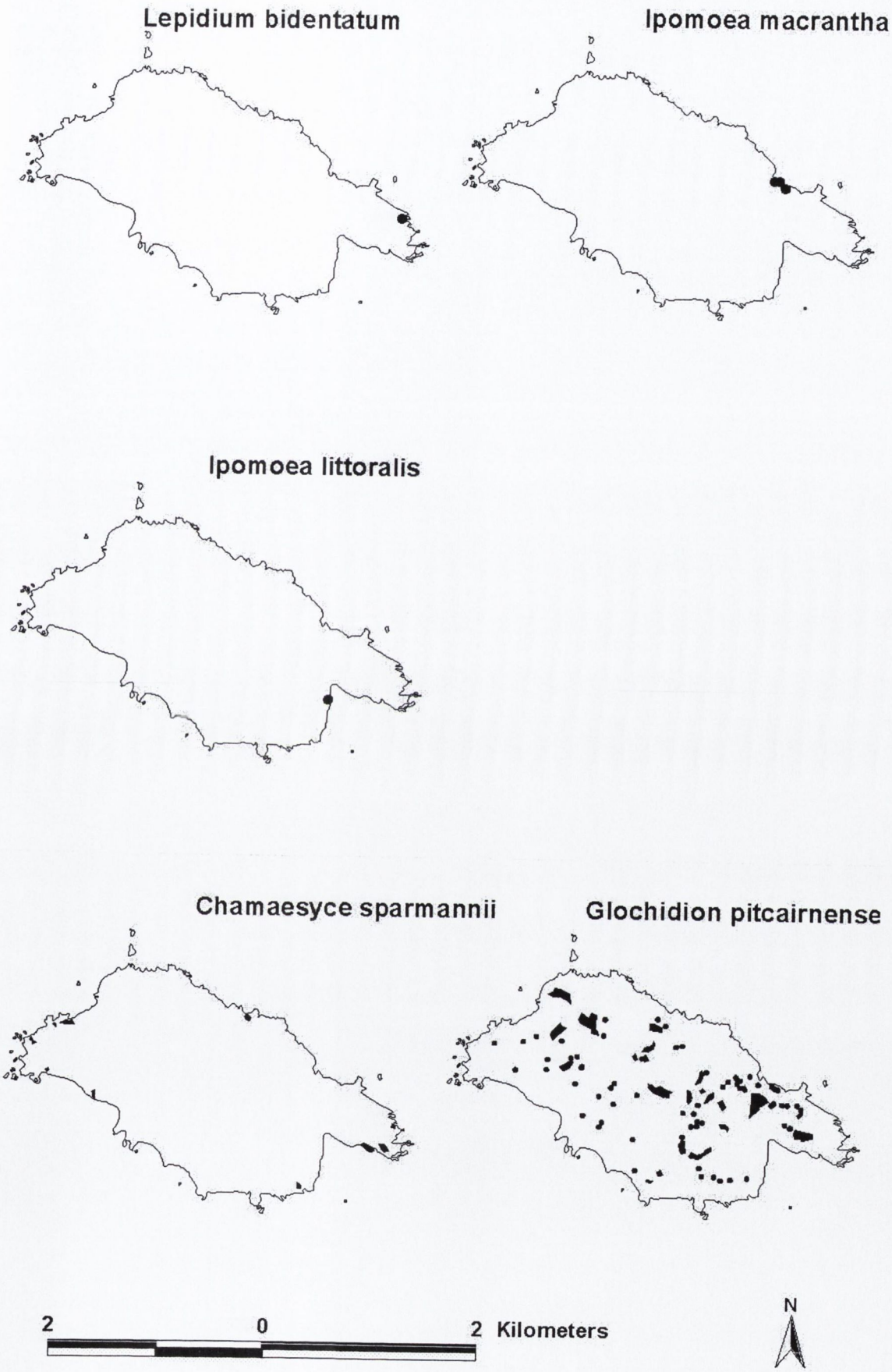


Figure 2.5 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Flacourtiaceae

Homalium taypau H.St.John (End)

Pitcairnese name: Taypau [StJ]

Medium sized tree to 15m tall but usually much less; bark characteristically covered in crustose lichen growth giving it a mottled appearance; flowers following disturbance events to produce racemes of small white/purple flowers (according to the Islanders it also flowers annually around Christmas time); not seen in seed, nor were seedlings observed. Commonly dominates woodland communities in which it occurs, but occasionally in mixed woodland with *Metrosideros collina* or *Syzygium jambos*. Found from coastal and low altitude woodlands to high altitude cloud forest, from all parts of the island (figure 2.6). Relied on heavily for timber in the past, and was the principal local timber source in 1934 (Gothesson 1997); as a result it may have been planted in some areas. Endemic to Pitcairn, with closely related species in the Austral and Cook Islands.

1997 collections: S. Waldren & N. Kingston 97-031; 97-118; 97-319; P. Bingelli 97-638

Other collections: Young 48; Ross; W. D. McCoy; St. John 14,981, 15,028 (holotype); Chapin; Florence & Waldren 11043

Xylosma suaveolens (J.R.Forst. & G.Forst.) G.Forst. (Ind)

Pitcairnese name: Sharkwood; Pin'e [StJ; Islanders]

Dioecious shrub or tree to about 10m tall; bark light grey, wood extremely hard; leaves simple, alternate and slightly serrate; fruit a black berry containing 4 seeds. Rare in native woodland and at roadsides, but only found at high altitudes in the island centre (figure 2.6). Female plants tended to have young plants and seedlings nearby, suggesting poor dispersal. Distributed from the Cook to the Pitcairn Islands, but several sub-species have been described within that range (subsp. *haroldii* from Henderson and Pitcairn).

1997 collections: S. Waldren & N. Kingston 97-142; S. Waldren 97-335

Other collections: St. John & D. Anderson 15,049; St. John 15,040; Florence & Waldren 11040

Goodeniaceae

Scaevola sericea Vahl (Ind)

Synonyms: *Scaevola frutescens* (Mill.) Krause [Brn]; *S. taccada* Vahl var. *tuamotuensis* H.St.John [StJ]

Spreading shrub up to 3m tall, but much smaller on Pitcairn; simple, alternate, oblanceolate, fleshy leaves, clustered at the stem tips; white flowers in axillary cyme. In 1997 found only from one coastal beach site at Down Issacs (figure 2.6) with *Lepturus repens*, but previously recorded from Bounty Bay as recently as 1991. Widely distributed from Madagascar, through Asia and Polynesia to the Hawaiian Islands.

1997 collections: P. Marriott 97-076; S. Waldren & N. Kingston 97-582

Other collections: Quayle (as *S. frutescens* in Brn); Fosberg 11,335 (as *S. taccada* var. *tuamotuensis* in StJ); Florence 10791

Haloragaceae

Haloragis sp. (End?)

Prostrate to sub-erect, slightly woody shrub; leaves opposite, decussate, dark glossy green above, paler and dull below, with slightly serrate margins; flowers and fruits not seen. Habitat includes coastal cliffs, rock faces and stable slopes with herbaceous communities. Locally distributed and restricted to the southern coastal regions of the island, especially around Tautama and Ginser Valley (figure 2.6). As there are were no flowers or fruits found it is difficult to determine this taxon to species level. It is probably closely related to *H. prostrata* or *H. erecta*. The first record for this taxon was made in 1997.

1997 collections: S. Waldren & N. Kingston 97-116; S, Waldren 97-342; S. Waldren 97-533

Hernandiaceae

Hernandia sonora L. (Ind)

Synonyms: *Hernandia peltata* Meisn.; *Hernandia nymphaeifolia* (C.Presl.) Kubitzki

Pitcairnese name: Tunina; Tunynut [StJ]

Tree to about 20m; leaves slightly peltate, more so in the larger young leaves; fruits pale greenish/white, changing to plum with age. Many seedlings and saplings observed in valley floors, especially around or downslope from mature trees, but few mature trees located. The light wood was formerly used for canoe construction. Scattered in degraded low altitude mixed forest. Locally abundant in Tedside, Tautama and Jack Willems Valley, rare elsewhere (figure 2.6). Interestingly in these locations as it consistently occurs near to *Ficus prolixa* (Banyan) trees. This species is distributed from East Africa through Asia to eastern Polynesia. The genus requires revision however, as in some cases *H. sonora* is placed into *H. ovigera* along with *H. stokesii* from Henderson and Rapa, *H. peltata* and *H. nymphaeifolia*.

1997 collections: S. Waldren 97-101; S. Waldren 97-334

Other collections: Ross 10; Young (as *H. peltata*); St. John 14,960 (as *H. nymphaeifolia*); Florence & Chepstow Lusty 10729

Leguminosae

Caesalpinia major (Medik.) Dandy & Exell (Ind)

Synonyms: *Caesalpinia bonduc* (L.) Roxb. [G]

Pitcairnese name: Taatremoe

Coarse, thorny liana, climbing and engulfing trees and other shrubby vegetation; leaves compound, exstipulate, with pairs of pinnae; fruit yellowish (not seen on Pitcairn). Found only at Aute Valley on the eastern side of the island, in and area of disturbed scrub and abandoned gardens (figure 2.6). Species has pantropical distribution, but the first confirmed record for Pitcairn was made in 1997.

1997 collections: S. Waldren & N. Kingston 97-605

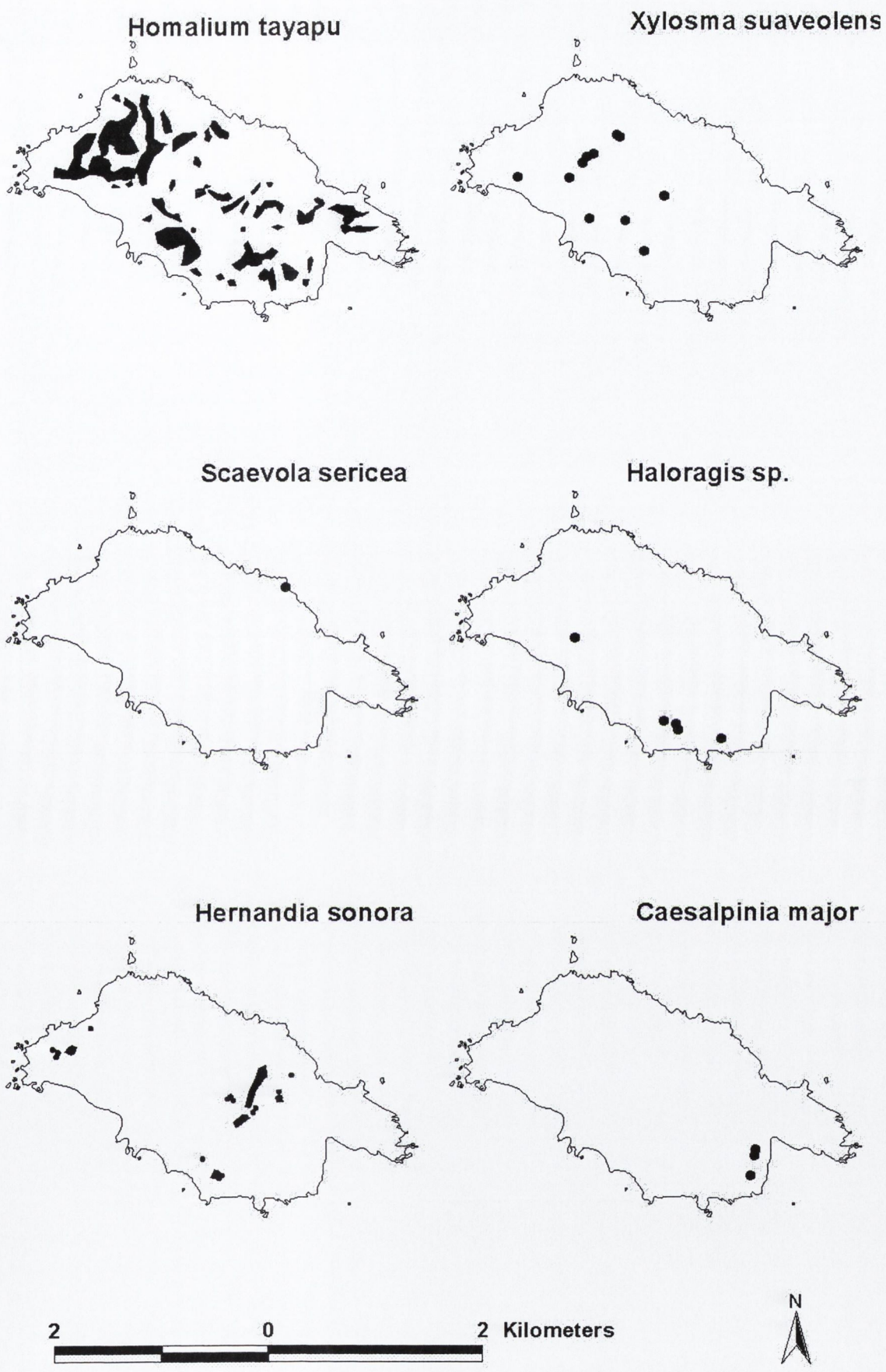


Figure 2.6 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Lythraceae

Pemphis acidula J.R.Forst. & G.Forst. (Ind)

Pitcairnese name: Miki miki [StJ]

Shrub or tree to 5m tall; leaves simple, opposite, lanceolate and small; flowers white, heterostylous; fruit a dry capsule containing numerous seeds. Typically occurs on coral and rocky substrates of atolls and Makatea islands, occasionally on rocky shores of high islands. Collected only once from Pitcairn in 1922.

Other collections: Quayle

Malvaceae

Abutilon pitcairnense Fosberg (End)

Pitcairnese name: Yellow fautoo [StJ]

Sprawling, densely tomentose shrub to 1.2m; leaves alternate, simple; flowers nodding, pale yellow in terminal cymes. Collected in 1898 and 1934 at Parlver Valley Ridge. Apparently observed by Twyford in 1958 [G], but unfortunately careful searches in 1997 failed to locate any plants. Endemic to Pitcairn, but related to species in the Gambier and Marquesas Islands.

Other collections: St. John 14,965 (holotype); Young 2

Hibiscus tiliaceus L. (Ind?)

Pitcairnese name: Burau [StJ; Islanders]; Fau; Pulau

Tree to 15m tall, erect or low-spreading and forming dense thickets; fibrous bark; leaves alternate, orbicular and large; flowers yellow, with 5 overlapping petals. Distributed across the island in mixed woodland, and occasionally dominating lowland woodland, particularly in coastal areas (figure 2.7). Pantropic species, and possibly a Polynesian introduction to Pitcairn.

Other collections: Beechey; Bennett; Moerenhout; Young 22, 23; Ross 22; St. John (sight record); Florence 10787

Hibiscus australense Fosberg (Ind)

Sub-erect or spreading, densely tomentose shrub to 3m tall; leaves broadly ovate; flowers in racemes at the tips of branches, pale to deep magenta. Rare, occurring in scrub communities in gullys close to the coast. Found in two locations on Pitcairn in 1997, one near Christians Cave, and the other at Down Rope (figure 2.7); the first records of this species in the Pitcairn Group. Species is also found in the Austral Islands.

1997 collections: S. Waldren & N. Kingston 97-583; N. Kingston 97-614

Thespesia populnea (L.) Sol. ex Corrêa (Ind?)

Pitcairnese name: Miro [StJ; Islanders]

Tree to about 12m; wood is hard with reddish brown or black streaks; leaves simple, alternate, ovate; flowers pale yellow; seed production is prolific. Found in woodland at St. Pauls, Tedside and Pulau usually in among *Homalium taypau* woodland, but many of

the plants had been planted there during a reforestation programme during the 1960's (figure 2.7). Species is distributed from Madagascar, through Asia and the Pacific, but is often considered of Polynesian introduction in eastern Polynesia.
1997 collections: N. Kingston 97-021

Menispermaceae

Cocculus ferrandianus Gaudich (Ind)
Synonyms: *Cocculus trilobus* (Thunb.) DC. [G]
Prostrate shrub with twining stems; leaves alternate, ovate, subcordate; dioecious, flowers with six petals; fruit blue-purple drupe. Never seen in flower or fruit on Pitcairn. Found on eroded slopes, and rocky coastal areas. Distributed on the south of the island at Tautama and Ginser valley (figure 2.7). Species is distributed from Malesia through Polynesia to Hawaii, but in the absence of flowers or fruit it is difficult to determine if the Pitcairn specimens are *C. ferrandianus* or *C. orbiculatus* (found in the Cook Islands).
1997 collections: S. Waldren & N. Kingston 97-231; N. Kingston & D. Bell 97-247
Other collection: Fosberg & R. Clark 11,296

Myrsinaceae

Myrsine aff. *niauensis* (End)
Synonyms: *Bumelia sp.*
Tree or shrub to 5m; leaves alternate, oblong, stiff; dioecious. Probably endemic to Pitcairn Island, but closely related to other *Myrsine* spp. from Polynesia, notably *M. niauensis* from the Tuamotus and *M. hosakae* from Henderson Island. Not refound in 1997.
Other collections: Young s.n.; Mathews (as *Bumelia sp.*); apparently also collected by Ross in 1934 and Lintott in 1957 (Gothesson 1997).

Myrtaceae

Eugenia reinwardtiana (Blume) DC (Ind)
Synonyms: *Eugenia rariflora* Benth. [Brn]
Pitcairnese name: Poope [Islanders]
Erect low shrub to 2 m; simple, ovate, opposite, coriaceous, dark glossy green leaves; flowers white; fruit an orange-red berry to 2cm long. Found in coastal cliff scrub, and on eroding coastal slopes. Locally common around Bounty Bay and the coast below Adamstown, but also found at Tedside, Tautama and Down Rope (figure 2.7). Probably also occurs in other inaccessible coastal areas that have not been surveyed. Species is found from Malesia and through Polynesia to the Hawaiian Islands.
1997 collections: S. Waldren & N. Kingston 97-079; S. Waldren & N. Kingston 97-081; P. Bingelli 97-087; S. Waldren & N. Kingston 97-580; S. Waldren & N. Kingston 97-607
Other collections: Quayle (as *E. rariflora* in Brn); Florence 10780, 10790

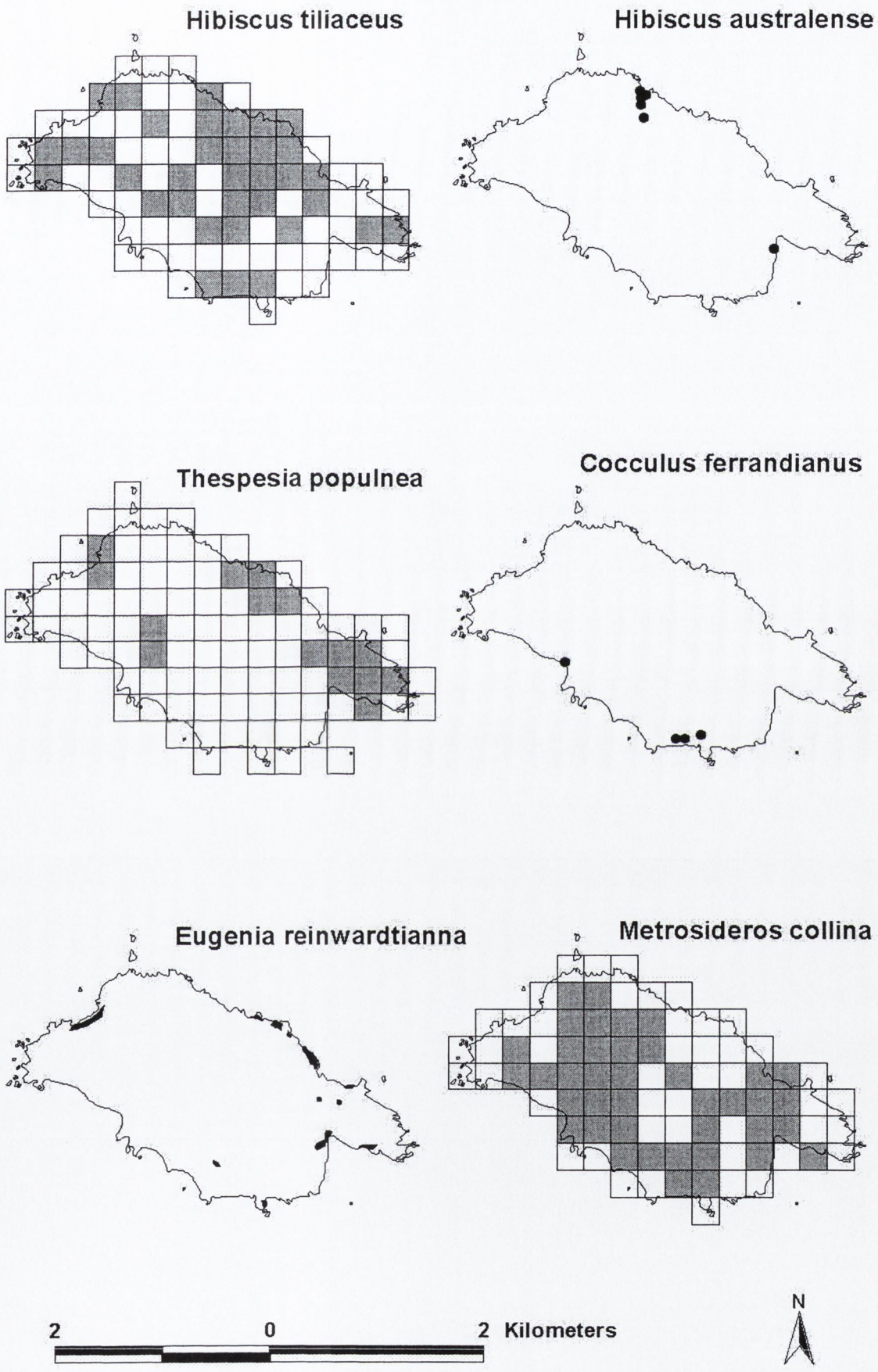


Figure 2.7 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Metrosideros collina (J.R.Forst. & G.Forst.) A.Gray (Ind)

Pitcairnese name: Rata; Lata [StJ; Islanders]

A shrub or tree, up to 30m in height, but usually smaller with spreading low branches and decumbent trunks; leaves opposite, simple, elliptic; flowers conspicuous with numerous red stamens; produces aerial roots in cloud forest, where the trees are characteristically covered in epiphytes. Common in moderate and high altitude forest, but found as a freely regenerating shrub on eroding slopes and ridges (figure 2.7). Species is distributed from Fiji through Polynesia to the Hawaiian Islands.

1997 collections: S. Waldren & N. Kingston 97-028; J. Starmer & P. Bingelli 97-047; S. Waldren & N. Kingston 97-597

Other collections: Beechey; Young 17; St. John 14,953, 14,951; Fosberg 11,217, 11,200; Florence 10768; Florence & Waldren 11045

Nyctaginaceae

Pisonia umbellifera (J.R.Forst. & G.Forst.) Seem. (Ind)

Pitcairnese name: Waewae [StJ]

Shrub or tree to 15 m; leaves opposite, oblong, mid-green; flowers white, unisexual; fruits elongate, very sticky. In the past the seeds were used to trap insects. Rare in low to mid-altitude mixed forest, especially in valley bottoms. Found on the south half of the island, in Issac's, Jack Willems and Faute valleys, as well as Tautama (figure 2.8). Species is distributed from Mauritius, through Asia and Australia to Polynesia and the Hawaiian Islands.

1997 collections: S. Waldren 97-103; S. Waldren & N. Kingston 97-139

Other collections: St. John 14,975

Oleaceae

Jasminum didymum G.Forst. (Ind)

Pitcairnese name: Easter vine [StJ; Islanders]

Climbing or prostrate vine; leaves 3-foliate, opposite; white flowers in many flowered cyme; fruit a black berry. Very rare in native woodland especially *Metrosideros collina* or *Homalium taypau* forest. In addition it may have been planted in some areas and especially around Adamstown. Most plants are be found at Alihow on the ridge overlooking Tautama and McCoys Valley (figure 2.8). The species is distributed from Australia, through Melanesia to Pitcairn Island.

1997 collections: S. Waldren & N. Kingston 97-602; S. Waldren 97-669

Other collections: St. John 14,952

Piperaceae

Peperomia blanda Kunth. var. *floribunda* (Miq.) H.Huber (Ind)

Synonyms: *Peperomia leptostachya* Hook. & Arn.

Pitcairnese name: Wild Joe [StJ]

Terrestrial, epiphytic, epilithic, creeping or erect, pubescent herb; leaves elliptic, fleshy, opposite or whorled; flowers tiny, held on long spike; seeds tiny, black, sticky. Abundant and forming extensive colonies on rocks and boulders in all woodland types in all parts of the island (figure 2.8). Taxon is distributed from Asia and Australia through Polynesia to the Hawaiian Islands.

1997 collections: E. Saul 97-010; S. Waldren & N. Kingston 97-030; S. Waldren & N. Kingston 97-206; S. Waldren & N. Kingston 97-314; S. Waldren 97-612; S. Waldren 97-672

Other collections: St. John 14,977 (as *P. leptostachya*); Waldren in Florence 10816; Florence 11025

Peperomia pitcairnensis (Lauterb.) C.DC (End)

Epilithic and epiphytic, creeping, erect, glabrous herb; leaves elliptic, opposite, fleshy; flowers tiny, held on spike; seeds tiny, black, sticky, produced on the flowering spike. Rare but widely distributed on rocks and trees in *Metrosideros collina* or *Homalium taypau* forest (figure 2.8). Endemic to Pitcairn Island, but related to other south-east Polynesian species.

1997 collections: S. Waldren 97-673

Other collections: Bennett 1834

Peperomia rapensis F.Br. (Ind)

Very similar to and easily confused with the previous species, but with minute hairs (<0.1mm) on the leaves and stem. Found on cliff faces and boulders in native woodland of *Metrosideros collina* or *Homalium taypau*. Distributed in the southern half of the island, especially around Tautama and Faute Valley (figure 2.8). This species is also found in the Austral Islands and on Rapa.

1997 collections: S. Waldren & N. Kingston 97-115; S. Waldren 97-613

Other collections: Fosberg & Clark 11,315; Florence 11016

Peperomia sp. (End)

Creeping herb, rooting along the stem; leaves very succulent, larger then in the previous three species, petiole forming decurrent ridges along stem; flowering spike also shorter and stouter then in the previous three species, to 5.6mm wide. Known only from a damp, shaded cliff face known as Down Cask at Tautama (figure 2.8). This was first collected in 1997, and is probably a new species and endemic to Pitcairn Island.

1997 collections: S. Waldren & N. Kingston 97-313; S. Waldren 97-611

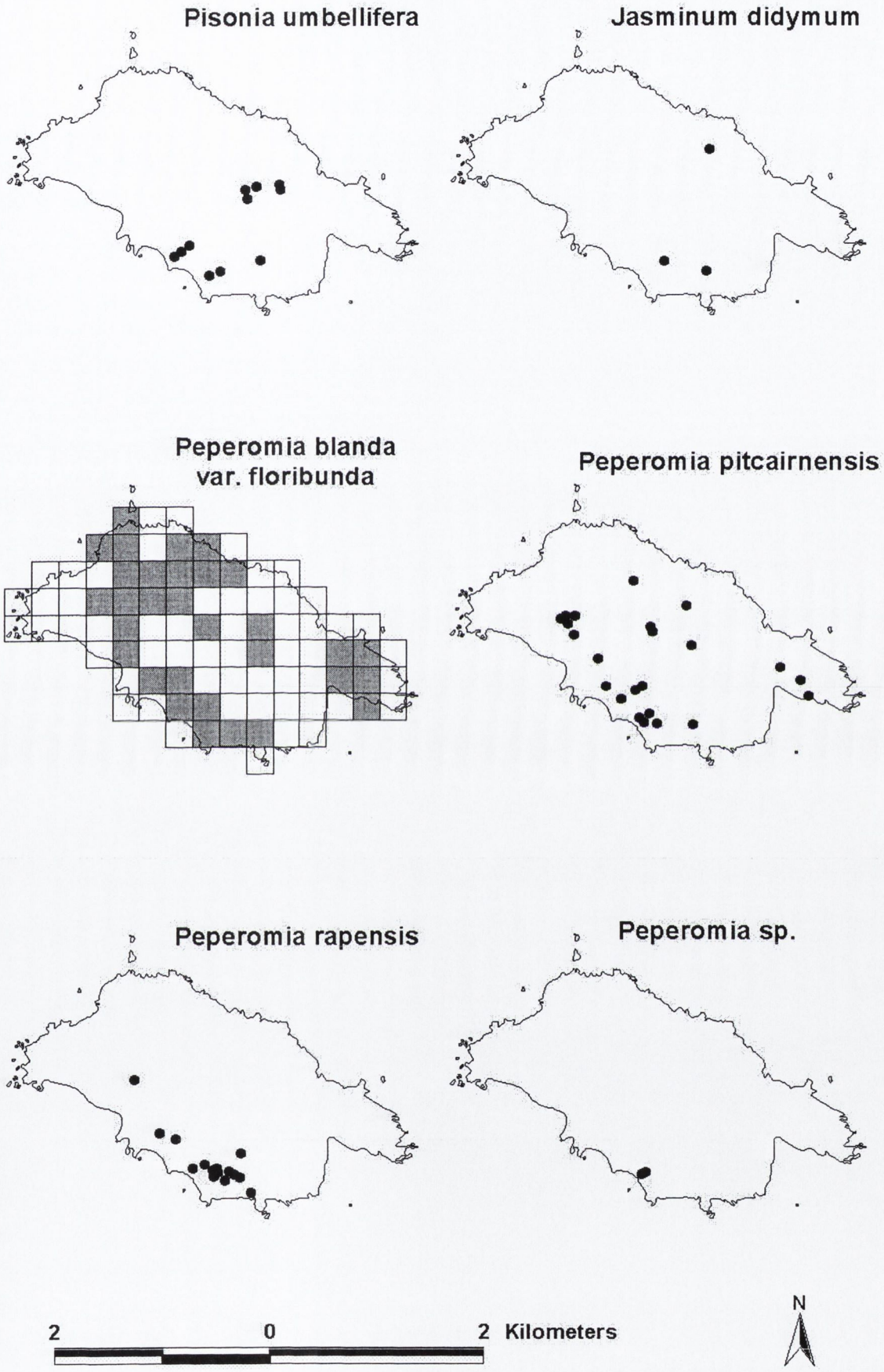


Figure 2.8 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Portulacaceae

Portulaca lutea Sol. ex Seem. (Ind)

Pitcairnese name: Sun plant; Iceplant [Pitcairn Islanders]

Prostrate, succulent herb, with red stems; simple, alternate leaves; flowers yellow. Found in all coastal habitats from all parts of the island (figure 2.9). The species is distributed from Fiji through Polynesia to the Pitcairn Islands.

1997 collections: J. Starmer & P. Bingelli 97-26; 97-68; S. Waldren & N. Kingston 97-82

Other collections: Quayle; Fosberg 11,338

Primulaceae

Samolus repens Pers. (Ind)

Erect or prostrate, succulent herb, rooting at nodes; flowers yellow. Rare in damp gullys and on wet rock faces from the southern coast of the island (figure 2.9). Taxon is also found in Australia, New Zealand, Easter Island and South America. The 1997 collection is the first record of this taxon from Pitcairn.

1997 collections: S. Waldren & N. Kingston 97-325; 97-315; S. Waldren 97-093

Rosaceae

Osteomeles anthyllidifolia (Sm.) Lindl. (Ind)

Pitcairnese name: Rock rose [StJ]

Prostrate, spreading, evergreen shrub; leaves pinnately compound; flowers white, clustered at branch tips. Found only at one site on rocks at Ships Lookout Point (figure 2.9). Several sites previously known to the Islanders were searched without success, indicating a decline in the species. This species is found from Fiji and New Zealand to Rapa, Pitcairn and the Hawaiian Islands.

Other collections: Young 47; Cuming 1385 (most of Cuming specimens are held at Kew, but a specimen was recently located in TCD)

Rubiaceae

Coprosma benefica W.R.B.Oliv. (End)

Synonyms: *Coprosma rapensis* F.Br.var. *benefica* (W.R.B.Oliv.) Fosberg [StJ; F&S]

Pitcairnese name: Red berry [StJ; C. Warren]

Small shrub or tree to 7m, bark dark grey-brown; leaves pale green, opposite, elliptic with lateral veins having distinct axillary glands, and minutely ciliate margins; dioecious; flowers inconspicuous, corolla pale yellowish green; fruits orange red, each containing 2 seeds. Very rare at edges of degraded *Homalium taypau* forest, or *Lantana camara* scrub. 12 individuals identified from the area around the Radio Station and McCoys Valley (figure 2.9), but previous records of the species have been collected from Down Rope, Adamstown and Parlver Valley Ridge. Species is endemic to Pitcairn Island, although very closely related to *C. rapensis* from Rapa and Mangareva, into which it is sometimes

reduced as a variety (Fosberg 1937). More recently it has been retained as a distinct species (Heads 1996) and as such is retained here. It differs in being a larger tree (*C. rapensis* is a shrub to only 3m in height), having larger and broader ciliate leaves, smaller flowers and fruits, with a less pronounced domatia in the axils of the veins, and longer petioles.

1997 collections: S. Waldren 97-063; S. Waldren & N. Kingston 97-228, 97-274

Other collections: Fosberg & B. Christian 11,267; St. John 14,984, 15,004; Fosberg & R. Clark 11,301, 11,313, 11,317

Cyclophyllum barbatum (G.Forst.) N.Hallé & Florence (Ind)

Synonyms: *Canthium barbatum* (G.Forst.) Seem. var *christianii* Fosberg [StJ]

Pitcairnese name: Christmas tree; Big Leaved Jessamy [Islanders]

Shrub or small tree to 3m tall; leaves opposite, ovate, simple; flowers rarely seen, produced in a few flowered cyme, white fading to yellow; fruits a pink drupe, also rarely seen on Pitcairn. Locally distributed in mid altitude native and disturbed woodland, especially in the eastern half of the island (figure 2.9). Most specimens seen were small and sterile, suggesting that most of the larger individuals had been cut down as Christmas trees. Species is distributed from Fiji and through Polynesia, although many subspecies and varieties have been described from within its range.

1997 collections: S. Waldren 97-062; S. Waldren 97-336

Other collections: Quayle; Young s.n.; Fosberg & B. Christian 11,235

Guettarda speciosa L. (Ind)

Pitcairnese name: High White [Islanders]; Tafano [StJ]

Tree to 10-12m; leaves opposite, obovate, rounded; white flowers strongly scented. Rare, scattered across the island in undisturbed patches of woodland, especially coastal woodlands (figure 2.9). The species is distributed from Africa, through Asia and Australia to Polynesia.

1997 collections: S. Waldren & N. Kingston 97-150; S. Waldren 97-343

Other collections: Cuming; Quayle; Young s.n.; Ross 19; Chapin; Florence 10767

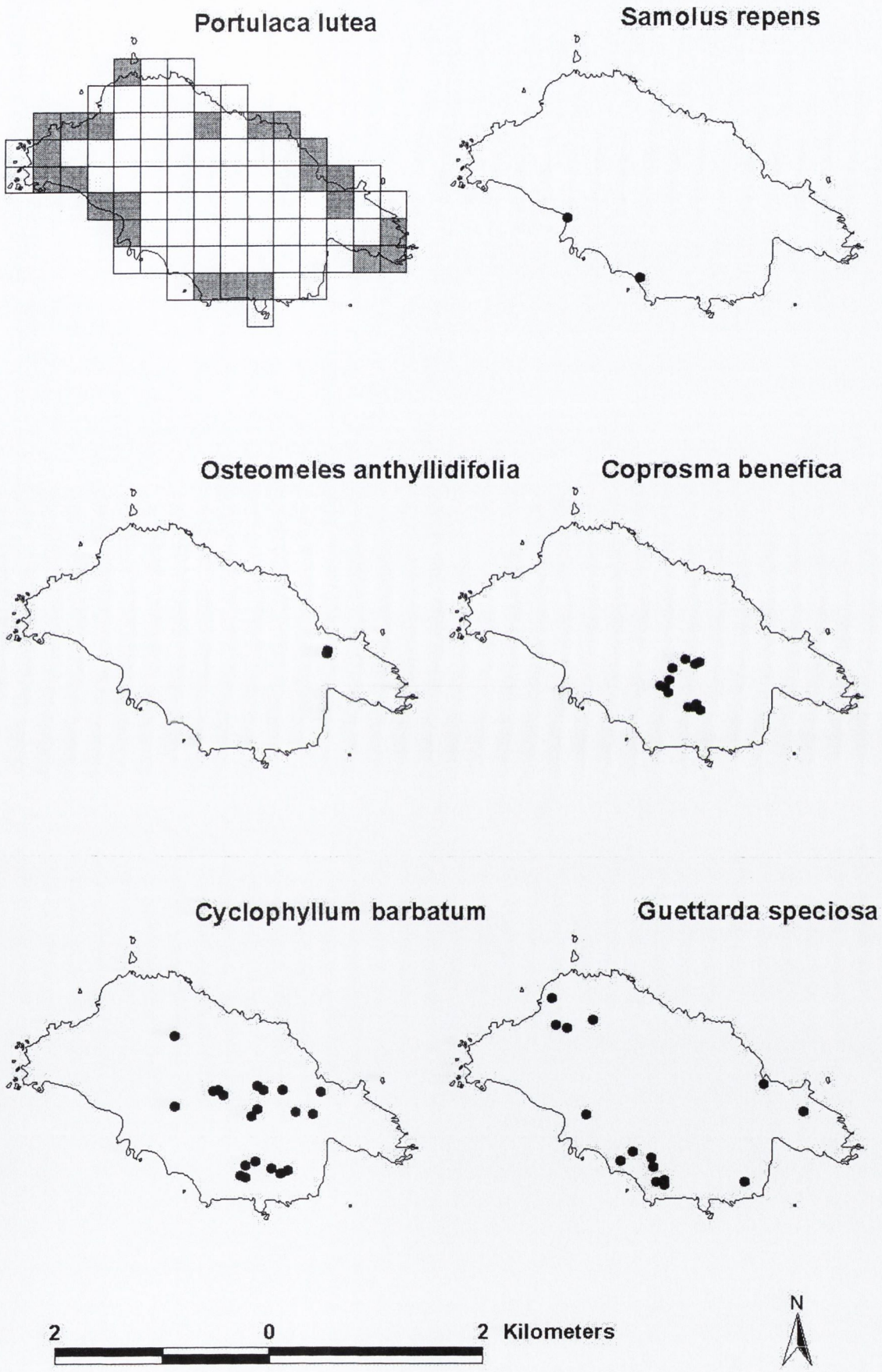


Figure 2.9 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Morinda myrtifolia A.Gray (Ind)

Synonyms: *Morinda forsteri* Seem. [StJ]

Pitcairnese name: Climber [StJ]

Glabrous woody climber or trailing shrub; leaves opposite, elliptic, with foveolate glands at axils of veins; flowers white, fragrant; fruits blackish with protrusions. Widespread but local in native and disturbed forest and scrub, especially under *Homalium taypau*, *Metrosideros collina* and *Pandanus tectorius* (figure 2.10). The species is distributed from Fiji across through Polynesia.

1997 collections: N. Kingston 97-017; J. Starmer & P. Bingelli 97-029; 97-171; 97-173; N. Kingston 97-237; S. Waldren 97-637

Other collections: Young 25; St. John 15,013 (as *M. forsteri*)

Psydrax odorata (G.Forst.) A.C.Sm. & S.P.Darwin (Ind)

Synonyms: *Canthium odoratum* (G.Forst.) Seem. [Twy]

Pitcairnese name: Got's Piss [C. Warren]; Small leaved Jessamy, Fine leaved Jessamy, Christmas tree [D. Brown]

Shrub or small tree to 10m, with light grey bark; leaves opposite, elliptic, leathery and dark green; flowers white and fragrant; fruit a black fleshy drupe. Local at the edges of disturbed *Lantana camara* and *Psidium guajava* scrub, regenerating freely. Found at mid-altitudes but not in the west of the Island (figure 2.10). The species is distributed from Fiji across through Polynesia to the Hawaiian Islands. St. John collected this taxon from Pitcairn, but failed to mention it in his account of the flora (Fosberg 1937; St. John 1987).

1997 collections: J. Starmer & P. Bingelli 97-140; S. Waldren 97-609

Solanaceae

Lycium sandwichense A.Gray (Ind)

Pitcairnese name: Pepe [StJ]; Banthorn [G]

Prostrate trailing shrub, succulent; leaves elongate, cylindrical; flowers pale mauve; fruits bright red. Found on cliff ledges and coastal rocky areas from all around the island (figure 2.10). The species is distributed from Polynesia to Easter and the Juan Fernandez Islands.

1997 collections: S. Waldren & N. Kingston 97-083

Other collections: Ross 55; Fosberg 11,342; Florence 10778, 10795; St. John 15,043

Ulmaceae

Celtis pacifica G.Planch. (Ind)

Pitcairnese name: Pin'e (error?) [StJ]

Tree to 10 m in height, with rounded crown; leaves alternate, simple; flowers minute; fruits a one-seeded black drupe. Only one tree found on Pitcairn in 1997, in a remnant of native woodland at Tautama associated with *Hibiscus tiliaceus*, epilithic ferns and

Peperomia spp. (figure 2.10). Previously it had been collected by H. St. John at St. Pauls. The taxon is also found in the Cook, Austral, Society, Marquesas and Gambier Islands.
1997 collections: N. Kingston & D. Bell 97-246; S. Waldren 97-527
Other collections: St. John 15,012

Urticaceae

Pilea sancti-johannis Florence (Ind)
Erect, or trailing succulent shrub to 1 m; leaves in whorls of 4, sessile with prominent midrib below, gradually tapered to the base, dark shining green above, paler beneath, with a sub-marginal vein; monecious, male flowers with 4 very pale greenish-yellow sepals and small corolla, females very reduced. In cultivation the youngest flowers are usually female, with increasing numbers of male flowers as the plant ages. Found at a few locations in rock crevices on a partially shaded steep cliff above Ginser Valley (figure 2.10). Species is also found on Mangareva in the Gambier Islands. This 1997 record is the first of this species for Pitcairn. It was first collected from Mangareva in 1934, but not described until 1997.
1997 collections: S. Waldren 97-341

MONOCOTYLEDONAE

Gramineae

Cenchrus calyculatus Cav. (Ind?)
Pitcairnese name: Pilipili; Sticking grass [StJ]
Coarse, erect grass, up to 1m tall; ligule tiny, with membranous hairs; spike-like inflorescence, 8-20cm long, barbed throughout. Only found at Tedside on cliff ledges in scrub, with *Nephrolepis* spp. and *Lantana camara* (figure 2.10). Previously also collected from St. Pauls. Found on rocky coasts and coastal thickets from New Caledonia and throughout Polynesia, but apparently declining in abundance throughout Whistler (1992).
1997 collections: S. Waldren 97-181
Other collections: Young 10; St. John 15,024 ; Fosberg & Clark 11,273

Lepturus repens (G.Forst.) R.Br. (Ind)
Stoloniferous grass, tufted; blades up to 35cm long, and 3-15mm wide; inflorescence a cylindrical spike. Rare, but found on coastal rocks and stony beaches at Down Issacs on the north of the island, and Down Rope of the south (figure 2.11). Both of the previous collections were from Bounty Bay, but it was not observed there in 1997. The species is distributed from Africa, across Asia and Australia to Polynesia, where it is a typical species of coastal habitats, and especially of atolls.
1997 collections: S. Waldren & N. Kingston 97-578
Other collections: Fosberg 11,336; Florence 10779

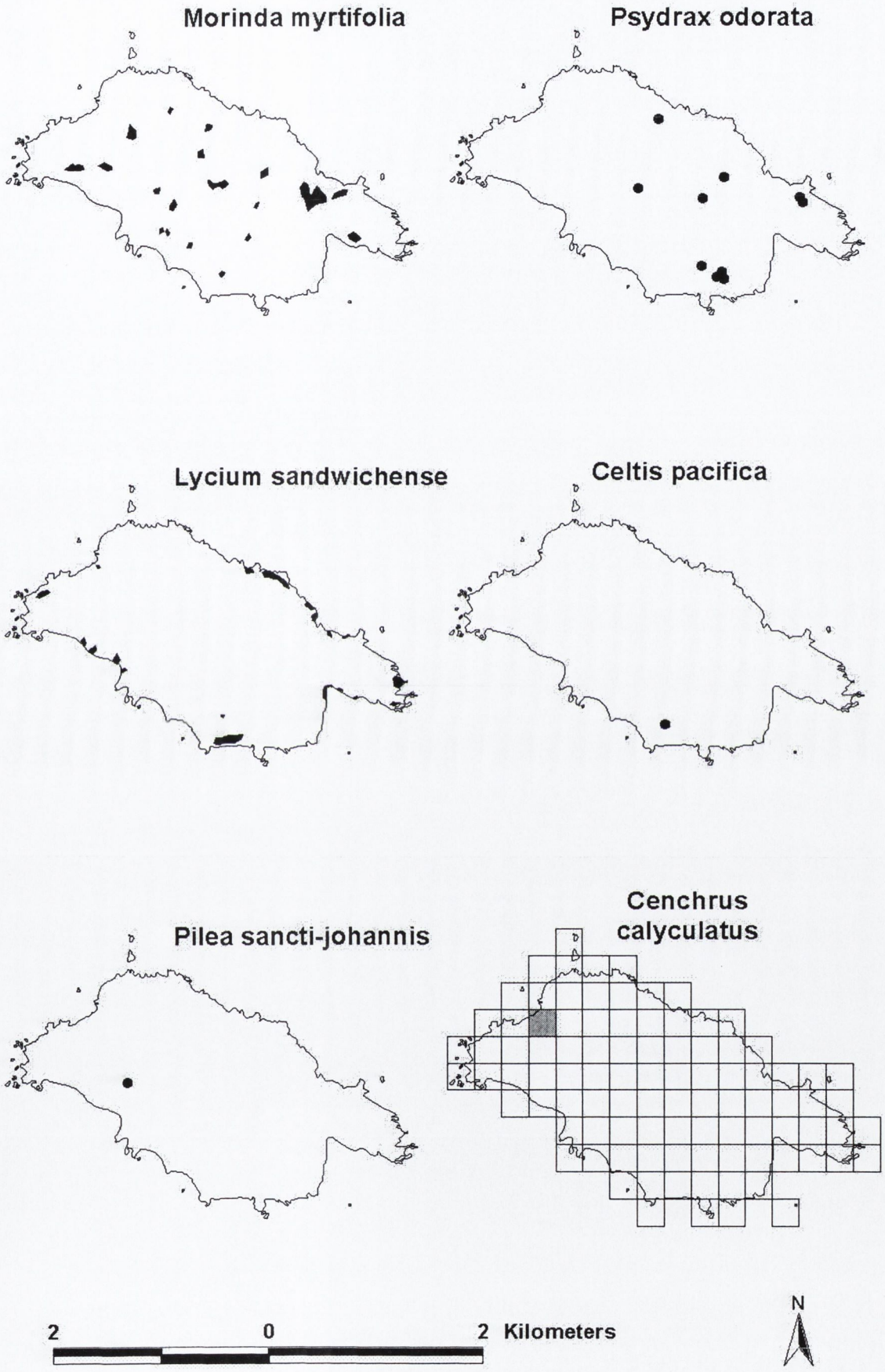


Figure 2.10 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Liliaceae

Dianella intermedia Endl. (Ind)

Pitcairnese name: Mo'u (St. John)

Rhizomatous herb, with finely serrate, linear leaves, up to 130cm tall; flowers blue-white; fruits metallic blue. In 1997 seen only at one area of coastal cliff at Down Rope, the same location as the original St. John collection in 1934 (figure 2.11). Distributed from New Zealand and Fiji to Polynesia.

Other collections: St. John 15,005

Orchidaceae

Taeniophyllum fasciola (G.Forst.) Rchb. (Ind)

A leafless, epiphytic orchid, with erect capsules; photosynthetic roots radiate from a central area holding the capsule; flowers not observed. Found in high altitude and cloud forest, on *Metrosideros collina, Homalium taypau, Xylosma suaveolens* and occasionally on *Syzygium jambos* (figure 2.11). Distributed from Fiji through Polynesia to Pitcairn.

1997 collections: E. Saul 97-013; J. Starmer & P. Bingelli 97-046

Other collections: St. John 14,958, 15,047; Florence 11027

Pandanaceae

Pandanus tectorius Parkinson ex Z (Ind)

Synonyms: *Pandanus pitcairnensis* H.St.John [StJ]; *Pandanus benignus* H.St.John [StJ]

Pitcairnese name: Palm [StJ; M. Warren]

Sparsely branched tree up to 10m tall, basally supported by aerial prop-roots; trunk armed with prickles; sword-like leaves, up to 1.5m long with hooked thorns along the margins and underside of the midrib; leaves clustering in spirals at the tips of branches; fruit formed of 50 or more woody phalanges, orange in colour and containing the seeds. Found throughout the island, on coastal cliffs to high altitude forest, and dominates in some areas of coastal forest (figure 2.11). The species is extremely variable and several varieties may occur, with some forms being of anthropogenic origin on the island. Distributed from Malesia and the Philippines, through Asia, Australia, Micronesia and Polynesia to Pitcairn and the Hawaiian Islands. The taxonomy of the group is confused and many species have been named from within the species complex.

1997 collections: S. Waldren & N. Kingston 97-323

Other collections: Fosberg 11,300 (*P. pitcairnensis* - holotype); Chapin 958 (as *P. benignus*)

PTERIDOPHYTA

Adiantaceae

Adiantum hispidulum Sw. (Ind)

Pitcairnese name: Maidenhair [StJ]

Terrestrial or epilithic fern with shortly creeping rhizome, forming patches up to 50 cm across; fronds delicate up to 30cm long, with shiny black stipe. Rare at mid altitudes, in areas of native woodland especially about *Homalium taypau* roots, and in rock crevices (figure 2.11). The species is widely distributed from Africa eastwards to Polynesia in both tropical and subtropical zones.

1997 collections: S. Waldren & N. Kingston 97-134; S. Waldren & N. Kingston 97-179; S. Waldren 97-541

Other collections: St John 15,031; Lintott 152a, 152b; Twyford 51

Aspidiaceae

Ctenitis cumingii Holttum (End)

Erect or shortly creeping rhizome; base of stipe with dense covering of scales to 2cm; tri to quadri-pinnate, light green fronds to 1m, with pale whitish-rusty ctenitoid hairs on upper side; scales more or less appressed to rachis & abundant; young sori yellow/green, maturing from yellow to brown. Local but widespread in native areas of damp woodland especially under *Homalium taypau* and *Metrosideros collina* woodland, or *Pandanus tectorius* and *Glochidion* spp. scrub. Found at high altitudes 120-340m from Garnets Ridge and Big ridge, across to McCoys and Faute Valleys (figure 2.11). Endemic to Pitcairn but closely related to the *Ctenitis sciaphila* group, and especially *C. rapensis* from Rapa. In 1991, *Lastreopsis* cf. *pacifica* was collected and misidentified as *C. cumingii*, which led to the conclusion in Waldren *et al.* (1995) that the species was extremely rare and limited to one location. The species is now known to be much more widely distributed.

1997 collections: S. Waldren 97-106; S. Waldren 97-110; 97-539; 97-544

Other collections: Cuming 1388 (holotype); St. John 14,968; Moverley 22,23; the collection of Florence 10758 is *Lastreopsis* cf. *pacifica*

Arachnoides aristata (G.Forst.) Tindale (Ind)

Synonyms: *Rumohra aristata* (G.Forst.) Ching [StJ; Ble]; *Polystichum aristatum* (G.Forst.) C.Presl. [B&B; Cop]

Fern with dark green, erect, 3-pinnate fronds with aristate ultimate segments, arising from a creeping rhizome which may form extensive colonies. Found in steep, shaded valleys under woodland of *Syzygium jambos, Metrosideros collina* or *Homalium taypau*. Found across the island at high altitudes 140-300m (figure 2.12). The taxon is distributed widely in the tropics and subtropics from Southeast Asia across to Polynesia.

1997 collections: S. Waldren & N. Kingston 97-006; S. Waldren & N. Kingston 97-007; S. Waldren & N. Kingston 97-160; S. Waldren 97-283; S. Waldren 97-520; N. Kingston 97-070

Other collections: Quayle (as *R. aristata*); St. John 14,969 (as *R. aristata*); Fosberg & B. Christian 11,310, 11,229 (as *R. aristata*); Lintott 154; Florence 10739

Lastreopsis cf. *pacifica* (Ind)

Fern with creeping rhizome; stipe wiry, with sparse scales; frond tripinnate, glandular, to 30 cm; ctenitoid hairs mainly on costae and rachis; microscopic indusia. The specimens from Pitcairn differ from herbarium material at Kew and the British Museum, in that they are more glandular and have smaller sori. Living material from TCD will need to be compared to material from elsewhere in the species range before an accurate determination can be made. Restricted to one location, on a wet rock face with *Trichomanes enderlichianum* in *Syzygium jambos* woodland at Browns Water, with a further single plant on a stream bank at Pulau (figure 2.12). This is the same location as the Florence collection was made in 1991. The species is also found in Samoa, the Cook and Society Islands.

1997 collections: S. Waldren & N. Kingston 97-175; S. Waldren & N. Kingston 97-220

Other collections: Florence 10758 (in error as *Ctenitis cumingii*)

Aspleniaceae

Asplenium obtusatum G.Forst. (Ind)

Pitcairnese name: Rock fern [Twy]

Tufted, epilithic fern up to 30cm in height, with shortly creeping rhizome and slightly fleshy pinnate fronds. Typical of coastal habitats, especially on cliffs, and among boulders and scree. Found in most coastal areas of the island except for the extreme north (figure 2.12). Also occurs in Australia, New Zealand, the Society, Austral and Hawaiian islands, Easter Island and Chile.

1997 collections: J. Starmer & P. Bingelli 97-025; S. Waldren & N. Kingston 97-089; S. Waldren & N. Kingston 97-320; S. Waldren 97-636

Other collections: Bennett; Lintott 170; Williams 3,083; Twyford 73; Florence 10775, 11019; Fosberg 11,343; Fosberg & R. Clark 11,291; Randall & Collier s.n.

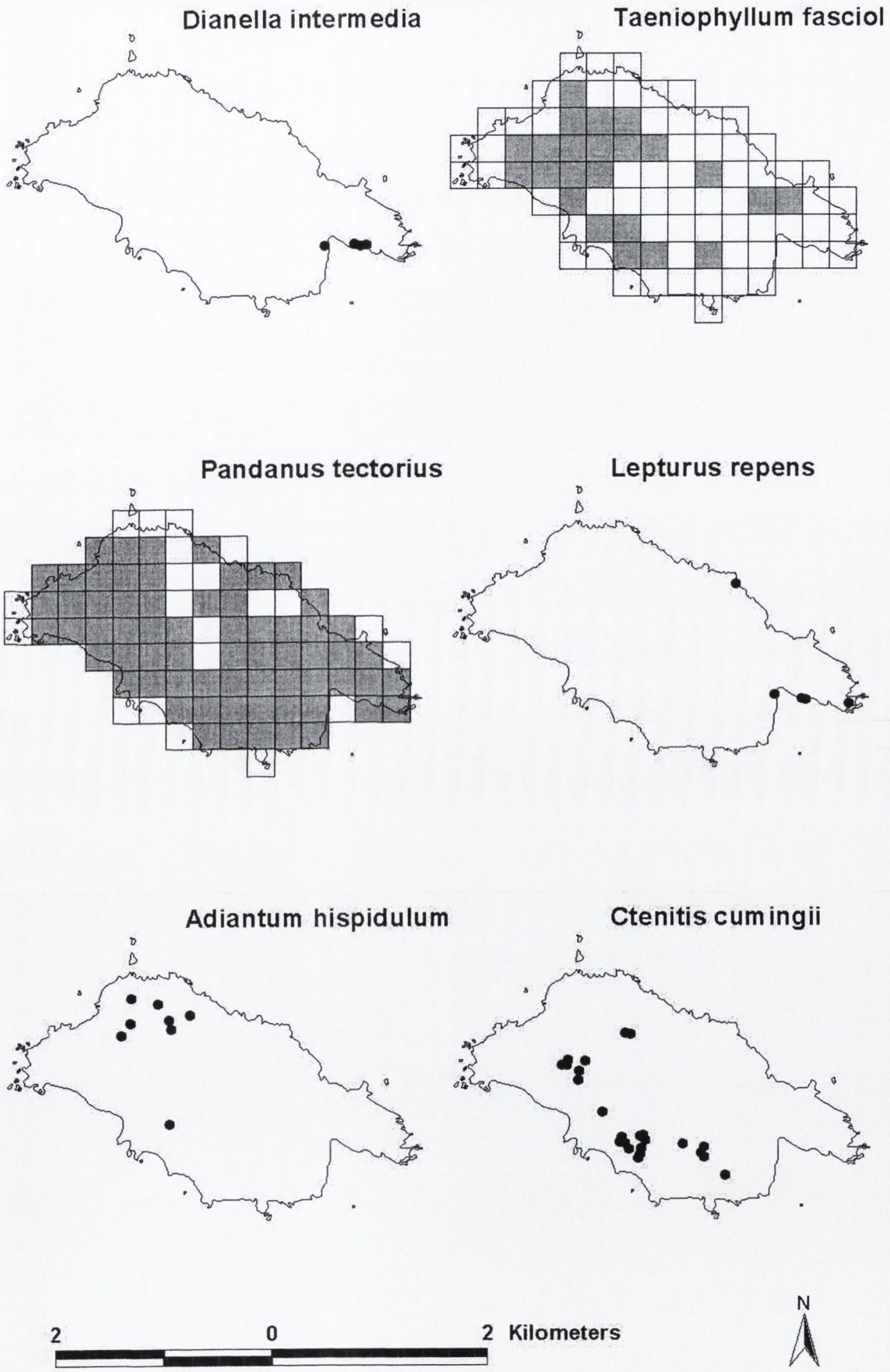


Figure 2.11 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Asplenium nidus L. (Ind)

Pitcairnese name: Dock [StJ]

Tufted epilithic or occasionally terrestrial fern, with entire fronds up to 1m tall on Pitcairn, and typically with distinct linear sori on underside. Found across the island, locally common in areas of native woodland (figure 2.12). Found from Africa through Asia and Polynesia to Pitcairn and the Hawaiian Islands. The *Asplenium nidus* and *A. australasicum* complex is in need of revision (R. Johns pers comm to S. Waldren), but until such a revision is carried out the name *A. nidus* is retained for the Pitcairn material.

1997 collections: S. Waldren & N. Kingston 97-178

Other collections: Lintott 153; St. John 14,970

Asplenium shuttleworthianum Kunze (Ind)

Pitcairnese name: Fine fern [Carol Warren]

Terrestrial or epilithic fern, arising in tufts; fronds lanceolate in outline, irregularly tri-pinnate; sori 2mm long, near tips of ultimate segments. Found mainly on coastal rocks and eroding coastal slopes, but also found on boulders in *Hibiscus tiliaceus* woodland, and low altitude native woodland. Occurs mainly near coasts in the southern half of the island, never in the northern half (figure 2.12). Found from the Kermadec Islands, to Fiji and Polynesia.

1997 collections: S. Waldren & N. Kingston 97-318, 97-321; S. Waldren 97-340, 97-516, 97-530, 97-534, 97-537

Other collections: Cuming 1,374 (holotype); Florence 10741, 10756, 10776, 11018

Loxoscaphe gibberosum T.Moore (Ind)

Pitcairnese name: Fine fern [Carol Warren]

Erect, tufted, terrestrial or epilithic fern; up to 1m, triangular in outline; sorus shorter and indusium wider then in *Asplenium shuttleworthianum*, otherwise similar in appearance. Found on steep slopes, in damp gullys and on rock faces in native woodland at mid altitudes right across the island (figure 2.12). Distributed from Fiji and Polynesia to Pitcairn, but absent from Samoa.

There is confusion between this species and *Asplenium shuttleworthianum*, as in general habit they look extremely similar and occur in overlapping habitats. There is no doubt that the two species are very closely related (Copeland 1947), but further genetic and physiological studies of these species are necessary to elucidate these taxonomic problems.

1997 collections: S. Waldren & N. Kingston 97-009, 97-088, 97-226; S. Waldren 97-536

Other collections: Cuming 1,273; Mathews; Lintott 157; Williams 3,012, 3,053; Twyford 43; Fosberg & B. Clark 14,297; St. John 15,002; Randall & Collier s.n.

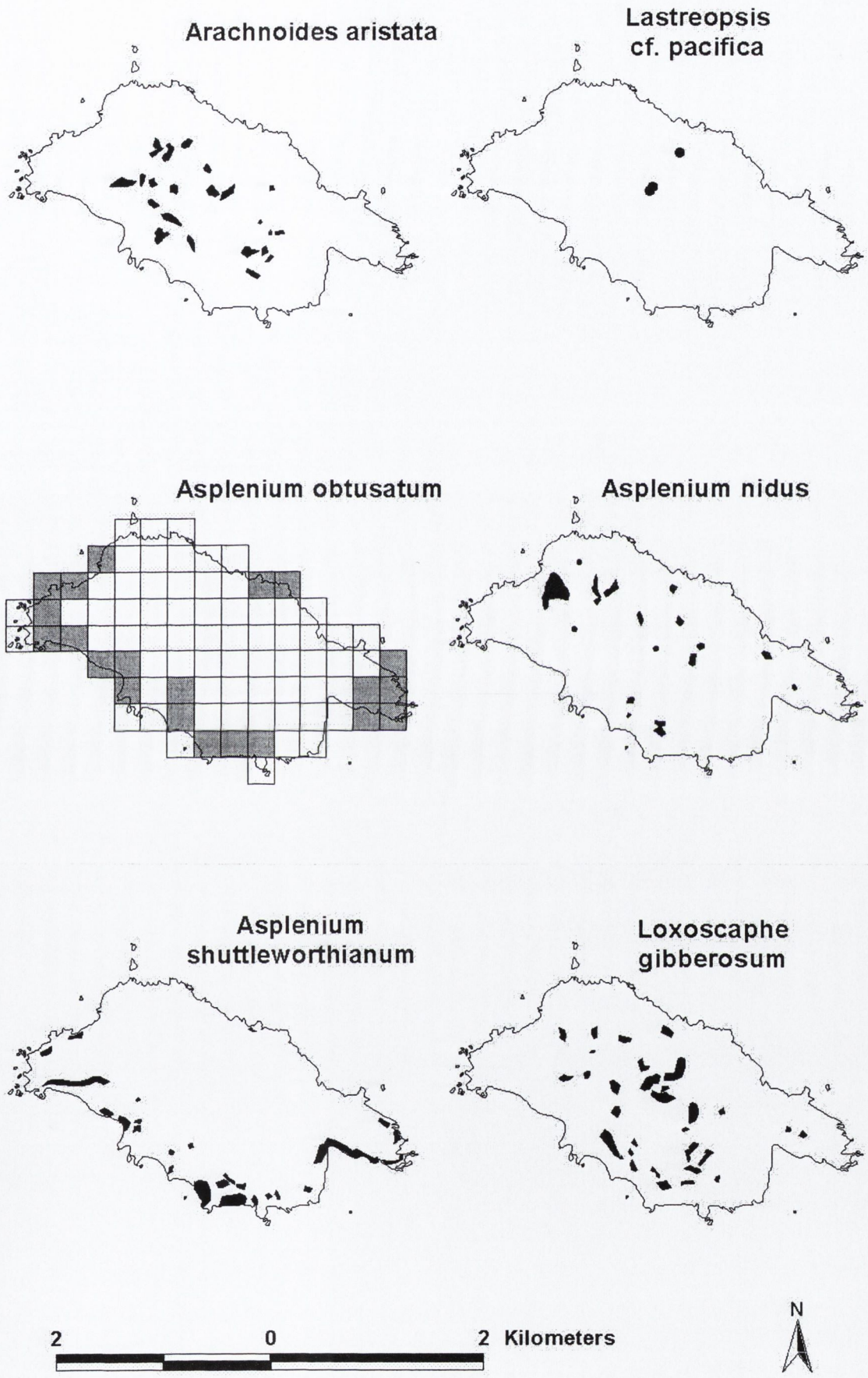


Figure 2.12 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Athyriaceae

Diplazium harpeodes T. Moore (Ind)

Synonyms: *Athyrium membranaceum* Mett. [StJ]; *A. pitcairnense* Copel. [StJ]; *A. polyanthes* (Sol. ex Baker) Copel. [Ble]

Erect, tufted fern up to 1.4m tall, with mid-green bi-pinnate fronds; linear sori in pairs on mature fronds. Found in damp gullys in *Syzygium jambos*, *Homalium taypau* and *Pandanus tectorius* forest, at mid to high altitudes (60-300m). Very rare and local, being found at only 5 locations, 3 with only a single plant, but from all areas of the island (figure 2.13). The taxon is distributed from Fiji across Polynesia to Pitcairn Island.

1997 collections: N. Kingston 97-072; S. Waldren & N. Kingston 97-149, 97-159, 97-317, 97-326, 97-603

Other collections: Fosberg & R. Clark 11,208 (as *Athyrium pitcairnense*)

Blechnaceae

Doodia media R.Br. (Ind)

Tufted, erect fern which may form extensive colonies; fronds pinnate, dark to mid-green, brittle; sori oblong in 2 rows on either side, and parallel to, the midrib. Found in steep gullys and roadsides under woodland canopies, typically at mid-altitudes in slightly disturbed *Syzygium jambos* and *Homalium taypau* woodland at Brown's Water, Tautama and McCoys Valley (figure 2.13). The taxon occurs from Australia and Fiji, through Polynesia to Easter Island, but is absent from Tahiti and Samoa.

1997 collections: S. Waldren & N. Kingston 97-011, 97-224; S. Waldren 97-286

Other collections: Quayle; Lintott 159a, 159b; Williams 3,044; Twyford 133,134; Florence 10738; St. John 14,976; Randall & Collier

Cyatheaceae

Cyathea medullaris (G.Forst.) Sw. (Ind)

Synonyms: *Cyathea cumingii* Baker [StJ]

Pitcairnese name: Black Fern [StJ], Man fern [Islanders]

Tree fern up to 7m tall with erect or arching black trunk, covered with spirally arranged leaf scars; fronds tri-pinnate, green on both surfaces, margins of pinnule segments slightly incurved; base of mid-green stipe covered in dense linear mid-brown palea, rough with small dark pustules; sori numerous. Moderately common in high altitude forest (<200m), in both native *Metrosideros collina* and *Homalium taypau* forest, and in non-native *Syzygium jambos* forest (figure 2.13). Also occasional on open eroding slopes with *Dicranopteris linearis* and at edges of *Lantana camara* and *Psidium guajava* scrub. The species regenerates freely, but many dead stems occur in areas where the species is no longer found. In some places the stems seem to have resumed growth after falling over on the steep slopes. The taxon occurs from Australia and New Zealand, through Melanesia to Polynesia and Pitcairn. Morphological measurements taken show variability

in the density of scales and size of the stem, stipe and fronds, and the Islanders actually distinguish two types based on the frond structure and unfurling.

1997 collections: S. Waldren 97-281, 97-282, 97-519; S. Waldren & N. Kingston 97-332

Other collections: Cuming 1,393 (as *C. cumingii* in B&B); Bennett; Mathews 7; Quayle (as *C. cumingii* in B&B); Chapin 951, 954; Fosberg & B. Christian 11,241 (as *C. cumingii*); St. John 14,978 (as *C. cumingii*); Chapin 983; Lintott 165; Williams 3,010, 3,011; Twyford 132; Florence & Waldren 11044; Randall & Collier

Davalliaceae

Davallia solida (G.Forst.) Sw. (Ind)

Epiphytic or terrestrial creeping fern, with a stout, scaly rhizome; fronds up to 50cm long, 2-4 pinnate, triangular lanceolate, dimorphic; fertile fronds are narrower with linear sori at margins. Found both as an epiphyte on *Metrosideros collina* in native woodland, on steep roadsides, and on eroding slopes with *Dicranopteris linearis* (figure 2.13). The species is distributed from Malesia and the Philippines across to Polynesia.

1997 collections: S. Waldren & N. Kingston 97-229

Other collections: Young 271; Quayle; Lintott 162; Williams 3013, 3052; Twyford 133, 134; Fosberg & R. Clark 11,270; Florence 10735

Nephrolepis biserrata (Sw.) Schott (Ind)

Tufted erect fern, sparsely scaly, with creeping rhizome; fronds over 1m long, pinnate; circular sori in single rows on either side of the costa. Abundant throughout the island in woodland clearings, scrub, gullys and eroding slopes (figure 2.13). Pantropical distribution.

1997 collections: S. Waldren & N. Kingston 97-148; S. Waldren 97-668

Nephrolepis cordifolia (L.) C.Presl (Ind)

Erect, stoloniferous fern; fronds pinnate and up to 50cm tall; sori in single rows on either side of the costa. Found at mid to high altitudes at forest edges and in clearings, also occasionally on cliffs (figure 2.13). Pantropical species.

1997 collections: S. Waldren & N. Kingston 97-261

Other collections: Florence 11030

Nephrolepis hirsutula (G.Forst.) C.Presl (Ind)

Pitcairnese name: Amo'a [StJ]

Erect fern, over 1m tall, with creeping rhizome; rachis scaly; margin of pinnules slightly crenate; sori in single rows on either side of the costa. Found on woodland edges and roadsides, at all altitudes (figure 2.14). Found from Australasia to Polynesia.

1997 collections: S. Waldren & N. Kingston 97-004; S. Waldren & N. Kingston 97-012; S. Waldren & N. Kingston 97-608

Other collections: Quayle; Lintott 169; Williams 3,074, 3,079; Twyford 136; Florence 10733, 10753, 11029; Fosberg 11,267; Chapin 997; Randall & Collier

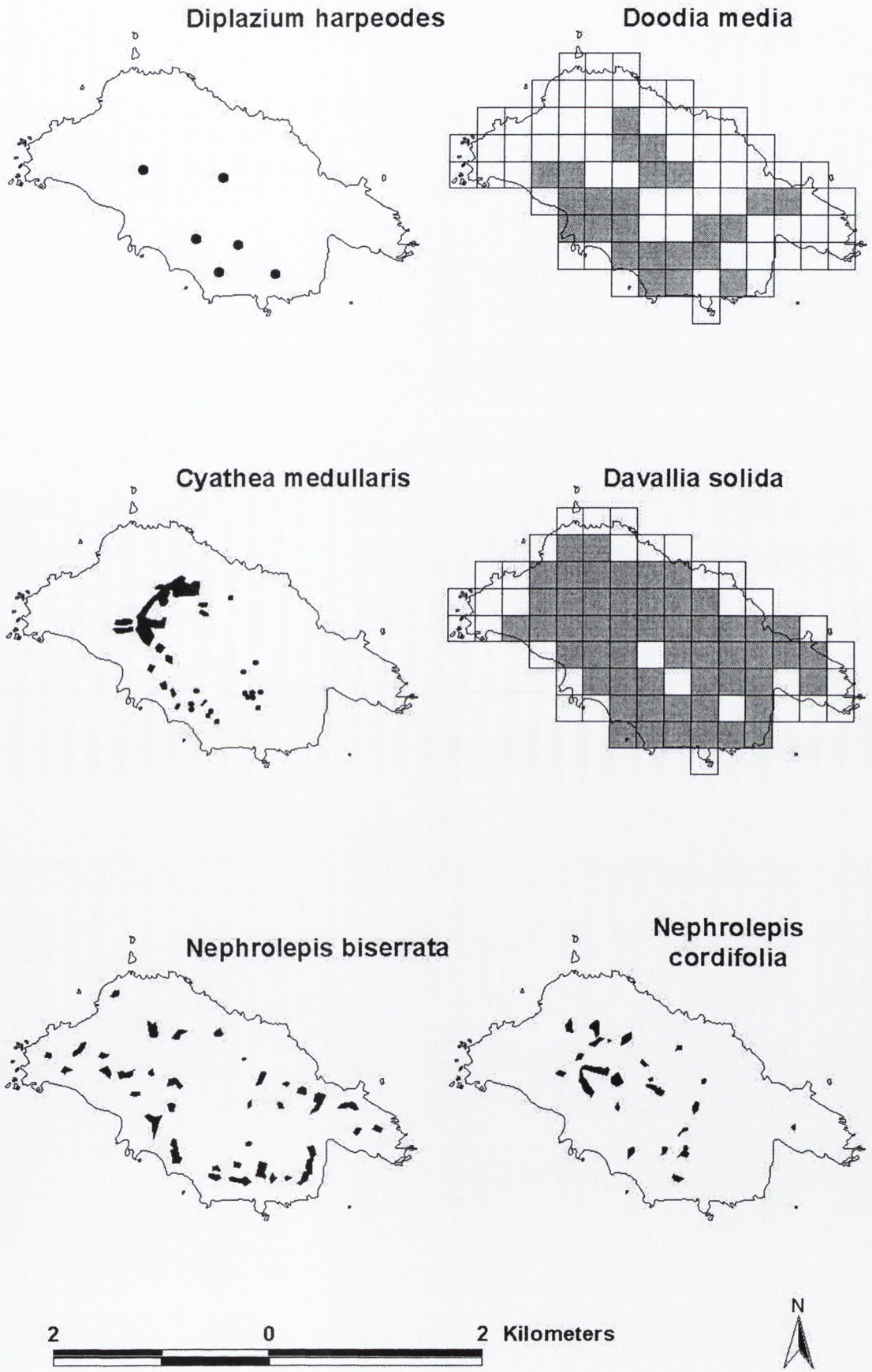


Figure 2.13 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Gleicheniaceae

Dicranopteris linearis (Burm.) Underw. (Ind)

Synonyms: *Gleichenia linearis* (Burm.) Clarke [B&B; Twy]

Pitcairnese name: Maidenhair fern [Carol Warren]

Terrestrial fern that forms vigorous tangled growths; fronds and stipes wiry, forked, with pinnules cut to the rachis; up to 3m tall, but much smaller on exposed slopes. Typical of eroding slopes, roadsides and weedy communities. Found right across the island (figure 2.14), and widely distributed in the Old World tropics and subtropics. Was reported as rare by St. John based on his 1934 observations, but is now extremely common.

1997 collections: S. Waldren & N. Kingston 97-264

Other collections: Quayle (as *G. linearis* in B&B); Lintott 163, 164; Twyford 135 (as *G. linearis*); Williams 3,038, 3,081; Florence 10752; Fosberg & B. Christian 11,221; St. John 14,955; Randall & Collier

Hymenophyllaceae

Trichomanes endlicherianum C.Presl (Ind)

Synonyms: *Crepidomanes enderlichianum* (C.Presl) P.S.Green [G]

Creeping, pendulous, epiphytic or epilithic delicate fern; fronds irregularly bi-pinnate, dark green, to 5cm; sori linear arising from cylindrical receptacle. Forms dense patches on rock faces in damp shaded woodland, at mid to high-altitudes (figure 2.14). The free living filamentous gametophyte was also found on Pitcairn. Species distributed from Asia and Australia across to Polynesia.

1997 collections: S. Waldren 97-677; S. Waldren & N. Kingston 97-169; S. Waldren & N. Kingston 97-222

Other collections: Lintott 155; Bennett; Florence 10755

Trichomanes tahitense Nadeaud (Ind)

Creeping, rhizomatous, epilithic fern, forming dense patches; frond peltate, 1-1.5cm diameter; sori linear, arising from cylindrical receptacle at the margins of the frond. Found on damp rocks often with *T. enderlichianum*, and in similar habitats (figure 2.14). Species is distributed through the high islands of Polynesia. The 1997 collection was the first record of the species from Pitcairn island.

1997 collections: S. Waldren & N. Kingston 97-170; S. Waldren & N. Kingston 97-223; S. Waldren & N. Kingston 97-262

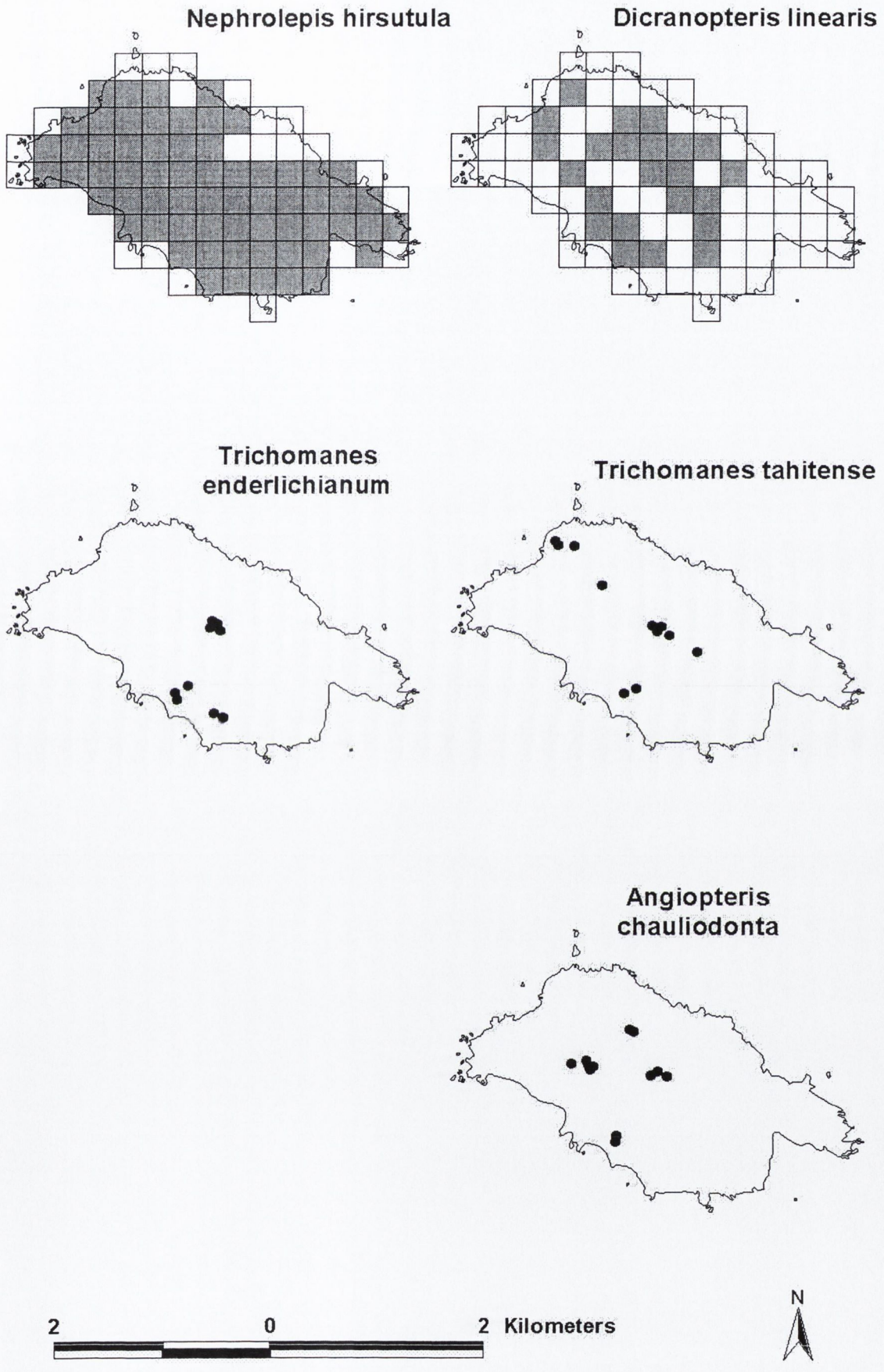


Figure 2.14 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Marattiaceae

Angiopteris chauliodonta Copel. (End)

Synonyms: *Angiopteris longifolia* Grev. & Hook. [B&B]

Pitcairnese name: Nehe [StJ; Islanders]

Large erect fern, with fronds to 4m, arising from globular rhizomes (commonly called stipules) in a rosette; densely covered in scales when young; fronds bi-pinnate, with pinnules slightly toothed; sori formed by two rows of sporangia. Found in isolated populations in native cloud forest at high altitudes, and in damp gullys at lower altitudes, notably in Brown's Water (figure 2.14). Endemic to Pitcairn island, but probably closely related to *A. longifolia* from the Cook, Austral and Society Islands.

1997 collections: J. Starmer & P. Bingelli 97-055; J. Starmer & P. Bingelli 97-056; N. Kingston 97-074; S. Waldren 97-109; S. Waldren & N. Kingston 97-174; N. Kingston 97-513; S. Waldren 97-515; S. Waldren 97-667

Other collections: Lintott 150; Twyford 130; Fosberg & B. Christian 11,242 (holotype); St. John 14,990; Florence 10757

Ophioglossaceae

Ophioglossum nudicaule L. (Ind)

Rhizomatous fern, forming open colonies; fronds arising singly or in small groups, 3 to 6 cm tall, leaf bases always cuneate; stem base white below substrate surface when fresh. Found on damp gravel ridges and eroding slopes on the north-side of the island (figure 2.15). Pantropical distribution. First recorded for Pitcairn in 1997.

1997 collections: S. Waldren & N. Kingston 97-883; 97-221; S. Waldren 97-239

Ophioglossum reticulatum L. (Ind)

Erect, pale green fronds arising singly from horizontal rhizome; sometimes forming extensive colonies; plants 5-20cm tall, with cordate leaf bases. Found in wet flushes and on open gravel slopes and ridges, on the northern side of the island, but at higher altitudes than *O. nudicaule* (figure 2.15). Pantropical distribution. First recorded for Pitcairn in 1997.

1997 collections: N. Kingston 97-881; S. Waldren & N. Kingston 97-259; 97-882; 97-176; S. Waldren 97-238

Polypodiaceae

Phymatosorus commutatus (Blume) Pic.Serm. (Ind)

Synonyms: *Phymatodes sylvaticum* Brack. [StJ]; *Microsorium vitiense* (Baker) Copel. [Cop]

Pitcairnese name: Am'ou [StJ]

Creeping, rhizomatous fern; rachis black or green; rhizome scales rounded; mid-green fronds up to 1.5m long, pinnate, but not cut to the costa, with distinct veins on the lower surface; sori small, scattered, punctiform and slightly pustulate on upper surface. Found

in cloud forest, steep gullys and damp shaded *Syzygium jambos* forest at high altitudes (figure 2.15). Distributed from Australia to Fiji and across Polynesia.

1997 collections: S. Waldren & N. Kingston 97-005; J. Starmer & P. Bingelli 97-054; N. Kingston 97-075; S. Waldren & N. Kingston 97-225

Other collections: St. John 14,982 (as *Phymatodes sylvaticum*); Fosberg & R. Clark 11,299, 11,312; Randall & Collier; Florence 10743

Phymatosorus powellii (Baker) Pic.Serm. (Ind)

Synonyms: *Polypodium pitcairnense* (Copel.) Brownlie [StJ]; *Phymatodes pitcairnense* (Copel.) Brownlie [Ble]; *Microsorum pitcairnense* Copel. [Cop]

Creeping, rhizomatous fern that may form extensive colonies; rachis and stipe black; rhizome scales dense and lanceolate-triangular; fronds mid-green; rounded sori, in single opposite rows on either side of the midrib and forming pustules on upper surface. Found at high altitudes on the southern side of the island at edges of *Metrosideros collina*, *Homalium taypau* and *Pandanus tectorius* forest (figure 2.15). Also known from Fiji, Samoa, Society and Cook Islands.

1997 collections: S. Waldren 97-060; S. Waldren & N. Kingston 97-232; S. Waldren 97-284

Other collections: Lintott 100; Williams 3,067, 3,084; Twyford 36, 37; Fosberg & Clark 11,311 (holotype); Florence & Waldren 11046

Phymatosorus scolopendria (Burm.) Pic.Serm. (Ind)

Synonyms: *Phymatodes scolopendria* (Burm.) Ching [StJ]; *Microsorum scolopendria* (Burm.) Copel. [Cop]; *Polypodium scolopendria* Burm. [Twy]

Pitcairnese name: Ahmu [StJ]

Epilithic or terrestrial fern with dark brown to black creeping rhizomes; fronds to 2m tall, variable, but dark green, pinnately divided nearly to the mid-rib when mature; sori in two rows. Very common, found in all habitats, especially in scrub and weedy communities (figure 2.15). Distributed from Africa through Asia and Polynesia to Easter Island.

1997 collections: S. Waldren & N. Kingston 97-053; 97-084; 97-316

Other collections: Quayle; Chapin 982; Fosberg 11,260 (as *Phymatodes scolopendria*); Fosberg & R. Clark 11,365; Randall & Collier s.n.; Florence 10792

Pyrrosia serpens (G.Forst.) Ching (Ind)

Synonyms: *Pyrrosia angustata* (Sw.) Ching [StJ]; *Cyclophorus macrocarpus* (Sw.) Desv. [Twy]

Pitcairnese name: Creeping fern [Twy]

Epiphytic and epilithic creeping fern; fronds fleshy, simple, up to 10cm long; relatively large sori in two opposite rows on either side of the midrib. Found throughout the island, both on open rock faces and in shaded woodland habitats (figure 2.15). The species is distributed from Fiji across to Polynesia.

1997 collections: S. Waldren & N. Kingston 97-038; 97-266; S. Waldren 97-113

Other collections: St. John 14,962 (as *P. angustata*); Randall & Collier s.n.; Florence 11026

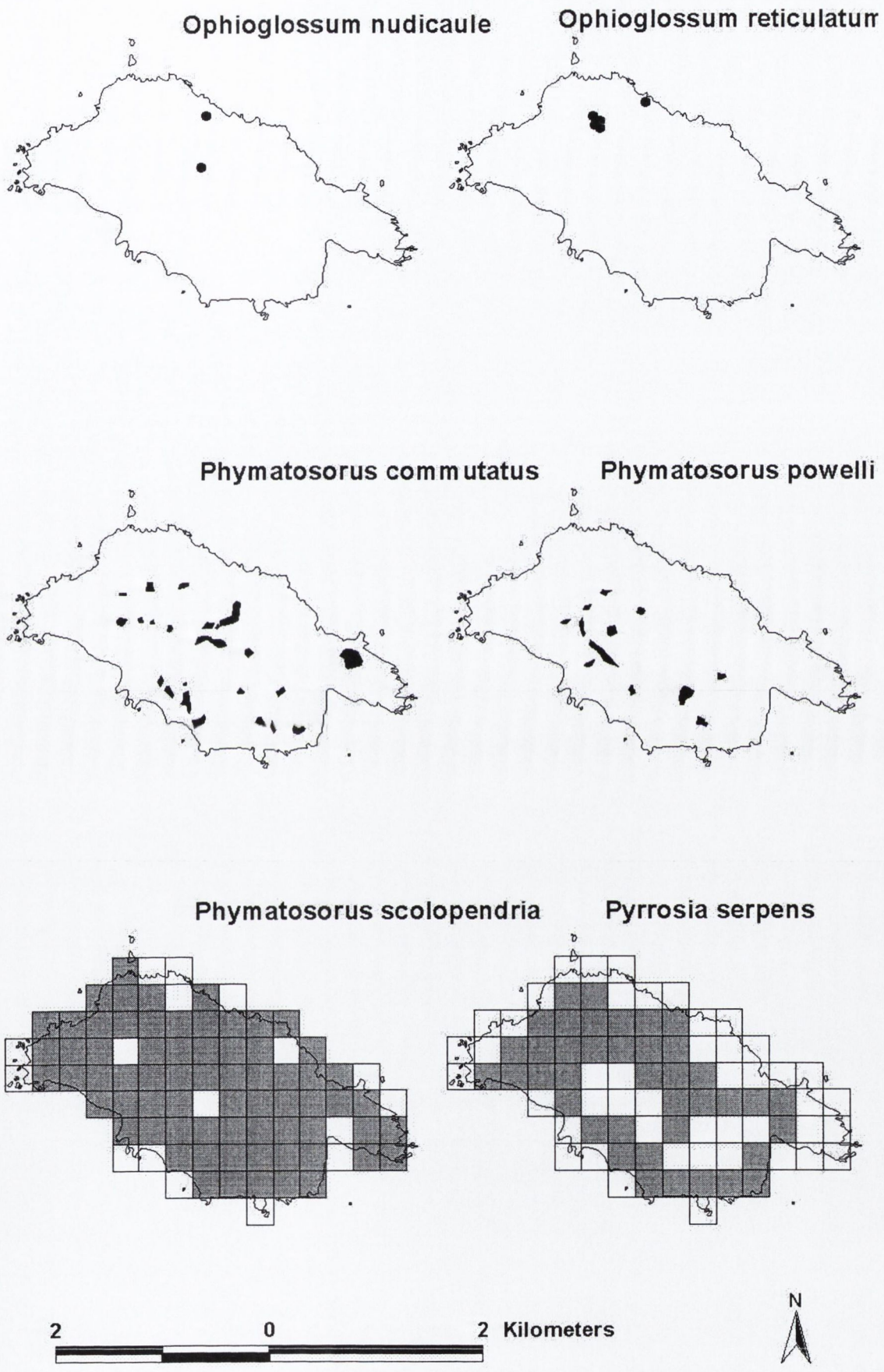


Figure 2.15 - Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

Thelypteridaceae

Christella parasitica (L.) Lév. (Ind)

Synonyms: *Cyclosorus parasiticus* (L.) Farw. [StJ]; *Dryopteris parasitica* (L.) Kuntze var. *pitcairnensis* E.Br. & F.Br. [B&B]

Pitcairnese name: Kou eva [StJ]

Terrestrial creeping light green fern; fronds lanceolate to 1m, with abruptly acuminate apex, and the lowest pinnae slightly smaller than those above and held at a plane pointing forward from the blade; rarely densely fertile. Found on roadsides and in native *Metrosideros collina, Homalium taypau* and *Pandanus tectorius* woodland at mid to high-altitudes. Common throughout Pitcairn (figure 2.16). Distributed from Southeast Asia to Polynesia. The Pitcairn collections lack the numerous orange glandular hairs on the costa and veins that are typical of this species.

1997 collections: S. Waldren & N. Kingston 97-008; S. Waldren 97-112; S. Waldren & N. Kingston 97-263

Other collections: Quayle; Lintott 156; Williams 3,049, 3,076; Twyford 100; St. John 14,949, 14,965 (as *Cyclosorus parasitica*); Fosberg & B. Christian 11,230, 11,231; Randall & Collier s.n.; Florence 10805

Macrothelypteris torresiana (Gaudich.) Ching. (Ind)

Pitcairnese name: Old Man Fern [Twy]

Large, terrestrial fern with a creeping rhizome, and dense covering of scales; fronds to 2m tall, triangular in outline, pale green, tri-pinnate. Not refound in 1997, but is reported to have been observed by Twyford and Lintott in the 1950's (Gothesson 1997), and was collected from Flatlands by Randall & Collier in 1971.

Other collections: Randall & Collier s.n.

Pneumatopteris costata Holttum var. *hispida* Holttum (Ind)

Fern arising in erect tufts; costa and rachis pubescent beneath; lowest pinnae reduced in size and scale-like. Found throughout Pitcairn in damp wooded valleys and on damp roadsides at mid to high-altitudes (figure 2.16). The species is distributed across Asia and the Pacific, but this variety is found only on Rarotonga, Pitcairn and Easter Island.

1997 collections: S. Waldren & N. Kingston 97-158; S. Waldren & N. Kingston 97-256

Other collections: Florence 10732

Vittariaceae

Vittaria elongata Sw. (Ind)

Epiphytic and epilithic, pendulous fern; rhizome shortly creeping, with long grey/brown scales; dark green, glossy, fronds linear, up to 40cm long but only 3-5mm wide, rarely bifurcating; sori linear located in a sub-marginal groove; both gametophytes and juvenile plants observed in several places. Widespread but very local, mainly at high altitudes in cloud forest under and on *Metrosideros collina*, under *Homalium taypau* and occasionally

under *Syzygium jambos*. Found at lower altitudes on the southern remote valleys of the island, notably in Faute Valley and Tautama (figure 2.16). The species is distributed from Africa, through tropical Asia to Polynesia and on to the Juan Fernandez Islands.
1997 collections: S. Waldren 97-884; 97-111; S. Waldren 97-288; S. Waldren 97-531
Other collections: Young 50; Lintott 151; St. John 14,956; Fosberg & R. Clark 11,309

LYCOPHYTA

Lycopodiaceae

Lycopodium cernuum L. (Ind)
Terrestrial with creeping rhizome; stems to 1m tall, branching, upper branches pendulous; leaves 2-3mm long; sporangia in leafy spikes. Occurring on roadside banks and eroding slopes *Dicranopteris linearis* and *Davallia solida* at high altitudes. Found only around High Point, Garnets Ridge and the Hollow, and is probably a recent coloniser (figure 2.16). Species is pantropical. Found for the first time on Pitcairn in 1997 and collected from a site where it was absent in 1991. First noticed on the island in about 1994 (D. Brown & B. Young pers comm).
1997 collections: S. Waldren & N. Kingston 97-027; S. Waldren & N. Kingston 97-161

PSILOPHYTA

Psilotaceae

Psilotum nudum (L.) Beauv. (Ind)
Pitcairnese name: Fern [Carol Warren]
Terrestrial and epiphytic, with shortly creeping rhizome; fronds up to 50cm tall, bearing synangia on uppermost branches, and scale-like sporophylls along length. Locally distributed across the island, but notably common as an epiphyte on *Ficus prolixa* (Banyan) trees, and terrestrially under *Homalium taypau* woodland. Distributed across the island (figure 2.16). Pantropical and widespread species; variable and in need of detailed study (A. C. Jermy pers comm).
1997 collections: J. Starmer 97-020; S. Waldren & N. Kingston 97-273; S. Waldren 97-285
Other collections: Lintott 167a, 167b; Williams 3,068; Twyford 129; Florence 10742; Fosberg & T. Christian 11,318

Two other species have been ascribed to Pitcairn Island but never collected there, and were not seen or collected during 1997. *Procris pedunculata* (J.R. & G. Forster) Weddell was reported by Lintott from Tedside and St. Pauls (Gothesson 1997). The species was not observed in 1997. This widespread species may have briefly colonised the island but not established a population, or it may be on Pitcairn in a small population that was overlooked in 1997. *Acrostichum aureum* L. was collected by Bennett, but the specimen was destroyed in Berlin. There is currently no suitable habitat for this species on Pitcairn.

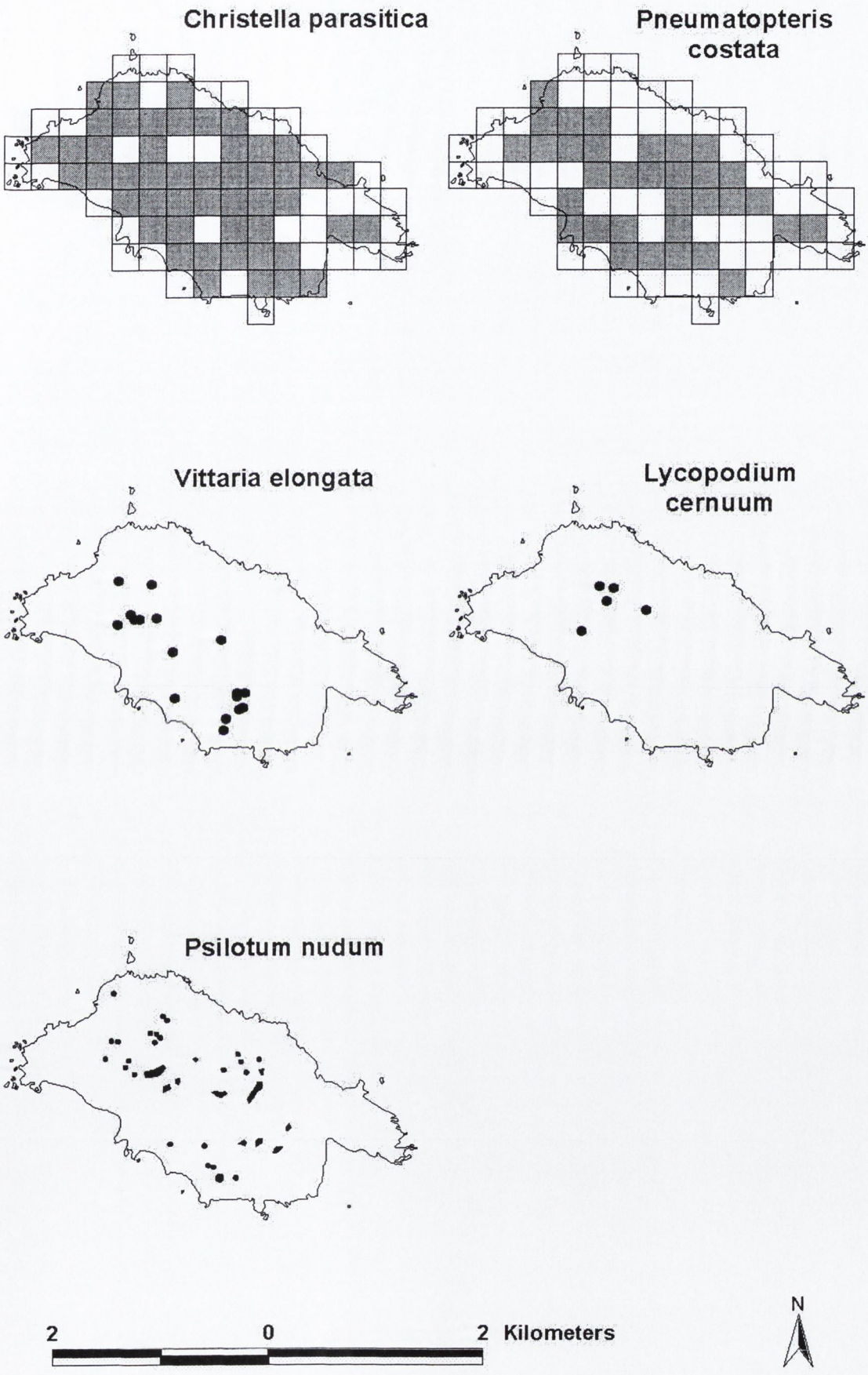


Figure 2.16 – Maps to show the distribution of species on Pitcairn Island. Dots show the location of individuals plants or populations. Where a species is more widespread the distribution within a 250m^2 grid is shown by shading.

2.4 Discussion

2.4.1 Features of the Flora

The native flora of Pitcairn is largely derived from the flora of Polynesia, to the west, but is relatively depauperate owing to the remoteness of the island and its young geological age. The current flora is a product of its anthropological history, with high numbers of introduced species. Some species were introduced during the period of Polynesian settlement from the 10th to the 15th Century but the majority of the introduced species have been brought in by the present islanders since their settlement in 1790. The origins and biogeography of the native flora will be discussed further in Chapter 4.

The native vascular flora is predominately composed of angiosperms, but with a high proportion of pteridophytes (37%). Endemism is however significantly lower in the pteridophytes. These characteristics are typical of island floras (Smith 1972). Northern parts of the island, especially around Adamstown, are more heavily planted with cultivated species, or invaded with non-native species. Similarly parts of Aute Valley and around Radio Station, where the islanders have cleared for gardens, have high levels of non-native species. Native and rare species are concentrated in certain parts of the island; in particular Tautama, High Point and Faute Valley hold the large populations of rare species (eg *Angiopteris chauliodonta, Peperomia rapensis, Peperomia pitcairnensis, Diplazium harpeodes*). These are also the areas with the highest percentages and numbers of native species, and so can putatively be determined as the biodiversity 'hotspots' of the island. Analyses of the conservation status of the species, and the vegetation in these areas, as will be carried out in later chapters, will aid in further identifying the most important areas for biodiversity.

It was often difficult to determine whether established species are native or introduced, as early non-invasive introductions often form part of the natural environment (eg *Hibiscus tiliaceus*). Often species can be native from one part of the Pacific, but probably introduced from other parts (eg *Ficus prolixa*, considered native in the Cook Islands, dubiously native in the Societies and probably introduced on Pitcairn).

A number of introduced species currently found on Pitcairn are listed in Cronk & Fuller (1995) as being invasive on islands similar to Pitcairn in the Pacific region. These species could become problematic on Pitcairn and as such should be closely monitored. The distribution for each of these species was mapped using the grid mapping system employed by this study (figure 2.17 & 2.18). The species are as follows:

Carpobrotus edulis (Aizoaceae)
Cestrum nocturnum (Solanaceae)
Lantana camara (Verbenaceae)
Leucaena leucocephala (Leguminosae)
Melia azedarach (Meliaceae)
Paspalum conjugatum (Gramineae)
Passiflora spp. (Passifloraceae)
Psidium cattleianum (Myrtaceae)
Psidium guajava (Myrtaceae)
Syzygium jambos (Myrtaceae)

Currently only *Syzygium jambos*, *Lantana camara*, *Psidium guajava* and *Paspalum conjugatum* cover significant areas of the island. *Psidium guajava* was first observed on the island in 1878, and first collected in 1931, while *Syzygium jambos* and *Lantana camara* were first observed and collected in the 1890's (Gothesson 1997). *Paspalum conjugatum*, however, was first collected in 1934 by Chapin (Gothesson 1997). St. John and Fosberg in the same year did not collect the species. This suggests that the species has spread rapidly since its introduction probably around 1930. *Melia azedarach* and *Cestrum nocturnum* have been on the island since 1898 and 1931 respectively (Gothesson 1997), but have not spread widely. Four *Passiflora* species are found on Pitcairn, the earliest of which to be introduced to Pitcairn was *P quadrangularis*, sometime around 1900. The most aggressive species however is *P. maliformis*, which was first collected as recently as 1957. It is found mainly around Adamstown and Aute Valley where it forms dense tangles in tree canopies. *Leucaena leucocepala*, *Psidium cattleianum* and *Carpobrotus edulis* are more recent introductions, first observed in 1987, 1991 and 1997 respectively. The spread of these species should be monitored closely, notably *Psidium cattleianum*, which is already present in 6 grid squares, 2 of which are on the southern side of the island. *Psidium cattleianum* is one of the major invaders in French Polynesia, notably in Tubuai where it has replaced virtually all of the *Metrosideros collina* cloud forest (J-Y Meyer pers comm. 2000; pers obs. 2000), and Cronk & Fuller (1995) classify it as a type 5 invasive species (scale of 1-5; type 5 are invasive species which threaten other plants with extinction). In addition, two further species *Canna indica* and *Crinum asiaticum* are spreading and represent a potential threat to the native flora.

Of the 100 most common species on the island, 54 are non-native and 29 of these are found in over 25% of the islands grid squares (see Appendix 3). The most common species on the island is the native weedy fern *Phymatosorus scolopendria*, recorded from over 80% of the island, but the second most common is *Lantana camara*, which is almost as common being found from 79% of the island.

2.4.2 Comparison with other island floras

Oceanic island floras are notable for the high levels of dioecy they contain, for example 14.5% in the New Zealand flora compared to 4.3% in the flora of the British Isles (Richards 1997). The Pitcairn Island flora is typical of oceanic floras containing 13.5% dioecious species all of which would be dispersed by birds (zoochory).

The level of endemicity on Pitcairn (13.6%) is low in comparison to some other islands, although this is a product of the islands young age and small size. Nearby, but larger, Henderson Island has 14.3% endemism, although it has no endemic fern species. The closest high islands to Pitcairn are the Gambier Islands and Rapa. The Gambier islands have 13% endemism, but Rapa has 35% endemism (Florence 1997a). However the Gambier Islands have a similarly sized flora to that of Pitcairn, with 71 species, while

Rapa has a flora estimated at about 189 species. This level of endemism is still low when compared to the remote island of St. Helena in the Atlantic Ocean, which has endemism levels of about 78% in a small flora of only 60 species (Smith 1972), or the Juan Fernandez Islands which has endemism of 60% (Mauchamp *et al.* 1998). These island groups, however, have both neo and paleo-endemics, while Pitcairn only shows neo-endemic species. The flora of the Pitcairn Group will be more critically compared to other Polynesian island groups in Chapter 4.

2.4.3 Concluding remarks

The survey presented here is the most thorough floristic survey to have been conducted on the island. In fact, as virtually all areas of the island were visited, it is probably the most detailed survey of its type for any of the islands of Polynesia. A detailed knowledge of the flora of the island is required for assessment of the vegetation on the island, as the individual species provide the component parts from which the vegetation communities are composed.

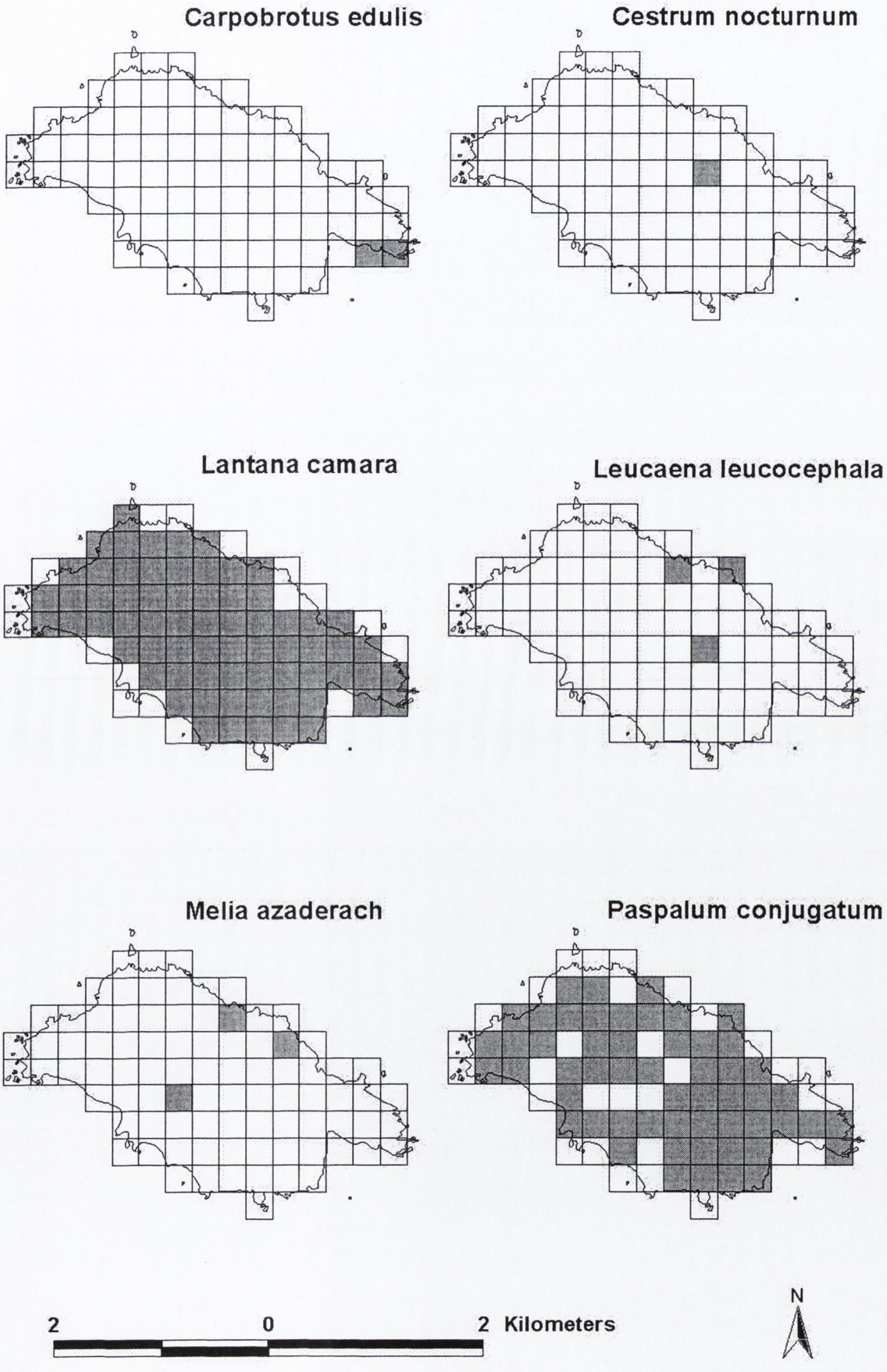


Figure 2.17 – Maps to show the distribution of selected non-native species on Pitcairn Island. The distribution within a 250m^2 grid is shown by shading.

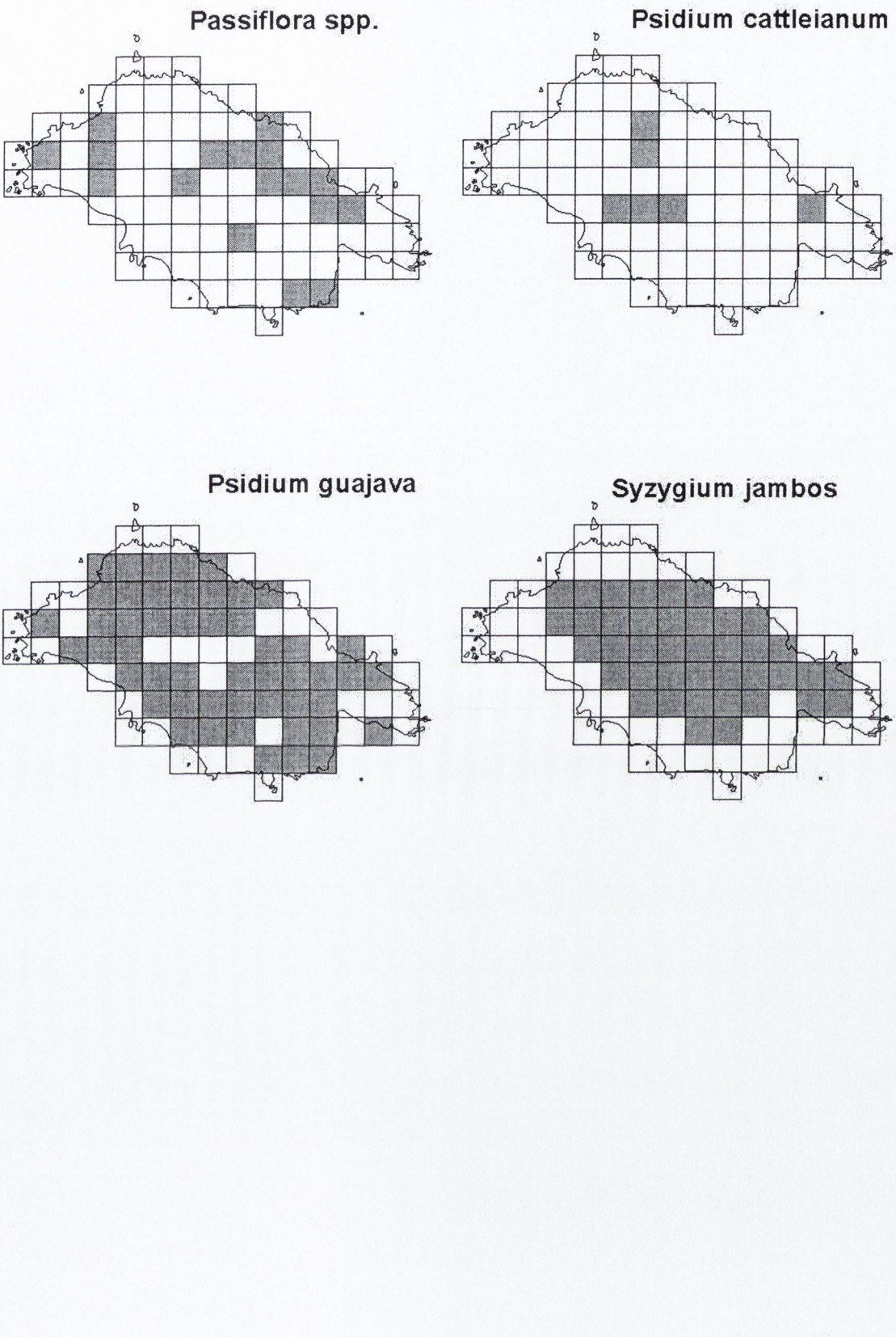


Figure 2.18 - Maps to show the distribution of selected non-native species on Pitcairn Island. The distribution within a 250m^2 grid is shown by shading.

Chapter 3: Vegetation of Pitcairn Island

3.1 Introduction

3.1.1 Vegetation studies

Vegetation, in contrast to flora (dealt with in chapter 2), refers to the assemblages of plant species occuring at a site. Information on vegetation communities is needed for many reasons including environmental impact assessment, environmental management, prediction of past and future vegetation, and biological conservation (Kent & Coker 1992). There has been much debate as to the best technique for defining vegetation. These techniques fall into two main categories - physiognomic and floristic (Kent & Coker 1992).

Physiognomic vegetation description is structural, based on morphology, life-forms, stratification and size of the species present, and is better for small scale classifications, such as world vegetation coverage (eg Fosberg 1967; Peterken 1967). Recent developments in remote sensing techniques provide the best tool for looking at large areas of the earth's surface to analyse, map and monitor ecosystem patterns, processes and changes (Gould 2000). Remote sensing is the process whereby information is acquired about the earths surface by non-contact methods using electromagnetic energy or seismic, gravitational, vibration or magnetic forces (Darch 1984). Remote sensing for vegetation mapping typically uses a camera or sensor to record an infrared or thermal image of the ground by satellite (Spellerberg & Sawyer 1999), as different species of plant reflect differing amounts of energy (Darch 1984). While remote techniques have enormous potential for small scale mapping, environmental management and prediction of species distribution, the predictive capabilities of models derived from remotely sensed data may not be accurate if factors other than vegetation (such as climate, altitude, latitude and longitude) are not incorporated into the models (Spellerberg & Sawyer 1999). Additional problems with remote sensing are distortion caused by cloud cover, the cost and time involved in obtaining usable images for much of the earths area, and the need for ground truthing of images (Darch 1984). Franklin (1993) concluded that remote sensing to determine vegetation types for oceanic islands did not delimit vegetation types to adequate levels and was too expensive. These conclusions were based on an analysis of Miti'aro in the Cook Islands. Out of five satellite images only 3 had less than 25% cloud cover, and although the image allowed successful delimitation of scrub and tree habitats, it did could not distinguish between disturbed and undisturbed or coastal and inland habitats (Franklin 1993).

Floristic vegetation description is based on the species present in the study area. It is more complex than physiognomic methods as it involves the assessment of the best method of sampling, identification of individual species and the collection of abundance or presence/absence data for each taxon. The usual sampling method is by means of quadrats, and extensive literature is available to determine the optimum size for

sampling, depending on the type of vegetation community (Kent & Coker 1992). Typically 0.5m^2 quadrats are used for bryophyte or lichen communities, 1m^2 or 2m^2 are used for grassland communities and 10m^2-50m^2 are used for scrub and woodland communities (Kent & Coker 1992). Identifications may be simple if a flora is available for the area, but in the case of remote and understudied floras it is necessary to collect samples and identify them at a later date in herbaria. Similarly there is much information available as to the optimum abundance measure to use, which depends on the logistics of, and reasons for, the study. Simple presence/absence measures are quick to collect, but give less qualitative information about the vegetation community than abundance data (Kent & Coker 1992).

The best way to undertake a vegetation survey is firstly to assess the purpose and the scale of the survey, and secondly to adjust it to suit the habitats being studied and the resources available. Collection of the data should never be isolated from the aims, objectives and methods of analysis (Jongman 1987), as data collection is only part of the larger project as a whole. Similarly the data need to be objectively analysed, and the output assessed for its validity in terms of the actual vegetation. Thus it is best to use several techniques when analysing the data and test if they are analogous (Kent & Coker 1992; Legendre & Legendre 1998).

3.1.2 Data analysis in vegetation studies

Data analyses in vegetation studies are used to summarise the data or to find causal or descriptive relations (Jongman 1987). Analytical techniques used are determined mostly by the objectives of the project, but are mostly multivariate due to complex and bulky nature of the data, with each statistical sampling unit being characterised by many attributes (Jongman 1987). Multivariate analyses can be divided into three groups: direct gradient analysis (regression analysis), indirect gradient analysis (ordination) and classification (cluster analyses) (Jongman 1987). Direct gradient analysis is used to explore relations between species and environmental variables, on the basis of observations at a series of sites, but analysing each species individually (ter Braak & Looman 1995). Ordination is the collective term for a suite of multivariate techniques that order a group of objects along a gradient, the aim being that points which fall close together, in a graphical summary of the data, are similar in composition (Digby & Kempton 1987; ter Braak 1995). Thus a complex multivariate data set is reduced to a small number of dimensions which account for the majority of the data variance. An ecological example would be the ordination of species or sites along an environmental gradient. Classification involves clustering techniques which group sets based on their similarity or composition (Kent & Coker 1992; Legendre & Legendre 1998).

Ordination

Ordination techniques are widely used across many disciplines to simplify complex multivariate data. Techniques popular with community ecologists are **Principal Components Analysis** (PCA), which is suitable for multivariate-normally distributed data, and **Correspondence Analysis** (CA) for which there is no underlying assumption of multivariate normality (ter Braak 1995). The importance of a PCA or a CA axis in explaining the total variation within a data set is reflected in the 'eigenvalue', values that represent the relative contribution of each component to the explanation of the total variation in the data (ter Braak 1995).

PCA is now widely acknowledged as having serious limitations as a method for the ordination of floristic data, as the assumption of multivariate normality is rarely met (Kent & Coker 1992), and the frequently used measures of cover/abundance (ie DOMIN, Braun-Blanquet scales) will not be normally distributed. PCA uses Euclidian distance, or absolute distance between sites and this can cause very large differences between site and species totals (ter Braak 1995).

CA is an indirect method of ordination, where the variation within the species data is examined independently of the environmental data. Sites are initially given arbitrary, unequal scores and species scores are calculated from their weighted average. This iterative process is repeated until scores stabilise, and the resulting values are the site and species scores of the first ordination axis. This process can be repeated to extract successive axes, which are uncorrelated with the initial axes.

CA suffers from the 'arch effect', a mathematical artifact caused by the fact that the second axis may simply be a distortion of the first axis, and so while the two axes are uncorrelated they are not independent of one another. This effect is removed by 'detrending', or recalculating the second axis scores so that they have an average of zero, and thus expressing them as deviations from a mean of zero (Kent & Coker 1992). Detrending rescales the axes so that the lowest scoring sample on each axis is zero and the length of an axis (gradient length) is the range of the site scores. Axis lengths are expressed in multiples of the standard deviation (sd) of species turnover. A species may be expected to appear, rise to its mode and to disappear again in about 4sd, and samples which differ by 4sd in scores can be expected to have no species in common (Gauch 1982; Kent & Coker 1992), representing a full turnover in species composition.

In **Detrended Correspondence Analysis** (DCA) (Hill & Gauch 1980) the eigenvalue for the first axis has the traditional interpretation of eigenvalues. However, the processes of rescaling and detrending destroys the correspondence between the eigenvalue and the structure along that axis. Thus eigenvalues in DCA cannot be interpreted as proportions of variance explained (McCune & Mefford 1997). The resulting ordination diagram of axes scores shows frequently-associated species close together, and dissimilar species

apart (Kent & Coker 1992). With the site ordination, each point on the graph represents the species composition of a site, where site scores are weighted mean values of the scores of the species that occur in them (Hill & Gauch 1980; Legendre & Legendre 1998). Thus similar sites ordinate close together, while dissimilar sites are far apart.

Canonical Correspondence Analysis (CCA) (ter Braak 1987) differs from DCA, and other indirect ordination methods, in that it relates species and environmental variables in the analysis and so gives a better measure of direct association. Thus the resulting ordination is a product of the variability of the environmental data as well as the variability of the species data (Kent & Coker 1992). CCA uses the same iterative approach as DCA, but within each averaging cycle a multiple regression is carried out between the site scores for an axis and various combinations of the environmental variables. The calculated best-fit values for quadrats for the combination of environmental variables giving the highest variance in the original axis score, is taken as the improved axis score (Kent & Coker 1992). Thus the ordination is 'constrained' by the environmental variables (Kent & Coker 1992).

CCA output provides two data sets, the first weighted average (WA) scores and the second linear combination of variables (LC) scores. LC scores can be considered as the maximally constrained scores (Palmer 1993), and are linked to the 'Intraset correlations' of ter Braak (1986). As in DCA the distances between sites on the resulting ordination plot are taken as a measure of their degree of similarity or difference (Kent & Coker 1992), but the site and species information is overlain with information regarding the relationships between species and each of the environmental variables. Such an ordination plot is known as a 'biplot'.

Superfluous environmental variables can increase the 'arch effect', as CCA is not detrended. Such variables are most likely to be correlated with the second axis, and thus removal of them will mean that the CCA should not need detrending (Kent & Coker 1992). Palmer (1993) however, tested CCA against CA and DCA, and found it not to be seriously affected by the arch effect, and advised against DCCA (Detrended Canonical Correspondence Analysis). There are situations where the 'arch effect' can arise naturally, and not as a mathematical artifact. In these situations DCA or DCCA will destroy this true arch, whereas CCA will preserve it (Palmer 1993; ter Braak 1995).

Recently CCA analyses have been criticised as misleading, because noisy data can have a large effect on the results. Also the environmental characters used are often measured for convenience rather than because they are best from the 'organismal' point. CCA therefore is of more use to investigate how patterns in the species data can be explained by environmental variables rather than for actually defining the community structure (McCune 1997; ter Braak 1995). Indeed all multivariate analysis techniques are really exploratory techniques, in that they are simplifications of the multivariate data to aid in its interpretation, rather than necessarily tests in themselves.

Classification

The clustering techniques used in classification are especially useful if the data is not continuous, as if the data is continuous the clustering will impose a group structure onto the data (van Tongeren 1995). The major division in cluster analysis methods is that made between divisive and agglomerative methods (Kent & Coker 1992; van Tongeren 1995). Divisive means that the method starts with all the objects as a group and successively breaks it down into smaller groups, while agglomerative analyses start from single objects which are agglomerated into larger clusters (Kent & Coker 1992; van Tongeren 1995). As with ordination, classification is widely used across many disciplines, and while it has been used extensively in ecological analyses, it has been most widely applied in taxonomic and molecular studies (discussed in more detail in Chapters 4 & 5).

Two-way indicator species analysis (TWINSPAN) is a polythetic divisive method of classification (Kent & Coker 1992). Clustering in this way means that large differences prevail over smaller, less important differences (Jongman 1987). A classification according to site is constructed and then used to assemble a classification of the species, according to their distribution within the sites. This information can be presented in dendrogram format, or the defined TWINSPAN groups superimposed onto other analyses (ie DCA & CCA) to give a spatial arrangement of the TWINSPAN clusters.

TWINSPAN stems from the view that each group of samples can be characterised by indicator species, or species that prevail on one side of the division. The divisions are made on the basis of the species composition of the whole quadrat.

TWINSPAN does not analyse abundance data directly, but is based on presence/absence. However, it approximates quantitative abundance data by creating a variable number of 'pseudospecies' representing abundance classes of a single taxon. The 'pseudospecies cut levels' are used to define the ranges of the abundance classes. Selection of appropriate cut levels of pseudospecies is important for retaining the quantitative nature of the data (McCune & Mefford 1997).

Correlation

Correlation analyses are used to determine the strength of relationships between variables (Kent & Coker 1992). For normally distributed data, the parametric method of Pearson's product-moment correlation is used, but due to the nature of data generated by vegetation studies, non-parametric methods such as Spearman's rank correlation are more widely used (Kent & Coker 1992). A significant result in the correlation analysis, however, does not necessarily mean that there is a causal relationship between the variables (Kent & Coker 1992).

3.1.3 Vegetation studies on Pacific Islands

Pacific islands, and tropical islands in general, have in the past been surveyed for their flora, with relatively few quantitative surveys of their vegetation being carried out. This is primarily due to the large amount of time required for vegetation studies, while floristic surveys can be carried out in just a few days visit. Floristic surveys have been discussed in Chapter 2.

The scale of this lack of information on the vegetation communities is shown in Mueller-Dombois & Fosberg's (1998) informative work on the vegetation of the tropical Pacific islands. While they have included information for most islands, in many cases the information is out of date, based on descriptions written by Fosberg following the Mangarevan Expedition of the Bishop Museum in 1934, without any quantitative analysis (eg Society Islands, Austral Islands, Pitcairn Islands). Other non-quantitative surveys include Paulay & Spencer (1989) for Henderson Island, Stoddart (1975c) for Aitutaki mainland and motus, and Stoddart & Sachet (1969) includes notes on the vegetation of Rangiroa in his survey of the islands geomorphology. Vegetation maps for some of the Polynesian islands are found in Papy (1954a,b) and again in Florence (1993), but are small scale and in some cases based on conjecture. All of these surveys use the dominant species present in areas to describe the vegetation communities.

Quantitative analysis of vegetation have been carried out recently by other authors for Mangaia (Merlin 1991), Oeno and Henderson Island (Waldren *et al.* 1995a). Merlin (1991) used transects through wooded raised coral makatea, encircling the volcanic interior of the island, to describe the vegetation communities of Mangaia makatea. He also took circular 1.5m plots to record the percentage cover of herbaceous species. This strategy successfully determined the vegetation communities and the relative importance of each tree species in the communities described, thus determining the dominance of native species in the makatea. However this strategy would prove unsuccessful over more diverse habitats, where tree and shrub species were not necessarily always present, and where differing substrates also featured.

Waldren *et al.* (1995a) used $10m^2$ quadrats in a partially stratified sampling procedure, sometimes along transect lines, but an effort was made to sample from all areas and from all habitat types. In addition quadrats were deliberately placed over rare species so that the floristic associations of rare species would be recorded. This strategy proved successful at delimiting vegetation groups for all vegetation communities on Henderson and Oeno islands, but as no environmental parameters were measured, only putative ecological effects could be derived.

3.1.4 Vegetation communities from the Pacific islands

Mueller-Dombois and Fosberg (1998) and Dahl (1980) defined the major vegetation units, which diversify locally, for the Pacific which they termed 'biomes'. Dahl (1980) lists over

27 terrestrial biomes and habitats for the Pacific, with 18 that occur in Polynesia (table 3.1). These are taken from an overall list of biomes which he estimates would total about 2,000 if all environmental factors were considered. These are largely native communities, but in some cases are influenced by secondary anthropogenic factors. Mueller-Dombois & Fosberg (1998) describe slightly modified biomes to those of Dahl (1980) and include 19 Pacific-wide vegetation biomes.

Table 3.1 - Matrix of biome and habitat occurrence by biogeographic province. Taken from Dahl (1980)

	Biogeographic province	Tonga-Niue	Samoa-Wallis	Tuvalu-Tokelau	Kiribati-Nauru	Phoenix-Line-Nth. Cook	Cook-Austral	Society	Tuamotu	Marquesas	Pitcairn-Gambier-Rapa
Island types	Volcanic	✓	✓				✓	✓		✓	✓
	Makatea	✓			✓		✓	✓	✓		✓
	Atolls		✓	✓	✓		✓	✓	✓		✓
Biomes/Habitats	Lowland rainforest	✓	✓				✓	✓	✓	✓	✓
	Montane rainforest		✓				✓	✓		✓	✓
	Bamboo forest							✓			
	Cloud forest		✓					✓		✓	✓
	Riverine forest		✓					✓			
	Swamp forest		✓								
	Semi-deciduous forest					✓					
	Mangrove forest	✓	✓	✓	✓						
	Atoll/beach forest	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Scrub	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Dwarf-shrub heath									✓	
	Bog					✓					
	Tree savanna	✓									✓
	Shrub savanna	✓									
	Grassland	✓	✓			✓	✓	✓	✓	✓	✓
	Freshwater marsh	✓	✓			✓	✓	✓	✓		
	Salt marsh	✓					✓				
	Rock desert	✓	✓							✓	✓

Each of these biome types found in Polynesia are detailed below, the descriptions modified from Mueller-Dombois & Fosberg (1998) and Dahl (1980).

- Lowland rain forest - tall, multi-storeyed, open ground and shrub layers; found on larger islands in Melanesia, but poorly represented on smaller oceanic islands; found in valley bottoms and coastal strips, but has been hugely altered by human activity and in many cases developed as tree-gardens and plantations (see below).
- Montane rain forest - similar to lowland rain forest, but lower stature and at higher altitudes, with many epiphytes; dominant community on moist hill-tops and mountain slopes in many tropical islands.
- Bamboo forest - dominated by bamboo; mainly found in tropical mountains

- Cloud forest - similar to the previous two groups but at higher altitudes and almost continuously shrouded in cloud or fog; low canopy, typically with small-leaved trees and large masses of epiphytic mosses and hepatics.
- Riverine, swamp and bog forest - on wet soils and along frequently flooding rivers; forest with palms, butressed and stilt rooted trees.
- Semi-deciduous or Mesophytic forest - found on leeward and drier slopes, and thus is seasonally dry; contains many sclerophyllous trees and shrubs; found extensively in Eastern Melanesia and Hawai'i; commonly developed into savannas (see below).
- Mangrove forest- tidally inundated scrub and forest, with a high salt tolerance; poorly represented in the Pacific, and introduced in its most easterly stations.
- Atoll/beach strand vegetation - generally halophytic vegetation lining rocky or sandy shores; adapted to high evaporation; may be herb, scrub or forest; skirts most Pacific islands, becoming more impoverished in the eastern Polynesian region.
- Scrub - scrublands or thickets; mainly of woody shrubs and up to 5m high.
- Dwarf-shrub heath - closed or open canopy of dwarf shrubs, with moss and lichen understory and grass cover in open areas.
- Montane bogs - in cloud-covered areas with gentle slopes and impeded drainage the cloud forest gives way to bog formation; sedges and sphagnum mosses abundant.
- Savannas - composed of sclerophyllous grasses and some shrubs; probably naturally limited in extent, but greatly expanded by anthropogenic activities.
- Montane grassland - higher altitudes again, above the cloud layer; dominated by grasses with some xerophytic shrubs; in the Pacific islands found only in Hawai'i, but also represented in New Guinea.
- Pastures - artificial grassland for cattle and sheep ranching; found covering extensive areas on New Caledonia, Hawai'i and on the Taravao plateau in Tahiti.
- Fernlands - dense and deep (up to 2m) tangles of *Dicranopteris linearis* with occasional scattered woody plants; found in naturally and anthropogenically disturbed areas, especially on erosion scars, in all Pacific islands, although in Fiji *Pteridium aquilinum* is commonly the dominant fern; may also be replaced with introduced *Miscanthus* spp. grasslands on richer soils, forming Savannas. (not included by Dahl, 1980)
- Plantations - found in a range of areas, with the species grown depending on soil types and other environmental conditions; purely an anthropogenic formation, but

found on all Pacific islands; crops grown include *Ananas comosus, Saccharum officinarum, Cocos nucifera, Coffea arabica, Musa* spp. and timber trees such as *Pinus caribaea* and *Casuarina equisetifolia.*

- Tree gardens - in valley bottoms and wet gulches; lush, tall forest with exotic fruit trees and shrubs, such as *Mangifera indica, Psidium guajava* and *Citrus* spp.; common on the coastal strip of high islands, and associated with human settlement; reverts to dense tangles of *Hibiscus tiliaceus* when deforested or left unattended. (Vegetable gardens and ruderal sites are also common around the coastal strip and near settlements, covering small areas between tree gardens).
- Salt marsh - herbaceous equivalent of mangrove swamp; also poorly represented in the Pacific.
- Wetland agriculture/Freshwater marsh - a culturally important anthropogenic formation, grown in areas previously covered by swamp forest; dominated by Taro (*Colocasia esculenta*) and other crop species in the Araceae (eg *Cyrtosperma chamissonis, Alocasia macrorrhiza* and *Xanthosoma* spp.).
- Rock desert - ground surface dominated by bare rocks or screes with occasional plant cover in crevices.

Eastern Polynesian islands have only two principal rock types, basalt of volcanic origin and limestone of organic origin. Hence, due to the relative simplicity of the substrate, the regional vegetation tends to be less complex than in Western Polynesia and thus does not include all of the 'biomes' mentioned above. As the islands are floristically poor, the vegetation assemblages are also limited and disharmonic (Mueller-Dombois & Fosberg 1998).

3.1.5 Previous vegetation studies on Pitcairn

Previous vegetation descriptions of Pitcairn island are limited to brief notes made by scientists whose main interest was either plant collecting or studies of Henderson Island (St. John 1987; Twyford 1958; Waldren *et al.* 1995a). All of these studies mention the highly disturbed nature of most of the island, and extensive areas of introduced species. Professor H. Lintott, who visited the island as a student plant collector in 1957, noted that the island was almost entirely covered in gardens or *Syzygium jambos* plantations, and any abandoned areas were choked with *Lantana camara* thicket, or badly eroding (pers. com. 1998). Waldren *et al.* (1995a) described several of the habitat types found, although they carried out no quantitative survey. They describe poorly developed coastal communities, highly disturbed lowland vegetation with many non-native species and mid-altitude slopes dominated by monospecific stands of *Syzygium jambos.* Native forest was dominated by the endemic tree *Homalium taypau,* with more diverse tree floras in the remoter valleys. In addition Waldren *et al.* (1995) suggested that the anthropogenically influenced communities such as *Dicranopteris linearis* fernlands were spreading as were

scrub habitats. This was based on the fact that *Dicranopteris linearis* was described by St. John (1987) as rare and local in 1934.

3.1.6 Aims of this study

The aim of this study was to fully document the vegetation of Pitcairn Island by investigating if there were clearly definable vegetation communities to be found on the island, and if particular environmental parameters influenced these communities. The significance of introduced species in defining the extant vegtation communities was also identified, and the species composition of the communities used to aid in assessing the conservation status of the native vegetation. Knowledge of the vegetation communities and their species assemblages, can then be used to determine the habitat requirements of rare and endemic taxa, and improve the success of future conservation activites.

3.2 Materials and Methods

Floristic vegetation description methods were used, but with several vegetation survey methods employed to ensure that the island was fully reviewed. In addition the use of more than one survey method meant that the data was collected at various levels of detail, making it scientifically sound and capable of being collected under the limitations of time and manpower (Kuchler 1967). The fieldwork was carried out from June to September 1997.

As mentioned previously in Chapter 2, a concurrent rat eradication programme on the island had cut an extensive grid of trails over the island area. This facilitated easier and quicker movement across the island and allowed us to sample from more areas, and from more densely vegetated areas, than would otherwise have been possible and so gave a more detailed picture of the plant communities present.

3.2.1 Quadrats

Vascular plants were recorded from $10m^2$ quadrats sampled from across the island, using similar techniques to Waldren *et al.* (1995a). The quadrats taken were non-random to ensure the inclusion of rare species in their communities, and therefore represent almost all of the extant species in the survey. This makes the data more useful when investigating species ecology and formulating recovery plans. In total 83 quadrats were taken (figure 3.1), and environmental data were recorded at each site. Fewer quadrats were taken from highly disturbed areas as the diversity was low, and the quantitative work was primarily to identify the plant communities in the areas of native vegetation. The result is an almost random stratified sampling procedure, but one that is also more efficient as it does not waste time on repeated sampling of similar vegetation (Kent & Coker 1992).

Species present in the quadrats were identified and their associated abundance values were recorded using the DOMIN scale (table 3.2) (Kent & Coker 1992), with the approximate cover of tree canopies being projected vertically and estimated. Bare rock, litter and bryophyte cover were also recorded. No effort was made to quantitatively record the bryophytes, but samples were taken for identification.

Table 3.2 – The abundance for taxa associated with the recorded values in the DOMIN scale (Kent & Coker 1992)

Value	Cover	Value	Cover
+	single individual - no measurable cover	6	26-33% cover
1	1-2 individuals - no measurable cover	7	34-50% cover
2	several individuals but less then 1% cover	8	51-75% cover
3	1-5% cover	9	76-90% cover
4	6-10% cover	10	91-100% cover
5	11-25% cover		

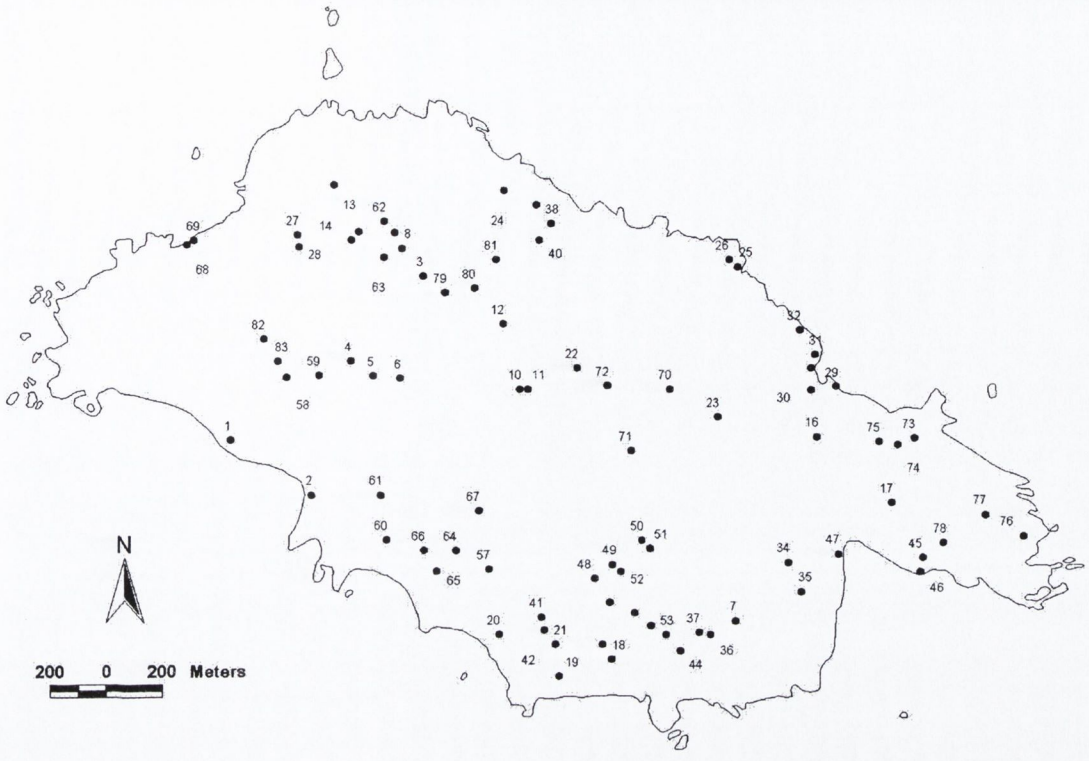


Figure 3.1 – Location of quadrats taken on Pitcairn Island.

3.2.2 Environmental data

Environmental parameters were recorded from each quadrat in order to help determine the ecological controls on the vegetation. Altitude was recorded using an altimeter, aspect and slope using a Recta sighting compass, and latitude and longitude using a Magellan Meridian XL GPS. Photosynthetically active radiation (PAR) was measured using a Skye Instruments PAR Quantum sensor (SKP 215). PAR is the component of solar radiation used in photosynthesis, between 400 and 700 nm (Jones 1993). Red (660nm) to far-red (730nm) ratio (R:FR) measurements were taken using a Skye Instruments R:FR sensor (SKR 110). A hemispherical photograph (see detail below) was taken at the centre of each quadrat for canopy analyses, and a soil sample was taken for laboratory analysis, also from the centre of the quadrat but from below the litter layer. The soil samples were air dried in the field and stored in zip-lock bags for transport back to Ireland. A summary table of environmental variables measured is in table 3.3 (section 3.2.5).

Hemispherical photography

Photographs were taken using a CANON AE1 camera body and a CANON Fisheye Lens, with the camera mounted on a tripod stand at a height of 1.3m at the central point of each quadrat. The top of the camera was aligned to face north, and was levelled using a spirit level. The photographic film used was ILFORD DELTA 100. No colour filters were used and the shutter speeds used were determined using a Pentax spotmeter.

The films were developed by hand so that the development procedure would be consistent for all of the films. The developer used was ID 11 (ILFORD) diluted 1:1 with water, and the fixer used was Agefix (Agfa) diluted 1:6 with water. The solutions used were all freshly prepared.

Photographs were scanned into a PC computer using a flatbed scanner, inverted using Corel Photopaint ver. 4, and analysed using Hemiphot (ter Steege 1994). Hemiphot allows the calculation of various light co-efficients from hemispherical photographs, using known data such as latitude/longitude, date, time and altitude. For this study it was used to calculate % Openness, Leaf Area Index (LAI), direct radiation (DSF), diffuse radiation (ISF), total radiation (TSF), direct, diffuse and total photosynthetic photon flux density (PPFD) for both above and below canopy, and red to far red ratio (R:FR; to compare with the value measured in the field). Leaf area index was calculated from:

$$LAI = {}^{area\ of\ leaf}\!/_{area\ of\ ground}$$

Radiation is the energy transferred through space in the form of electromagnetic waves, with direct radiation coming directly from the sun and diffuse radiation being scattered or reflected by the atmosphere and clouds (Jones 1993). Photosynthetic photon flux density (PPFD) is the number of photons (quanta of light) per unit area per unit time, with direct PPFD being transmitted directly from the sun and diffuse PPFD being scattered or reflected by the atmosphere or clouds (Scurlock & Prince 1993).

In several cases the negatives were too dense to be scanned directly into the computer. In these cases the negatives were bathed in a Haddous reducing solution [2.5g Potassium ferricyanide (BDH chemicals); 5g Ammonium thiocyanate (Merck Chemicals); 500 ml distilled water] until the image began to fade, and then refixed in hypo [100g Sodium thiocyanate (BDH chemicals); 500ml distilled water] to stop the reaction, and thoroughly rinsed to remove any residue. This reduction was successful in all cases.

3.2.3 Soil analysis

For each of the soil samples pH, Loss on ignition (LOI), colour and granularity were measured, in order to crudely characterise the soil.

Colour and granularity were measured using standard Munsell colour charts. These charts aid in measuring the percentage coarse and granular fragments in the soil, as well as assigning categorical values for the soil colour, representing the dominant colour spectra, the hue, the shade (paleness) and the chroma (brightness).

pH

The protocol for measuring pH was taken from Grimshaw (1989), but the quantities used were modified due to a lack of material. pH was read using an ion-sensitive electrode on three replicates for each soil sample. The pH electrode was stored in a 3M Potassium

Chloride solution and was calibrated using standard buffer at pH 7. The slope was then corrected using standard buffer at pH 4. The pH meter was calibrated every day before use. An automatic temperature probe connected to the pH meter was used to account for variation in temperature. 5g soil was weighed out, large lumps were removed, and 10ml distilled H_2O added. The mixture was stirred well to form a slurry and left to settle for 15 min before reading the pH. The readings were taken after the meter had settled, but before drifting occurred. Drifting occurs following the dissolution of particles. The electrode was washed with distilled water between readings.

As pH is measured on a logarithmic scale, in order to calculate the mean pH for each sample it was first necessary to determine the anti-log (to the base of 10) for each value, calculate the mean of these anti-logged values, and then determine the log (to the base of 10) of the resulting mean value.

Loss on Ignition

LOI gives an estimate of organic matter in the soil by raising the temperature of the soil gradually and causing the ashing of organic material. Percentage LOI was carried out using a protocol modified from Grimshaw (1989).

The air-dried soil samples were oven-dried to a continuous weight at 80°C. Crucibles that had been stored in a desiccator were weighed and labelled with pencil. Crucibles were half filled with oven-dried soil and reweighed, and three replicates were prepared for each soil sample. The crucibles were then placed in a Thermolyne 6000 furnace and heated [1 hour @ 150°C, 30 min. @ 180°C, 30 min. @ 200°C, 30 min. @ 220°C, 30 min. @ 240°C, 1 hour @ 300°C, 5 hour @ 550°C]. The crucibles were then left in the furnace to cool overnight, before being removed to a desiccator. If the crucibles were still warm, they were left to cool fully in the desiccator. The cooled crucibles were then reweighed. The percentage loss on ignition was calculated using the weights of the soil sample before and after being heated in the furnace.

3.2.4 Mapping

An overall vegetation map for the island was drawn by simply recording the vegetation types by eye from high altitude vantage points, following initial exploration of all areas. The vegetation types were chosen from the dominant species present as suggested by Kuchler (1967). This allowed a very basic map showing the dominant species to be compiled at the end of the period of fieldwork on the island, when all areas had been observed in the field and a detailed knowledge of what was present in all parts of the island had been obtained. This map drawn by eye was then adjusted where necessary once the analysis of the quadrats had been completed. The area under each habitat type could also be calculated from the vegetation map.

Basic maps of vegetation types observed by eye are very useful for initial planning of land use management (Kuchler 1967). Results from the analysis of quadrat data reinforced the

vegetation map taken by eye and also gave information about the vegetation communities on the island.

3.2.5 Data analysis

Data analyses were primarily by multivariate techniques including Two Way Indicator Species Analysis (TWINSPAN) for community classification, and both Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) for ordination. These multivariate analyses are measures of association (or similarity) between quadrats, and allow study of spatial patterns in vegetation. Ordination views the distribution of plant species as series of continua along environmental gradients, while classification clusters sites and species to structure the data. Classification contrasts with ordination, but the use of both techniques together ('complementary analysis') has become increasingly popular in recent decades (Kent & Ballard 1988).

For TWINSPAN nine pseudospecies were defined using the DOMIN scores of 0, 1, 2, 3, 4, 5, 6, 7 and 8 (as in Waldren *et al.* 1995a). As the environmental data were non-normal, Spearmans rank correlation analyses were carried out for the environmental variables, to see if any were closely associated and as such to be removed from the analysis. For the CCA environmental variables were assigned as either quantitative or categorical. Quantitative variables were those which had been directly measured, or obtained from another analysis, such an those derived from the hemispherical photographs. Categorical variables were those which had been measured by categorisation into classes, the value of which have no relation to each other, such as those describing the soil colour characteristics. Table 3.3 gives information as to the variable type for each of the environmental variables.

Preliminary analyses of the data included all samples and species, however, it was found that if rare species (ie species that only occurred once in the data set) were removed, the resulting analyses were more readily interpreted. This is because even with the rare species values down weighted, they had a strong influence on the analysis. As quadrats were deliberately taken to encompass rare species, it was thought that in order to do a realistic vegetation analysis they should be removed. Such rare species have little influence on the analysis, may not determine the vegetation structure, but may cause the ordination to be artificially aligned (Legendre & Legendre 1998). Results from both CCA and DCA analysis carried out after the removal of the rare species data gave lower eigenvalues. Analyses were also carried out using only the data for native species in the quadrats. The resulting vegetation groups were similarly distributed, and so it was decided to use the full data set including the non-native vegetation.

Table 3.3 - Environmental variables used with information about how, when and where they were measured, and the variable type assigned for use in CCA analysis.

Environmental variable	How & when measured	Variable type	Environmental variable	How & when measured	Variable type
Soil pH	Ion electrode in laboratory	Quantitative	% bare rock cover	Estimated in field	Quantitative
Soil LOI	Furnace in laboratory	Quantitative	% litter cover	Estimated in field	Quantitative
Hue	Munsell Soil Chart	Categorical	% Openness	Hemispherical photograph	Quantitative
Dominant spectra	Munsell Soil Chart	Categorical	PPFD direct above canopy	Hemispherical photograph	Quantitative
Spectra value	Munsell Soil Chart	Categorical	PPFD diffuse above canopy	Hemispherical photograph	Quantitative
Chroma	Munsell Soil Chart	Categorical	PPFD total above canopy	Hemispherical photograph	Quantitative
% Coarse fragments	Munsell Soil Chart	Quantitative	PPFD direct below canopy	Hemispherical photograph	Quantitative
% Granularity	Munsell Soil Chart	Quantitative	PPFD diffuse below canopy	Hemispherical photograph	Quantitative
Aspect	Compass in field	Quantitative	PPFD total below canopy	Hemispherical photograph	Quantitative
Altitude	Altimeter in field	Quantitative	DSF	Hemispherical photograph	Quantitative
Slope	Compass in field	Quantitative	ISF	Hemispherical photograph	Quantitative
R:FR	In field	Quantitative	TSF	Hemispherical photograph	Quantitative
PAR	In field	Quantitative	R:FR	Hemispherical photograph	Quantitative
% moss cover	Estimated in field	Quantitative	LAI	Hemispherical photograph	Quantitative

Correspondence analyses (DCA & CCA) are more easily related to TWINSPAN than Principal Components Analysis (PCA), which is no longer recommended for analysis of floristic data (Kent & Coker 1992). However, results from DCA, CCA and TWINSPAN were also compared with outputs from PCA, NMDS and Ward's Cluster Analysis, and the results were found to be comparable.

A Monte Carlo test of 100 runs was carried out to test the robustness of the multivariate analysis. Monte Carlo tests randomly shuffle the data after each run, and allow comparison of the stress obtained with the real data against the stress obtained for the randomised data.

Two data matrices were compiled, one for the quadrat data and one for the environmental data, using MS Excel 97. PC-ORD for windows (McCune & Mefford 1997), Data Desk (Data Description Inc., Ithaca, New York) and Microsoft Excel 97 were used for the data analyses. Maps were compiled using ArcView GIS version 3.1. Errors in the rescaling algorithm from earlier DCA analyses packages such as CANOCO (ter Braak 1992), DECORANA (Hill & Gauch 1980) and PC-ORD, have been corrected in PC-ORD for windows.

3.3 Results

3.3.1 Correlations of environmental variables

Environmental variables were tested for any correlations in the dataset, as it was thought that variables such as measured and derived (from hemiphot) R:FR values, LOI and %litter cover, or other light measurements might be correlated, and this would cause autocorrelation in the data set.

Environmental variables were initially tested for normality but as in most cases the data was non-normal, Pearson's product-moment correlations could not be used and so Spearman's rank correlation was calculated (appendix 3). As a total correlation gives an absolute value of 1, a correlation of above 0.95 was considered to be exceptionally high enough that leaving these variables in the analysis would be meaningless. This did not, however, remove all of the theoretically significant correlations. Direct, diffuse and total PPFD above canopy were correlated and so the direct and diffuse variables were removed. Similarly direct, diffuse and total PPFD below canopy were correlated and again the direct and diffuse variables were removed. Altitude was also correlated with total PPFD above, but both variables were left in the analysis as they were considered important. ISF and TSF were also correlated with total PPFD below canopy and removed.

3.3.2 TWINSPAN

TWINSPAN analysis revealed 14 interpretable vegetation groups, the dendrogram for which is plotted in figure 3.2. The divisions were obtained from the 0/1 pattern on the PC-Ord TWINSPAN output table. The dendrogram was then drawn to reflect this pattern. For TWINSPAN divisions '1' is positive while '0' is negative. Environmental and indicator species data for each group are summarised in table 3.4 (environmental) and table 3.5 (species).

Groups 0 and 1 divided very irregularly, with 67 quadrats in Group 0 and only 16 in Group 1. Group 1 contained only coastal quadrats, with the indicator species *Portulaca lutea* and *Asplenium obtusatum*, and Group 0 contained all of the other quadrats, with *Nephrolepis hirsutula* as the indicator species. Coastal areas did contain very different species from woodland, gardens and grasslands, and so this division would be expected, reflecting major ecological constraints in vegetation development.

Group 00 contained quadrats taken in *Syzygium jambos*-dominated woodland, and the group divided from 01 based on *Syzygium jambos* as the indicator species. The former group was further sub-divided into the two groups 000 and 001. Group 000 are all quadrats taken from an area known as Brown's Water, while Group 001 are quadrats from other parts of the island. Group 001 divided with *Psilotum nudum* as the indicator species. Both 000 and 001 had a high incidence of native species, 87.9% and 74.1% respectively. In addition these quadrats had the highest LOI (26.9%), litter cover (mean

DOMIN value 8.7) and moss cover (mean DOMIN value 3) values for the island, suggesting a high organic component. The light environment in group 00 quadrats was also extreme, with the highest LAI (0.8), and lowest PAR levels (7.4 μmol m^{-2} s^{-1}), DSF (0.66), total PPFD below canopy (26.94 μmol m^{-2} s^{-1}), % openness (46.85%) and red to far red ratio (R:FR [measured] 0.34; [derived] 0.74). These suggest a dense canopy casting heavy shade.

Table 3.4 - Summary of the main TWINSPAN groups with the key environmental variables for each group.

		000	001	01000	01001	01010	01011	01100	01101	01110	01111	100	101	110	111
Sample size		2	3	11	15	3	14	2	9	5	3	8	3	2	3
Substrate	**PH**	6.03	5.54	6.62	6.51	6.61	6.48	6.35	6.57	5.18	6.27	6.76	7.24	6.65	7.15
	LOI	24.6	26.9	20.8	22.2	26.3	24.0	11.1	13.8	14.1	11.2	7.6	5.4	18.6	9.2
	% Granularity	3.00	2.33	2.18	2.73	2.33	2.21	1.50	2.11	1.60	1.33	1.88	2.00	2.50	2.00
Aspect	**N315-45**	2		3	3		3		6		2		2	2	1
	S135-225			2	4	2	4	2	2	2	1	6	1		
	E45-135		3	2	6	1	7					1			2
	W225-315			4	2				1	3		1			
Altitude	**0-100m**			4	6	1		2	2			8	3	2	3
	101-200m		1	6	9	1	5		4		2				
	201-300m	2	2	1		1	8		3	4	1				
	300+m						1			1					
	Mean	200.0	236.7	152.3	156.5	143.3	225.7	70.0	179.9	272.0	199.0	31.9	5.3	17.5	3.7
Slope		54.00	40.00	36.20	43.10	58.30	42.90	58.50	37.20	45.00	30.00	52.75	68.70	56.00	30.30
R:FR (measured)		0.34	0.65	0.70	0.65	0.95	0.67	1.41	1.17	1.11	1.16	1.20	1.15	0.93	1.21
R:FR (derived)		0.74	0.77	0.92	0.86	0.88	0.80	1.23	1.12	1.07	1.10	1.13	1.06	0.95	1.05
PAR		7.40	9.90	151.89	102.97	361.10	259.11	159.10	935.94	1317.40	946.53	602.25	819.33	485.00	246.57
Moss cover*		3.0	1.0	1.0	0.9	1.0	1.5	1.5	0.8	1.6	1.0	0.8			0.3
Bare rock cover*		5.5	1.3	3.5	3.1	1.7	0.9	7.0	4.1	4.8	6.0	6.8	7.2	6.7	7.2
Litter cover*		5.5	8.7	6.7	6.6	7.7	7.6	4.5	3.9	5.0	2.7	2.6	5.0	5.5	3.0
% Openness		46.85	53.28	70.78	63.15	66.32	60.45	70.86	86.24	85.24	86.77	77.18	82.05	76.94	71.78
Total PPFD above		41.13	41.25	40.97	40.98	40.93	41.21	40.68	41.02	41.38	41.13	40.56	40.45	40.50	40.45
Total PPFD below		26.94	28.31	32.08	29.93	29.33	27.40	28.69	38.99	37.49	40.44	34.31	38.72	35.71	35.34
DSF		0.66	0.69	0.79	0.73	0.71	0.67	0.70	0.95	0.90	0.99	0.84	0.97	0.89	0.88
LAI		0.80	0.64	0.42	0.50	0.37	0.55	0.32	0.15	0.14	0.12	0.25	0.19	0.17	0.32

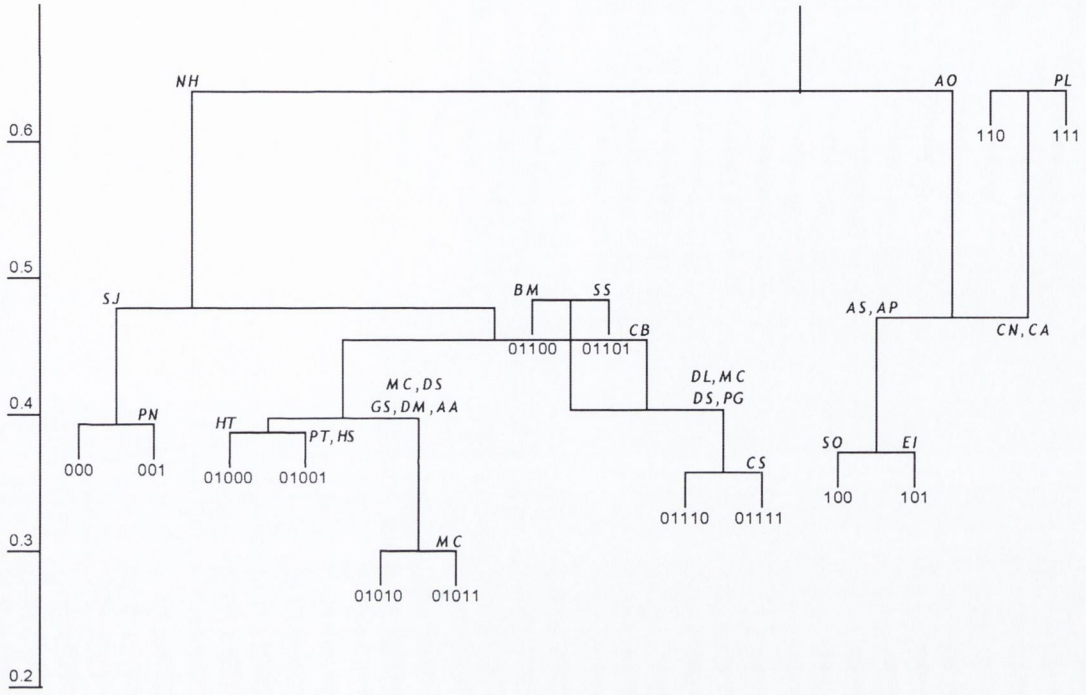
* - mean DOMIN value

Table 3.5 – Summary of the main TWINSPAN groups with indicator species mentioned in text.

	000	001	01000	01001	01010	01011	01100	01101	01110	01111	100	101	110	111
*Nephrolepis hirsutula**		IV	IV	V	V	V	V	IV	III	II	II	II	III	
Syzygium jambos	V	V	I	I		I		I	I					
*Psilotum nudum**		V		I		I	III							
*Homalium taypau**		II	V	III	IV	III		I	II	II				
*Pandanus tectorius**			I	IV		III		II			II		V	II
*Glochidion spp**			I	III	IV	IV		II						
*Hibiscus tiliaceus**			I	II										
*Metrosideros collina**		II				V	III		V	II				
*Davallia solida**		IV		II	II	V	III	II	V	V				
*Doodia media**				I	IV	III	III							
*Arachnoides aristata**	III	II			IV	II			II					
*Bidens mathewsii**							V				II			
Sorghum sudanense			I					III	I					
Conyza bonariensis			I				V	V	IV	V				
*Dicranopteris linearis**						I			IV	II				
Psidium guajava			I	I		II		IV	V	V				
*Chamaesyche sparmannii**												IV		
*Asplenium obtusatum**							III				IV	II		IV
*Asplenium shuttleworthianum**							V				V			
*Apium prostratum**								I			V			
Eleusine indica												V		
Crinum asiaticum													III	IV
*Portulaca lutea**								I			IV	IV		V
*Cyathea medullaris**	V	IV			V	I								
Lantana camara			III	II	IV	III	III	V	III	V				
*Phymatosorus scolopendria**			II	III	IV	IV	V	III	III	V	V	V	V	IV
Mean total species	8.50	9.33	9.09	9.39	13.00	11.50	12.50	13.11	10.00	13.33	9.88	9.00	5.00	6.67
Mean % native species	87.9	74.1	59.5	69.3	78.5	80.6	62.2	24.2	54.6	41.0	70.0	45.7	70.0	75.5

* - native species
% occurrence of species in TWINSPAN group – V=81-100%; IV=61-80%; III=41-60%; II=21-40%; I=1-20%

Figure 3.2 - TWINSPAN dendrogram for each of the 14 vegetation groups, plotted against the eigenvalues at which the division occurred. (+ve divisions occur to the right; -ve to the left).



Legend: AA - *Arachnoides aristata;* AO - *Asplenium obtusatum;* AP - *Apium prostratum;* AS - *Asplenium shuttleworthianum;* BM - *Bidens mathewsii;* CA - *Crinum asiaticum;* CB - *Conyza bonariensis;* CN - *Cocos nucifera;* CS - *Chamaesyche sparmannii;* DL - *Dicranopteris linearis;* DM - *Doodia media;* DS - *Davallia solida;* EI - *Eleusine indica;* GS - *Glochidion* species; HS - *Hibiscus tiliaceus;* HT - *Homalium taypau;* MC - *Metrosideros collina;* NH - *Nephrolepis hirsutula;* PG - *Psidium guajava;* PL - *Portulaca lutea;* PN - *Psilotum nudum;* PT - *Pandanus tectorius;* SJ - *Syzygium jambos;* SO - *Sonchus oleraceus;* SS - *Sorghum sudanense.*

Group 01 contained a total of 62 quadrats, which subdivided into 8 groups. Group 010 and 011 separated with the positive indicator species *Conyza bonariensis.* This division separated inland woodland (010) from inland scrub (011) habitats. Group 010 further subdivided into two groups; 0100 and 0101. Group 0100 and 0101 were separated by the positive indicator species *Metrosideros collina, Davallia solida, Glochidion* spp., *Doodia media* and *Arachnoides aristata.* Group 0100 was subdivided again, as was group 0101.

Group 01000 described woodland dominated by *Homalium taypau,* containing a high proportion of ferns (mean of 59% of species recorded in quadrat) and epiphytes. Quadrats from this division are spread across the island. *Homalium taypau* is the main indicator species for this group. The group 01001 contained quadrats with species-rich native mixed forest, usually dominated by *Pandanus tectorius* woodland. Several species were indicators of this group, the main ones being the tree species *Pandanus tectorius* and *Hibiscus tiliaceus.* This group was distributed mainly across the North and East of the island.

Group 01010 separated a group of only 3 quadrats, describing species rich mixed woodland, located mainly on the south of the island, containing species such as the trees *Metrosideros collina* and *Glochidion* spp. and the ferns *Davallia solida, Doodia media* and *Arachnoides aristata.* This woodland has the highest R:FR for woodland recorded on the

island (0.95), suggesting an open canopy with much light penetration allowing a diverse ground flora to develop.

Group 01011 was much larger, having 14 quadrats and the indicator species *Metrosideros collina*. This group described native, species-rich, *Metrosideros collina* woodland, with *Davallia solida* and other native species (80.6% of species recorded). This large group subdivided further into 2 groups, based on geographical location, 010110 having quadrats from McCoys and Faute Valleys on the south and central parts of the island, and 010111 having similar *Metrosideros* woodland from other parts of the island. Quadrats in this group were all from high altitudes, always above 100m and generally above 200m. This group also had the lowest bare rock cover from the island (mean DOMIN value 0.9) suggesting a dense forest with many epilithic and epiphytic species.

Similarly, cluster 011 subdivided into two groups; 0110 and 0111. Group 0110 and 0111 were separated based on the positive indicator species *Dicranopteris linearis, Metrosideros collina, Davallia solida* and *Psidium guajava*. Group 0110 further divides with the positive indicator species *Sorghum sudanense* and the negative indicator species *Bidens mathewsii*. Group 01100 separated out scrub from the Tautama area of the island in the south. It was unusual as the only inland lowland scrub division, with a mix of lowland scrub species and some more coastal species (eg *Haloragis sp., Bidens mathewsii*), with the average altitude of quadrats in the group being only 70m (as opposed to 180+m for the following 3 groups). These quadrats had a large number of species, both native (64% of species recorded) and non-native, mixed with herbs, shrubs and ferns. This group had the highest R:FR for the island (1.41 [measured]; 1.23 [derived]), showing open, unshaded conditions.

Group 01101 described ridge vegetation, with very high numbers of non-native grasses and shrubs (74.6% of species recorded were non-native). The indicator species for this group was the introduced grass *Sorghum sudanense*. The group 0111 described vegetation from eroding areas that were being re-colonised. The indicator species for this group were the ferns *Dicranopteris linearis* and *Davallia solida*, and the woody species *Metrosideros collina* and *Psidium guajava*. The environment in these quadrats was extreme, with the highest light levels (1317.4 $\mu mol\ m^{-2}\ s^{-1}$), highest DSF (0.99), % openness (86.77), highest totals for above and below canopy photosynthetic photon flux density (41.38 & 40.44 $\mu mol\ m^{-2}\ s^{-1}$ respectively), lowest pH (5.18) and highest altitudes (mean 272m, one quadrat over 300m). This group was further subdivided with group 01110 containing quadrats from inland slopes, while group 01111 contained ridge crest quadrats.

All of the groups in the Group 1 were coastal sites. Group 10 were all quadrats from the south coast of the island, with the indicator species *Asplenium shuttleworthianum, Asplenium obtusatum* and *Plantago major*. These are typical of the fern-rich rocky coastal communities. Group 100 separated with the indicator *Sonchus oleraceus*, and further subdivided into Groups 1000 and 1001, the latter containing the indicator species

Asplenium obtusatum and *Portulaca lutea*. Group 101 included coastal sites that had a high number and abundance of grasses and weeds present, such as the indicator species *Eleusine indica*. This group shows the lowest LOI (5.44%), litter cover (DOMIN value 2.6), slope (68.7) and highest pH (7.24).

Group 11 contains all of the northern coastal sites, and separated with the indicator species *Cocos nucifera* and *Crinum asiaticum*. Group 110 contained sites that had a high level of tree cover, and a deep and dense ground cover of leaf litter, supporting virtually no herbaceous ground flora. This resulted in a low mean species number per quadrat (only 5). In addition this group showed the highest LOI for coastal communities (18.6%). Group 111 included quadrats from coastal rocky areas with the indicator species *Portulaca lutea*. This group had the highest incidence of native species in the coastal communities, and highest incidence of bare rock cover (DOMIN value 7.2).

3.3.3 DCA

DCA of the quadrat data was carried out and the resulting graphs were plotted for both the site and species scores (figure 3.3-3.5; table 3.6). To aid in the interpretation of the DCA graphs, the TWINSPAN clusters were superimposed onto the axes to view the identified community types spatially, and indicator species identified by the TWINSPAN analysis were labelled. For clarity TWINSPAN groups were divided into 4 community types, each with a different symbol, namely *Syzygium jambos* communities, other woodland communities, scrub communities and coastal communities.

Table 3.6 - Summary statistics for DCA analysis

	Eigenvalue*
Axis 1	0.651
Axis 2	0.461
Axis 3	0.353

* - see DCA section 3.1.2 for explanation

The plot of axis 1 against axis 2 (figure 3.3) shows distinct clusters for each of the TWINSPAN groups. For axis 1 the clusters show a transition from woodland vegetation, at the lower end of the scale to coastal communities on the higher end. The lowest axis 1 values are for quadrats in the *Syzygium jambos* dominated woodland, mid values for the woodland quadrats containing native tree species (*Homalium taypau, Hibiscus tiliaceus, Metrosideros collina*), and the higher values for scrub communities culminating with the highest values for coastal communities. Mid values also have many of the understory species associated with the diverse native woodland communities, such as *Davallia solida, Psilotum nudum* and *Asplenium shuttleworthianum*. *Bidens mathewsii, Phymatosorus scolopendria* and *Pandanus tectorius* ordinated between the scrub and coastal communities as these are species that occur in both inland and coastal habitats. Axis 2 shows a transition from woodland communities at the lower and mid scores to scrub habitats at the high scores. Coastal woodland quadrats ordinated at the lower end of the axis, but

other sites are intermediate. Axis 2 separated out the woodland communities, with higher altitude groups 01010 and 01011 separating from the overlapping groups 01000 and 01001. The higest score for axis 2 is the species score for *Dicranopteris linearis* which is the indicator species for the ridge scrub and eroding habitats in groups 01110 and 01111. Typical scrub taxa such as *Lantana camara, Psidium guajava* and *Conyza bonariensis* also ordinated in among the scrub communities.

Figure 3.4 shows a plot of axis 1 against axis 3. Axis 3 separated the woodland communities 01000 and 01001, with *Homalium taypau* having a high axis 3 score while *Hibiscus tiliaceus* has a low score. Scrub, upland native and *Metrosideros collina*-dominated woodland, and *Syzygium jambos* woodland are not differentialted by axis 3. More separation of the coastal commmunities is observed on axis 3, with woodland habitats having lower values, rocky habitats intermediate values and grass dominated habitats having highest values. Figure 3.5 shows axis 2 plotted against axis 3.

Spearmans rank correlations were carried out to correlate the environmental variables to the DCA axis site scores (table 3.7), and see if any underlying effects of ecological factors could be identified as influencing the site or species ordinations. 12 variables were highly correlated with axis 1 ($p<0.001$), 9 highly correlated with axis 2 and 1 correlated with axis 3. Of the 12 variables correlated with axis 1, the most highly correlated were R:FR and % openness, and a negative correlation with LOI, Altitude, Litter cover and total PPFD above canopy. The most highly correlated with axis 2 was PAR, and only % openness was highly correlated with axis 3.

With this additional, but putative information about the ecological effects on the vegetation groups, some of the vegetation patterns shown by the DCA ordinations can be explained further. The positive correlation of axis 1 with both R:FR and % openness explains the progression from *Syzygium jambos* woodland, with its dense canopy at low scores to open coastal habitats with no canopy at high scores. The negative correlation with altitude, LOI and litter cover is easily explained as the coastal communities with the high scores are at sea level in rocky habitats, while woodland communities are at higher altitudes and have more litter cover. Similarly, total PPFD above canopy values will be lower in areas with no canopy and open conditions. The positive correlation of axis 2 with PAR will also partly be explained by altitude (correlation with axis 2 of 0.429), as higher PAR levels are found in the open ridge and scrub communities which largely occur at the higher altitudes. LOI and % litter would be expected to be correlated as the amount of litter present ultimately affects the organic content of the soil. Similarly the measured and derived R:FR values could be expected to be co-incident, although they are not due to the fact that the derived values (0.74-1.23) have a smaller range than the measured values (0.34-1.41).

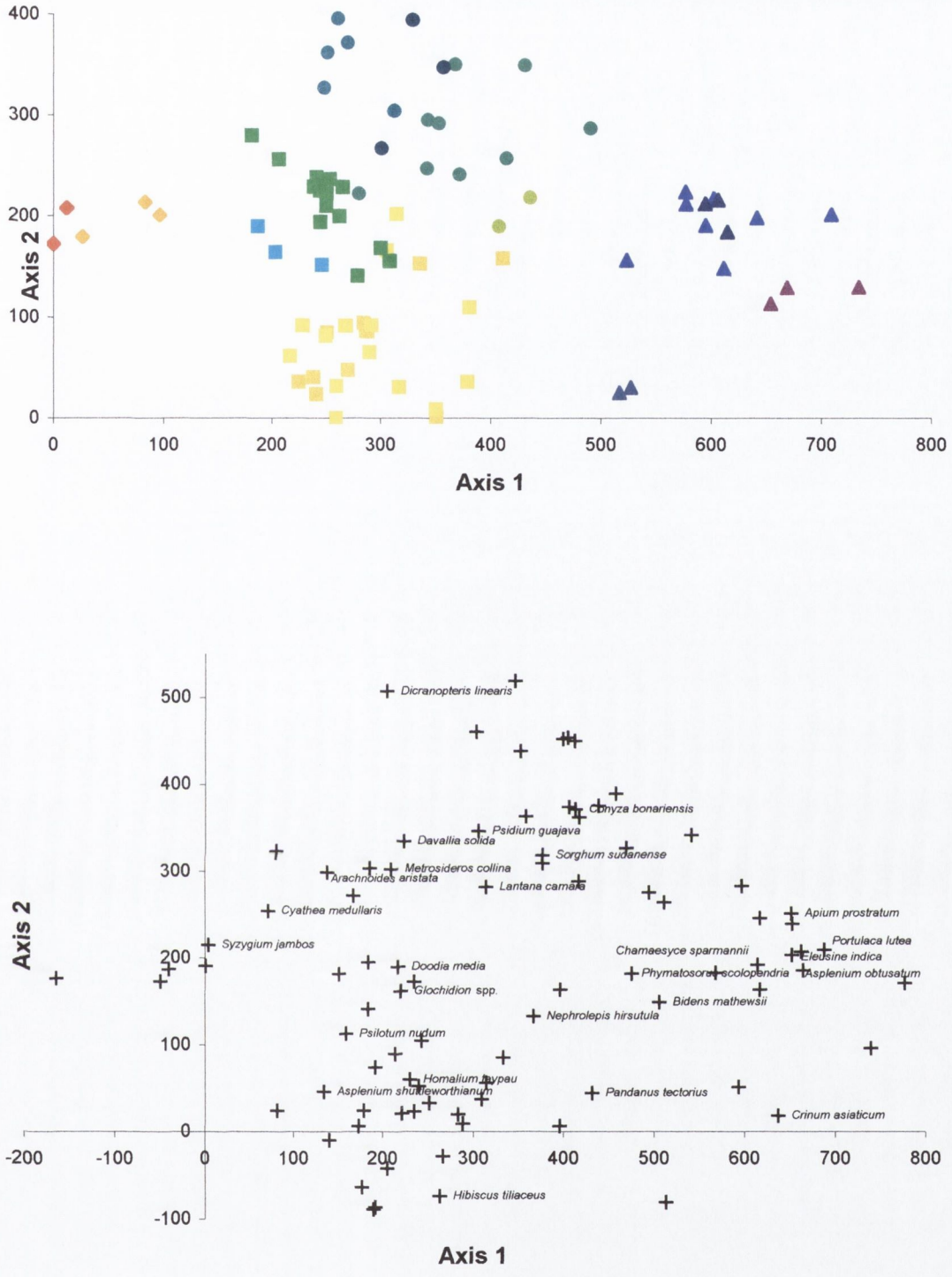


Figure 3.3 - DCA axis 1 plotted against axis 2, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Key: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +

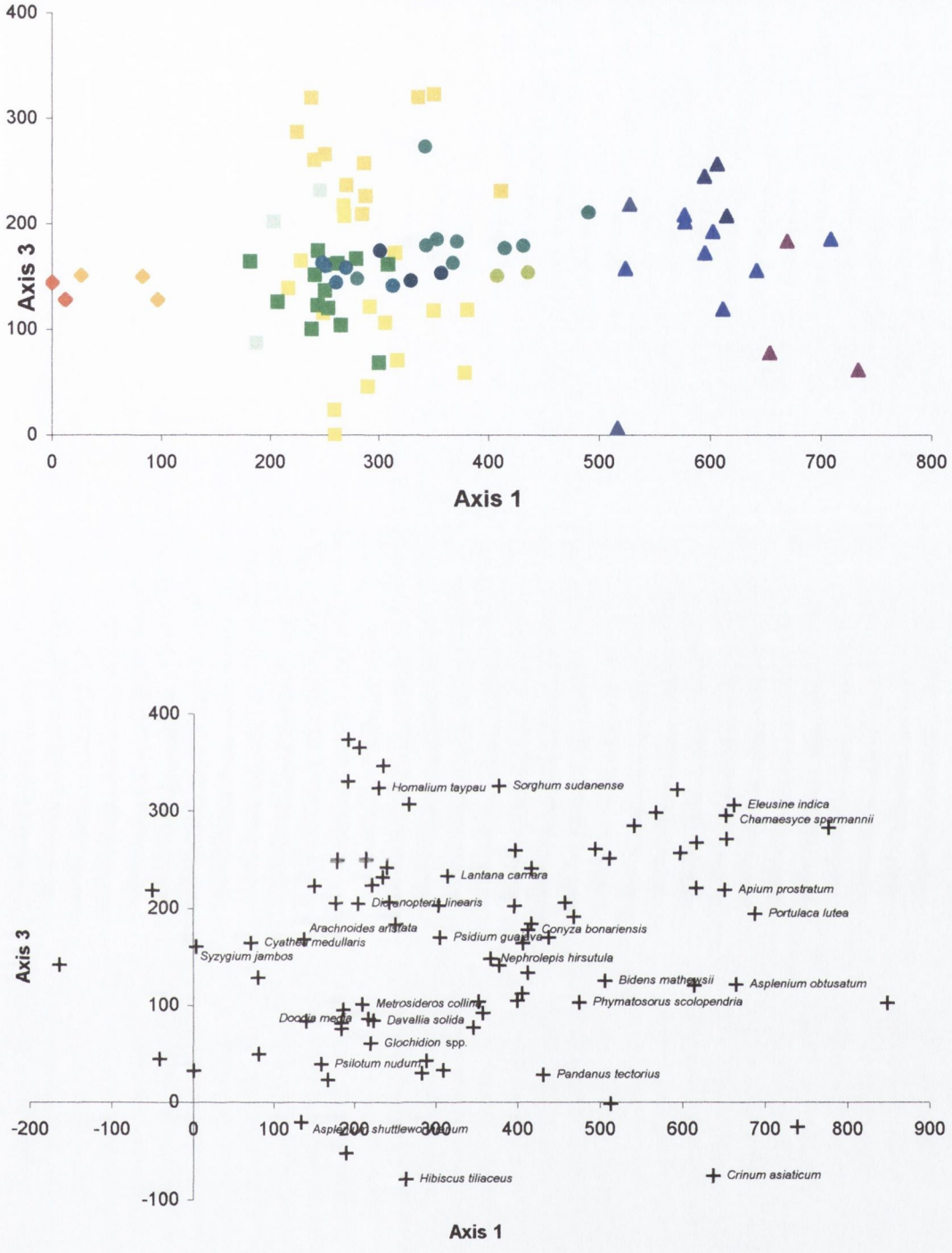


Figure 3.4 - DCA axis 1 plotted against axis 3, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Key: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +

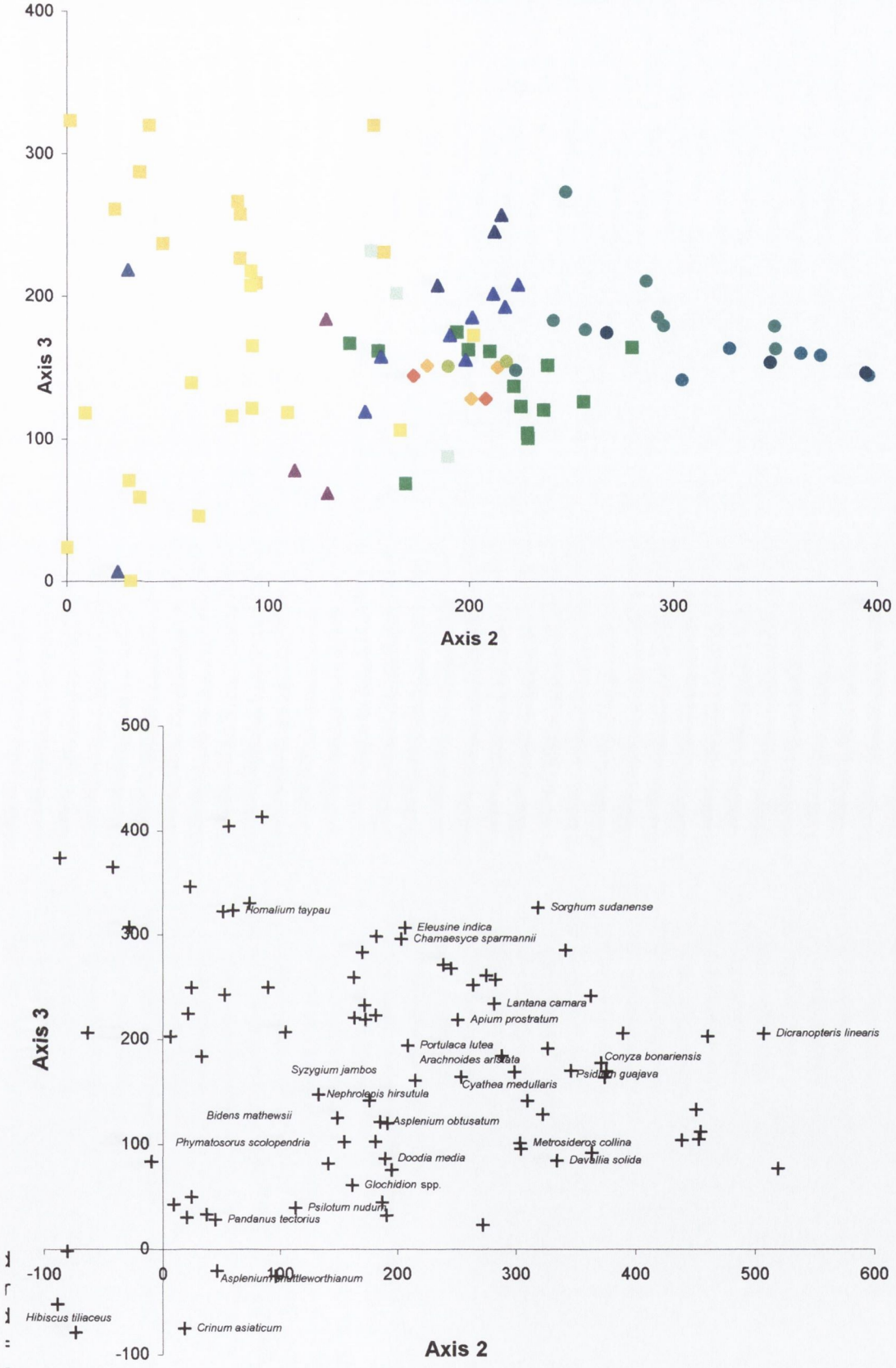


Figure 3.5 - DCA axis 2 plotted against axis 3, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Key: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +

Table 3.7 - Spearman's rank correlation scores for the environmental variables against the DCA axis site scores.

	Correlations		
Variable	**Axis 1**	**Axis 2**	**Axis 3**
% Granularity	-0.193 n.s	-0.293 **	-0.037 n.s
% Coarse fragments	-0.030 n.s	-0.040 n.s	-0.024 n.s
pH	0.430 ***	-0.323 **	0.150 n.s
LOI	-0.596 ***	-0.300 **	-0.217 n.s
Aspect	0.066 n.s	0.063 n.s	0.334 **
Altitude	-0.618 ***	0.429 ***	-0.147 n.s
Slope	0.003 n.s	0.036 n.s	-0.040 n.s
R:FR (measured)	0.542 ***	0.479 ***	0.106 n.s
R:FR (derived)	0.646 ***	0.393 ***	0.260 *
PAR	0.344 **	0.533 ***	0.194 n.s
Moss cover	-0.357 **	0.060 n.s	-0.160 n.s
Bare rock cover	0.421 ***	0.124 n.s	0.143 n.s
Litter cover	-0.556 ***	-0.274 *	-0.062 n.s
% Openness	0.521 ***	0.420 ***	0.383 ***
Total PPFD above	-0.618 ***	0.425 ***	-0.148 n.s
Total PPFD below	0.489 ***	0.438 ***	0.308 **
DSF	0.500 ***	0.390 ***	0.317 **
LAI	-0.486 ***	-0.397 ***	-0.308 **

n.s - >0.05; * - $p < 0.05$; ** - $p < 0.01$; *** - $p < 0.001$

3.3.4 CCA

As superfluous environmental variables, or those that affect axis 2, can cause the 'arch effect' in CCA, it was first necessary to analyse the data with all variables, to identify any superfluous variables for this data set, and then following removal of these variables, reanalyse the data. Hue, chroma, dominant spectra and spectra values were removed as they are categorical variables and thus eliminated immediately in CCA. % Granularity, PAR, % openness and PPFD total below canopy, were more highly correlated with axis 2 than either axis 1 or 3, and so were removed.

The second analysis was then carried out with a Monte Carlo test of 100 runs to test the robustness of the analysis. Monte Carlo analysis showed the CCA analysis to be extremely robust, but the Species with Environment correlation to be less robust, particularly for axis 3 (table 3.8). This suggests that no single environmental factor, but rather a combination thereof, is significant in defining the ordination, and thus the vegetation community at a site. Ordinations presented here use the LC scores as recommended by Palmer (1993).

Table 3.8 - CCA summary statistics following the removal of superfluous variables.

	Eigenvalue	p*	% variance explained**	Pearson Correlation, Spp-Envt.***	p*
Axis 1	0.626	0.0100	46.1%	0.936	0.0600
Axis 2	0.442	0.0100	32.5%	0.913	0.0100
Axis 3	0.291	0.0100	21.4%	0.827	0.6400

* p = proportion of randomised runs, in Monte Carlo test of 99 runs, with eigenvalue greater than or equal to the observed eigenvalue [ie p = (1 + no. permutations ≥ observed)/(1 + no. pernutations)]

** % variance explained by axis 'x' = $\left[eigenvalue_x / \sum eigenvalues \right] x100$

***Correlation between sample scores for an axis, derived from the species data and the sample scores that are linear combinations of the environmental variables

As for the DCA, CCA graphs were plotted for both the site and species scores, and overlain with the TWINSPAN clusters to aid interpretation. In addition biplot scores (generated by the CCA analysis) for correlated environmental variables were plotted onto the graphs. The axis 1 and axis 2 scores from the CCA showed a pattern similar to the DCA, but with the axis 1 scores in reverse order (figure 3.6). Hence high axis 1 scores were *Syzygium jambos* woodland, mid scores were other native woodland and scrub, while the lowest scores were coastal communities. Axis 2 showed the same community distribution as for the DCA, but axis 3 was not readily interpretable (figure 3.7 & 3.8). As expected axis 1 explains more of the variation (eigenvalue 0.626; 46.1% variance explained) than axis 2 (eigenvalue 0.442; 32.5% variance explained) or axis 3 (eigenvalue 0.291; 21.4% variance explained). All of the axes however explain substantial amounts of the variance in the data set, and as axis 3 was not readily interpretable from the TWINSPAN groupings it was necessary to consider the environmental effects on the axes.

Axis 1 was positively correlated with several environmental variables (table 3.9), namely pH, LOI, altitude, % litter cover, LAI, and total PPFD above canopy, while R:FR (both measured and derived) and % bare rock were negatively correlated. pH, altitude, R:FR and total PPFD above canopy are positively correlated with axis 2, while LOI, LAI and % litter cover are negatively correlated. pH and aspect are positvely correlated with axis 3 and % bare rock cover is negatively correlated. The variables correlated to CCA axis 1 are also correlated to DCA axis 1. Thus the woodland communities had the highest LOI and % litter values, with values increasing with axis 1 score. Altitude increased towards the *Metrosideros collina* woodland group (01010). R:FR ratio increased with decreasing axis 1 score but also with increasing axis 2 score, thus increasing towards the coastal rocky communities (100, 111), *Dicranopteris linearis* scrub communities (01110, 01111), and Tautama scrub community (01100). Figure 3.6 also shows how the Tautama scrub community is similar to the coastal communities, even though the groups are separated by TWINSPAN. Lower R:FR values were found in the *Homalium taypau, Syzygium jambos, Hibiscus tiliaceous and Pandanus tectorius*-dominated woodland communities (000 & 001, 01000 and 01001 respectively), which had the higher axis 1 scores and lower axis 2 scores.

CCA axis 2 and 3 were correlated with different environmental variables than the DCA axis 2 and 3. DCA axis 2 was correlated with PAR, but PAR was removed from this CCA analysis. The correlation of CCA axis 2 to R:FR was explained in the same way as the DCA axis 2 correlation with PAR, in that a higher R:FR ratio would be expected in the more open habitats of the ridge crests and scrub, with higher axis 2 scores. DCA axis 3 showed no correlations, but the axis 3 scores for CCA are not comparable to those for the DCA, and thus are explained by pH. Woodland habitat soils, with the exception of the highly eroded and disturbed *Syzygium jambos* woodland, show higher pH values than the scrub and coastal habitats. The lowered pH in *Syzygium jambos* woodland may be due to leaching due to excessive erosion in these areas.

Table 3.9 - Correlation scores, from PC-Ord CCA output, for the key environmental variables

	Correlations†			Biplot scores		
Variable	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
% Coarse fragments	-0.146 n.s	-0.172 n.s	0.263 *	-0.071	-0.085	0.119
pH	-0.411 ***	-0.411 ***	-0.509 ***	-0.199	-0.204	-0.231
LOI	0.798 ***	-0.373 ***	-0.213 n.s	0.386	-0.185	-0.097
Aspect	-0.104 n.s	0.169 n.s	-0.406 ***	-0.050	0.084	-0.185
Altitude	0.791 ***	0.480 ***	-0.089 n.s	0.383	0.239	-0.040
Slope	-0.006 n.s	-0.185 n.s	0.305 **	-0.003	-0.092	0.139
R:FR (measured)	-0.567 ***	0.533 ***	0.002 n.s	-0.274	0.265	0.001
R:FR (hemiphot)	-0.603 ***	0.467 ***	-0.152 n.s	-0.292	0.232	-0.069
Moss cover	0.259 *	0.139 n.s	0.314 **	0.125	0.069	0.143
Bare rock cover	-0.572 ***	0.174 n.s	0.401 ***	-0.277	0.087	0.182
Litter cover	0.601 ***	-0.396 ***	-0.091 n.s	0.291	-0.197	-0.041
Total PPFD above	0.780 ***	0.484 ***	-0.075 n.s	0.377	0.240	-0.034
DSF	0.066 n.s	-0.067	-0.102 n.s	0.032	-0.033	-0.046
LAI	0.402 ***	-0.403 ***	0.229 *	0.195	-0.200	0.104

†Correlations are "intraset correlations" of ter Braak (1986); correlations of the environmental variables with the axes, which are standard Pearson correlations.

n.s - >0.05; * - $p < 0.05$; ** - $p < 0.01$; *** - $p < 0.001$

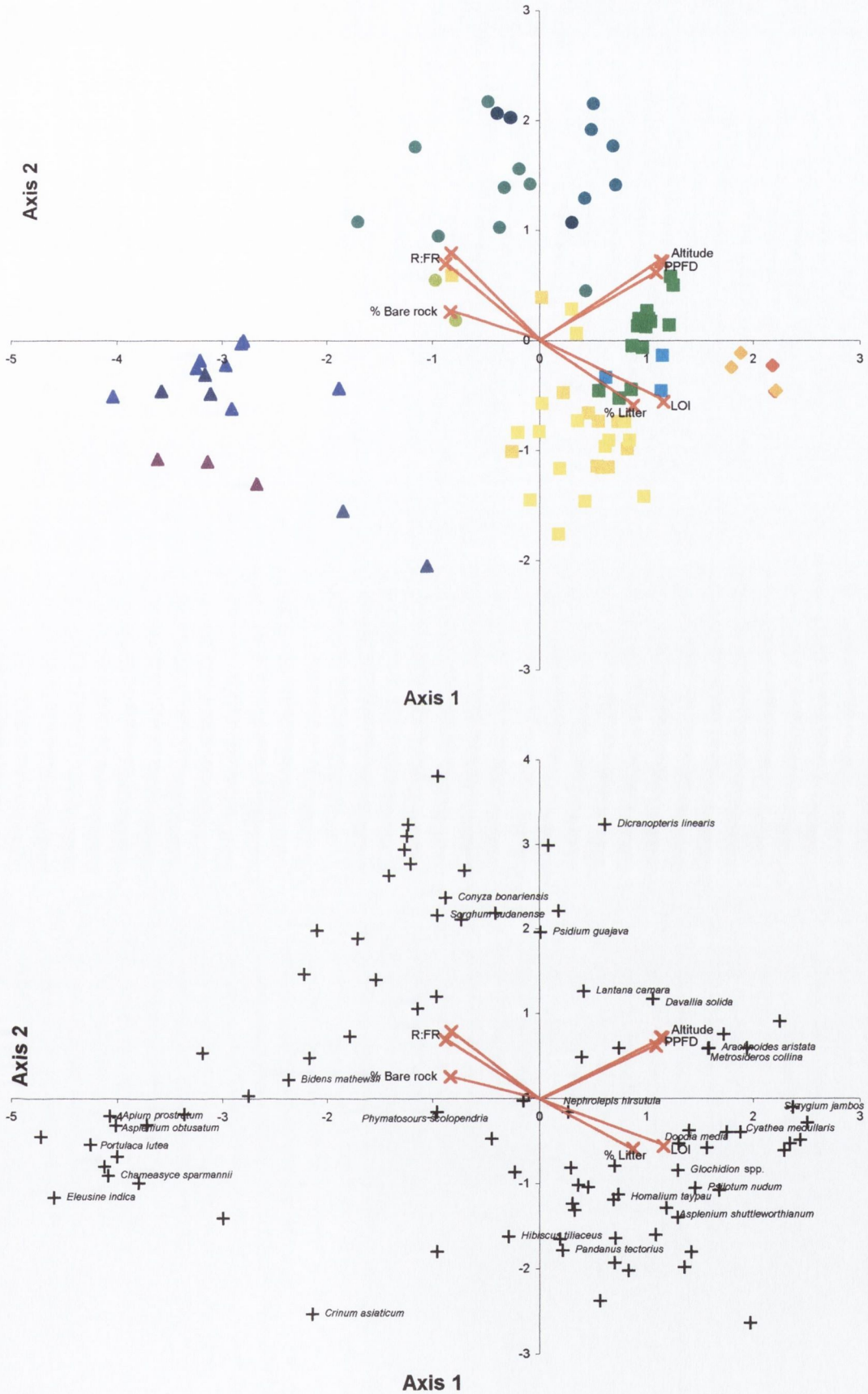


Figure 3.6 - CCA axis 1 plotted against axis 2, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Environmental variables are labelled on both plots.
Legend: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +. Environmental variables: x

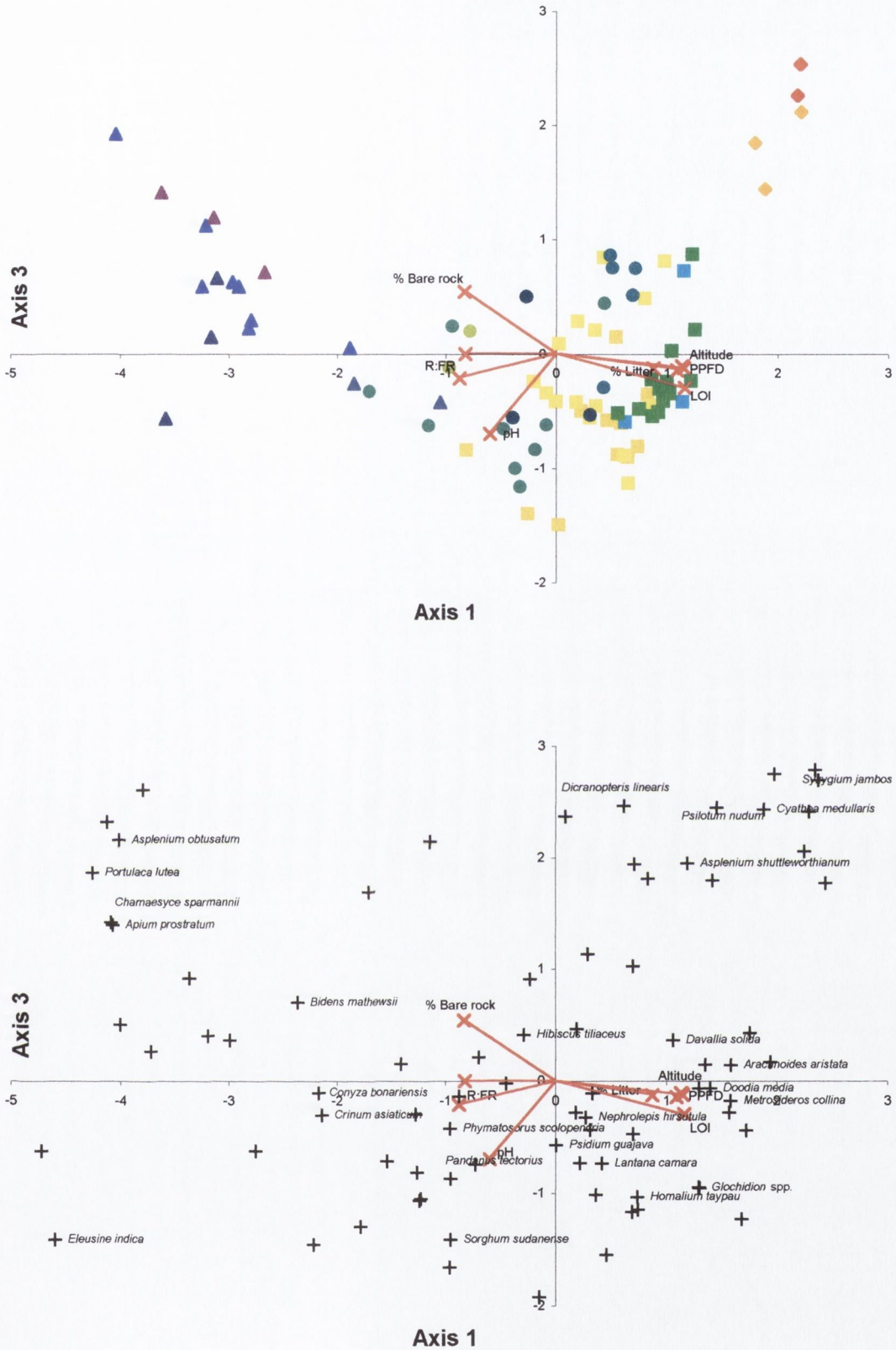


Figure 3.7 - CCA axis 1 plotted against axis 3, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Environmental variables are labelled on both plots.
Legend: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +. Environmental variables: x

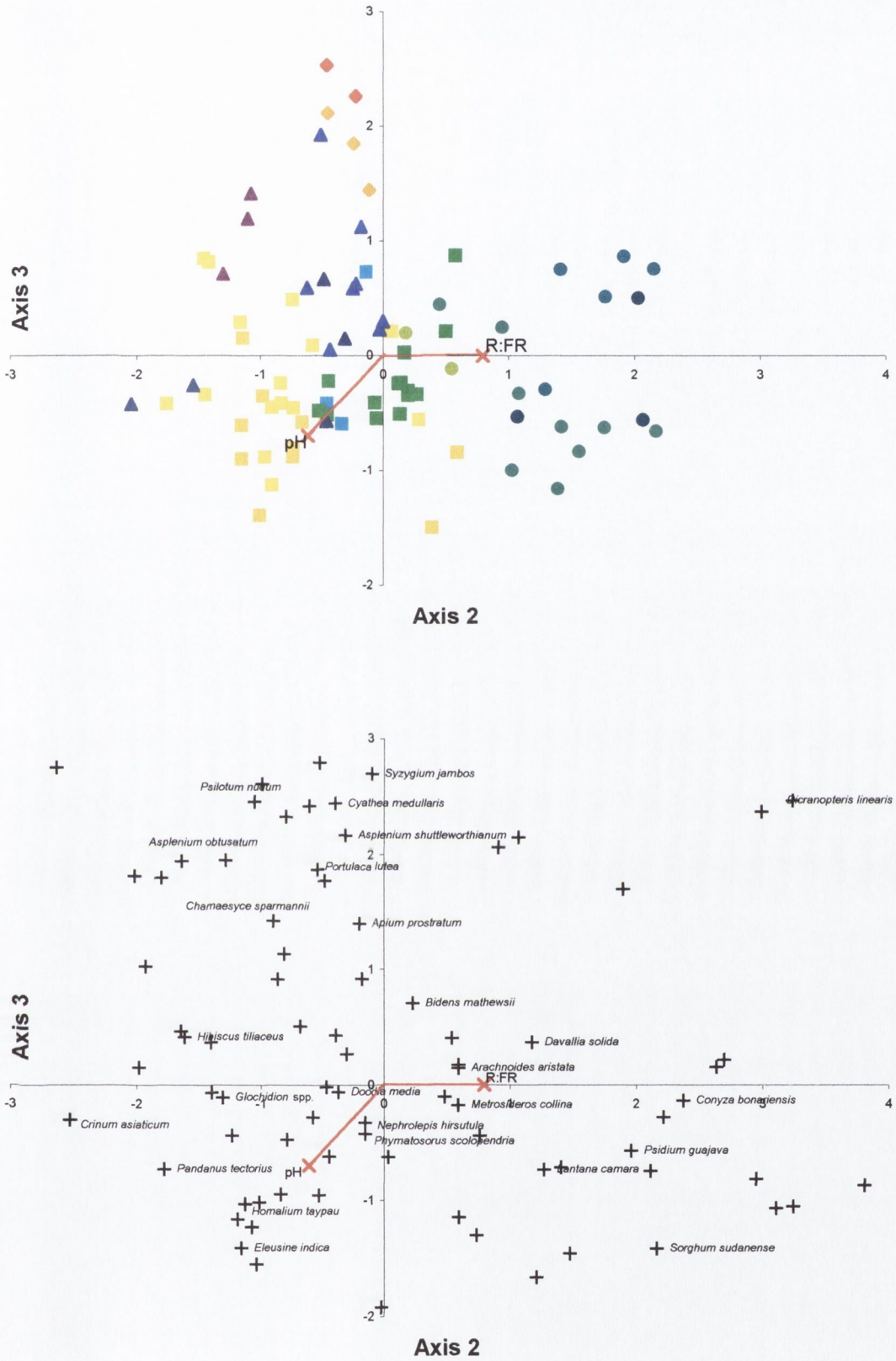


Figure 3.8 - CCA axis 2 plotted against axis 3, with TWINSPAN groupings superimposed onto the axes in the top figure, and species plotted in the bottom figure with indicator species labelled. Environmental variables are labelled on both plots.
Legend: *Syzygium jambos* communities: ◆ = 000; ◆ = 001; Woodland communities: ■ = 01000; ■ = 01001; ■ = 01010; ■ = 01011; Scrub communities: ● = 01100; ● = 01101; ● = 01110; ● = 01111; Coastal communities: ▲ = 100; ▲ = 101; ▲ = 110; ▲ = 111. Indicator species: +. Environmental variables: x

3.3.5 Mapping analysis

An overall vegetation map for the island was compiled and is presented in figure 3.9. A map of the quadrats, labelled with their TWINSPAN groupings was overlayed onto this map and were found to correspond well with the dominant vegetation groups identified by eye. In fact very little adjustment was necessary, with only one woodland in the east end of the island being changed from mixed woodland to *Homalium taypau-Metrosideros collina* woodland. The map has both *Pandanus tectorius* and *Hibiscus tiliaceus* woodland groups, but these groups were put together in group 01001 by the TWINSPAN analysis. Similarly, TWINSPAN separated *Metrosideros collina* and *Homalium taypau* woodland, but these are together on the vegetation map taken by eye. The map also has Banyan trees (*Ficus prolixa*) delimited as in some cases they covered large areas. The settlement areas are also delimited, where no quadrats were taken and no attempt was made to define vegetation communities which were largely gardens and cultivated areas, and these are labelled as Settlement on the map taken by eye. Some coastal quadrats were taken from areas which are cliff areas on the overall map, as assigning vegetation types to coastal cliffs proved difficult. Thus coastal cliff areas can be considered as coastal rocky communities, with sparse coverage of vegetation.

The woodland community of *Homalium taypau* and *Metrosideros collina* covers the largest area, although covering only a slightly larger area than that under *Syzygium jambos* woodland (table 3.10). *Lantana camara* scrub also covers an equivalent area to that under *Syzygium jambos* woodland. Thus nearly 40% of the vegetated area of the island is under almost monospecific stands of these two invasive species. *Lantana camara* scrub and *Canna indica* scrub can be considered together in order to relate them to the weedy scrub community identified by the TWINSPAN analysis.

Table 3.10 – The area of Pitcairn Island under each of the vegetation communities identified by the mapping analysis. The area is presented in both m^2 and km^2 for accuracy and clarity. The percentage of the total area and the total vegetated area are also presented.

Vegetation community	Area in m^2	% Total area vegetated	% Total island area
Homalium taypau & *Metrosideros collina* woodland	170043	19.88	14.58
Hibiscus tiliaceus woodland	31111	3.64	2.67
Pandanus tectorius woodland	83983	9.82	7.20
Mixed woodland	94722	11.08	8.12
Syzygium jambos woodland	167770	19.62	14.39
Lantana camara scrub (Weedy scrub)	169225	19.79	14.51
Canna indica scrub (Weedy scrub)	3884	0.45	0.33
Fernlands	23985	2.80	2.06
Grassy coastal scrub	9519	1.11	0.82
Rocky coastal	14219	1.66	1.22
Banyan (*Ficus prolixa*) stands	3511	0.41	0.30
Settlement	83184	9.73	7.13
Cliffs	394148	0.00*	33.80

* - this is inaccurate, as in places the cliffs areas are vegetated, but impossible to access or survey.

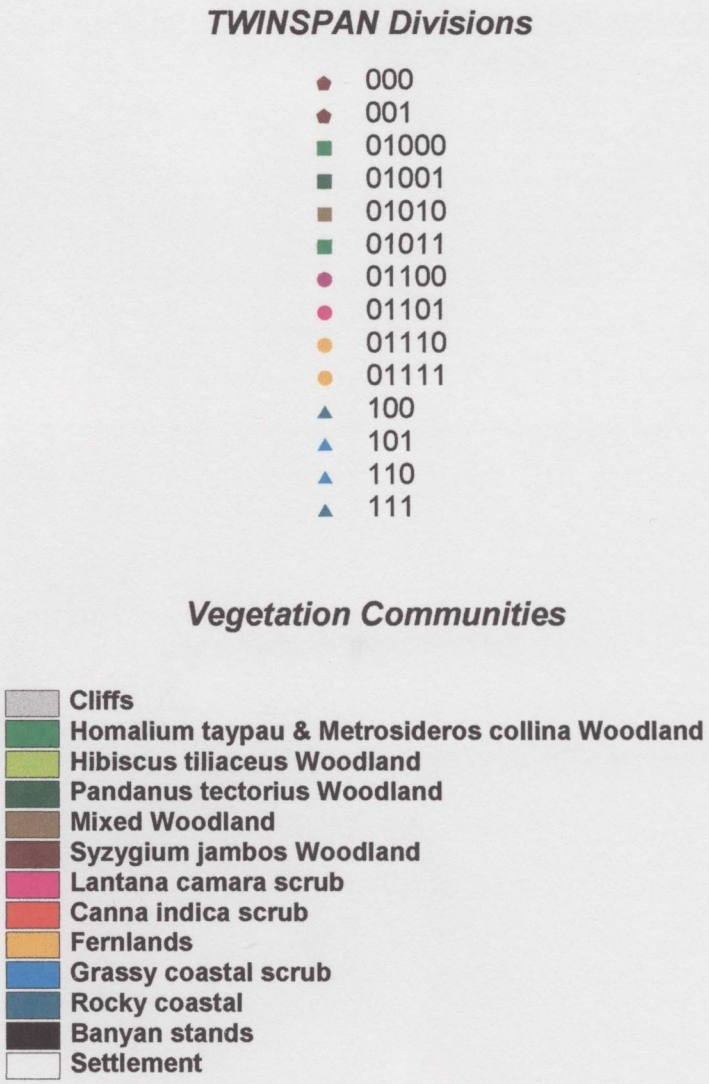
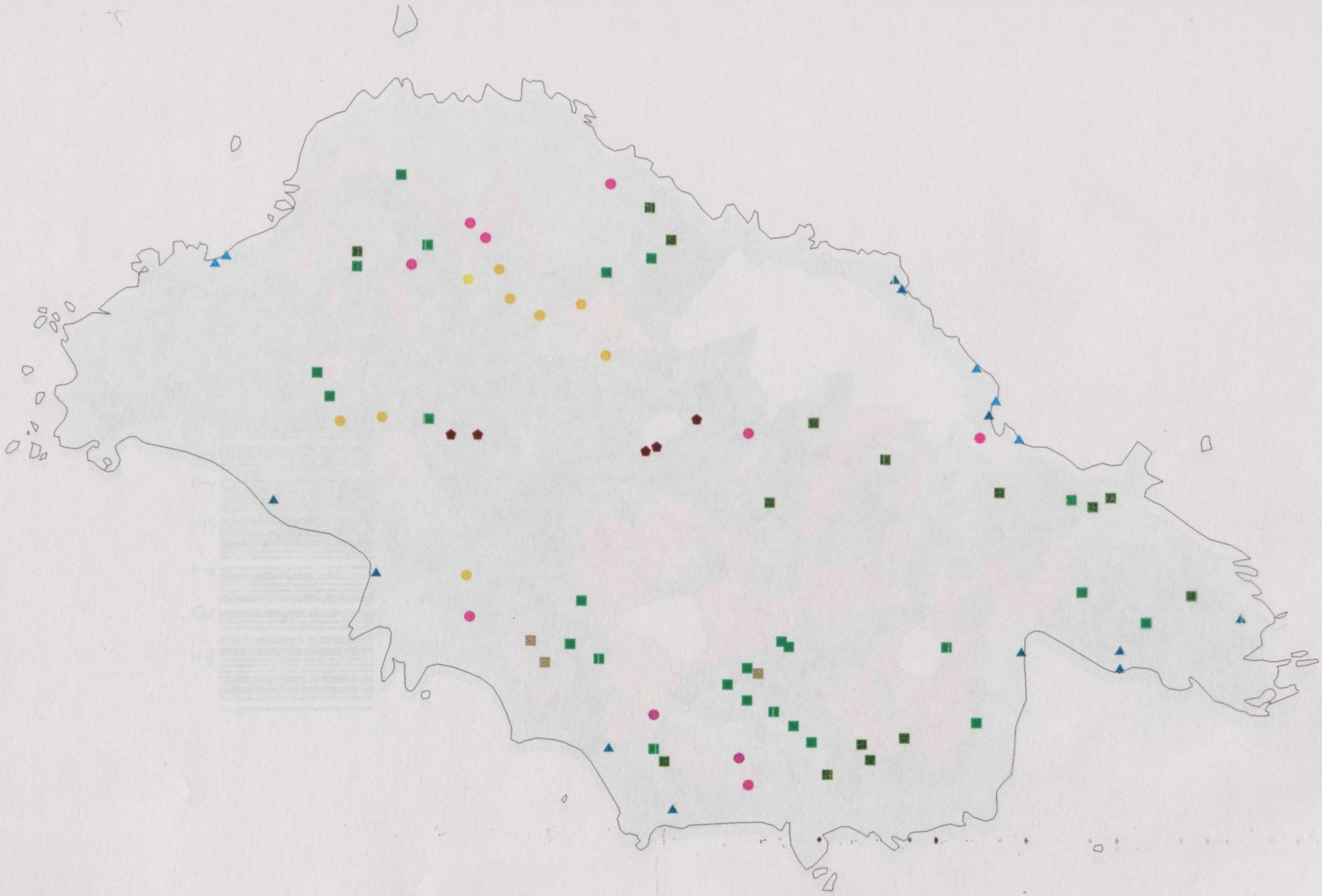
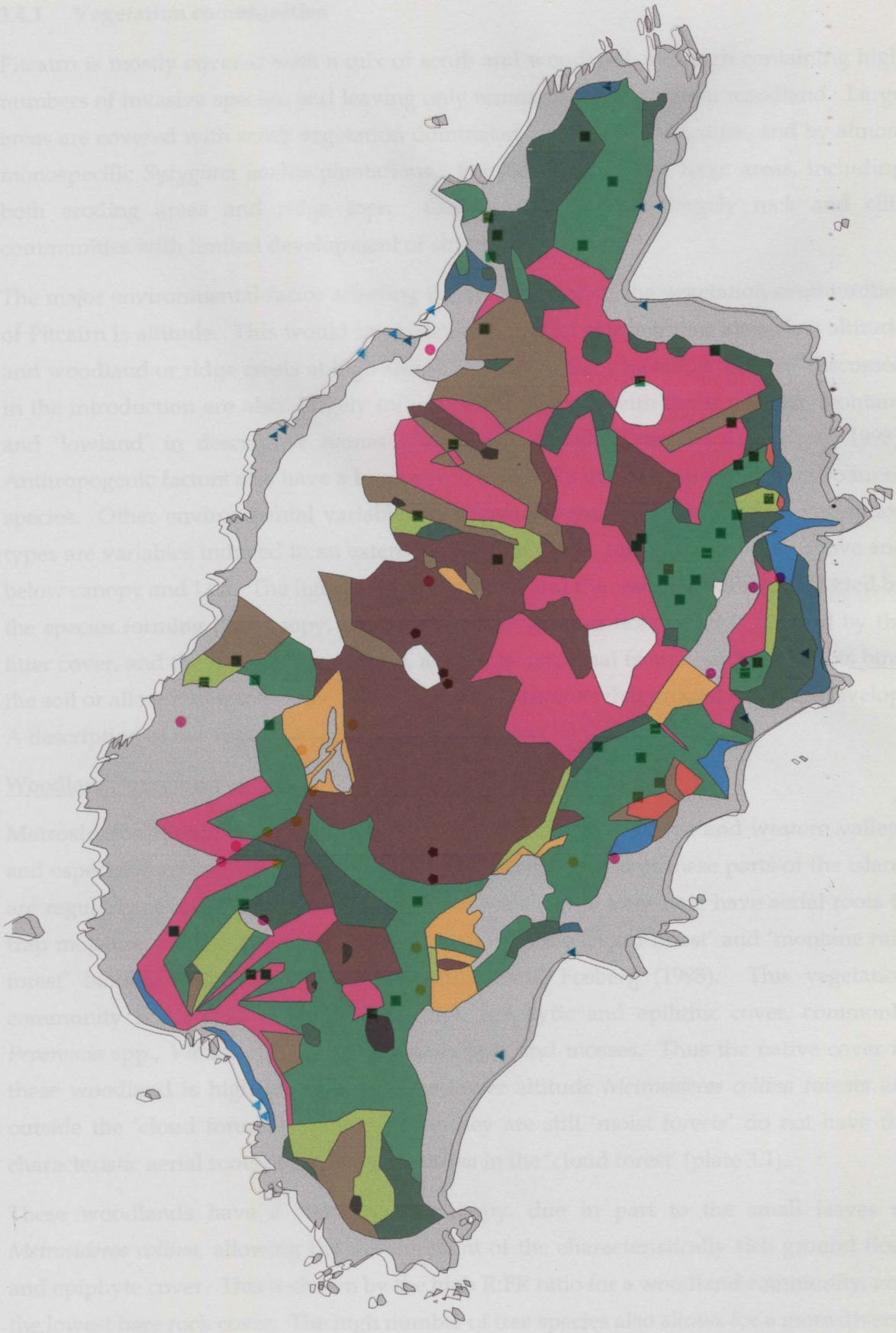


Figure 3.9 - Map to show the distribution of vegetation communities on Pitcairn Island. Overlay shows the quadrats locations coloured to show assignment to TWINSPAN vegetation communities.





3.4 Discussion

3.4.1 Vegetation communities

Pitcairn is mostly covered with a mix of scrub and woodland, although containing high numbers of invasive species, and leaving only remnants of fully native woodland. Large areas are covered with scrub vegetation dominated by non-native species, and by almost monospecific *Syzygium jambos* plantations. Fernlands also cover large areas, including both eroding areas and ridge tops. Coastal vegetation is largely rock and cliff communities with limited development of strand vegetation.

The major environmental factor affecting the composition of the vegetation communities of Pitcairn is altitude. This would be expected as coastal communities are at low altitude and woodland or ridge crests at high altitudes. The Pacific vegetation 'biomes' discussed in the introduction are also largely influenced by altitude with terms such as 'montane and 'lowland' in descriptive names (Dahl 1980; Mueller-Dombois & Fosberg 1998). Anthropogenic factors also have a large affect, especially due to clearance and introduced species. Other environmental variables that have a significant effect on the vegetation types are variables induced to an extent by the vegetation, such as light levels above and below canopy and LOI. The light levels penetrating and the resulting R:FR are affected by the species forming the canopy, and so define the ground flora. LOI is affected by the litter cover, and the microbes in the soil, as well as erosional factors, such as if roots bind the soil or allow it to wash away. This will also determine what ground flora can develop. A description of the vegetation communities follows.

Woodland communities

Metrosideros Woodland is found at high altitudes in the southern and western valleys and especially around the highest peak of the island. Several of these parts of the island are regularly covered in cloud and the *Metrosideros collina* trees here have aerial roots to trap moisture (plate 3.2), equating the vegetation to the 'cloud forest' and 'montane rain forest' biomes described by Mueller-Dombois and Fosberg (1998). This vegetation community is also characterised by a high epiphytic and epilithic cover, commonly *Peperomia* spp., *Vittaria elongata, Trichomanes* spp. and mosses. Thus the native cover in these woodland is high (over 80%). The lower altitude *Metrosideros collina* forests are outside the 'cloud forest' zone and while they are still 'moist forests' do not have the characteristic aerial roots of *Metrosideros collina* in the 'cloud forest' (plate 3.1).

These woodlands have a low density canopy, due in part to the small leaves of *Metrosideros collina,* allowing the development of the characteristically rich ground flora and epiphyte cover. This is shown by the high R:FR ratio for a woodland community, and the lowest bare rock cover. The high number of tree species also allows for a more diverse habitat than in some of the monospecific woodland communities. This vegetation community shows what native woodland on the island may have been like prior to

human settlement, with a mixed woodland dominated by *Metrosideros collina* and *Homalium taypau*, but with many other native tree species, such as *Coprosma benefica*, *Xylosma suaveolens* and *Glochidion* spp.

Homalium woodland may have been managed for timber in the past and so forests that are pure stands of *Homalium taypau* may not represent natural vegetation. The natural situation is more likely *Homalium taypau* mixed with *Metrosideros collina* as in Faute and McCoys Valleys, to form 'montane rain forest' and 'cloud forest'. *Homalium taypau* woodland is distributed in patches across the island and intergrades with *Metrosideros collina* woodland in many parts of the south of the island. It tends to have a species-poor ground flora with more of the common and weedy native ferns such as *Nephrolepis hirsutula*.

A lack of *Homalium taypau* seedlings in any of the woodlands is an enigma, especially as the species was observed in flower regularly. Interestingly the closely related *Homalium acuminatum*, in the Cook Islands, only flowers following a climatic disturbance, such as a cyclone, but many seedlings have been observed on the forest floor (Gerald McCormack pers. comm.; pers. obs.). Breeding biology and regeneration of this genus in the Pacific will need to be investigated further. Similarly no seedlings of *Pisonia grandis*, the dominant tree on Henderson Island, have been observed (S. Waldren pers. com). For some species, therefore, seedling growth may be ephemeral, with almost all soon perishing, except under certain favourable conditions (S. Waldren pers. com.).

Syzygium Woodland covers the largest area of the island for a single species (0.17km^2), including one of the most important sites on the island for rare native fern species. While this site is very rich and diverse, the populations here are in decline, and *Angiopteris chauliodonta* numbers have reduced drastically in the last 30 years (B. Christian pers comm.). This is due to dense shade cast by the canopy cover, which has a high LAI and allows low light transmission. Also the invasion of *Syzygium jambos* has probably had an effect on the humidity levels in the valley, to which pteridophytes would be especially sensitive. Before the introduction of *Syzygium jambos*, introduced for firewood about two centuries ago, these areas would have been 'native montane rain and lowland forest' with a rich understory of native fern species. Other problems faced by these sites are increased erosion as the soil is not bound by tree and ground cover roots, and there is evidence of such erosion in most *Syzygium jambos* woodland on steep slopes. The fact that this woodland type separated so readily in the analyses shows the dramatic effect of this introduced species on the Pitcairn environment.

Mixed woodland also covers large areas of the island, but with a varied species composition. On the north and east of the island it is typified by the trees *Pandanus tectorius* and *Hibiscus tiliaceus*, with *Glochidion* spp. shrubs and trees. On the southern and western parts of the island mixed woodland areas are drier and typically epiphyte-poor, and found at low to mid altitudes, below the level of cloud forest. They contain a large

number of native species and are probably typical of what much of the islands 'lowland valley and ravine forest' was like prior to human habitation. It is therefore potentially a remnant of a previously more widespread vegetation group. Threats to this forest are from increased invasion by species such as *Lantana camara* which prevents regeneration of native species (Mauchamp *et al.* 1998). Forest of *Hibiscus tiliaceus* also falls into this group, which in some cases is secondary forest in areas that were previously cleared but have since been abandoned.

Scrub communities

Weedy Scrub is very common across the island, covering over 20% of the vegetated area of the island, caused by clearance, goat trampling and invasion by scrubby non-native species. The resulting scrub varies in species composition depending on how and where it has formed. Trampled areas and especially ridges tend to have a low number of native species and are typified by scrub of *Lantana camara, Psidium guava, Conyza bonariensis* and the grass *Paspalum conjugatum.* These ridges would probably have been originally covered with a low forest of species such as *Cerbera manghas, Xylosma suaveolens* and *Pandanus tectorius,* or *Dicranopteris linearis* fernlands on eroded slopes. Areas that were cleared for cultivation but have since become invaded tend to be more grass-dominated.

The area around Tautama is also covered in weedy scrub but with more native species, and due to its low lying nature more coastal species. Typical species here are the endemic *Bidens mathewsii,* and ferns, such as *Nephrolepis hirsutula* as well as non-native species such as *Conyza bonariensis* and *Lantana camara.* The area of scrub is probably spreading as the non-native species prevent the regeneration of native forest species such as *Pandanus tectorius* and *Hibiscus tiliaceus,* and thus expand in to these adjacent forested areas (plate 3.3).

It is difficult to relate this vegetation type in terms of the Pacific biomes discussed in the introduction to this chapter, and it is more useful to divide it depending on its location and origin rather than on the dominant species. The 'savanna' biome, covering areas originally cleared for gardens, is probably the most appropriate, but on Pitcairn it is dominated by the grass *Sorghum sudanense* rather than *Miscanthus* spp as on other Pacific and Polynesian islands. The dominance of pteridophyte species such as *Nephrolepis* spp. and invasive species such as *Lantana camara* describe 'ridge-crest scrub' communities (not defined in the main Pacific 'biomes' but also referred to in Mueller-Dombois & Fosberg (1998) for the Society Islands). These are also anthropogenically induced communities, through clearance and goat trampling.

Plate 3.1 - *Metrosideros collina* woodland from McCoys Valley on the leeward side of the island. Note the ferns rich understory

Plate 3.2 - *Metrosideros collina* woodland from High Point on the windward side of the island. Note the aerial roots, typical of this species in cloud forest, and contrasting to the same species from drier woodland shown in plate 3.1.

Plate 3.3 - Ginser Valley on the south of the island showing steep slopes, cliffs and ridge crest scrub.

Plate 3.4 - The Hollow on the north of the island. An area of naturally eroding slopes and fernlands (a *Dicanopteris linearis* stand can be seen in the foreground). The monospecific dense woodland stand in the top left hand corner is *Syzygium jambos* woodland.

Fernlands are common on areas that have suffered recent erosion and landslides, as is typical right across the Pacific region. They are dominated by *Dicranopteris linearis*, but also contain many other species depending on how recently they were laid bare. There is an obvious cycle of species that would invade after these periods, and this can be seen in detail in areas such as 'The Hollow' (plate 3.4). *Dicranopteris linearis* and *Lycopodium cernuum* are the first species to invade, with *Ophioglossum* spp., lichen and bryophyte species in damp areas. These bind the soil sufficiently allowing other fern species, such as *Davallia solida* and *Cyathea medullaris*, to invade followed by trees and shrubs, such as *Pandanus tectorius* and *Metrosideros collina*. Due to the most common location of these areas on the dry, leeward, north facing slopes, they also have extreme light conditions. These are the areas that are unfortunately now open to invasion by the introduced species *Lantana camara, Sorghum sudanense, Psidium guajava* and *Syzygium jambos*, and fernlands containing these non-native invasive species are now more common than native areas.

Fernlands are native communities that would have always existed on Pacific islands. However this vegetation community is spread through anthropogenic activities and especially from burning of leeward slopes. It is the most common undoubtedly pyrophytic community of tropical Pacific islands, making *Dicranopteris linearis* the most common fern species in the Pacific (Nunn 1990).

Coastal communities

Coastal rock habitats and **Coastal scrub** habitats are easily distinguished by the species present and by the geographical location. On the south coast of the island the species are different in many cases to those from the north side of the island. Southern species seem to require a wetter and more shaded climate than those on the north of the island. Rocky habitats include taxa such as *Peperomia* spp., *Asplenium shuttleworthianum, Cocculus ferrandianus, Haloragis sp.* and *Bidens mathewsii*, while scrubby habitats tend to be dominated by non-native species such as *Sonchus oleraceus* and *Eleusine indica*. In addition these scrubby habitats contain the larger native coastal species such as *Bidens mathewsii*, and *Haloragis sp.*. The north coast is drier and due to its location next to the main settlement of Adamstown, tends to be more heavily invaded and disturbed. *Pandanus tectorius* and *Cocos nucifera* form a tall coastal forest with virtually no ground flora, except for the large invasive species *Crinum asiaticum*, along the stretch north of Adamstown, in a vegetation formation that has been common since pre-European times right across the Pacific. However, rocky areas on the north of the island also house the best examples of typical Pacific island strand vegetation, with *Eugenia reinwardtianna, Ipomoea spp., Portulaca lutea, Scaevola sericea, Chamaesyce sparmannii* and *Lepturus repens*. These species are typical of dry coastal and sandy shores across the Pacific, but are very limited in extent on Pitcairn in comparison to other islands such as Oeno and Henderson, which have a fringing reef and thus a more protected and sandy shoreline.

3.4.2 Vegetation history

It is only possible to speculate about what the vegetation cover of the island was prior to settlement from the remnants of almost pristine forest still present. It is likely that *Metrosideros collina* and *Homalium taypau* forest covered most of the higher altitude regions. This would have been epiphyte-rich with a dense pteridophyte ground flora in the areas of 'montane rain forest' and 'cloud forest'. This type of woodland may have persisted into the valleys, and become a 'lowland ravine forest' with large tree species such as *Pisonia umbellifera, Glochidion* spp., *Hernandia sonora, Pandanus tectorius* and *Celtis Pacifica*. Smaller tree and shrub species such as *Coprosma benefica, Psydrax odorata, Cyclophyllum barbatum, Cerbera manghas* and *Cyathea medullaris* would also have been present, especially on the steep upper slopes and ridges. Following human settlement there is evidence that several of these species may have been exploited and cultivated for use in canoe making (eg *Hernandia sonora*) and house building (eg *Glochidion* spp.).

Coastal areas would have been as some are today, with rocky areas dominated by fern species such as *Asplenium shuttleworthianum* and *Asplenium obtusatum,* and scrubby areas with shrubs such as *Bidens mathewsii, Ipomoea* spp. and *Dianella intermedia,* and the grass *Lepturus repens*. Coastal woodland would have been largely *Pandanus tectorius* and *Hibiscus tiliaceus* (if it is native) as can be seen now at Tautama. Owing to the nature of the soil and island substrate, there would have always been areas of eroding slope and fernlands, especially following disturbance events such as storms or heavy rains. The eroding areas are now exacerbated by the islanders management practices and the activity of goats.

Polynesian settlers in the 10th century would have introduced crops such as *Musa* spp., *Artocarpus altilis, Cocos nucifera, Aleurites moluccana, Cordyline fruticosa* and *Ficus prolixa* (Florence *et al.* 1995; St. John 1987). It is interesting that none of the taxa introduced by Polynesians became seriously invasive, and in many cases it is difficult to decide if the species were introduced or if they are a feature of the native vegetation, as in the case of *Thespesia populnea, Hibiscus tiliaceus* and *Pandanus tectorius* (Fosberg 1991; Waldren *et al.* 1999b; Whistler 1991). A list of the species probably introduced by the Polynesian settlers is given in Appendix 1.

Many species have been either deliberately or accidentally introduced since the arrival of the Bounty Mutineers and the subsequent contact with Europe and America. There are currently 250 non-native species on the island (see section 2.3.1 & appendix 1), and many have become major pests, or have the potential to do so. Originally larger areas were cultivated due to a higher population, but as the population has dwindled, many areas have reverted back to scrub. *Musa* spp., *Cocos nucifera* and *Citrus* spp. trees in many remote valley areas are also remnant from when the island was more densely populated. In addition large areas of *Syzygium jambos* woodland that were managed for fuel wood are

now being left uncut, and the larger trees are arching together to form a complete and dense canopy.

3.4.3 Comparison with other Polynesian Islands

The present vegetation of Pitcairn Island is comparable to that of other Polynesian islands, but with a more depauperate flora, and lacking several of the vegetation types that occur on the very high volcanic islands in the other island groups (Mueller-Dombois & Fosberg 1998). The low altitude of the island also reduces the distinction between the leeward and windward communities, so preventing the development of dry forest, high altitude grassland and montane bog biomes.

Due to its age and subtropical location, Pitcairn has no fringing reef and therefore no terrestrial coral substrates as with the high islands of the Australs, two of which have areas of elevated limestone as well as volcanic soils, and two of which have large lagoon areas with extensive coastal sandy substrates (pers obs. 2000). This lack of coral substrate also differentiates Pitcairn vegetation from vegetation on the atolls scattered throughout Polynesia, but especially in the Tuamotus. The lack of a protective fringing reef also means that the coast is less gradually sloping, as in the Society islands, but more like the steep cliffs found in the Marquesas, and parts of Rapa. The Marquesas, however, differ in that they are located further into the tropical zone and so sustain quite different species (Mueller-Dombois & Fosberg, 1998).

Other Polynesian islands have also been more greatly altered and affected by a longer history of human habitation. Pitcairn does not have the large areas cleared for coconut (*Cocos nucifera)* and coffee (*Coffea arabica)* plantation that are common in the Society Islands, Austral Islands and Gambier Islands. Instead, due to less intensive agriculture, such plantations are confined to the areas around habitation and in some of the more accessible valleys. Other vegetation types that are absent from Pitcairn include wetland and coastal communities such as mangrove swamps, salt-marshes and wet-land agriculture. Marsh areas are especially common in the Austral islands, resulting in an aquatic habitat and the suite of associated species (eg *Nymphacea* cf. *lotus, Lepironia articulata*) (Mueller-Dombois 1998; pers. obs.).

Native forests on Pitcairn fall under the category of montane rain forests, with small areas of cloud forest as defined by Muller-Dombois and Fosberg (1998) for Pacific islands. Pitcairn is too low to have large areas of cloud forest as in the Society Islands, but has areas with features of cloud forest at the highest altitudes, such as extensive epiphyte cover, aerial roots on *Metrosideros collina* trees and continuous cloud cover during wet periods. On Pitcairn these forests occur with abundant pteridophyte growth in the understory. This is a feature also noted for the Society Islands by Fosberg (1992), and personally observed on Tubuai in the Austral Islands. Tubuai is similarly a relatively low island (max. 422m), but has an area of cloud forest on the highest peak, with *Metrosideros*

collina with aerial roots and dense moss and epiphyte cover (pers. obs. 2000). Unfortunately, although Tubuai is a much larger island than Pitcairn (45km^2), it has a much smaller area under native cloud forest, as the highest peaks are very heavily invaded with *Psidium cattleianum*, or have been burned and are now covered with fernlands.

Non-native secondary forest and scrub is common at lower elevations and in valleys. This is common right across the Pacific in areas where non-native crops and trees were planted in among native trees, and is referred to as the 'tree garden' biome (Mueller-Dombois & Fosberg 1998). The dense tangles of *Hibiscus tiliaceus* that develop in these valley bases once they are abandoned were observed especially in the Water Valley area of Pitcairn (an area of Polynesian settlement; M. Weisler pers comm to SW), and to a lesser extent in Tautama. Other valleys are still maintained for fruit gardens, even if only sporadically visited (eg St Pauls & valleys around Adamstown).

As with all Pacific high islands fernlands are a common feature of the landscape. These are especially dominated by *Dicranopteris linearis*, and occur on areas where erosion is common, and on drier leeward sides. This vegetation type is native, but is exacerbated by human disturbance, and is so common at roadsides, ridges affected by goat trampling and also at sites of recent landslides. Woody species are also present in older fernlands, and non-native species commonly use these areas for increasing their range, such as *Psidium guajava* and *Lantana camara* scrub referred to earlier as invading ridge-tops on Pitcairn. Fernland is however relatively uncommon on Pitcairn (only 2.8% of total cover) in comparison to the other more heavily disturbed Polynesian islands such as Tubuai which has at least and probably a lot more than 10% fernland cover (pers. obs 2000). However the area under fernland on Pitcairn seems to have increased since the 1930's (see St John 1987).

Coastal vegetation on the north side of the island is typical of Polynesia, with species such as *Scaevola sericea* and *Lepturus repens* occurring on the rocky shore and *Pandanus tectorius* forests farther back. The south coast is especially similar to the rocky shores of the uplifted Austral islands (Rurutu and Rimatara) with *Lycium sp.*, *Bidens sp.* and *Chamaesyce sp.* (pers. obs. 2000). Coastal areas differ from other coastal regions of Polynesia in that they are less disturbed by plantations and human habitations, and also have poorly developed strand communities lacking typical species such as *Pemphis acidula, Suriana maritima, Timonius polygamus.*

3.4.4 Concluding remarks

This chapter set out to determine if distinct vegetation communities could be defined for Pitcairn and what environmental factors influence these communities. Table 3.10 gives summary information about the vegetation communities derived from the data analysis. Each of the vegetation communities for Pitcairn can be related to the Pacific 'biomes'

described in section 3.1.4, and derived from the 'biomes' of Dahl (1980) and Mueller-Dombois & Fosberg (1998). Several environmental factors influence these vegetation communities, notably the altitude and light environment of the site. All of the habitat types contain large proportions of introduced species, and this has serious implications for the future conservation of both the vegetation types and rare species occurring therein.

Table 3.11 - Summary table of vegetation communities defined by TWINSPAN with the geographic distribution of the group on Pitcairn, and the Pacific 'biome' to which the community corresponds.

TWINSPAN Group	Community type	Location on Pitcairn	Pacific biome
000	*Syzygium jambos* woodland	Browns Water	Plantation forest
001	*Syzygium jambos* woodland	Central plantations	Plantation forest
01000	*Homalium taypau* woodland	Widespread in remote areas	Montane rain forest
01001	Mixed Woodland	North & East	Lowland rain forest
01010	Mixed Woodland	South	Lowland rain forest
01011	*Metrosideros collina* woodland	Widespread in remote areas	Cloud forest
01100	Tautama scrub	Tautama	Scrub
01101	Ridge scrub	Inland ridges and slopes	Savanna
01110	Fernlands	Inland slopes	Fernlands
01111	Fernlands	Coastal ridges	Fernlands
100	Rocky coastal	South	Strand vegetation
101	Coastal scrub	South	Strand vegetation
110	Coastal woodland	North	Strand vegetation
111	Rocky coastal	North	Strand vegetation

Chapter 4 : Phytogeographic relationships of the Pitcairn Islands

4.1 Introduction

4.1.1 Biogeography of the Polynesian region

The first biogeographic scheme of the world that recognised Polynesia as a division on its own was that of Schouw in 1823, for plants (Kay 1979). Since then numerous schemes using virtually all groups of organisms have also recognised the Polynesian realm, with some even using further sub-divisions within Polynesia. Gressit's (1956) classification based on insects placed south-east Polynesia as a subdivision of a much larger region that continued from Malaysia and Indo-China across to Easter Island, but separated Australia and New Zealand into a different region (Kay 1979; Stoddart 1992). Brownlie (1965) when discussing the pteridophyte flora of the Pacific, described it as an extension of the Malaysian area, while Copeland (1938) commented that eastward from Fiji the evidence of a direct connection with New Zealand becomes progressively weaker. Schilder in 1961 published a division based on the distribution of cowry shells (Mollusca, Gastropoda), which was the first to distinguish Easter Island from Polynesia (Kay 1979). Udvardy (1975) simply stated that the biota of the Pacific Islands was to the greatest extent derived from that of the Indomalayan (Oriental) Realm, but included the Juan Fernandez Islands as related to the western Pacific biota.

van Balgooy (1960) placed all the islands of south-east Polynesia together in the same large province (Cooks, Australs, Societies, Marquesas and Tuamotus) and described their flora as being 'paleotropical, depauperated Malaysian'. An exception was the island of Rapa, which he separated and placed as a subordinate of the Australian-New Zealand flora. In his scheme Easter Island is also placed as a subordinate of the Australian-New Zealand Province. In van Balgooy's later analysis (1971) he moved Rapa and Easter Island and placed them as districts of the south-east Polynesian province. More recently van Balgooy *et al.* (1996) stated that due to the considerable overlap in provinces, the floristic provinces could not be classified into a hierarchical system. In this later analysis he again moved Easter Island, this time as a subset of the South American flora.

Brown (1935) was the first to assess the flora of the southeast Polynesian region, and he divided it into 6 regions:

1 = Marquesas Islands

2 = Society Islands

3 = Tuamotu Islands

4 = Austral Islands

5 = Rapa

6 = Pitcairn & Gambier Islands

It is not clear from the text what these 6 divisions are based on, but the information from which they were derived was very limited, with only 251 species being known from the region at that time, mostly from the Society and Marquesas Islands. As many of the collections were very recent, and hence poorly understood, 87% of these species were thought to be confined to the Polynesian region, and only 2 species were assigned a pantropical distribution. Brown also suggested that 82% of the species were of American origin.

More recently the divisions proposed by Dahl (1980) also divided up the island groups of Polynesia, but unfortunately the analysis was confined to the area covered by the South Pacific Commission. In this scheme Tonga, Samoa, the Society, Marquesas and Tuamotu Islands all have their own region, while the Australs share a region with the Cooks, and Rapa shares with the Pitcairn group. These divisions were actually modified from the IUCN (1974) biotic provinces, with some boundaries moved and a new province for Rapa, the Gambier and Pitcairn Islands introduced. The IUCN (1974) biotic provinces were based on the 'prevailing climatic climax vegetation' for an island.

General patterns that can be addressed for the Pacific are that there is a gradual reduction of species from west to east across the Pacific, and that islands in the eastern half of the Pacific have virtually nothing in common with the flora of the Americas (Kay 1979). A further generalisation about the distribution of the Pacific island biota is that disjunct, discontinuous and patchy distributions are frequent phenomena, and that distribution patterns are associated with island type (Kay 1979). The biota of atolls are composed of few species, most of which are widely distributed on tropical strandlines, while even a slight elevation is accompanied by a substantial increase in the floristic diversity (Fosberg 1984; Sachet 1967; van Balgooy *et al.* 1996). Differences in the flora based on island type relate to the fact that atolls are ephemeral structures, subject to constant change and having resulting 'weedy' native floras exhibiting little endemism, while high islands have significant species diversity where dynamic processes of speciation and extinction occur (Brownlie 1965; Kay 1979).

4.1.2 Position of Pitcairn in previous schemes

As stated in section 4.1.1, most previous biogeographic studies left the whole of south-east Polynesia as a single region, and did not subdivide it further (Kay 1979; Stoddart 1992). In most cases this south-east Polynesia region included the Austral, Society, Tuamotu, Marquesas and Pitcairn Islands, as well as Rapa and Easter Island. Exceptions are van Balgooy (1960) who separated out Rapa and Easter Island from the rest of South-east Polynesia, and Thorne (1963) who also included the Cook Islands.

Biogeographic schemes that subdivided the islands within the south-east Polynesian region placed the Pitcairn and the Gambier groups together (Brown 1935; Dahl 1980).

Dahl (1980) also placed Rapa in the same division. Brown (1935) numbered the total flora of the area to be 41 species, which he describes as being of largely American origin.

4.1.3 Methods in assessing phytogeographic relationships

Since the early 19th century, attempts have been made to classify various regions of the globe from biological and environmental perspectives (de Candolle, 1820 in Kay, 1979). Studies have been both speculative and quantitative using one or more groups of organism in determining the divisions. Various terminologies have been employed for the resulting divisions, with terms such as realms, regions, subregions and zones, or provinces and sub-provinces being found in the literature (Kay 1979; Stoddart 1992). Schemes using such terminology have had many critics, notably Rosen (1988) and Stoddart (1992). Rosen (1988) suggested that provinces are not in themselves a method, but rather are a conceptualisation about the nature of biotic distributions. A common consequence is that studies based on different groups of organisms lead to rival, or apparently irreconcilable schemes of provinces (Rosen & Smith 1988). Rosen & Smith (1988) reject the idea that objective biogeographic provinces can be identified, and prefer methods which use the relationships between sample localities alone to develop historical hypotheses, such as the use of the 'parsimony analysis of endemicity' method to group localities based entirely on presence/absence data, independently of any existing arrangement of the localities in space. Stoddart (1992) recommended analyses based on island type as being most appropriate, as due to the homogeneous nature of atolls they do not comply to MacArthur and Wilson's (1967) theories making them unproblematic in terms of regionalisation, and thus the problem of tropical biogeography resolves itself into the consideration of the biotas of high islands (NB - motus, the small islets which together make up an atoll may comply, see Woodroffe, 1986) , and to a lesser extent makatea islands (as they have virtually all been subject to high levels of disturbance). Although categorisation of islands into particular biogeographic provinces or regions is problematic, these analyses have value in that they establish the biogeographical context within which the compositional structure of a particular island or archipelago needs to be placed (Whittaker 1998).

4.1.4 Aims

The study presented in this chapter makes a biogeographic assessment of the flora of the Pitcairn Islands. The worldwide distribution for all of the species is collected, so that it can be determined from where the flora may have originated and if any consistent patterns in the species distributions can be determined. In addition the dispersal mechanisms shown by the species are assessed to determine how the flora may have migrated to the island group.

4.2 Materials and Methods

4.2.1 Data collation

Once a completed species list for Pitcairn Island had been determined (see Chapter 2) a list was compiled for the Pitcairn Island Group (to include Henderson Oeno & Ducie whose floras are given in Florence *et al.* 1995), and the worldwide distributions for each species and genus were compiled in a presence/absence matrix for species in the geographical units defined below. As such a certain amount of subjectivity was employed to determine some species distributions. Species for which native status was uncertain were included (eg *Hibiscus tiliaceus, Thespesia populnea*); in most cases these species were widespread pantropical Indo-Pacific species, and thus did not affect the resulting data analysis. For some endemic species, especially those for which the synonymy and status was uncertain, the distribution of closely related species was also compiled (ie *Coprosma benefica; Lastreopsis* cf. *pacifica*). Data were compiled from many sources, listed at the end of this section.

Only native vascular plants (polysporangiates, or angiosperms and pteridophytes) were chosen for use in this study, as these are the groups for which distribution information is most readily available. Other plant groups, such as lichens, bryophytes, algae and fungi, are rarely included in floristic studies of the Pacific, and as such their distributions are incomplete or unknown. The study analysed vascular plant distributions at both the genus and the species level, as while genus level is most widely used for smaller scale studies of the Pacific (eg van Balgooy, 1971), it was felt that species level would be more appropriate for larger scale studies. Only native plants were used as the natural processes of plant migration and dispersal were under study, rather than anthropological progression in the area. Finally, only species occurring on the Pitcairn group of islands were used, as the main aim of this study was to consider the origin and formation of the flora of the Pitcairn group, rather than a biogeographical analysis of plant distribution in Polynesia or the Pacific region.

4.2.2 Dispersal types

Species and genera were assigned dispersal classes based on the dispersal mechanism employed. Five classes were defined modified from those used in van Balgooy (1971) and Florence *et al.* (1995), as follows:

1 = Active zoochory (ingested by animal)

2 = Passive zoochory (attachment to animal)

3 = Hydrochory (water dispersal by flotation)

4 = Anemochory (wind dispersal)

5 = More then one of the dispersal mechanisms 1-4

The number of propagules in a single dispersed unit was also recorded. This allowed quantification of the number of potential colonising individuals that could arise from a single dispersal event.

4.2.3 Distribution types

Species and genera were assigned general distribution classes, based on their world distributions, modified from the classes used by van Balgooy (1971). The classes are as follows:

1 = Worldwide/TransPacific

2 = Old World

3 = Indo-Malesian

4 = Australian

5 = Pacific (including Melanesia and New Zealand)

6 = Polynesian*

7 = Endemic to Pitcairn Group

* - West Polynesia, Central Polynesia, Rapa, Marotiri Rocks, and the Hawaiian, Cook, Society, Austral, Marquesas, Gambier, Tuamotu and Pitcairn Island groups.

4.2.4 Geographic units

The World was divided into geographic units, with the continents and larger landmasses being delimited using van Balgooy (1971), and the Pacific island divisions being modified to agree with those of Mueller-Dombois & Fosberg (1998). Further modifications, based on UNEP-Earthwatch (1998) separated the Tuamotu Islands group of Mueller-Dombois & Fosberg (1998) into ten groups, in particular separating out the Gambier Group and the Pitcairn Group which contain high islands and makatea. For this analysis the other island groups of French Polynesia were treated separately, as were Easter Island and the Juan Fernandez Islands. Divisions used are shown in figure 4.1.

Geographic units are as follows:

- Eurasia - including Europe, former USSR, the Middle East, Mongolia and northern China.
- Africa - including islands of the Indian ocean
- East Asia - Japan and eastern China
- South-east Asia - southern India, Myanmar and the Indo-China peninsula.
- Malesia - Malaysia and Indonesia
- The Philippines
- Australia

- West Melanesia - Papua New Guinea, Solomon and Bismarck Islands
- East Melanesia – Fiji, New Caledonia, New Hebrides, Vanuatu, St. Cruz and Loyalty Islands.
- New Zealand – North and South Islands, also Kermadec Islands, Norfolk, Lord Howe and the Chatham Islands.
- Micronesia – Caroline Islands, Bonins, Marianas, Guam and Tuvalu, also the Marshall and the Gilbert Islands.
- West Polynesia – incorporating the islands of Samoa and Tonga.
- Central Polynesia – Line Islands, Tokelau, Christmas Islands, Kiribati and the Phoenix Islands. Also includes the northern Cook Islands.
- Cook Islands – southern Cook Islands
- Society Islands
- Austral Islands
- Rapa – including Marotiri rocks
- Marquesas Islands
- Tuamotu Islands – subdivided into 10 groups as follows:

  - Actaeon Group
  - Centre East Group
  - Centre West Group
  - Disappointment Islands
  - Duke of Gloucester Group
  - East Group
  - King George Islands
  - North-West Group
  - Pallisier Islands
  - South Group

- Gambier Islands – including Timoe
- Pitcairn Islands
- Hawaiian Islands
- Easter Island – including Sala y Gomez
- Juan Fernandez Islands
- East Pacific Islands – Revilla Gigedo Islands, Clipperton, Cocos, Galápagos and Desaventuradas Islands.
- South America
- Central America
- North America

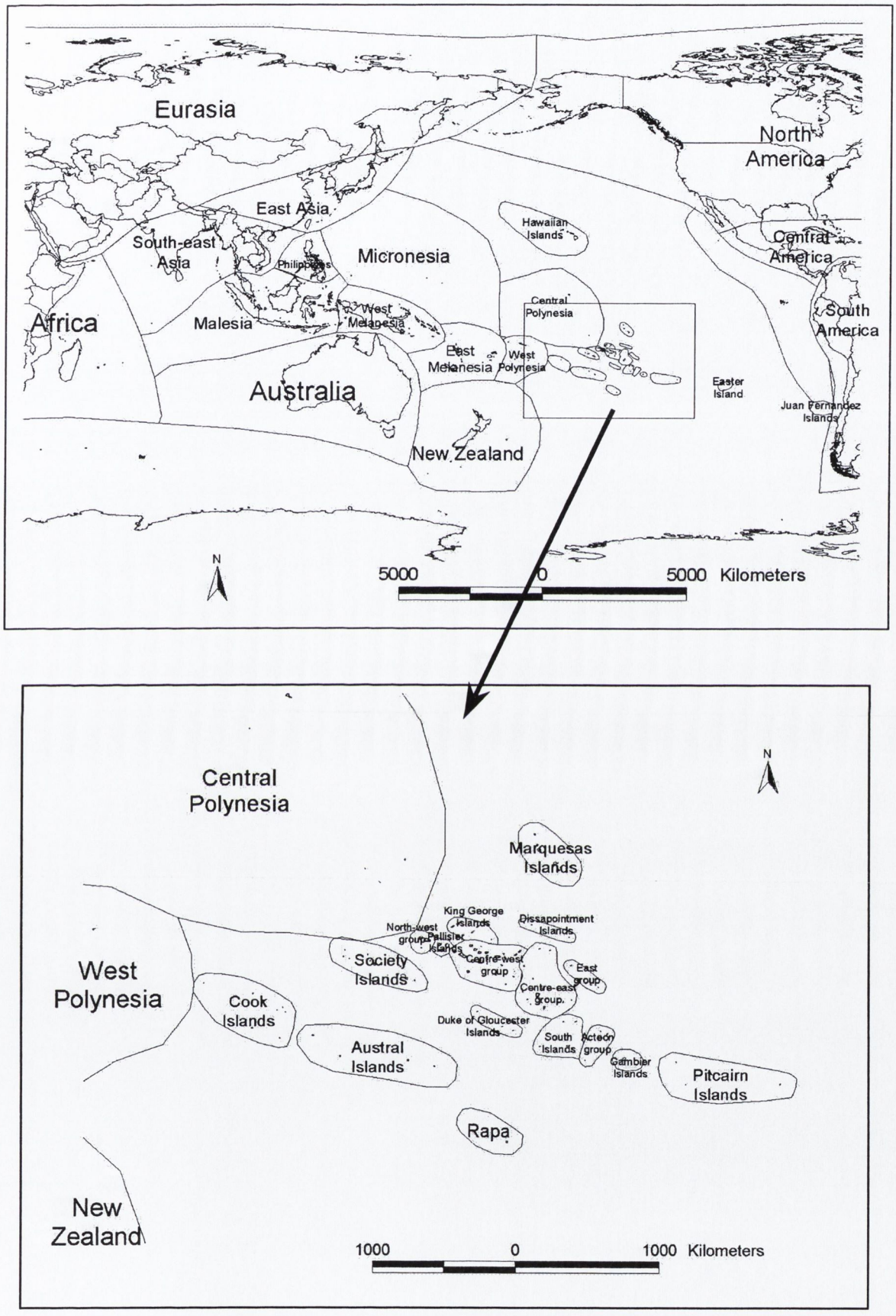


Figure 4.1 - World geographic units used in this study. The lower map shows a close up of the regions in Polynesia. All of the regions explained in the text (see section 5.2.4).

4.2.5 Environmental parameters

Environmental data for each island group in the Polynesian region were also collated. These included:

- Latitude and Longitude - the mean value for the island group.
- Land area - total land area for the island group; measured in metres squared (m^2).
- Altitude - highest altitude recorded in the island group; measured in metres.
- Maximum age - measured in millions of years, the age of the oldest in the island group. (NB An exception is the Hawaiian islands where between 34 and 30 million years ago no islands were above sea level rendering all of the terrestrial biota extinct (Clague 1996). In this case 34 million years is used as the maximum age, as that is the maximum time that the current flora has had to colonise and speciate.)
- Distance from nearest continent - mean distance in kilometres from the island group to either Australia or South America, depending on which is closer.
- Distance to Pitcairn Group - the nearest distance from an island in the Pitcairn group, to an island in another defined group.
- Island types - whether the island group was comprised of atolls (value 1), atoll and makatea (2), high volcanic islands (3) or all island types (4).
- Population - most recent available figure for the human population in the island group.
- Isolation Index - a measurement of the isolation of the island group from potential sources of colonisation (Earthwatch 1998).

$$Isolation = \sqrt{A} + \sqrt{B} + \sqrt{C}$$

where 'A' is the distance to the nearest same size or larger island, 'B' is the distance to the nearest island group, and 'C' is the distance to the nearest continent. The values were calculated for each island in the group and the mean value taken.

- Ecosystem Index - the number of biomes, based on either existing classifications or on the islands description and structure; less than 5 biomes is typical of impoverished low coral islands, 5 to 10 biomes indicates some distinct vegetation types, 10 to 25 biomes types would be found on high islands with some habitat diversity and differentiation of biomes with altitude, 25 to 40 biomes types shows considerable diversity of habitats, and more than 40 biomes approaches continental areas in richness.

- Invasive Index - based on the number of invasive species and on their aggressiveness in island situations. Where:

  0 = few or no introductions

  1 = some introductions (ie rats, common weeds)

  2 = common domestic introductions (dogs, cats, pigs)

  3 = some problems with invasive species

  4 = major problems with invasive species

  5 = devastated by invasive species

- Reliability Index - whether the data was useful and accurate, based on well documented information, or simply suspected on the basis of inadequate data. Classed as:

  0 = no reliable data

  1 = poor data (both partially complete and out of data)

  2 = data only partial or out of date

  3 = good recent data (within the last 10 years)

- Total species - the total number of recorded plant species in the island group.
- % Endemism - the percentage of endemic plant species in terms of the total flora of the island group.

4.2.6 Data sources

Data was sourced where possible from recently completed floras, but in other cases from taxonomic literature, web-sites and older floras. In addition information was taken from various general books relating to the Pacific islands. Field observations made on the Islands of Rimatara, Rurutu, Tubuai and Raivavae in the Austral Islands, Mangareva in the Gambier Islands, and Tahiti, Moorea, Huahine and Raiatea in the Society Islands, during 1997 and 2000 were also incorporated. A record was kept of all of the data sources, listed below:

Australian Biological Resources Study 1993

Australian Biological Resources Study 1994

Bridson 1985

Brooke *et al.* 1996

Brown & Brown 1931

Brown 1931

Brown 1935

Brownlie 1961

Cheesman 1903

Christensen & Skottsberg 1920a

Christensen & Skottsberg 1920b

Clague 1996

Copeland 1932

Copeland 1938

Copeland 1947

Doty 1954

Florence 1997b

Florence *et al.* 1995

Fosberg & Renvoize 1980

Fosberg & Sachet 1967

Fosberg & Sachet 1981

Fosberg 1973

Fosberg *et al.* 1983

Gothesson 1997

Brownlie 1965
Brownsey 1977
Heywood 1978
Holttum 1964
Holttum 1973
Holttum 1976
Holttum 1978
Holttum 1985
Huguenin 1974
Hunt *et al.* 2000
Lam 1938
McCormack 2000
Merrill 1947
Mueller-Dombois & Fosberg 1998
Oliver 1935
Florence 1996
Florence 1997a
Rougerie 1995
Royal Botanic Gardens, Kew 1906-1996
Royal Botanic Gardens, Kew 1993
Sherff 1926
Skottsberg 1920-1956
Skottsberg 1922a
Skottsberg 1922b
Skottsberg 1951
St. John & Philipson 1962
St. John 1987
Stoddart & Sachet 1969
Stoddart 1975a
UNEP-Earthwatch 1998
Hallé 1980
Heads 1996
van Balgooy 1971
van Balgooy 1975
van Balgooy 1984
van Balgooy 1993
van Steenis & van Balgooy 1966
van Steenis 1963
Waldren *et al.* 1995b
Waldren *et al.* 1999b
Wheeler & Carillet 1997
Wilder 1934
Yunker 1937
Zizka 1991

4.2.7 Data analyses

Exploratory analysis of the data set was carried out using cluster analyses with the Sørensen coefficient as a distance measure, and group averaging as the clustering procedure (an agglomerative clustering method, sometimes refered to as UPGMA). The Sørensen coefficient (also known as the Bray-Curtis coefficient) was used as it is thought to perform better than other distance measures such as Jaccard distance or Pearson-Product moment correlations (Fasham 1977; McCune & Mefford 1997), as it gives weight to the species that are common to the samples (in this case geographic units) rather than to those that only occur in either sample (Kent & Coker 1992). The Sørensen coefficient can be used to produce a distance matrix for multivariate analysis, such as NMDS. It is calculated by:

$$S = 1 - \left({}^{2W}/_{A+B} \right)$$

where W is the sum of shared abundances, and A and B are the sums of abundances in individual sample units.

NMDS is an ordination technique which uses an iterative search for a ranking and placement of n entities on k dimensions (axes) that minimizes the stress of the k-dimensional configuration. The calculations are based on an n x n distance matrix calculated from the n x p-dimensional main matrix, where n is the number of rows and p is the number of columns in the main matrix (Legendre & Legendre 1998). "Stress" is a measure of departure from monotonicity in the relationship between the dissimilarity (distance) in the original p-dimensional space and distance in the reduced k-dimensional ordination space. This technique differs from the more widely used Principal Co-ordinates Analysis (PCoA) in that it computes non-Euclidean distances, and thus gives

less weight to outliers (ie it computes proportional distances rather than absolute distances of abundances of species between sites) (McCune & Mefford 1997). NMDS can also summarise distances in fewer dimensions (Legendre & Legendre 1998). In some cases rotation of the NMDS axes will maximize the loadings of individual variables on the dimensions of the reduced ordination space, and this is done in PC-Ord by means of a varimax rotation, an orthogonal rotation, in that the perpendicularity of the coordinate system is preserved McCune & Mefford (1997).

Exploratory analysis was used to determine which data set gave the most readily interpretable results. This was then followed by further multivariate analyses of the data. CCA and DCA gave low eigenvalues, and did not easily explain the variation found. NMDS of 5 unrotated dimensions using the Sørensen coefficient was ultimately used as it gave the lowest stress values. This method uses a similar technique to that of 'parsimony analysis of endemicity' as it classifies areas according to their shared taxa.

As the environmental data were not normally distributed, Spearman rank correlations were carried out to see if any of the environmental parameters were correlated. None were, and so were all used in the resulting analysis. In order to determine what environmental variables could explain the variation found in the NMDS dimensions, the final NMDS output for the regions was correlated with the environmental data set, using Spearman rank correlations.

More detailed explanations of DCA, CCA and correlations can be found in section 3.2.5. PC-ORD ver. 3.2 and MS Excel 2000 were used for the data analysis. Maps were compiled using ArcView GIS ver. 3.1.

4.3 Results

4.3.1 Dispersal mechanisms and their success

An assessment of the dispersal mechanisms employed by the flora of the Pitcairn group of islands found that of the four dispersal mechanism assigned to the species, anemochory was the most frequent, but only slightly more so than active zoochory (table 4.1). Anemochory was however rarely found in the angiosperms in this dataset. Zoochory was by far the most successful mechanism for dispersal, occurring 57 times in the data set, with active rather than passive methods prevailing. Mechanisms involving a single propagule were by far the most frequent, being found 83 times in the data set. Both hydrochory and active zoochory are the mechanisms more likely to result in more than one coloniser being dispersed in a single dispersal event, but in many cases of passive zoochory more than one propagule will attach to the dispersal agent. In theory anemochory of a single propagule seems unlikely to result in successful dispersal events, however in practice virtually all pteridophyte species can produce sporophytes by apogamy from a single unfertilised gametophyte, and in some cases also produce further gametophytes by apospory from leaf gemmae. Thus even if a single spore reaches an island it may result in successful colonisation.

Table 4.1 - Number of times each of the four dispersal mechanism arises in the Pitcairn flora, and the number of propagules dispersed in each case. The number of propagules being the number of potential individual plants that could develop from each dispersed unit.

	Propagule number					
Mechanism*	**1**	**2**	**3-6**	**7-10**	**10+**	**Total**
Active zoochory	14	7	4	6	1	32
Passive zoochory	21	1	3	0	0	25
Hydrochory	14	8	3	1	1	27
Anemochory	34**	0	0	0	0	34
Total	83	16	10	7	2	

* - 11 species employ more than one mechanism
** - 31 pteridophytes and 3 angiosperms (Taeniophyllum fasciola, Metrosideros collina & Sececio stokesii)

Species with a Pacific-wide distribution dominate the Pitcairn flora (21.1%; see table 4.2). Old World, Worldwide and Endemic species also form large components of the flora. There were no species recorded with an American distribution. There were also very few species (6) with an Australian distribution, but this may be due to some species that may have originated in Australia and spread both east and west, being misclassified and assigned to classes 1 or 2. The low number of Indo-Malesian species may also be due to misclassification. Pteridophytes tend to have more widespread distributions and the Pitcairn flora is typical, with 8 of the 31 pteridophyte species having Worldwide distributions.

Table 4.2 - The number of Pitcairn group species occurring in each distribution class. The percentage of the total native flora is in parentheses after the species number.

Class number	Region	Number of species
1	Worldwide/TransPacific	19 (16.7%)
2	Old World	23 (20.2%)
3	Indo-Malesian	8 (7.02%)
4	Australian	6 (5.26%)
5	Pacific	24 (21.1%)
6	Polynesian	15 (13.1%)
7	Endemic to Pitcairn Group	19 (16.7%)

Figure 4.2 shows the dispersal mechanism for species in each of the distribution classes, and some patterns can be derived from the graphs. Worldwide/TransPacific species are mostly water dispersed, with all the wind dispersed species being pteridophytes. Old World species are also most likely to be water dispersed, but with an increasing number of zoochorous species. Pacific species however, are very likely to be dispersed by an animal agent, in particular through bird ingestion. Polynesian and endemic species are the same. Only one endemic species was likely to be hydrochorous, *Abutilon pitcairnense*, and as this species is now probably extinct the exact dispersal method was unable to be determined but is based on closely related species.

Figure 4.3 shows the propagule number for the species in each of the distribution classes. Dispersal using a single propagule dominates all distribution classes, but increasing numbers of species in the Pacific, Polynesian and Endemic classes contain more than one propagule in their dispersed unit. This explains the increased number of Pacific species on Pitcairn, as a population is most likely to establish if more than one propagule arrives in a dispersal event, and dispersal events are more likely to be successful when the distance between the islands is reduced.

As complete species lists are available for all of the islands in the Pitcairn group, it is possible to analyse distribution and dispersal within the island group. Figure 4.4 shows the total species number, and percentage of the total flora in each of the 7 worldwide distribution classes. Pitcairn and Henderson show similar patterns, with most of the species having Pacific distributions, and slightly less in each of the Old World and Worldwide categories. The atolls of Oeno and Ducie however differ in that the dominant element in their flora is Old World and Worldwide.

In figure 4.5, which shows the dispersal mechanisms for the species found on each of the islands in the Pitcairn group, a different pattern again emerges. The dominant dispersal mechanism for the Pitcairn flora is anemochory, explained by the large number of pteridophyte species in the flora, as is typical for high islands. Zoochory is the most common method found in the Henderson flora, and hydrochory the most common for both Oeno and Ducie. This pattern is expected due the nature of Worldwide and Old

World species are dispersed by hydrochory (figure 4.2), and the fact that these atolls are dominated by species with such distributions. An assessment of the number of species, in each of the islands floras, that employ more than one dispersal mechanism shows that the smaller floras are more likely to contain species that can be dispersed in more than one way (table 4.3). This accounts for the success of these species in colonising even the remotest island (ie Ducie), where 66.6% of the flora is dispersed in more than one way (the two species *Lepturus repens* & *Argusia argentea*).

Table 4.3 - The number and percentage (in parentheses) of the total flora of each of the Pitcairn Islands that employ more than one dispersal mechanism.

	Total species	No. of sp. in the flora that have more than one dispersal mechanism	% of the total flora that have more than one dispersal mechanism
Pitcairn	81	4	4.94%
Henderson	64	9	14.1%
Oeno	17	4	23.5%
Ducie	3	2	66.6%

Figure 4.6 again shows that as Worldwide and Old World species are more likely to produce only one propagule per dispersal unit, that is also the most common propagule number found in the floras of Oeno and Ducie (see also figure 4.4). The higher number of single propagule species on Pitcairn in relation to Henderson is again due to the larger pteridophyte flora found on the high island.

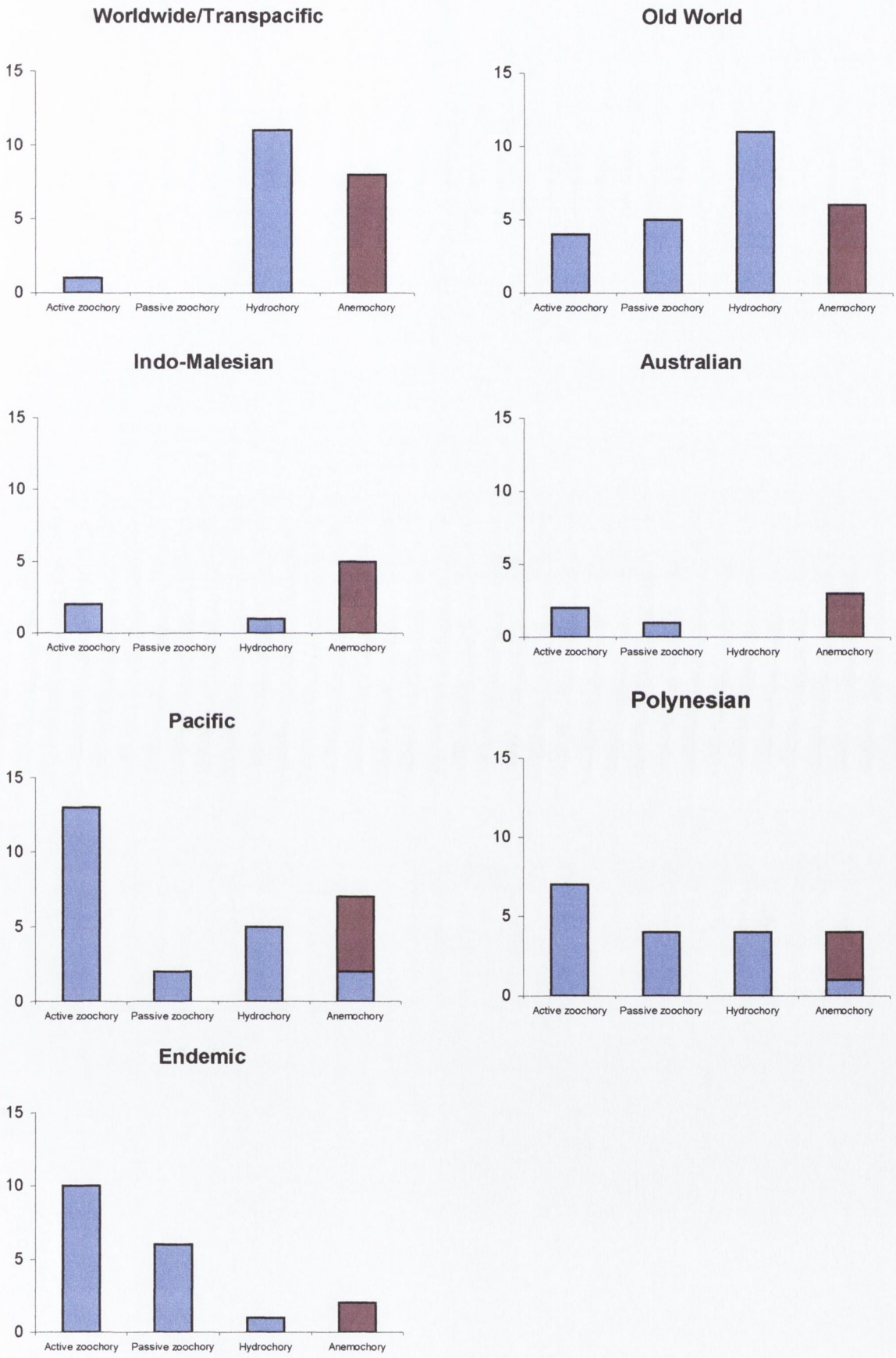


Figure 4.2 - Number of species (y -axis) in each of 4 dispersal classes. The data is presented for each of the distribution classes. Key: angiosperms = ; pteridophytes = .

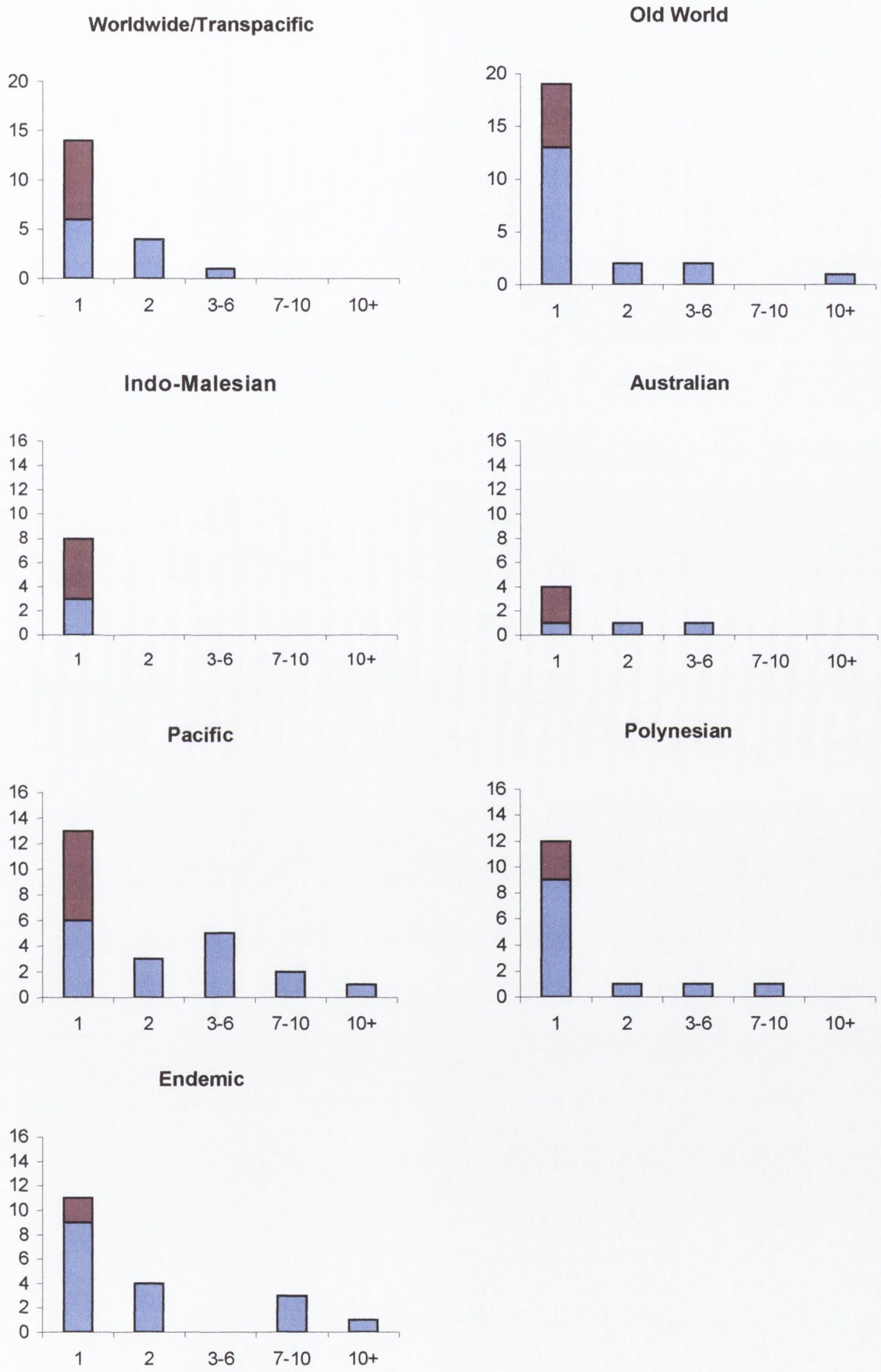


Figure 4.3 - Number of species (y -axis) in each of 5 classes of the propagule number contained in a single dispersed unit (or seed), defined for each of the distribution classes. Key: angiosperms = ; pteridophytes = .

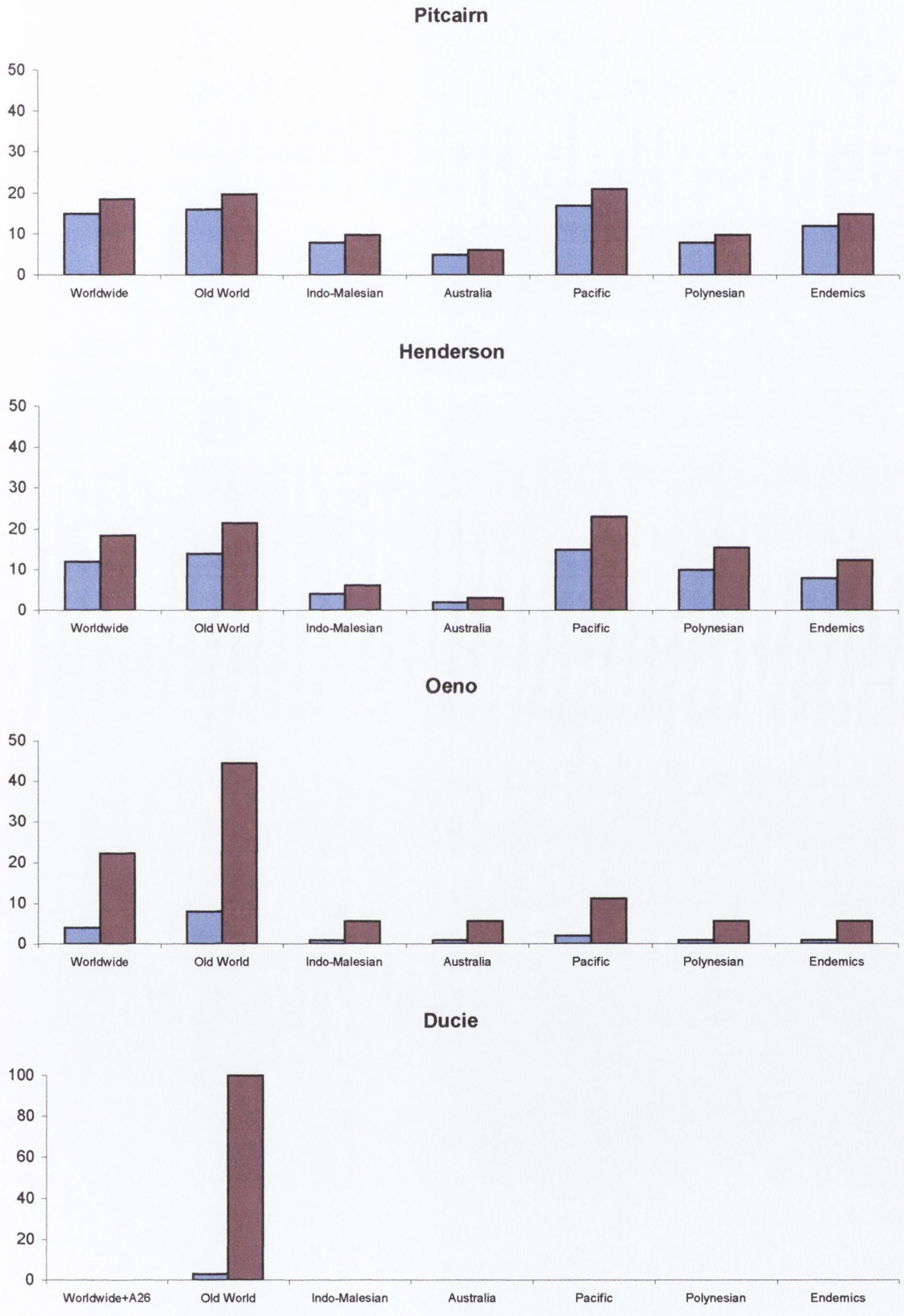


Figure 4.4 - Number of species (y -axis) in each of the 7 distribution classes, calculated for each of the 4 islands in the Pitcairn group. Column 1 ▮ shows the actual number of species in the class, while column 2 ▮ shows the % of the total flora of the island in the class.

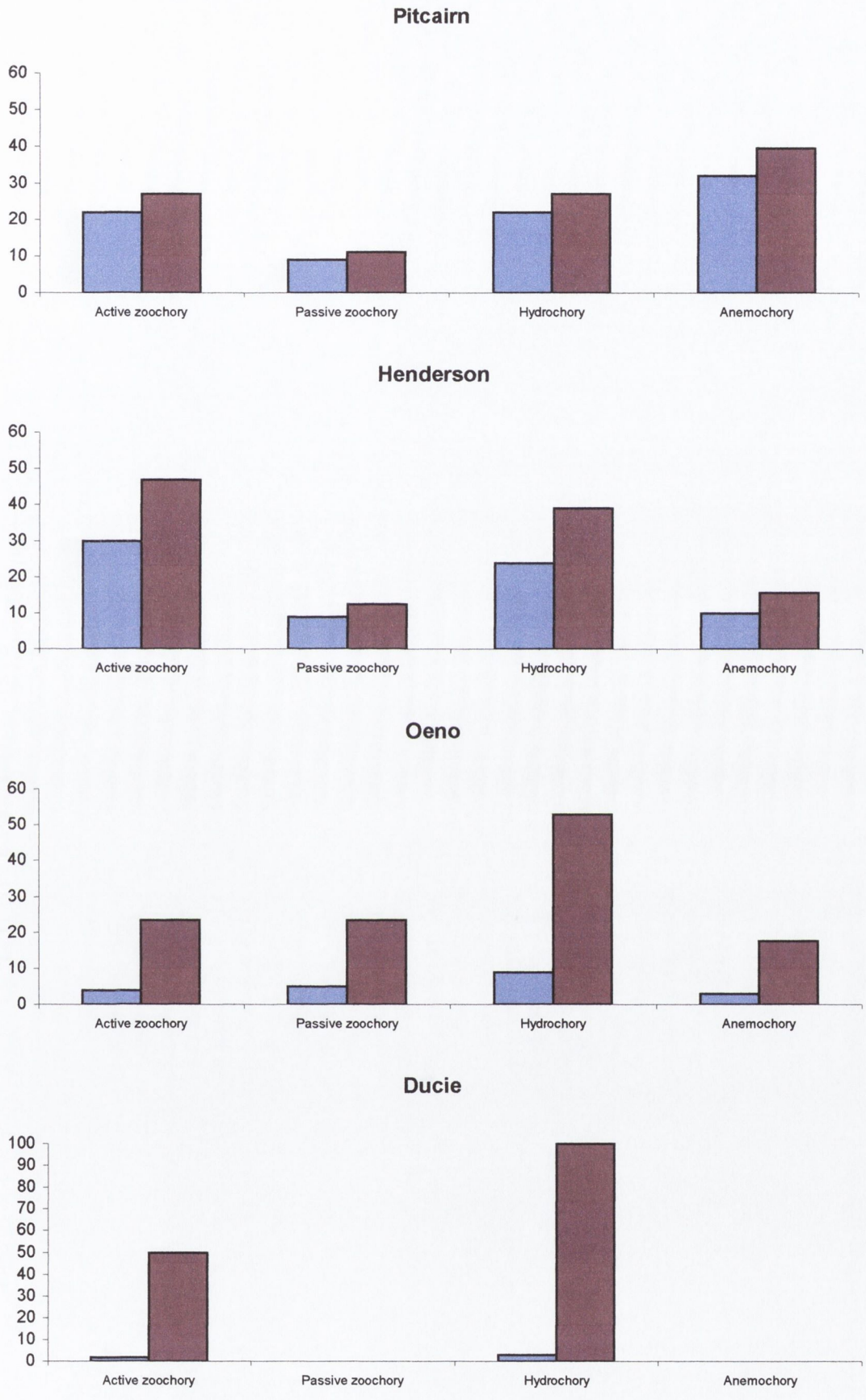


Figure 4.5 - Number of species (y -axis) in each of 4 dispersal classes, calculated for each of the 4 islands in the Pitcairn group. Column 1 ▮ shows the actual number of species in the class, while column 2 ▮ shows the % of the total flora of the island in the class.

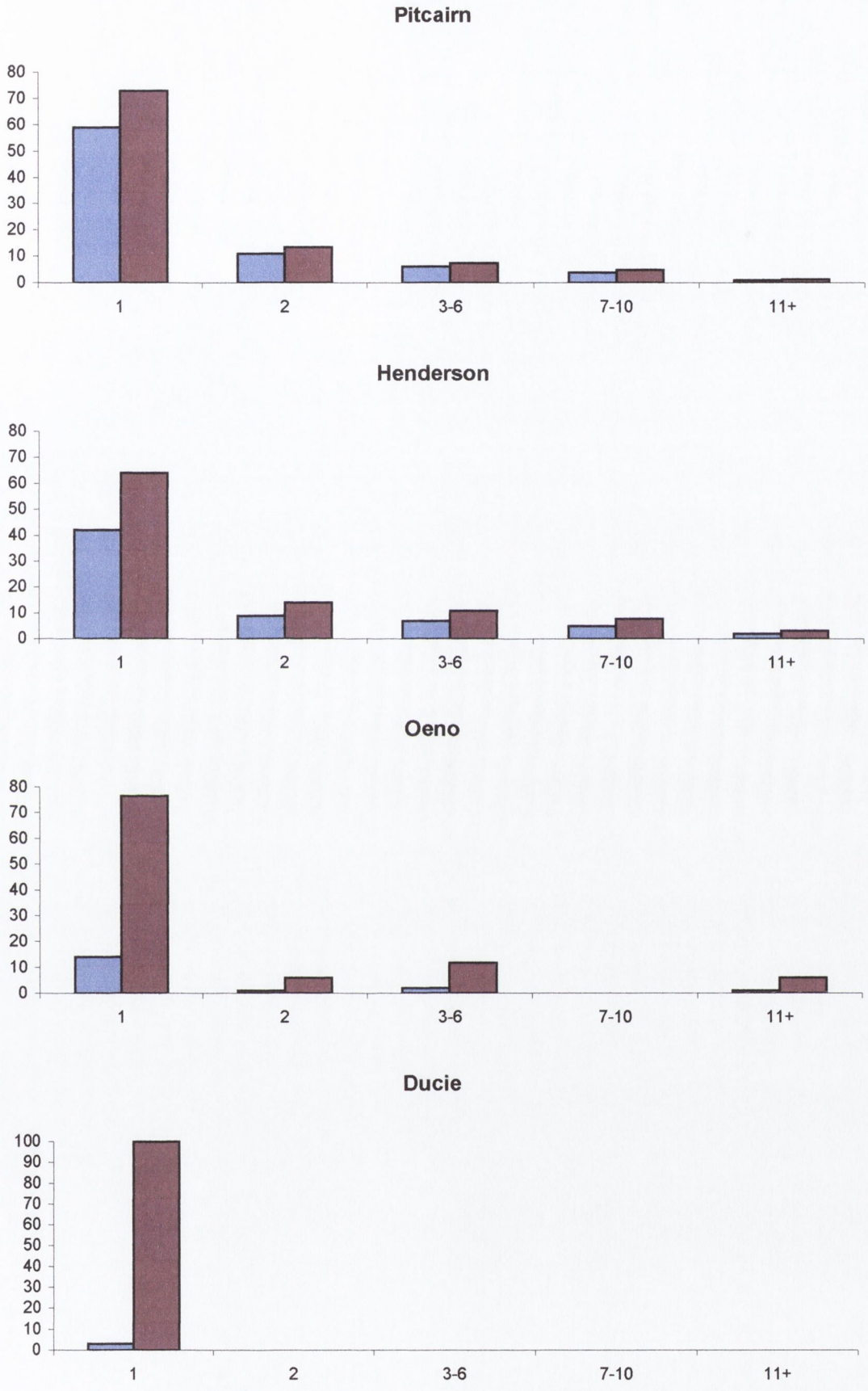


Figure 4.6 - Number of species (y -axis) in each of 5 classes of the propagule number contained in a single dispersed unit (or seed), calculated for each of the 4 islands in the Pitcairn group. Column 1 ▮ shows the actual number of species in the class, while column 2 ▮ shows the % of the total flora in the class.

4.3.2 Mapping analysis

Distribution maps (figure 4.7 & 4.8) showing the number of taxa from the Pitcairn group flora that occur in the other geographic units defined in section 4.2.4, showed slightly different results depending on whether genus or species level is being used. At the genus level there was little definition between the regions (figure 4.7). However a strong southern hemisphere influence was obvious, with the least genera in common between the Pitcairn group and North America and Eurasia to the north. There was also an influence of Transpacific genera, with a similar number of common genera between the Pitcairn group and New Zealand to the west and South America to the east. The strongest similarities were with East Melanesia, West Polynesia, the Cook Islands, Society Islands and Austral Islands. All of these island groups contained all of the island types and habitats found in the Pitcairn group and lie at comparable latitudes.

Distributions mapped at the species level showed more definition between groups (figure 4.8). The Pitcairn group had the least similarities with Eurasia and America, and Pacific islands to the east of Pitcairn (ie Easter, Juan Fernandez and East Pacific Islands). The highest similarities were with the Austral, Society and Cook Islands, and to a lesser extent with West Polynesia and East Melanesia. The species level therefore allowed further subdivisions to be made based on the same groupings found at the genus level. The lowest similarities within Polynesia were with the Tuamotu Island groupings which have fewer island types (mainly atolls) and thus fewer habitat types. An exception to this was the North-west group, which contains a makatea island similar to Henderson island in the Pitcairn group, and thus shows more species similarities.

Assessing the number of common species between the island groups in Polynesia and Pitcairn (table 4.4), showed the same patterns. The Pitcairn groups had the highest similarities with island groups that have all island types (atoll, makatea and high), such as the Australs and Societies, even though these islands are not necessarily the closest in terms of distance. The similarity was somewhat affected by distance however, as although the Cook Island group contains all of the island types, there are fewer species in common with the Pitcairn group. Pitcairn Island itself had the strongest connections with groups with high islands, and the lowest connection with the Tuamotu group of atolls (only 33 species). Henderson Island had the lowest connections with island groups containing no atolls or makatea, such as Rapa and the Marquesas (31 & 35 species respectively). Oeno, which has the most depauperate flora of only 17 species, similarly has a low similarity to Rapa and the Marquesas as they contain no atoll habitats.

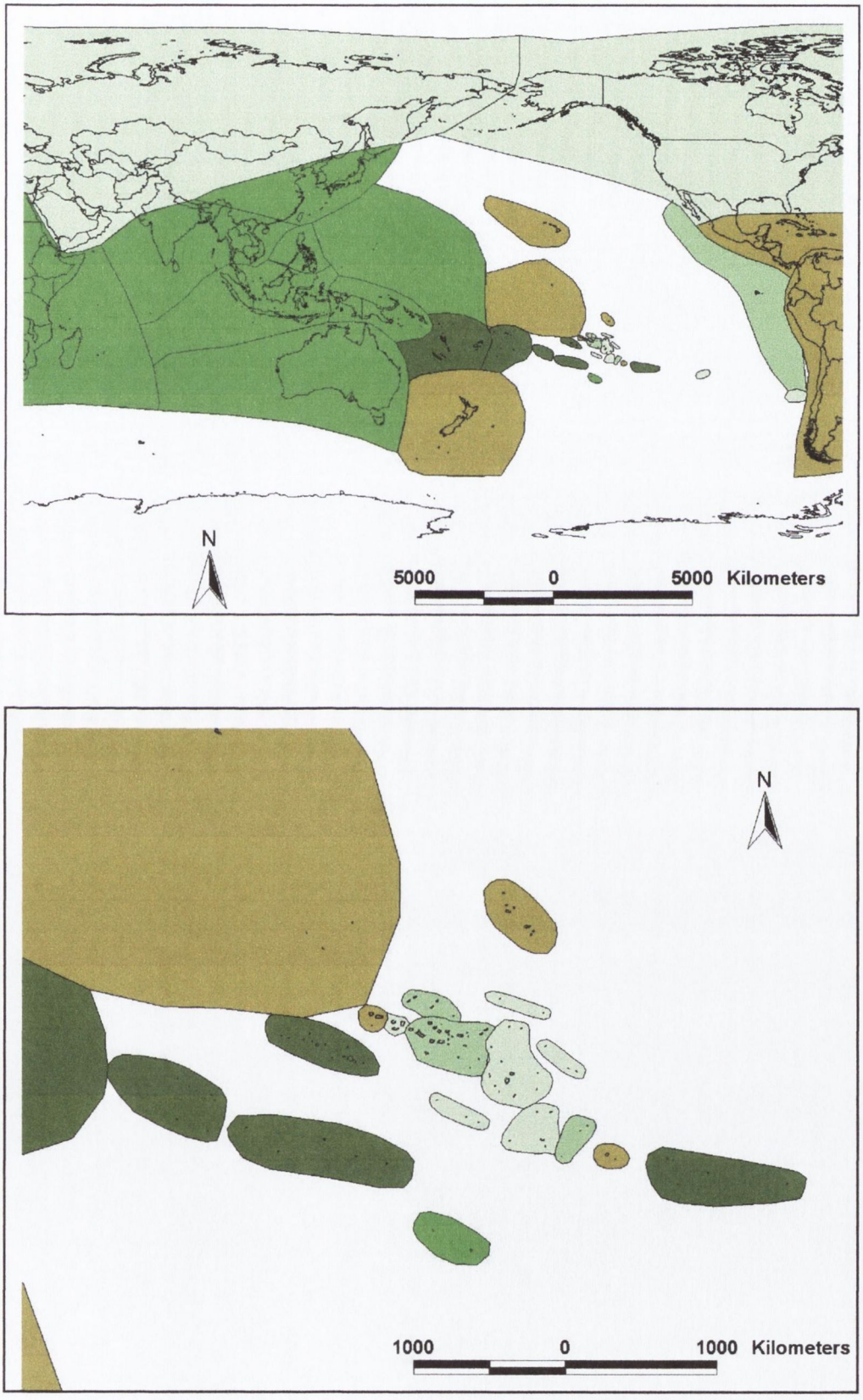
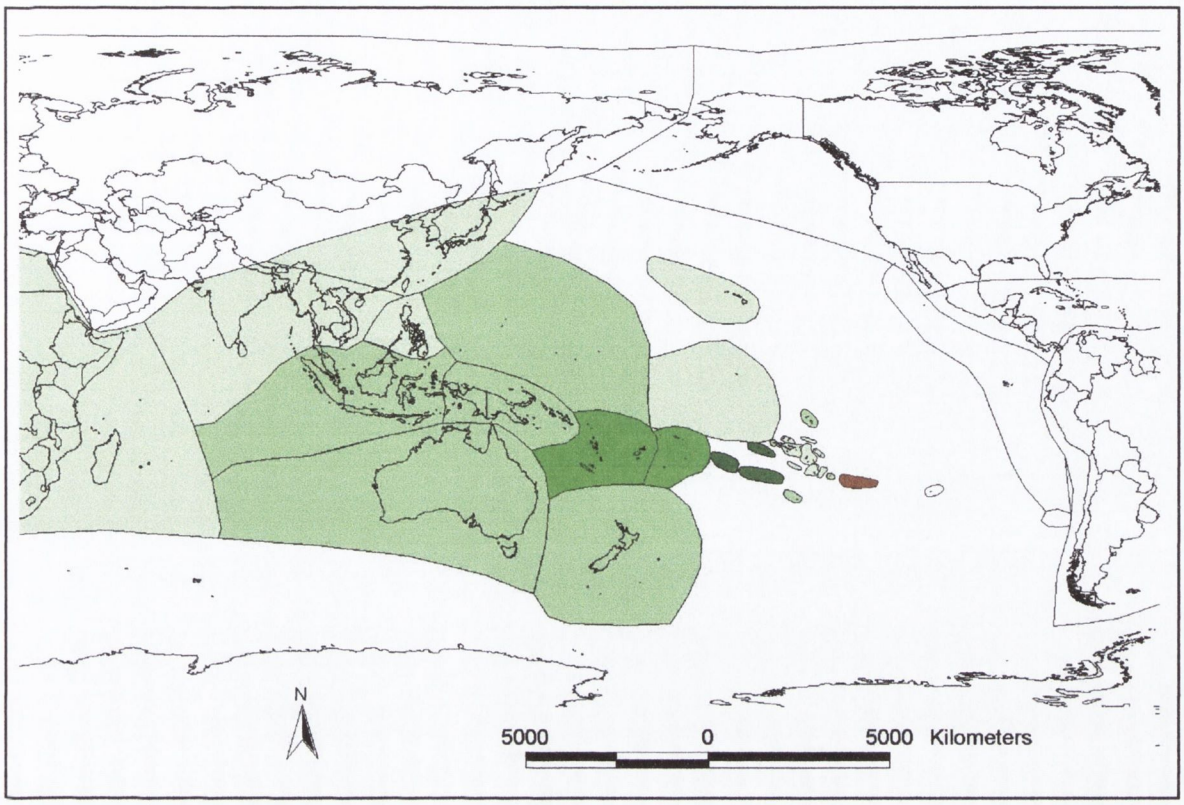


Figure 4.7 – Number of common genera between Pitcairn and other regions of the World (above) and Polynesia (below). Regions are defined in the text and figure 5.1. Colour categories are: 13-27 genera - ; 28-43 genera - ; 44-64 genera - ; 65-80 genera - ; 81-90 genera - .



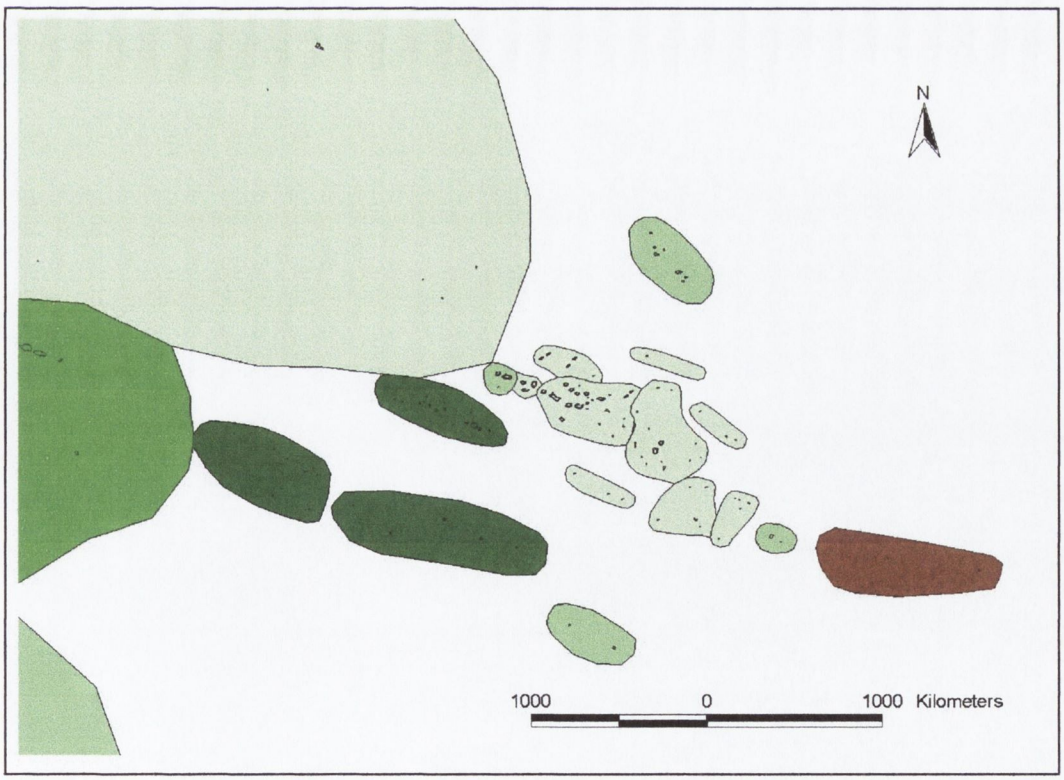


Figure 4.8 – Number of common species between Pitcairn and other regions of the World (above) and Polynesia (below). Regions are defined in the text and figure 5.1. Colour categories are: 0-20 species - ; 21-40 species - ; 41-60 species - ; 61-75 genera - ; 75-90 genera - ; 91-113 genera - .

Table 4.4 - Common species between the Pitcairn Islands of Pitcairn, Henderson and Oeno, considered both separately and together as a group, and the Polynesian island groups used in the analysis, non-Pitcairn data from Florence (1987), Florence *et al.* (1995) and Florence (1997). Island groups in order of increasing distance from Pitcairn.

	Pitcairn	Henderson	Oeno	Pitcairn Grp.	Gambiers	Tuamotus	Rapa	Marquesas	Australs	Societies	Cooks
Pitcairn	****										
Henderson	33	****									
Oeno	10	17	****								
Gambiers	46	36	16	57	****						
Tuamotus	33	42	16	50	43	****					
Rapa	47	31	8	58	30	25	****				
Marquesas	42	35	8	56	46	32	27	****			
Australs	60	52	16	83	64	64	-	82	****		
Societies	59	50	16	82	-	77	92	140	146	****	
Cooks	58	44	16	76	-	-	-	-	-	-	****
Total species	81	65	18	114	71	95	188	278	220	575	293

Figure 4.9 shows the relationships between the the floras of the Society, Austral and Cook Island groups based on the Pitcairnese element in their floras. Only 7 species were not found on the Austral Islands, but 6 species are only found in the Austral group. This suggests that the flora of the Pitcairn group is most closely related to the flora of the Austral Islands. Figure 4.10 shows the comparable relationship for the Austral, Gambier Islands and Rapa. While Rapa and the Gambier are closer to Pitcairn, they are less closely associated to Pitcairn floristically than the Austral Islands.

Within the Pitcairn group itself, Pitcairn and Oeno showed the lowest similarity, having only 10 shared species, while the highest similarity was between Henderson and Pitcairn with 33 common species. However 17 species were common to Henderson and Oeno, which is over 90% of the Oeno flora. Ducie was not included here as only 3 widespread species have been ever recorded from the island, and in the most recent survey only 2 species (*Pemphis acidula* & *Argusia argentea*), both of which are recorded from Pitcairn and Henderson. Figure 4.11 shows the relationships between the floras of the three islands, Pitcairn, Henderson and Oeno. It is clear from this diagram that the three islands support very different floras, even though the islands are geographically close together. No species were common between Oeno and Pitcairn that were not also found on Henderson, and only 10 species are found on all three islands. This suggests that the flora of Oeno is made up of widespread species, and thus supports figure 4.4. Twenty-three species are common between Henderson and Pitcairn, but not found on Oeno, which suggests that these are inland species, not supported on the strand habitats found on Oeno. Forty-eight species were found only on Pitcairn, which suggests that these are volcanic high island

species found on the high slopes and volcanic soils of Pitcairn. These species would not be tolerant of the limestone and associated dry habitats found on Henderson (eg pteridophytes which generally require a damper habitat). Similarly the 25 species found only on Henderson are probably species adapted to the dry limestone habitat and absent from the damper or more shaded high island habitats. In addition several strand species may be found on Henderson that are not found on Oeno, owing to the larger area available for colonisation on Henderson, and the presence of coastal cliff habitats.

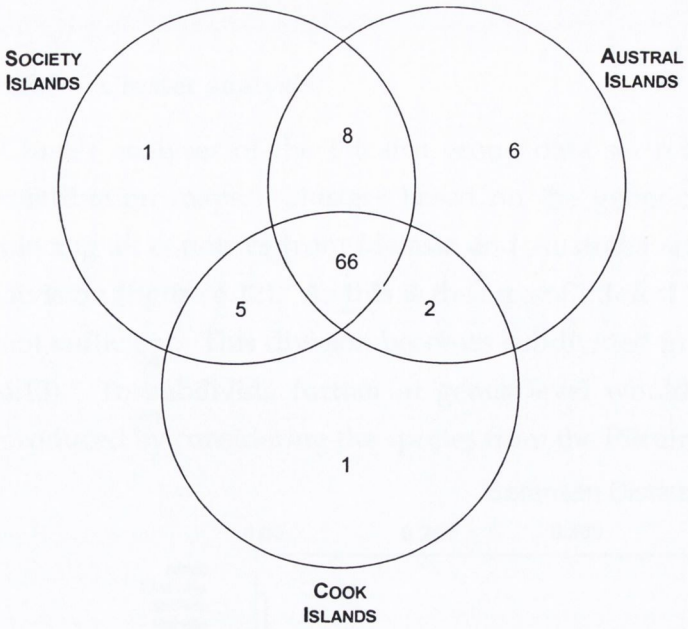


Figure 4.9 – Venn diagram to show the relationship between the Pitcairnese element in floras of the Society, Austral and Cook Islands. Each circle represents the flora of the island group, with the overlap representing the number of common species in the floras of the islands.

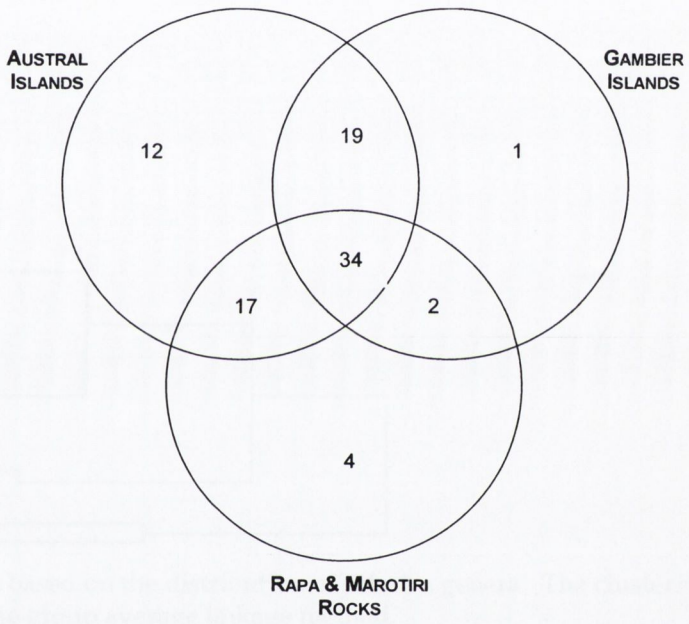


Figure 4.10 – Venn diagram to show the relationship between the Pitcairnese element in floras of the Austral and Gambier Islands and Rapa. Each circle represents the flora of the island group, with the overlap representing the number of common species in the floras of the islands.

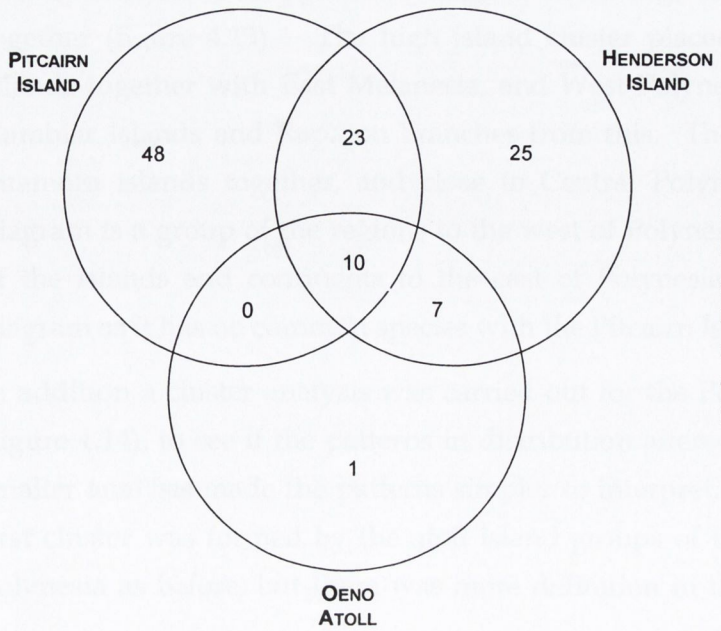


Figure 4.11 – Venn diagram to show the relationship between the floras of the islands in the Pitcairn group. Each circle represents the flora of the island, with the overlap representing the number of common species in the floras of the islands.

4.3.3 Cluster analysis

Cluster analyses of the Pitcairn group data set reinforce the patterns presented in the distribution maps. Clusters based on the generic data alone showed little definition placing all countries from Malesia and Australia across to the Pitcairn group in a single division (figure 4.12). As this is the area of interest in this study this level of definition is not sufficient. This division becomes subdivided in the cluster using species data (figure 4.13). To subdivide further at genus level would require a data set larger than that produced by considering the species from the Pitcairn group alone.

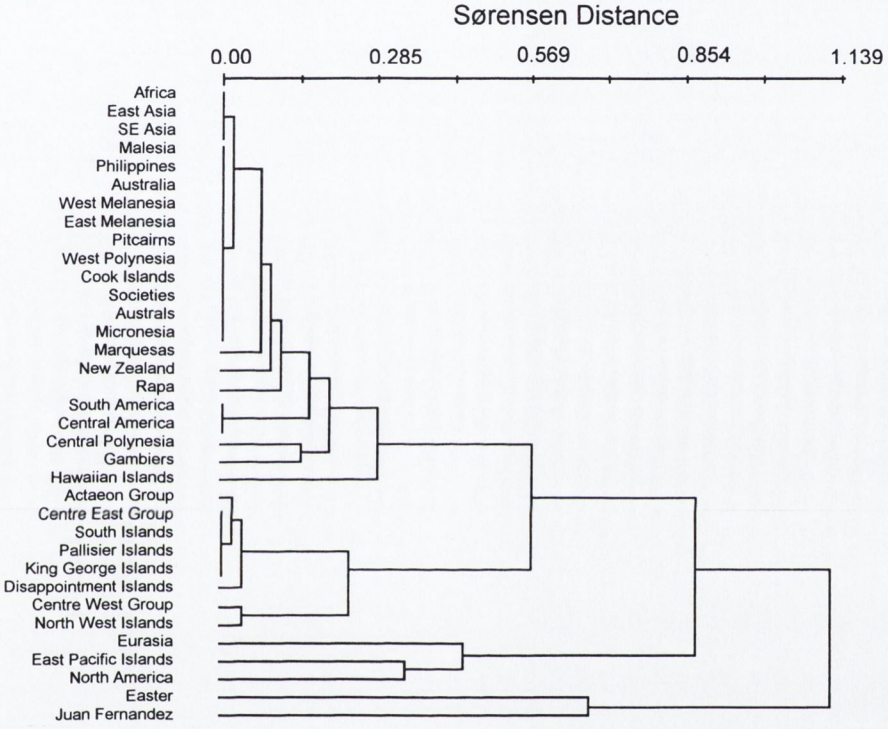


Figure 4.12 - Cluster diagram of regions based on the distribution of Pitcairn genera. The clustering procedure uses Sørensen distance and the group average linkage method.

Cluster analysis at the species level grouped the high islands, and the atolls of Polynesia together (figure 4.13). The high island cluster placed the Cook, Society and Austral Islands together with East Melanesia, and West Polynesia, the Pitcairn, Marquesas and Gambier Islands and Rapa on branches from this. The atoll cluster grouped all of the Tuamotu islands together, and close to Central Polynesia. At the top of the cluster diagram is a group of the regions to the west of Polynesia, and at the borttom is a group of the islands and continents to the east of Polynesia. Eurasia is not on this cluster diagram as it has no common species with the Pitcairn Island group.

In addition a cluster analysis was carried out for the Polynesian island groupings alone (figure 4.14), to see if the patterns in distribution altered with the smaller data set. This smaller analysis made the patterns simpler to interpret, with three distinct clusters. The first cluster was formed by the atoll island groups of the Tuamotu Islands and Central Polynesia as before, but there was more definition in the divisions. The second cluster

contained the Cook, Austral and Society islands grouped together, close to West Polynesia, with the Pitcairn, Marquesas, Gambier Islands and Rapa also separating individually, but all within the same cluster. The Hawaiian Islands separated out on their own.

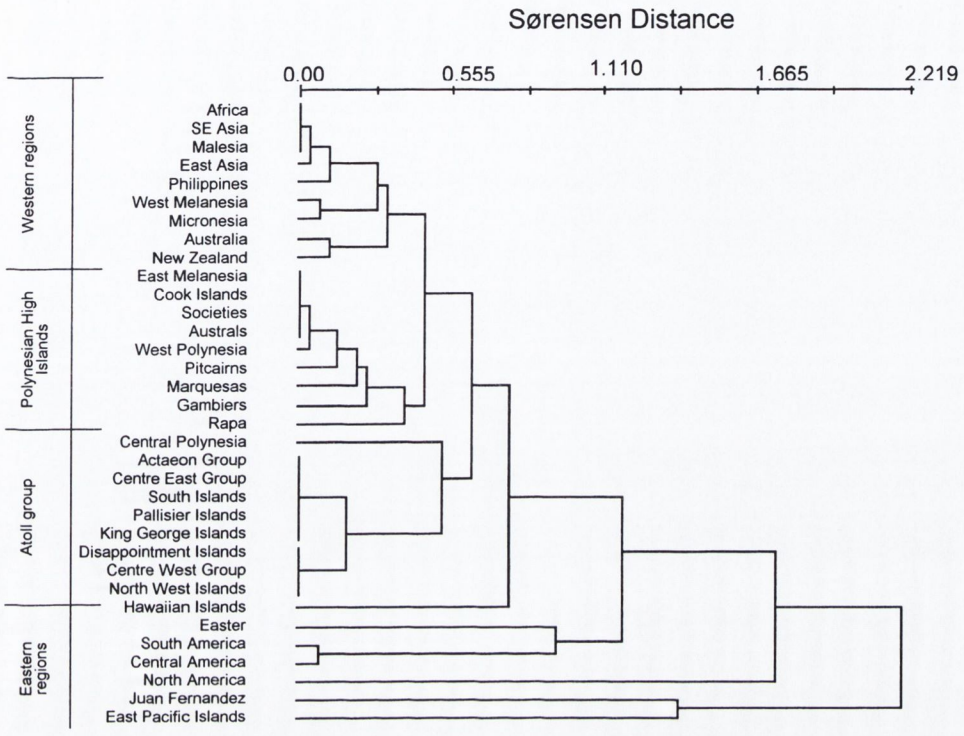


Figure 4.13 - Cluster diagram of regions based on the distribution of Pitcairn species. The clustering procedure uses Sørensen distance and the group average linkage method.

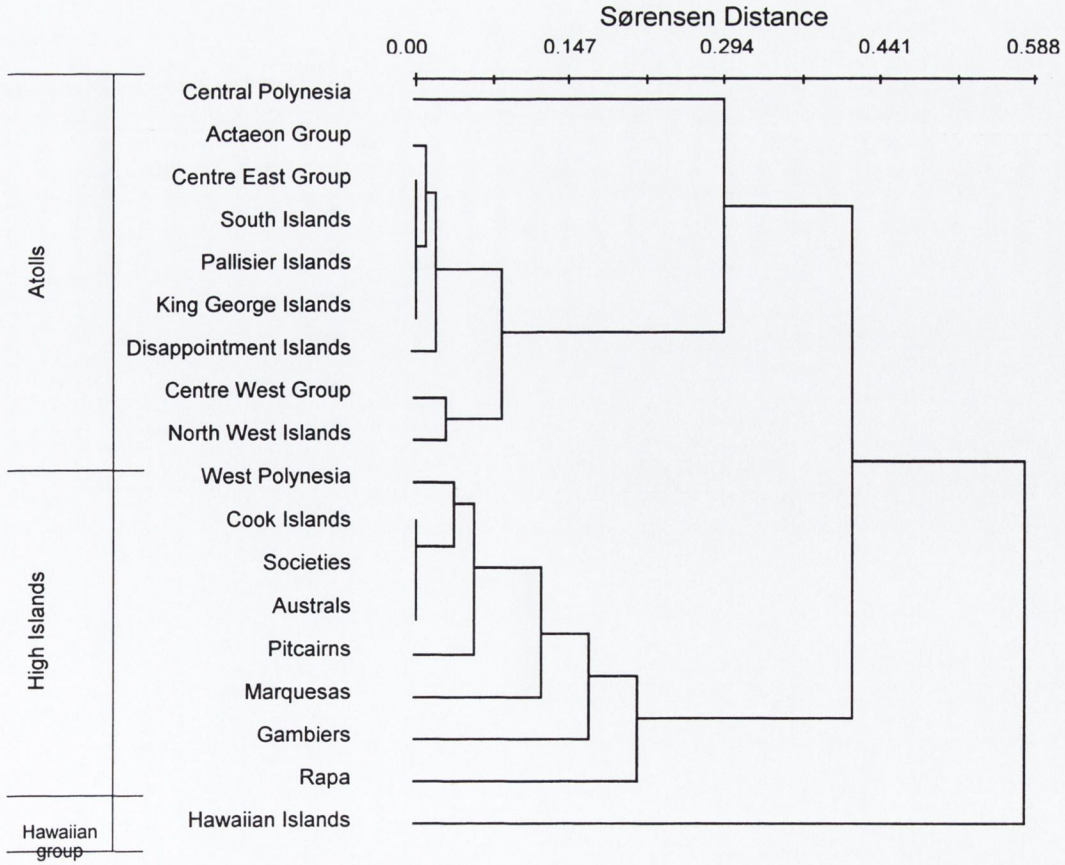


Figure 4.14 - Cluster diagram of Polynesian regions based on the distribution of Pitcairn species. The clustering procedure uses Sørensen distance and the group average linkage method.

A cluster analysis for the Pitcairn group species data set also showed some interesting results (figure 4.15). The species endemic to the Pitcairn group formed a cluster, as expected. These species are predominately dispersed by zoochory, either active (ingestion) or passive (adherence). An exception is *Samolus repens*, which is a transpacific species, but found nowhere else in the region of Polynesia, included in this data set. The next cluster contained all species with narrow distributions in Polynesia, and a range of dispersal types.

The third cluster contained largely water dispersed (hydrochorous) species that dominate the strand lines of all Polynesian islands and the low-lying wooded interiors of atolls. This was followed by a cluster of species that are found in the interior of high islands, with the upper taxa being found both on volcanic and makatea islands, while the lower taxa (largely anemochorous species) are confined to volcanic islands. There are notable exceptions to these general patterns within the clusters (eg *Psilotum nudum* and *Diplazium harpeodes* in the coastal cluster). This suggests that the cluster diagram is showing ecological groupings, suggesting that the species occurring on an island strongly relates to the habitats available, and to a lesser extent to the dispersal ability of the species. It also suggests that species adapt to the habitat appropriate to their dispersal mechanism, with strand species being water dispersed, while inland and higher altitude species are wind and bird dispersed.

Cluster analyses considering only the pteridophyte species (not reported here) gave results similar to those produced by the genus level analysis. This is because pteridophytes tend to be more widespread, with easily dispersed spores and low levels of speciation.

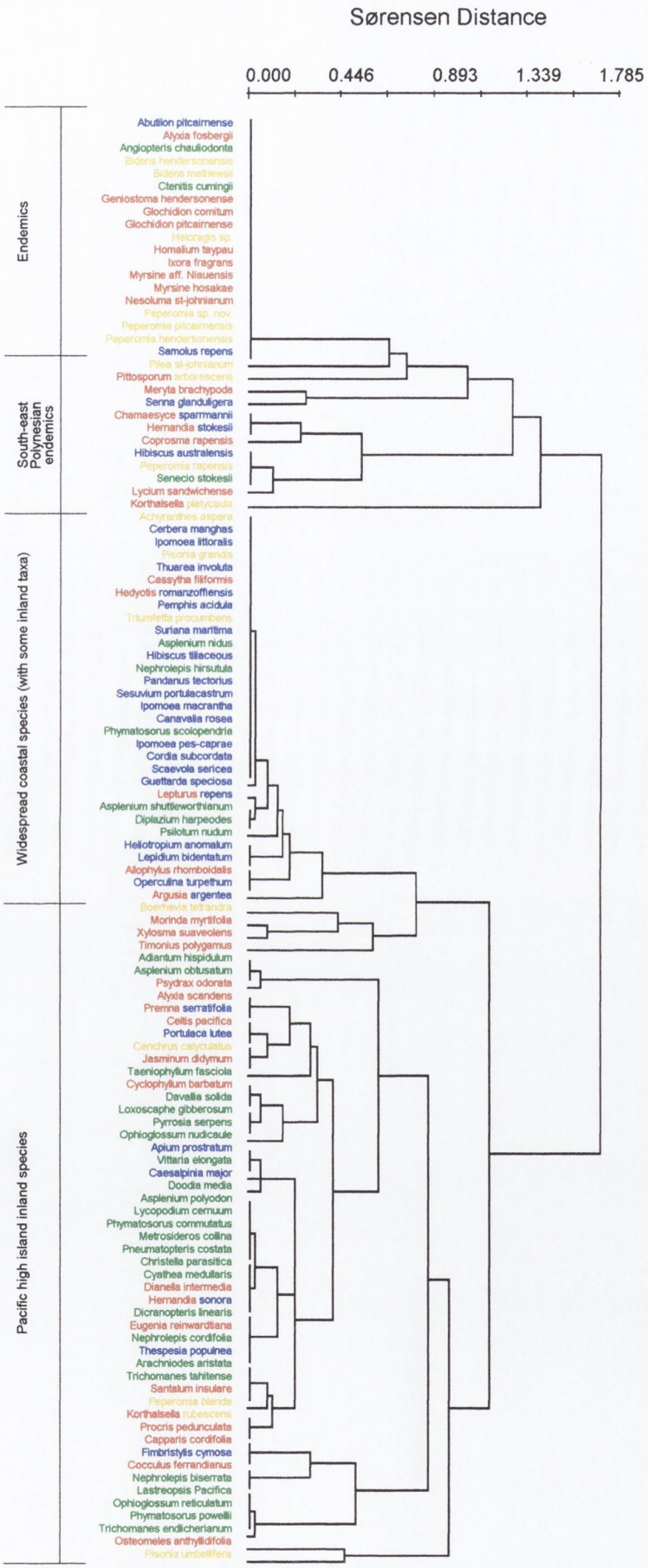


Figure 4.15 - Cluster diagram of Pitcairn species based on their distribution in Polynesia. Colours refer to dispersal mechanism with: Red = Active Zoochory; Yellow = Passive Zoochory; Blue = Hydrochory; Green = Anemochory. For species dispersed by more then one mechanism the branch label is coloured twice. The clustering procedure uses Sørensen distance and the group average linkage method.

4.3.4 Ordination

NMDS ordination using 5 unrotated dimensions gave the lowest stress values (table 4.5) for the Pitcairn species in the Polynesian region dataset (the same data set as used for figure 4.14), and these dimensions are plotted in figure 4.16 & 4.17. The Spearman rank correlations of the 5 NMDS dimensions with the environmental variables are shown in table 4.6. None of the variables are correlated with each other (data not shown), nor are any significantly correlated with any of the 5 dimensions. The Polynesian data set was chosen as it was the dataset for which the most complete set of environmental variables could be compiled. Other regions were considered too large and heterogeneous to calculate most of the environmental variables used.

Table 4.5 - Stress and 'p' values for NMDS of 5 dimensions unrotated for the dataset of Pitcairn species in relation to the Polynesian regions.

	Stress	p
Dimension 1	**19.980**	**0.0100**
Dimension 2	**8.360**	**0.0100**
Dimension 3	**4.059**	**0.0100**
Dimension 4	**2.480**	**0.0100**
Dimension 5	**1.810**	**0.0100**

p = proportion of randomised Monte Carlo test runs with stress ≤ observed stress (ie p = (1 + no. permutations ≤ observed) / (1 + no. permutations)

The Pitcairn group had a score of almost zero on dimension 1. The Tuamotu islands all had negative axis scores as do the Gambier and Marquesas Islands. The Cook, Austral and Society Islands all ordinate close together and close to Rapa. The Hawaiian islands had the higest axis 2 score and were distant to all of the other groups. Dimension 2 also ordinates with low axis scores for the Tuamotu islands, and in the plot showing Dimension 1 and Dimension 2 together (figure 4.16) the Tuamotu groups form a distinct cluster. All of the high island groups had a positive score on dimension 2, with Rapa having the highest axis score. Dimension 3 has a very short axis and so does not separate the island groups very widely. The Hawaiian islands had the lowest axis 3 score, while Rapa again had the highest score. All of the island groups with positive axis scores for dimension 4 (figure 4.17) were high islands with the exception of the North-west Tuamotu group, which has however an uplifted atoll as well as low atolls. The rest of the Tumotu islands, the Marquesas and Hawaiian islands have negative dimension 4 scores. Dimension 5 again has all high island groups on the positive axis, but has ordinated the Pitcairn group among the Tuamotu groups on the negative side of the origin. Pitcain ordinates almost coincident with the North-west group, suggesting that the island type, in this case makatea is causing this clustering.

Several environmental variables showed significant Spearmans rank correlation values of with the NMDS dimension scores. As none of the variables had a significant influence on

the clustering, those with a higher score and showing some relationship were noted. Dimension 1 showed a positive correlation with Longitude, Distance from Pitcairn and Total Plants. This explained the position of the Hawaiian group (figure 4.16), distinct from the other island groups, as the Hawaiian group is the most westerly group (ie the highest latitude) the is the farthest from Pitcairn and has the highest total number of plants due to its large size (the Hawaiian group (16692.4 m^2) is over 10 times larger then the next largest group, the Societies (1614 m^2)). The position of Pitcairn virtually on the origin is due to the fact that distance from Pitcairn is zero for this point. The position of the Tuamotus related to the fact that they have the lowest total plant scores. Dimension 2 correlated with Altitude, Island type, Invasive index, Total Plants and % plant endemism, all increasing with increased axis scores. This again accounted for the positioning of the Tuamotu cluster, as these island groups score low for all of these factors. Dimension 3 correlated with no environmental variables. Dimension 4 is positvely correlated with only one, Island type. This explained the position of groups with more then one island type on the positive side of the axis, and explains why the Marquesas cluster in with the Tuamotu groups; the Marquesas is solely comprised of high islands. Dimension 5 correlateed with Altitude, Invasive Index, Total Plants and % Plant endemism, and shows a distribution similar to that of dimension 2, which is correlated to the same factors.

Table 4.6 - Spearmans rank correlation for environmental variables with NMDS dimensions 1-5

	Dimension 1	*Dimension 2*	*Dimension 3*	*Dimension 4*	*Dimension 5*
Latitude	*0.391 n.s*	*0.356 n.s*	*0.362 n.s*	*0.418 n.s*	*0.279 n.s*
Longitude	*0.706 **	*0.150 n.s*	*-0.244 n.s*	*-0.109 n.s*	*0.285 n.s*
Area (km2)	*0.418 n.s*	*0.153 n.s*	*-0.394 n.s*	*-0.006 n.s*	*0.171 n.s*
Altitude	*0.454 n.s*	*0.798 ***	*0.276 n.s*	*0.479 n.s*	*0.838 ***
Max. age (myr)	*0.248 n.s*	*-0.395 n.s*	*-0.490 n.s*	*-0.351 n.s*	*-0.342 n.s*
Distance to continent (km)	*-0.381 n.s*	*-0.209 n.s*	*0.088 n.s*	*-0.238 n.s*	*-0.185 n.s*
Distance from Pitcairn (km)	*0.562 **	*0.181 n.s*	*-0.258 n.s*	*-0.156 n.s*	*0.334 n.s*
Island type	*0.470 n.s*	*0.791 ***	*0.424 n.s*	*0.702 **	*0.731 ***
Population	*0.419 n.s*	*0.190 n.s*	*-0.252 n.s*	*0.040 n.s*	*0.369 n.s*
Isolation Index	*0.102 n.s*	*0.106 n.s*	*0.009 n.s*	*-0.390 n.s*	*0.053 n.s*
Ecosystem number	*0.195 n.s*	*0.332 n.s*	*-0.246 n.s*	*0.142 n.s*	*0.341 n.s*
Invasive Index	*0.387 n.s*	*0.758 ***	*0.393 n.s*	*0.328 n.s*	*0.799 ***
Reliability number	*0.412 n.s*	*0.342 n.s*	*0.014 n.s*	*0.291 n.s*	*0.163 n.s*
Total Plants	*0.602 **	*0.679 **	*0.063 n.s*	*0.204 n.s*	*0.512 n.s*
% Plant endemism	*0.397 n.s*	*0.839 ***	*0.327 n.s*	*0.421 n.s*	*0.776 ***

n.s - >0.05; * - $p < 0.05$; ** - $p < 0.01$; *** - $p < 0.001$

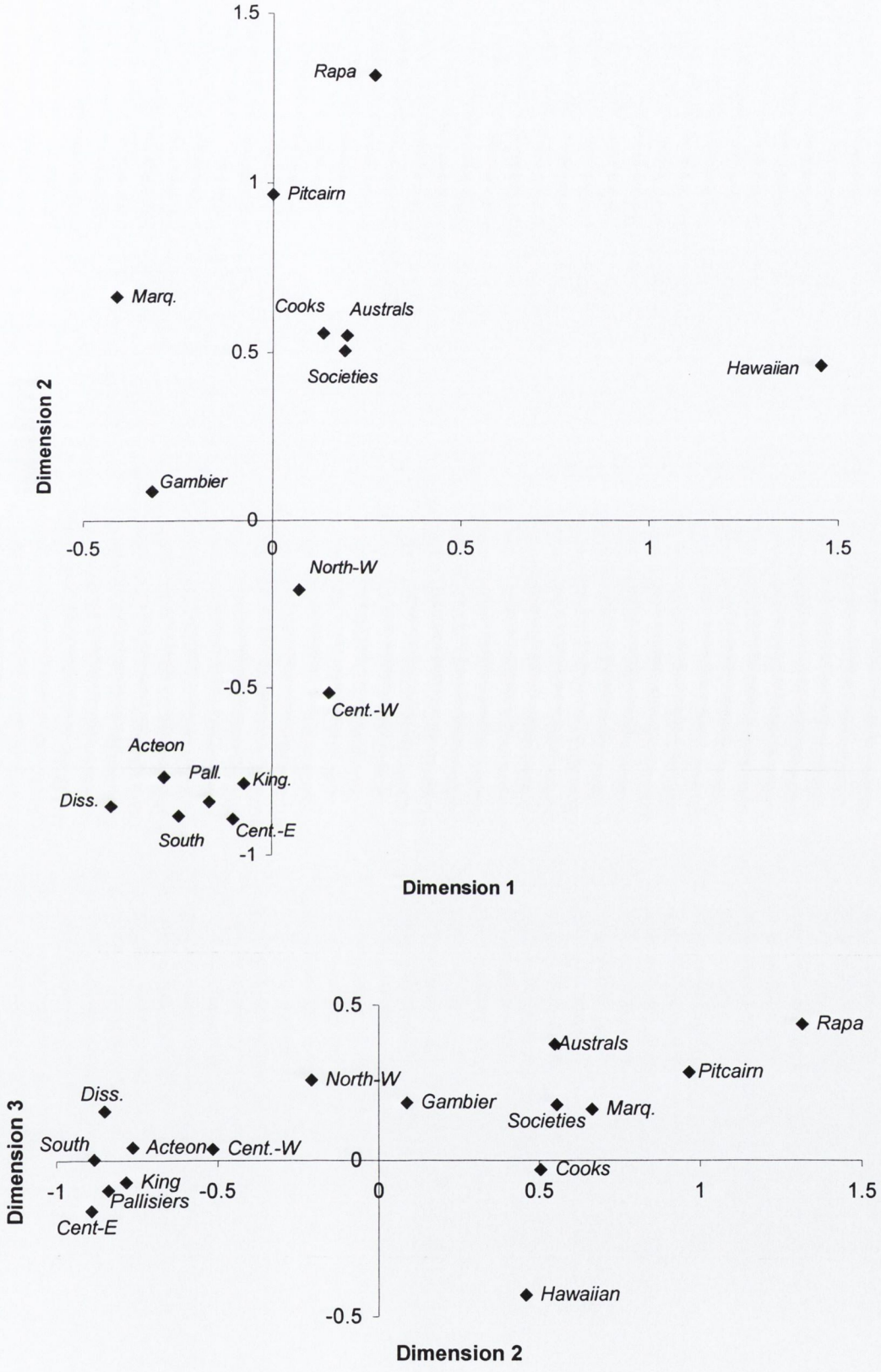


Figure 4.16 - NMDS ordinations, with Dimension 1 plotted aginst Dimension 2 (above), and Dimension 2 against Dimension 3 (below), for Polynesian islands. Key: Cent.-E = Centre east group; Cent.-W = Centre west group; Diss. = Disappointment islands; King = King George islands; Marq. = Marquesas islands; Pall. = Pallisier islands

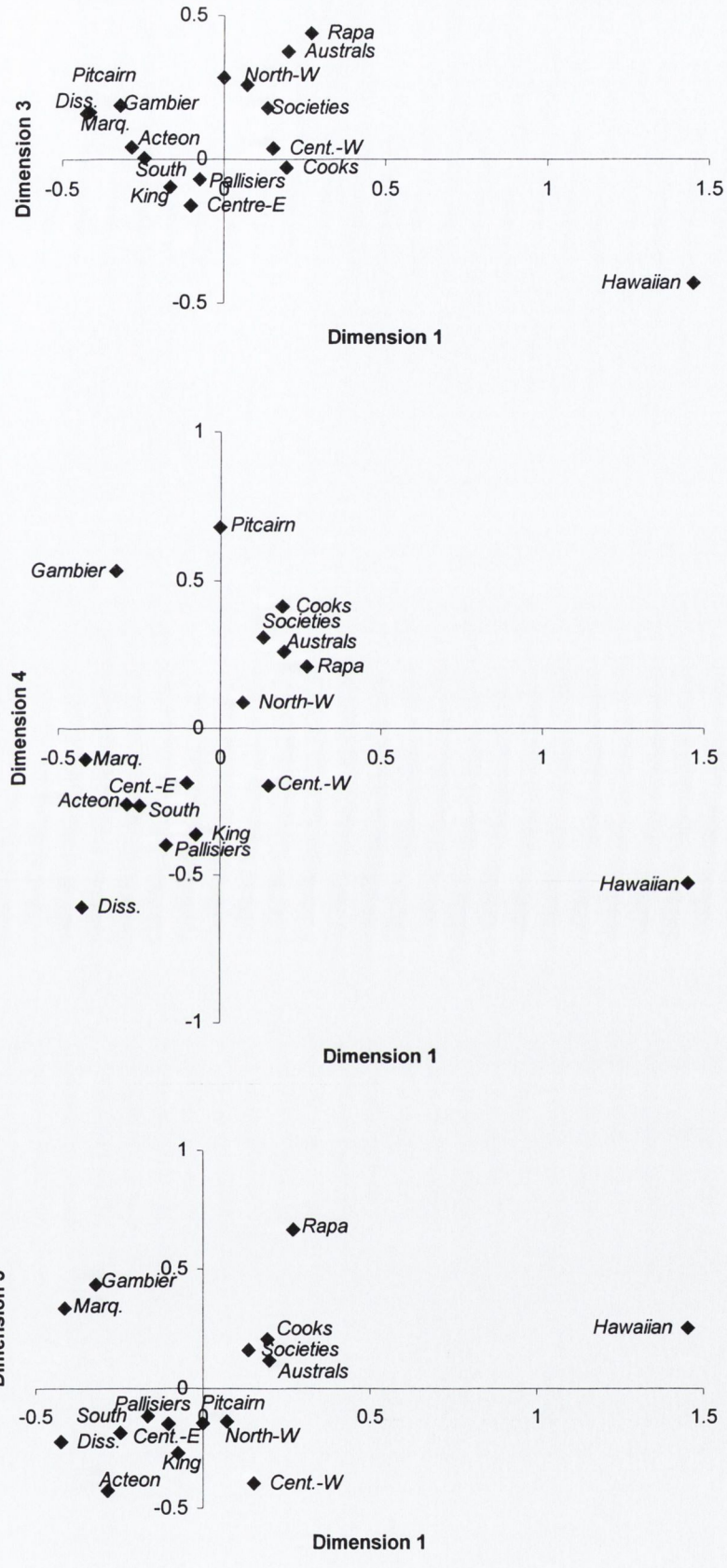


Figure 4.17 - NMDS ordinations, with Dimension 1 plotted aginst Dimension 3 (above), Dimension 1 against Dimension 4 (middle) and Dimension 1 against Dimension 5 (below), for Polynesian islands. Key: Cent.-E = Centre east group; Cent.-W = Centre west group; Diss. = Disappointment islands; King = King George islands; Marq. = Marquesas islands.

4.4 Discussion

4.4.1 Phytogeographic patterns

The first factor to emerge from this analysis is that the flora of Pitcairn shows virtually no affinity with that of the continent of America, nor with any of the islands in the eastern Pacific. There is also little connection with the continents of the northern hemisphere (ie Eurasia and North America). The origin of the flora is therefore from the west, migrating from Malesia through Melanesia and across the Pacific islands to Polynesia. Within Polynesia the connections are also to the west, from the Societies and Austral Islands. There are also strong connections with other Polynesian island groups that contain high islands, such as the Marquesas, Gambier, Cook Islands and Rapa, and with the North-west group of the Tuamotus that contains an uplifted atoll similar to Henderson Island.

The strongest associations with the Society, Austral and Cook islands are because these island groups also contain all of the island types found in the Pitcairn islands. However, they have larger floras as they are closer to the main floristic source (the Indo-Malesian region). The strong association is therefore due the Pitcairn flora being essentially a subset of the larger flora of these island groups. This is supported by the presence of several species originally thought to be endemic to the Australs and Rapa being found in the Pitcairn group (eg *Hibiscus australense; Peperomia rapensis; Senecio stokesii*).

The Marquesas and Rapa groups contain no atolls or makatea islands and so lack a large number of the habitats that would be found in the Societies, Australs or Pitcairns. Similarly the Tuamotu groups contain no high islands, and so are also lacking in upland habitats. The strong floristic affinity between Oeno and Ducie and the atolls of the Tuamotus and Central Polynesia, is swamped by the effects of the larger floras of Henderson and Pitcairn when the flora of the group is taken together (but see table 4.4). All of the species found on Oeno and Ducie, with the exception of the endemic *Bidens hendersonensis* var. *oenoensis*, are also found in the Tuamotu group. Similarly 42 species (out of 64 in total) from Henderson are also found on Makatea, another uplifted atoll in the North-west Tuamotu. This explains why the environmental variable of 'island type' correlated with 3 out of the 5 NMDS axes, and why island groups with similar island types fall together in the cluster and NMDS analyses.

If the origins of the endemic flora of the Pitcairn group are also considered, the link with the Cook, Society, Austral chain is strengthened. Table 4.7 shows where closely related species for the Pitcairn group endemics are found and thus from where these species may have originated. It should be noted that these relationships are largely speculative and have not been tested phylogenetically, being based both on generic distributions in the Pacific and in some cases reviews in the literature (see section 4.2.6). The strongest floristic affinities are found with Rapa and the Austral Islands, as well as the Society and Cook Islands, thus supporting the other analyses. The closest association with Rapa is

unexpected based on the cluster analyses and Venn diagrams (figure 4.8, 4.13, 4.14), but there are actually only 12 species from the Pitcairn group not found on Rapa. Considering the strength of the association between the Austral and Pitcairn groups, however, the affinities with Rapa may not be due to a direct link, but rather both Pitcairn and Rapa may have been separately colonised by ancestral species from the Austral Islands, which in some cases then speciated separately. Examples to consider are *Glochidion comitum* and *G. pitcairnense* which may have evolved from *G. raivavense* found in the Austral islands, but are closely related to *G. longfieldiae* from Rapa which may have also originated from G. raivavense; *Peperomia pitcairnensis* which probably evolved from *P. rapensis*, a species also found in the Australs and Rapa; *Peperomia hendersonensis* may have evolved from *P. pallida*, a widespread species across Polynesia, but one that is most common on the makatea fringes of Rurutu and Rimatara in the Austral Islands (pers obs 2000). In addition there are four species common between Rapa and the Pitcairn group with closely related species in the Austral Islands, so there is certainly some link between the island. *Peperomia* would be an example of a genus with a high degree of genetic plasticity, and thus an ability to radiate and speciate into different habitats.

Table 4.7 - Locations of species that may be closely related to the endemic species found in the Pitcairn group.

Genus	East Melanesia	New Zealand	West Polynesia	Cook Islands	Society Islands	Austral Islands	Rapa	Marquesas Islands	Tuamotu Islands	Gambier Islands	Hawaiian Islands
Abutilon			✓					✓	✓	✓	
Alyxia	✓		✓		✓	✓	✓	✓	✓	✓	
Angiopteris				✓	✓	✓	✓	✓			
Bidens			✓		✓	✓	✓	✓	✓	✓	✓
Coprosma				✓	✓	✓	✓			✓	
Ctenitis			✓	✓	✓	✓	✓				✓
Geniostoma	✓			✓			✓	✓		✓	
Glochidion	✓			✓	✓	✓	✓	✓	✓	✓	
Haloragis		✓				✓	✓				
Homalium				✓		✓			✓		
Ixora	✓		✓	✓	✓	✓	✓	✓	✓		
Meryta				✓	✓	✓	✓	✓			
Myrsine				✓	✓	✓	✓				
Nesoluma				✓	✓	✓	✓				✓
Peperomia				✓	✓	✓	✓	✓	✓	✓	
Total	4	3	5	11	11	13	13	9	7	7	3

Previous biogeographic analyses have rarely been conducted at the scale used here. Therefore the only analyses that support the results of this study are those by Dahl (1980) and Stoddart (1992). Dahl (1980), however, simply named the regions and their features, but did not carry out any assessment of relationships between the regions. The study presented here completely contradicts the conclusions of Brown (1935) that the flora of the region is of American origin; no features of the flora of Pitcairn are of American origin. In addition Brown describes the flora as being 87% confined to the Polynesian region, with only 2 pantropic species. This study also shows this not to be the case. Brown's (1935) research was based on limited knowledge of the Polynesian floras (his work was confined to the Marquesas Islands, and most of the other island groups had not yet been surveyed), and was at a time when new species were being described without proper comparisons between collections from other islands (Spellerberg & Sawyer 1999). Even so, his was the first analysis to note both the high degree of endemism in the flora, and the floristic affinities between Rapa and New Zealand (van Balgooy 1971).

Stoddart (1992) discussed the limitations of previous regional schemes, but did not carry out an analysis or add to the schemes already in place. He did however recommend that analysis should take island type into consideration when developing regional schemes, a factor taken into consideration in this study and indeed shown to have an effect. Having struggled with the problem of the phytogeographic regionalisation of the Pacific (van Balgooy 1960; van Balgooy 1971), van Balgooy (1996) supports Stoddart's view that a hierarchical system of regions is impractical and classifications should be based on the patterns shown in analyses based on island type.

Other regional schemes have tended to leave all of Southeast Polynesia together, thus separating it from the Cook Islands, Hawaiian islands, Samoa and Tonga. The lack of subdivision at the genus level found in this study testifies to the homogeneity of Southeast Polynesia as a biogeographic unit and thus supports other biogeographic analyses conducted at smaller scales to a level. The analysis presented here, however, does not support the inclusion of Easter island in the southeast Polynesian region, nor does it support the exclusion of the Cook Islands.

4.4.2 Factors contributing to these phytogeographic patterns

From the cluster diagram shown in figure 4.12 it can be inferred that dispersal mechanism has an effect on the distribution of taxa, and indeed the clusters also show ecological groupings. Bird dispersed (both active and passive zoochory) and anemochorous species are associated with high islands and to a lesser extent makatea habitat types. Anemochorous species may also be transported on mud adhered to the feet of birds, as the seeds and spores of these taxa are very tiny, but it is impossible to predict how commonly this would occur. Hydrochorous species form a distinct ecological group in the cluster diagram, that represents typical strand and atoll habitat communities. Sea-

borne plants may also be spread inland secondarily by zoozhory, as many hydrochorous species are also dispersed by zoochory (eg *Argusia argentea, Hedyotis romanzoffiensis, Premna serratifolia, Hernandia* spp.). There are also records of viable plant fragments and whole plants being washed up on islands and establishing there (Carlquist 1996).

Approximately 40 birds have been recorded from either the islands of the Pitcairn Group or crossing the ocean area between the islands, and at least four landbirds became extinct during the period of Polynesian habitation (Brooke 1995; Wragg 1995). Most of the sea birds and migrants are carnivores, feeding on fish, but the landbirds are commonly either omnivores or frugivores (Brooke & Jones 1995; Imber *et al.* 1995; Jones *et al.* 1995; Trevelyan 1995). Studies on the feeding biology of the Henderson fruit dove (*Ptilinopus insularis;* plate 4.1) show that it feeds on the fruits of 19 species (Brooke & Jones 1995). Two extinct frugivores a ground dove (*Gallicolumba* sp.) and a pidgeon (*Ducula* sp.) would have browsed from a similar number of species, but also probably from the species with larger fruits (eg *Santalum insulare*) (Brooke & Jones 1995). In addition the migrant Bristle-thighed curlew (*Numenius tahitensis*) and the Stephen's Lory (*Vini stepheni*) have been observed feeding on fruits (Brooke & Jones 1995). These frugivores would have acted as dispersers for the plant species through the Pitcairn islands and farther afield, and there are almost certainly other migrant and vagrant birds that feed on fruit, but have not been observed doing so in the Pitcairn group.

Plate 4.1 - The endemic Henderson Island fruit dove (*Ptilinopus insularis*) resting on *Pandanus tectorius*.

van Balgooy (1960) and Sachet (1967) conclude that the highest percentages of widely distributed species are found on atolls, and this is also found in the distributions described here (see figure 4.4). Thus while these analyses do not take habitat types into

consideration, species from particular habitats cluster together. Dispersal mechanism and available habitats thus strongly affect the flora of the islands in the Pitcairn group and may well influence the phytogeography of the group more than any other factors.

As climatic factors, sea currents, sea levels and island geologies do not remain static, it is necessary to look past environments in discussing the plant colonisation of the Pitcairn group. In the period since the formation of the islands in the Pitcairn group, sea levels have not been lower than about 150m below current sea levels (section 1.4.3). However, during periods of high sea levels before the formation of Pitcairn, Oeno, Ducie and Henderson (then an atoll) may have been totally submerged during certain periods, thus removing all of the terrestrial biota. Since the formation of Pitcairn and subsequent uplift of Henderson, there have been terrestrial habitats above water even during periods of high sea levels. During periods of low sea level there are several seamounts that may have been above water level and supported a terrestrial biota. Figure 4.18 shows the locations of seamounts and reefs that may have formed islands during such periods, and there would have been a number of emergent islands in the vicinity of Pitcairn, most notably to the west. There are also a number of seamounts and reefs around the Austral Islands, Rapa, the Cook Islands and across towards Fiji (in East Melanesia and the source of most of the Polynesian flora). Aside from a volcanic seamount close to Pitcairn, and another near Henderson, there are no seamounts or reefs between Pitcairn and Easter Island. The presence of these potential islands during cooler, windier and stormier periods would have allowed them to act as additional stepping stones for species to migrate to and colonise Pitcairn. Since the trade winds blowing from the southeast predominate during warmer periods, the anemochoric element of the flora would have only been dispersed in an easterly direction to Pitcairn during periodic climatic events, such as the El Niño or Cyclone events. However, during the cooler periods, and with the aid of storms and stepping stone islands, dispersal by anemochory would have been optimal. Tryon (1970) notes that pteridophytes can disperse up to 1500km if conditions are suitable. In addition zoochorous dispersal may have been more successful during these times as migratory birds would be transported larger distances on the wind currents.

Sea currents in the region of the Pacific under study move in the opposite direction to the trade winds, towards the south east (Irwin 1992; Kirch & Hunt 1997), and this provides a simple explanation of the dispersal of hydrochorous species towards the Pitcairn Islands. While the possible occurrence of earlier high islands in the Pacific could have altered the transport distance, nevertheless the ranges of these species must have been established by long-distance migration (Tryon 1986). Stepping stone islands are more important to species whose propagules tend to be dispersed by zoochory, hydrochory or on floating rafts (ie birds, mammals & arthropods), and less important to anemochorous species (MacArthur & Wilson 1967).

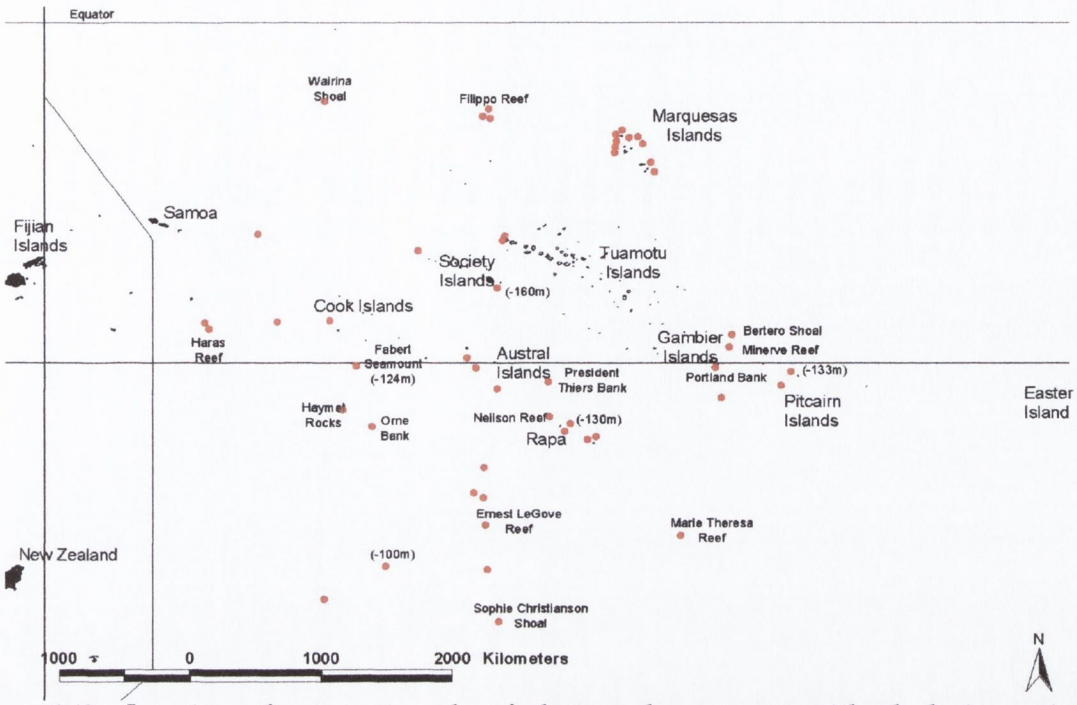


Figure 4.18 – Locations of seamounts and reefs that may have emergent islands during periods of lowered sea levels. Potential islands are marked with red dots. Figure is derived from charts 4607 and 4061 of the Admiralty series.

In van Balgooy's (1960 & 1971) biogeographic regional analyses of the Pacific, Rapa is segregated into its own region, separate to the Polynesian region, of which it is geologically more associated. This division is based on the fact that the flora is more closely associated with that of Australia and New Zealand and forms a more southern element than that of Polynesia. It is interesting to note that there are several submerged reefs and banks to the south west of Rapa towards New Zealand, that could have acted as stepping stone islands for non-Polynesian species to colonise Rapa (eg *Corokia* - found in New Zealand, Australia and Rapa; *Hebe* – found in New Zealand, Australia, Rapa and the Falklands). This theory might also account for some of the oddities found in the Pitcairn flora, notably *Samolus* cf. *repens*, found in Australia, New Zealand, Pitcairn, Easter Island and South America. This can be extended to species found in the Polynesian flora that are not seen in that of Melanesia or Indo-Malaysia, the usual sources for Polynesian species, but rather from New Zealand and Australia (eg *Asplenium obtusatum* - found in Australia, New Zealand, Polynesia, Easter Island and South America). Migration between Australia and South America was probably possible until the end of the Tertiary, when the Pleistocene glaciation completely covered East and West Antarctica with a massive ice-sheet (Smith 1970), and this explains the number of transPacific species and genera with disjunct distributions in South America and Australia (including *Samolus repens* & *Asplenium obtusatum*).

4.4.3 Discrepancies in the phytogeographic patterns

Looking at the distribution of species within the Pitcairn group also raises some questions as to why certain species are not more widely dispersed within the archipelago.

Homalium taypau is an example of an endemic species that is confined to the volcanic interior slopes of Pitcairn Island. Closely related species occur in the Cook and Austral Islands, but in the Austral Islands the species is found growing on both volcanic and makatea substrates. *Homalium taypau* could in theory, therefore, occur on Henderson Island. It seems unusual that a species so dominant on Pitcairn does not occur on nearby Henderson, especially as the species is probably bird dispersed. The explanation may lie in the fact that many *Homalium* sp. require a disturbance event (such as a severe storm or cyclone) to flower and seed (G. McCormack pers com 2000), and since such disturbances are not common on Pitcairn, this dispersal has not had a chance to occur. Other species that occur on Henderson, but could also occur on Pitcairn include *Senecio stokesii*, *Geniostoma hendersonensis* and *Nesoluma st-johnianum* (based on observations of these or closely related species occurring on volcanic substrates in the Austral Islands).

As well as considering species that could be more widespread within the archipelago, it is also necessary to examine the many species and genera that do not occur in the Pitcairn group but could do so based on their distributions and habitat requirements (distribution, habitat and dispersal information taken from van Steenis, 1963; van Steenis & van Balgooy, 1966; van Balgooy, 1975, 1984, 1993). *Cyrtandra* is one such genus occurring in Malesia and the Pacific islands including the Cook, Society, Austral and Marquesas Islands, and has speciated widely on these islands. It is a genus of herbs and shrubs that occur in forest undergrowth, and can probably be dispersed by both active zoochory and hydrochory. It would be ideally suited to forest habitats on Pitcairn Island, but is not found there. *Sophora* is another genus found in New Zealand, Rapa, Austral and Hawaiian Islands, Easter Island and across to the Juan Fernandez Islands. Like *Haloragis* spp. or *Samolus repens*, it is thus a typical example of the southern element in the Pacific flora. Its habitat includes mountain slopes and streams, and its dispersal mechanism is by hydrochory. Again it would be ideally suited to forests on Pitcairn, and Pitcairn would provide an ideal stepping stone for its distributions across the Pacific between New Zealand, Rapa, and Easter or Juan Fernandez. *Nesogenes euphrasioides* is typical of coral island seashores and is distributed across the Tuamotus and Cook Islands. It would only be a small step for this genus to occur on Oeno and Henderson Islands, and an error in van Balgooy (1975) actually records it from Ducie. Similarly *Colubrina asiatica* is a worldwide species, found extensively in Polynesia, and typical of seashore, rocky and forest habitats at low elevations. It is dispersed by flotation and this mechanism has proved very successful in its widespread colonisation of remote locations. It would be suited to all of the Pitcairn Islands, especially Oeno and Henderson. *Byttneria* is a genus made up mostly of American and Madagascan species. It has an unusual distribution in the Pacific, not being found in Melanesia or western Polynesia, but in the Society, Marquesas and Gambier Islands. It is thus one of the few species in Polynesia derived from recent American origin. It is a genus of forest shrubs and climbers that are dispersed

by passive zoochory. As it has a limited distribution in the eastern Pacific, it is perhaps not surprising that *Byttneria* is not found in the Pitcairn group, but due to the proximity of the Gambier high islands to Pitcairn, it would seem reasonably likely that it would be dispersed there. *Fitchia* is a genus restricted to Rarotonga, Rapa, the Society Islands and Mangareva. A specimen of *F. nutans* attributed to Henderson by Cuming was a mislabelled collection from Tahiti (Florence *et al.* 1995). The genus is characterised by a reduced dispersal ability with only relict spikes remaining on the fruits (Whittaker 1998). There are numerous other examples of genera that could occur in the Pitcairn group, such as *Gahnia, Fagraea, Oparanthus* and *Myoporum.*

Due to its remoteness the flora of the Pitcairn group is a subset of the larger flora of South-east Polynesia, notably the Austral, Cook and Society Islands. Therefore the fact that these genera and species do not occur may be due to the simple fact that they have not yet colonised there. The Pitcairn group is also out of the line of cyclones which affect the Cook, Society and Austral Islands, and thus aid in dispersal between these groups. In addition the young age of Pitcairn Island itself influences the flora. For several million years until the formation of Pitcairn there would have been no high islands in the group, as Oeno, Ducie and Henderson were all atolls. During some periods these atolls may have been completely submerged, essentially sterilising the terrestrial biota of the islands. Since the formation of Pitcairn, both Henderson and Pitcairn have been suitable habitats for a large number of species, with extensive areas of woodland. Therefore the young geological age could account for many of the discrepancies in the flora. For example *Sophora, Byttneria* and *Fitchia* may simply have dispersed right over where Pitcairn was forming as an submerged volcanic seamount. The new records found for Pitcairn as part of this expedition (section 2.3.1) are in many cases coastal species that occur in very small population numbers (eg *Samolus repens, Ipomoea littoralis, Haloragis sp.*) which may be very recent colonisers, or may have been overlooked by previous surveys. This supports the idea that species such as *Colubrina asiatica* and *Nesogenes euphrasioides* may either have not yet arrived in the group, or may have been overlooked. Similarly these species may have existed in the past on Pitcairn and become extinct due to the natural species turnover cycle which has been suggested for islands which are at equilibrium (MacArthur & Wilson 1967).

4.4.4 Problems with the data

There is a large potential for error in compiling and analysing data of this sort. In many cases the floras are unknown or under collected, especially as many early collectors were mainly interested in useful and food plants and no full floristic survey has been carried out in many of the Pacific islands. In addition many collections have incomplete location information, often simply citing an island group, or general area (ie South Pacific). These problems have also been noted by van Balgooy (1971), Chown *et al.* (1998) and Fosberg (1984).

Misidentified specimens, and errors in the published record are all too common and seriously affect analyses of this sort (Spellerberg & Sawyer 1999). This is less of a problem when dealing at the genus level, but may be a major source of error at the species level (van Balgooy 1971). Examples of this include a record of a *Coprosma* sp. from Tubuai which was a *Psidium* sp. *Coprosma* spp. are some of the most biogeographically important in the Pacific, while *Psidium* spp. are introduced invasive species. Another example is the misidentification by a 1991 expedition of *Lastreopsis pacifica* on Pitcairn island as *Ctenitis cumingii*, with *Ctenitis cumingii* not being collected by them. Obsolete synonymy also causes confusion and many of the species named here require taxonomic revisions.

Due to the nature of island floras containing narrow endemic species, there is also a danger that species may have become extinct since human occupation of the island, and so will not be recorded. There are many examples of taxa, in particular useful plants, whose distribution would have a major affect on this analysis, and may have become extinct on many Pacific islands (eg *Santalum* spp. now extinct on Juan Fernandez, remaining in the Austral islands on only one motu). In this data set the presence/absence method has been used, but without accounting for pseudo-absences (taxon exists but has not yet been recorded) or reversal-absences (due to the extinction of the taxon from a geographical region).

Only vascular plants are considered in this analysis as it is the relationships and origins of the Pitcairn group vascular flora that are of interest here. Further studies should undoubedly consider other taxonomic groups. However, Carson (1996) suggested that biogeography could not exist without considering plants, as their distributions are not only more stable than in animals, but also frequently serve as specific determinant substrates of various animal species.

van Balgooy (1971) argues strongly for the use of the genus as a working unit in biogeographic analyses, mainly because at the genus level one is less likely to encounter problems with synonymy or poorly defined species. He does however concede that the species distributions give a clearer and more detailed 'phytogeographic picture'. Tryon (1986) in his biogeographic analysis of fern species does not consider genera, as he considers the basic biogeographic features to be those of species. As mentioned previously, in this data set the delimitation of species has been used conservatively, in some cases grouping endemic species known to be closely related (eg *Coprosma benefica*), and ignoring divisions at the level of subspecies (eg *Xylosma suaveolens*; *Cyclophyllum barbatum*; *Santalum insulare*).

Using the genus as a working unit also means that widespread genera (eg *Asplenium*; *Peperomia*) will show no biogeographic patterns, but the same genera have many species which show biogeographically interesting and useful distributions in the Pacific and Polynesia. Thus studies at the level of genus may fail to pick up some biogeographic

patterns at the large scale, the scale of interest in this study. Other disadvantages inherent to the generic method are that genera, whether large or small, are treated at the same level, and also genera are not uniformly known with some being the subject of recent revisions, and some not (van Balgooy 1960).

Ideally a study at this scale would consider island by island distributions and thus be able to pick up more differences by island type. This type of study has been recommended by Stoddart (1992) as he considers biogeographic provinces that do not take island type into consideration to be flawed. Unfortunately, however, as such island by island floristic data are not yet available, an analysis such as that would increase the effect of pseudo-absences in the data set. Steps are being taken to rectify this situation in initiatives such as the ongoing '*Flore de la Polynésie française*' (J. Florence pers comm, 1997) and the '*Cook Island Natural Heritage Project*' (G. McCormack & E. Saul pers comm, 2000). In contrast to Stoddart (1992), however, Whittaker (1998) argues that if island by island data are used there is a complicating effect of within-archipelago rather than island-mainland distance effects, thus supporting the use of the data set here.

4.4.5 Implications of this analysis in terms of Pacific biogeography

Stoddart (1992) discusses the difficulties associated with existing biogeographic schemes, and suggests taking island type into consideration as the best solution. This study supports this idea, but finds that it is not island type alone, but also habitat availability that may be the most important factors affecting species distribution patterns in the Pacific region. Thus the results here echo MacArthur & Wilson (1967) who also suggested that ultimately habitat availability would be found to be the dominant factor affecting the construction of island biotas. This coupled with a depauperate flora, due to distance from the nearest continent, accounts for the species found in the Pitcairn flora. Separating analyses by island type alone will not account for homogeneity and endemism within archipelagos. An example of such a species is *Glochidion pitcairnense* which is endemic to both Pitcairn (high island type) and Henderson (makatea island type). Completely dividing island types will not account for similarities such as this.

The results presented here show that as the Pitcairn group contains all of the island types it provides a good model of species distributions in a simplified format. Differences are clearly seen between the floristics of a species poor remote atoll (Ducie), a less remote and slightly more diverse atoll (Oeno), a makatea island (Henderson) and a high island (Pitcairn). The results also suggest that analyses in future should look at the distribution of habitats to explain floristic distributions. However, the same habitats on different islands do not necessarily contain the same species, since some islands have higher species diversity due to other factors. An example would be a comparison between *Metrosideros collina*-dominated cloud forest on Tahiti and Pitcairn. On Tahiti this forest type occurs at high altitudes (1000m+; Mueller-Dombois & Fosberg, 1998), and with many

diverse plant species in the community, while on Pitcairn it occurs at lower altitudes (200m+) and with less plant species in the community, but it is still one of the most diverse habitat types on the island. Direct comparison of the similarity between the habitat types is difficult and does not explain phytogeographic relationships between the islands. However, the consideration of habitat types in conjunction with the actual species present, may prove to resolve many of the problems associated with phytogeographic regionalisation systems.

4.4.6 Concluding remarks

The flora of the Pitcairn Islands is derived from the flora of the other island groups in the south-eastern Polynesian region, notably those of the Austral, Society and Cook Islands. The flora would seem to be predominantly derived from that of the Austral Islands. The Polynesian flora is in turn derived largely from the flora of the Indo-Malesian region. The migration methods of the flora are closely linked to the habitats in which the taxa occur, with strand species arriving through hydrochory, while taxa that occur farther inland arriving through zoochory and anemochory. Therefore, it is not simply dispersal of propagules to islands which limits their occurrence, but also the availability of a vacant niche in which they can establish a viable population before events that might lead to their extinction are experienced.

In terms of regionalisation of the Pacific, the results of this analysis using Pitcairn group floristic data only, suggest that South-east Polynesia is a valid biogeographic unit. This unit should contain the Cook, Austral, Society, Marquesas, Gambier, Tuamotu and Pitcairn Islands with Rapa, but exclude Easter Island, Tonga and Samoa. This disagrees with most biogeographic regionalisations published to date, notably in the inclusion of the Cook Islands and exclusion of Easter Island (see van Balgooy 1971 & Stoddart 1992). However, the closeness of the association between the Pitcairn group and the Cook Islands found in this analysis (see figure 4.14), closer even than with the Marquesas Islands, suggests that this inclusion is valid.

Even though the flora of the Pitcairn group is essentially a subset of the flora of the Polynesian region, the results of this analyses still show the biogeographic relationships found when using a larger data set for the whole of Pacific. This demonstrates that even though the Pitcairn island group has a impoverished and disharmonic flora, due to its age and location, the fact that the group contains all of the oceanic island types found in the region, and thus a representative sample of the habitats available in the region, means it can serve as a useful model for Pacific biogeographic analyses.

Chapter 5 : Conservation biology of Pitcairn plant taxa

5.1 Introduction

5.1.1 Species based conservation

In order to most effectively conserve species, it is first necessary to prioritise them according to their conservation needs. If this is not done scarce conservation resources can be wasted, or taxa in need of urgent conservation may not be recognised. In the past species were often categorised based on intuitive classifications, but this led to taxa with widespread but sparse and declining populations being consistently overlooked (Rabinowitz *et al.* 1986), and a lack of repeatability between assessors (Mace & Lande 1991). Explicit schemes, using indices to score taxa, foster greater accuracy and precision in risk classification, and thus are more defensible in the face of challenges (Keith 1998), and reduce subjectivity in prioritisation based on the biases of the assessor.

Hawkes (1987) prioritised taxa entirely based on their usefulness to mankind, while Breininger *et al.* (1998) prioritised animals within the Kennedy Space Center Island complex (KSC) using an index based on the species' vulnerability to extinction, functional role and the relevance of the KSC populations in the context of the US. Thus keystone species obtain high scores as they tend to have low population numbers, but species that have large populations in the KSC, but are endangered in the US obtain lower scores. While this approach is useful for identifying conservation priorities within a reserve area, it uses absolute population numbers and so reduces the importance of smaller, non-keystone species which have larger populations, but whose threat of extinction is no less imminent. Maxted *et al.* (1997) recommended assigning conservation priorities to taxa based on several factors:

- In and ex-situ actions in progress
- Socio-economic use
- Biological importance (ie keystone species)
- Threat of genetic erosion
- Geographic distribution (but ignoring endemics)
- Priorities of the conservation agency (authority)
- Cultural importance
- Cost, feasibility and sustainability
- Legislation
- Ethical and aesthetic considerations
- Genetic distinctiveness

The scheme of Maxted *et al.* (1997) focused on genetic erosion rather than species extinction, and ignored endemic species, using the justification that such species are not a true measure of diversity, but rather an arbitrary measure of geographical distribution. However, this is not necessarily valid for narrow island endemics, which due to extreme geographical and temporal isolation may be very genetically distinct from the most closely species, and as such should be assessed individually. This scheme also did not include 'degree of endangerment', a factor included in most other assessments of priority taxa (Center for Plant Conservation 1991).

Rabinowitz *et al.* (1986) describes seven forms of rarity (see section 1.2.1) and highlights the importance of habitat specificity, geographic range and local abundance in assigning species to rarity categories. She emphasises the importance of using quantitative methods when prioritising taxa so that all forms of rarity are not considered, and best conservation practises are designed on a species by species basis. Curtis & McGough (1987) add attractiveness, accessibility and remoteness along with habitat factors as important in species prioritisation.

IUCN (The World Conservation Union; previously the International Union for the Conservation of Nature and Natural Resources) Red data categories have been used for approximately 30 years to provide a guided system by which species can be assigned a level of extinction threat that can be applied consistently by different people and will facilitate comparisons across widely different taxa (IUCN 1994). The criteria for assigning these threat categories have been developed over time, with the current categories and criteria being adopted in 1994 (IUCN 1994) (discussed further in section 5.1.2). By assigning IUCN categories to species it is possible to categorise widely different taxonomic groups and regions in terms of their conservation importance, with conservation of the most critically endangered taxa being the highest priority. While there is much discussion about the limitations of the IUCN criteria and categories (Breininger *et al.* 1998; Keith 1998; Mace & Lande 1991; Maxted *et al.* 1997), their use is widespread and the data are readily accessible through internet searchable databases (Species Survival Commission 2000). While the scheme may not be fully workable for all conservationists, it provides a basic standard from which species may be prioritised, and then appropriate amendments can be made using the intuitive knowledge of the researcher. Widely used and explicit schemes define an agenda for data collection that is essential for the ongoing assessment and management of threatened species in the worldwide context (Keith 1998).

5.1.2 IUCN Categories & Criteria

There are 8 IUCN categories; Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Low Risk (LR), Data Deficient (DD) and Not Evaluated (NE). All taxa listed as Critically Endangered qualify for Vulnerable and Endangered, and all listed as Endangered also qualify for Vulnerable. Together these three categories are described as 'threatened'.

Categories are determined based on evaluation against certain criteria, as laid out in IUCN (1994). These criteria address attributes that affect risk of extinction: rates of decline in population and distributional range, the actual range and population size, population fragmentation and population viability. The criteria specify thresholds in these parameters that must be met if a species is to qualify for one of the three threatened categories.

As it will never be clear which criteria are appropriate for a particular species in advance, each species should be evaluated against all of the criteria, and any criterion met should be listed. The importance of listing the criteria met as a basis for assigning a category is emphasised by Batianoff and Burgess (1993). Methods involving estimation, inference and projection are acceptable when deciding on the most appropriate criteria. In cases where a wide variation in estimates is found, it is legitimate to apply a precautionary principle and use the estimate (providing it is credible) that leads to listing in the category of highest risk, as it highlights the conservation needs and the need for further information relating to the species in question (IUCN 1994).

The category of threat is not necessarily sufficient to determine priorities for conservation action as it simply provides an assessment of the likelihood of extinction under current circumstances. A system for assessing priorities for action, however, will include numerous other factors concerning conservation action such as costs, logistics, chances of success, and the taxonomic distinctiveness of the subject (IUCN 1994; Maxted *et al.* 1997).

The criteria are most appropriately applied to whole taxa at a global scale, rather than to those units defined by regional or national boundaries. Regionally or nationally based threat categories, which are aimed at including taxa that are threatened at regional or national levels (but not necessarily throughout their global ranges), are best used with two key pieces of information: the global status category for the taxon, and the proportion of the global population or range that occurs within the region or nation (IUCN 1994). However, the categorisation process should only be applied to wild populations inside their natural range, and to populations resulting from benign introductions (defined in the draft IUCN Guidelines for Re-introductions as "..an attempt to establish a species, for the purpose of conservation, outside its recorded distribution, but within an appropriate habitat and eco-geographical area") (IUCN 1994).

The criteria result in the designation of one of the following categories (IUCN 1994):

- Extinct (EX) - A taxon is extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.
- Extinct in the wild (EW) - A taxon is extinct in the wild when it is known only to survive in cultivation, in captivity or as a naturalised population (or populations) well outside the past range.
- Critically endangered (CR) - A taxon is critically endangered when it is facing an extremely high risk of extinction in the wild in the immediate future if the causal factors continue operating (as defined by any of the appropriate criteria).

- Endangered (EN) - A taxon is endangered when it is not critically endangered but is facing a very high risk of extinction in the wild in the near future (as defined by any of the appropriate criteria).
- Vulnerable (VU) - A taxon is vulnerable when it is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future (as defined by any of the appropriate criteria).
- Lower Risk (LR) - A taxon is lower risk when it has been evaluated and does not satisfy the criteria for any of the categories critically endangered, endangered or vulnerable. Taxa included in the Lower Risk category can be separated into three subcategories; conservation dependent (cd) if their status relies on a conservation programme, near threatened (nt) if close to qualifying for vulnerable, and least concern (lc) if they qualify for neither of these.

Data deficient (DD) - A taxon is data deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. If the range of a taxon is suspected to be relatively circumscribed, if a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

Not Evaluated (NE) - A taxon is not evaluated when it is has not yet been assessed against the criteria.

A major criticism of the IUCN scheme is the fact that the area of occupancy of a species holds such weight in the criteria, resulting in species that have a small area of occupany (eg smaller then IUCN's critically endangered threshold of 10km^2), but would other wise be considered low risk, falling into one of the threat categories (Keith 1998; Waldren *et al.* 1995b). Similarly the IUCN criteria do not account for species which have naturally small or dispersed populations, or skewed demographic structure in the populations, nor do they account for species life-histories, habitat attributes or the relative stability of the habitats in which the species occur (Keith 1998; Waldren *et al.* 1995b).

5.1.3 Genetic analysis in conservation biology

As discussed in section 1.2, the ultimate goal of conservation biology is to maintain the evolutionary potential of species by maintaining natural levels of diversity, in order that the species will be able overcome stochastic factors which could otherwise result in the species extinction (Lande & Barrowclough 1987). Knowledge of the genetic structure and relationships within and between populations leads to more accurate population management from the beginning of conservation efforts, when options may be the most flexible (Haig 1998).

The use of molecular analysis as an integral component in the conservation of rare and endangered species is still in its infancy, but is becoming more widely used as the

techniques become more accessible and less expensive. The preservation of genetic variation is a fundamental aim of nature conservation, as genetic diversity is essential in the ability of populations to respond to long and short term environmental change (Frankel & Soulé 1981; Rossetto *et al.* 1995). Scientific approaches to the conservation of genetic resources require a detailed knowledge of the distribution of genetic variation within and between populations of the organism in question (Dawson *et al.* 1993; Frankham & Ralls 1998; Haig 1998). In addition knowledge of the partitioning of genetic diversity within and between populations or individuals can be used to select appropriate genotypes to maximise genetic diversity when formulating long term conservation strategies (Haig 1998; Rossetto *et al.* 1995).

Traditionally analyses of genetic variation within and between populations was carried out using morphological techniques. This became more useful as microscopy and chemical analysis techniques became more readily available. In recent years DNA-based techniques have become more popular and are in some cases taking over from the more traditional, but laborious methods. The recent development of polymerase chain reaction (PCR) for amplifying DNA has led to a revolution in the applicability of molecular methods, but as techniques vary in the way that they resolve genetic differences, the type of data they generate and the taxonomic levels at which they can be applied (Karp *et al.* 1996), care must be exercised when choosing the technique to use based on the problem being addressed and the degree of resolution required (Hillis & Moritz 1990; Parker *et al.* 1998). The utility of a genetic marker for the detection of population differences depends strongly on the number and extent of polymorphisms at the loci examined (Nei 1987).

5.1.4 Molecular techniques

PCR is a rapid procedure for the *in vitro* enzymatic amplification of a specific segment of DNA, by means of automated thermocyclers (Parker *et al.* 1998). In the reaction DNA to be amplified is denatured by heating, and in the presence of DNA polymerase and excess dNTP's, oligonucleotides that hybridise specifically to the target sequence can prime new DNA synthesis (Ausubel *et al.* 1997). As the sequences of the regions flanking the locus being amplified must be determined prior to the reaction, methods using random primers (known sequences of base pairs) have become popular, as they allow the identification of genetic markers relatively quickly without requiring knowledge of the genome or sequence information (Parker *et al.* 1998). PCR thus allows the identification and separation of species and individuals using a unique genetic fingerprint (Parker *et al.* 1998). However, as small amounts of tissue material are used in the DNA extraction, and smaller amounts of DNA are used in the PCR reaction, PCR techniques are very sensitive to contamination (Parker *et al.* 1998). PCR techniques widely used in biodiversity evaluation include randomly amplified polymorphic (RAPD), amplified fragment length polymorphisms (AFLP) and inter-simple sequence repeats (ISSR) (Karp *et al.* 1996).

A commonly used PCR technique for the detection of genetic variability is Randomly Amplified Polymorphic DNA (RAPD) (Williams *et al.* 1991). RAPD involves the use of commercially available random primers, typically 10 base pairs long, which result in the amplification of several DNA fragments. Unlike other techniques RAPD surveys the whole genome, revealing coding or non-coding regions, repeated or single-copy sequences (Williams *et al.* 1991). There is no specific knowledge of a particular DNA sequence required (Parker *et al.* 1998). These fragments can then be separated on an agarose gel in the presence of Ethidium bromide, and visualised under UV light. The presence or absence of DNA products (seen as bands) are then scored and the data converted into 1/0 matrices for calculation of genetic distance (Karp *et al.* 1996).

This technique has been successfully used to assess variation in agricultural species and their wild progenitors (Russell *et al.* 1993; Sharma *et al.* 1996), to monitor the levels of variation in germplasm collections (Liu & Date 1997), to resolve taxonomic questions in species (Sharma *et al.* 1996) and to determine population dynamics and genetics (Ayres & Ryan 1997; Dawson *et al.* 1993; Russell *et al.* 1993). RAPD technology is also thought to be more liable to detect variation in inbred species than other techniques (Williams *et al.* 1993, in Dowe *et al.* 1997). RAPD analyses survey the entire genome, rather then selected fragments, as with minisatellites and allozyme markers, therefore providing unbiased estimates of genetic and clonal identity, making them useful in the development of breeding programmes and recovery strategies (Stewart & Porter 1995). RAPD will consistently find more polymorphism than AFLP or ISSR (Lu *et al.* 1996; Parker *et al.* 1998).

The RAPD technique is particularly useful for population studies (Parker *et al.* 1998; Williams *et al.* 1991), as it can distinguish genetically distinct individuals from clonal individuals (Parker *et al.* 1998). It has major advantages in molecular ecology because of its wide applications and the fact that it requires the least in technology, labour and cost, without the necessity of radioactivity and requiring only small amounts of DNA (Dawson *et al.* 1993; Fischer *et al.* 2000; Hadrys *et al.* 1992).

Dawson *et. al.* (1993) used *Hordeum spontaneum* populations from Israel to test the applicability of RAPD markers in population studies. They found that RAPD markers detected high levels of polymorphism, higher than isozymes, and were successful in assessing the genetic diversity within and between the populations under study. They also suggested that RAPD analysis would be useful for the sampling of genetic variation within the available gene pool for conservation purposes.

Dowe *et. al.* (1997) present one of the first studies to use RAPD technology in the formulation of a conservation strategy for the critically endangered palm *Carpoxylon macrospermum*, but found the DNA difficult to extract, and no variation was detected by the technique employed. Palacios *et. al.* (1997) similarly found no variation using RAPD

to test the variability within *Limonium cavanillesii*, a critically endangered plant species from Spain, nor did Martin (1998) find any variation in *Otanthus maritimus* from sites in Ireland.

Limitations of the RAPD technique are primarily in its sensitivity to reaction conditions and thus its lack of reproducibility (Hadrys *et al.* 1992; Karp *et al.* 1996). However, Skroch and Nienhuis (1995) concluded that if reaction conditions were consistent this problem was overcome, but they reported that scoring error between researchers caused a major bias in the data. In addition the presence of bands of the same molecular weight does not necessarily equate to homologous fragments, and single bands sometimes comprise several co-migrating fragments (Karp *et al.* 1996). The short length of RAPD primers will reduce the specificity of genome scanning, resulting in a large number of annealing sites that may also produce some artifactual amplification products (Hadrys *et al.* 1992; Parker *et al.* 1998). RAPD analysis has also been reported to underestimate the levels of within population variation (Bartish *et al.* 1999). However, even with these major limitations, the errors are not significant enough to result in differences in genetic distance estimates greater than expected by chance (Skroch & Nienhuis 1995).

Amplified fragment length polymorphisms (AFLP) is another PCR-based technique, and one that is even more recent then RAPDs (Vos *et al.* 1995). It involves restriction of the genomic DNA using restriction endonucleases, and then the PCR amplification of the resulting fragments. It is very useful for studying molecular genetic variations between closely related species or varieties (Liscum & Oeller 1995), and it is easier to score then other PCR techniques (Lu *et al.* 1996). Problems with AFLP include that the bands often cluster around the centromeres (Karp *et al.* 1996), and also the fact that the technology is costly. In some studies AFLP has been found to find lower levels of polymorphism than other PCR techniques, and cannot always distinguish all individuals being studied (Lu *et al.* 1996; Saliba-Colombani *et al.* 2000). However as the technique has only recently become widely used, there is debate as to its relative efficiency for molecular studies, with some suggesting it is less efficient than RAPD analysis (Saliba-Colombani *et al.* 2000), while other suggesting it is more efficient.

Inter-simple sequence repeats (ISSR) use primers designed with a 1 to 3 nucleotide anchoring sequence followed by a di or tri-nucleotide repeating sequence. In theory these SSR regions are randomly distributed throughout the genome (Wolfe *et al.* 1998). In comparisons with other PCR techniques, ISSR's were found to result in very different cluster diagrams than oher methods (AFLP, RAPD and Microsatellites) (Lu *et al.* 1996). This is because the target sequences that the primers used may be clustered on the genome, and thus bias the reaction and yield overlapping results (Lu *et al.* 1996; Wolfe *et al.* 1998).

5.1.5 Distance measures

In order to quantify the genetic variation within and between populations it is necessary to use numerically calculated distance measures. Since the development of molecular techniques a large number of existing and newly developed distance measures have been applied. Calculation, quantification and correct use of distance measures for within and between population variance are discussed in detail by Manly (1985), Nei (1987), Hartl & Clark (1997) and Karp *et al.* (1996).

Genetic distance is the extent of gene differences between populations or species that are measured by some numerical quantity (Nei 1987). It usually refers to the gene differences as measured by a function of gene frequencies (Nei 1987). As it is not possible to sample all genes in a species or population, distance has to be estimated by sampling a certain number of loci from a sample of individuals. Calculation of the % polymorphic loci in the sample data gives a quick estimate of diversity (Nei 1987). However it is subject to sampling error depending on the number of loci and primers chosen and is thus an arbitrary measure of diversity (Nei 1987).

Shannon's index of phenotypic diversity (Lewontin 1972; King and Schaal 1989; Russell *et al.* 1993) is also commonly used to determine within and between population diversity. The index 'H' is calculated as:

$$H = -\sum p_i \log_2 p_i$$

where 'p_i' is the frequency of a polymorphic loci.

Gene diversity statistics (Nei 1973) are widely used (Ayres & Ryan 1997; Dawson *et al.* 1993; Scribner *et al.* 1994; Stewart & Porter 1995). These calculations assume that the loci chosen are a random sample from the genome (Nei 1987). Total observed diversity estimates (H_T), can be partitioned into within population diversity (H_S) and between population diversity (D_{ST}), where:

$$H_T = H_S + D_{ST}$$

Gene diversity between populations can then be expressed relative to the total population diversity as:

$$G_{ST} = D_{ST} / H_T$$

Proportion of diversity present within populations can then be calculated by using: $1 - G_{ST}$

F-statistics are used to calculate the overall reduction in average heterozygosity at any one level of the population hierarchy relative to another more inclusive level of the hierarchy. It is therefore informative when examining the overall level of genetic divergence among populations (Hartl & Clark 1997), or when calculating the average number of migrants between populations per generation (Karp *et al.* 1994). Values in the range 0-0.05 indicate little genetic divergence while values over 0.25 indicate high levels of genetic divergence

(Wright 1978, in Hartl & Clark 1997). F-statistics can be calculated for populations from RAPD data using the methods of Wright (1931), Weir and Cockerham (1984) and Lynch and Milligan (1994), as these methods do not require information about heterozygote frequencies. The method of Weir and Cockerham (1984) is more appropriate to studies of species with few small populations as this method includes sample size and population number in the calculations and is thus recommended by many authors (Ayres & Ryan 1997; King & Schaal 1989; Slatkin & Barton 1989).

Wright (1931) is calculated using the equation:

$$F_{ST} = Var(p) / [a(1-a)]$$

where 'a' is the average frequency of one of the alleles in the population, and 'Var(p)' is the variance in frequency of the allele among individuals.

Weir and Cockerham (1984) calculates using the equation:

$$F_{ST} = \frac{s^2 - \frac{1}{2n-1}\left[p(1-p) - \frac{r-1}{r}s^2\right]}{\left[1 - \frac{2nC^2}{(2n-1)r}\right]p(1-p) + \left[1 + \frac{2n(r-1)C^2}{(2n-1)r}\right]\frac{s^2}{r}}$$

where 'r' is the number of populations, 'p' is the average sample frequency of the allele, 'n' is the average sample size, 's^2' is the sample variance of the allele frequency over populations and 'C^2' is the squared coefficient of variation of sample sizes.

Lynch and Milligan (1994) calculates using the equation:

$$F_{ST} = \frac{H_B}{H_T} \times \left[\frac{H_B Var(H_W) - H_W Var(H_B) + (H_B - H_W) Cov(H_B H_W)}{H_B {H_T}^2}\right]^{-1}$$

where H_B is the heterozygosity of individual populations, H_T is the heterozygosity of all populations and H_W is the average expected heterozygosity within populations (equation taken from Apostol *et al.* 1996). 'Cov' is short for covariance, 'Var' is short for variance.

The effective migration rate for all methods is calculated using the equation:

$$N_M = 1 - \left(F_{ST} / 4F_{ST}\right)$$

A chi-squared (χ^2) goodness of fit test can then be carried out to test the significance of the F_{ST} values, using the equation:

$$\chi^2 = 2NF_{ST}$$

Where 'N' is the total sample size. The degrees of freedom are given by (k-1)(s-1); where 'k' is the number of alleles per locus and 's' is the number of populations (equation taken from King & Schaal 1989).

Traditional measures tend to give overestimated values for genetic distance with small sample size, however Nei's (1978) unbiased estimate of genetic distance corrects for this.

If the sample size is too small the diversity value may be 0. Genetic distance matrices can be used to graphically present relationships between individuals or populations by means of phylogenetic trees.

UPGMA (unweighted pair-group method with arithmetic mean) is the simplest method for constructing a phylogenetic tree using distance matrices, and is often the best method for recovering the 'true tree' (Nei 1987). The method's ability to produce the most easily interpretable tree has been noted by other authors, in particular those working with rare species and those with small populations (Ayres & Ryan 1997; Dowe *et al.* 1997; Stewart & Porter 1995). UPGMA is based on the assumption of a constant rate of evolution and does not allow for stochastic errors, and so may be considered inferior to other methods (Nei 1987). However, as the 'true tree' for a data set is rarely known in advance, it is difficult to determine the relative efficiencies of different tree-making methods but computer simulation models show UPGMA often performs best (Nei 1987). UPGMA should be only used for constructing simple trees, and cannot be used as an estimator of gene substitutions at each branch, or for data with a high degree of heterogeneity among branches (Nei 1987).

5.1.6 Aims

The aim of this section was to quantitatively assess the native flora of Pitcairn in terms of its degree of threat and thus identify necessary conservation measures that need to be undertaken. More detailed analysis was then made of three taxa, selected for their rarity and degree of threat. This was carried out to demonstrate how recently developed techniques of molecular analysis could determine the genetic variation within and between populations of threatened species in order to scientifically develop conservation strategies for these species.

5.2 Materials and Methods

5.2.1 Conservation assessment of flora

IUCN Red data threat categories were assigned to all indigenous and endemic species following the criteria detailed in IUCN (1994). The IUCN threat scores give information about the global threat status for the species, and for conservation purposes on Pitcairn Island this is inadequate. Therefore it was necessary to assign an accurate threat status to all species in terms of their distribution on Pitcairn Island itself. For this threat numbers were assigned to all native species based on modifications of the approaches of Rabinowitz *et al.* (1986) and Curtis & McGough (1987), and used for the Pitcairn flora in Waldren *et al.* (1999).

The following criteria and scores were used to assess threat number:

- Population size - the class intervals selected weights the scores in favour of smaller populations

  0 = 1000+ individuals

  1 = 501-1000 individuals

  2 = 101-500 individuals

  3 = 51-100 individuals

  4 = 11-50 individuals

  5 = 5-10 individuals

  6 = 1-4 individuals

- Distribution - The scores were calculated by expressing the number of grid squares (see section 2.2.2) in which a taxon was recorded as proportion (p) of the 75 squares possible, and converting this by a cubic function standardised to give a maximum score of 4. The cubic function weights the scores in favour of taxa that occurred in fewer grid squares, and spreads the taxa evenly across the scores.

$$Score = [2(1-p)]^3 / 2$$

- Attractiveness

  0 = Taxon not obviously attractive

  1 = Taxon with attractive foliage or flowers

- Usefulness

  0 = Taxon with no known or potential uses locally

  1 = Taxon with some potential or minor use

  2 = Taxon representing an important local resource

- Remoteness - occurring in sites that are rarely likely to be visited

  0 = Taxon generally occurring in populations remote from tracks or settlement

  1 = Taxon with at least some populations moderately close to trackways

  2 = Taxon with the majority of populations close to trackways and habitation

- Accessibility - populations that are difficult to reach (on cliffs, for example) though not necessarily remote.

  0 = Access to all populations very difficult

  1 = Easy access to all populations

- Habitat specificity

  0 = Taxon occurs in a variety of habitats

  1 = Taxon occurs in a moderate habitat range

  2 = Taxon restricted to a narrow habitat range

- Habitat vulnerability

  0 = At least some of the habitats in which the taxon occurs are stable

  1 = Habitats may become unstable or threatened

  2 = Habitat unstable or threatened

  3 = Taxon occurs in habitats which are unlikely to persist in present form (including vulnerability due to invasive species)

Threat number was calculated for each taxon by summing the scores for each category. The categories of population size, geographic distribution on Pitcairn and habitat vulnerability have been given a greater weighting in calculating the threat score, and attractiveness and accessibility have been down weighted. We were unable to add a category on regeneration because this was impossible to assess for some taxa. The maximum threat score under this method was 22, with a minimum of zero. This threat score gives a value for the species distribution on Pitcairn Island only. As such, widespread species which have a limited distribution on Pitcairn may obtain a higher score than rare endemic species as they have a higher risk of extinction on the island.

In addition an IUCN threat category was assigned to each species based on their distribution within Pitcairn Island itself. This can be done if the 'area of occupancy' criteria in the IUCN guidelines (criteria B) is ignored. Therefore species which are globally widespread but restricted on Pitcairn will receive a threat category. This was carried out for comparison with the calculated threat scores.

5.2.2 Selection of species for more detailed study

Ideally, when compiling conservation strategies for threatened species, a detailed knowledge of the genetic variation within and between the populations of the species is obtained. However, due to time and logistic constraints it was not possible to carry out

such a detailed assessment for all of the threatened species on Pitcairn. Instead it was decided to select three of the most threatened taxa and develop a step by step model by which one or other populations could be easily and cost effectively assessed for their conservation needs.

5.2.3 Population survey

A population survey was carried out in the field for each of the three species. For each population (or individual in the case of *Coprosma benefica*) the name of the site was recorded, as were the numbers and sizes of mature, fertile and juvenile individuals, habitat and ecological information. In the case of *Angiopteris chauliodonta* the individuals were assigned to a size class based on the length of the longest frond.

5.2.4 Sample collection

Tissue samples for DNA analysis were collected in July-September 1997, placed in zip-lock bags in the field and rapidly dried in silica gel. Collections of *Angiopteris chauliodonta*, *Coprosma benefica* and *Lastreopsis* cf *pacifica* were made on Pitcairn island, while three other collections were made from *Angiopteris* spp. populations, one from each of Tahiti, Moorea and Huahine islands. While the ideal method is to extract DNA from fresh samples, silica gel dried samples have proven to be nearly as successful (Chase & Hills 1991). A ratio of 10:1, fresh material:silica gel was kept where possible, in order to dry the samples as quickly as possible. If possible the sample material was kept intact as this reduces cell damage. When the silica gel became hydrated it was changed for freshly desiccated silica gel, and this was continued until the sample was totally dry. When the material was fully dehydrated the amount of silica gel was reduced.

Where possible six collections were made from each of the populations of *Angiopteris chauliodonta* found, with care being taken not to sample from obvious clones. In two of the smallest populations, Faute Valley and Garnets Ridge, three collections were made. One collection was made from each *Coprosma benefica* individual known, thus representing the entire global population. Forty collections were made from the population of *Lastreopsis* cf *pacifica*. Samples collected were of leaf or frond material, and were collected from young, actively growing shoots, if available.

5.2.5 DNA Extraction

DNA was extracted using a protocol taken from Scally (2001) and Martin (1998), which was modified from Hillis 1990. Quantities were changed as less dried than fresh material is needed in the initial stages (Chase & Hills 1991). All chemicals used in the following protocols were of analytical grade.

0.1-0.3g of dried tissue sample was placed in a mortar with liquid nitrogen. The sample was then ground to a fine powder with a pestle. The liquid nitrogen freezes the sample while grinding and prevents enzymes breaking down the DNA. The material was then

divided between two 1.5ml microfuge tubes, each tube containing 0.05-0.1g of leaf material, and 1ml of 2% CTAB extraction buffer [150mM Tris[hydroxymethyl]aminomethane hydrochloride (Tris-HCl) (pH 7.5), 1M NaCl, 15mM Ethylenediaminetetra-acetic acid (EDTA) (pH 8.0) and 1% Hexadecyltrimethylammonium bromide (CTAB)] was added. The tubes were inverted gently and then incubated in a water bath at 65^{0}C for 45 minutes, with occasional gentle inversion to mix the extraction buffer and plant material.

500µl of chloroform:isoamyl alcohol (24:1) was then added to each tube, and the tubes inverted gently before being left at room temperature for 15 minutes. The tubes were then centrifuged for 5 minutes at 13,000 rpm in a centrifuge, before the upper (aqueous) layer was pipetted into a fresh tube and re-extracted with chloroform:isoamyl alcohol. The tubes were again centrifuged for 5 minutes at 13,000 rpm and the supernatant was pipetted to a fresh tube. 1ml of ice cold isopropanol was added and the tubes were then placed at -20^{0}C overnight to precipitate the DNA.

Following precipitation the tubes were removed from the freezer and centrifuged for 5 minutes at 13,000rpm. The alcohol was poured off and the pellet was washed with 500µl of 95% ethanol. The tube was gently flicked to ensure that the pellet did not stick to the sides of the tube and was more thoroughly washed. Again the tubes were centrifuged and the pellet washed with 75% ethanol. The ethanol was poured off and the tubes were allowed to dry in an incubator at 60^{0}C until all traces of ethanol had disappeared from the sides of the tube and the pellet.

100µl of TE [10mM Tris-HCl (pH 7.5), 1mM EDTA (pH 8.0)] was added to each tube and the pellet re-dissolved. Because DNA is very soluble in water the pellet usually dissolved readily. If it did not dissolve easily the volume of TE was increased or the tube was placed at 37^{0}C for two minutes. In some cases undissolved gelatin-like material was present and had to be removed by centrifugation, with the supernatant being transferred to a fresh tube.

Determination of the concentration and purity of the DNA was then assessed by gel electrophoresis by running the samples mixed with 1µl loading dye [40% Sucrose, 0.25% Bromophenol blue] on a 1.5% agarose gel (8 x 6 cm) stained with ethidium bromide in 1xTBE [45mM Tris-HCl, 44mM Boric acid, 1mM EDTA], at 125 volts for 15 minutes, in a Horizon® 58 gel rig. The samples were run against a ladder of known DNA concentration. The gel was illuminated under UV light and photographed using a Kodak Digital Science DC120 Zoom Digital Camera. Concentration was estimated by comparison with the standard of known concentration. If there was excessive smearing 1µl of RNAse was added to each tube and the tube placed at 37^{0}C for 30 minutes. The samples were stored in a freezer at -20^{0}C.

This protocol was satisfactory for the extraction of DNA from *Angiopteris chauliodonta* and *Lastreopsis* cf *Pacifica*. For *Coprosma benefica* it was unsuccessful in extracting DNA of a adequate quality for PCR reaction. Several extraction protocols were tried, but QIAGEN® DNeasy™ plant mini kits were found to yield the best quality DNA and so were subsequently used. These kits require small amounts of plant material (maximum 0.02g), and necessitate minimal contact with the sample.

Plant material was weighed into 1.5ml microfuge tubes and ground immediately using sterile sand that had been stored at -80°C. 400µl of buffer AP1 and 4µl of RNAse A stock solution was added and the tubes vigorously vortexed to completely mix the solution and plant material. The tubes were then incubated for 15 minutes at 65°C, with the solution being mixed by inversion every 5 minutes. 130µl of buffer AP2 was then added and the tubes incubated for 5 minutes on ice. The lysate was transferred by pipette to the QIAshredder® spin column surface, with the column placed in a 2ml collection tube, and centrifuged for 2 minutes at 15,000 rpm. The liquid flow through was then transferred to a new 1.5ml tube, but any debris was not transferred. The amount of liquid collected was estimated and 0.5 volume of buffer AP3 and one volume of ethanol were added and mixed well by pipetting. 650µl of the resulting mixture was added to the membrane of the DNeasy™ mini spin column, placed in a 2ml collection tube, and the columns centrifuged for 1 minute at 8000rpm. The flow through was discarded and the process repeated with any remaining solution. The flow through was again discarded, and 500µl of buffer AW were added to the column membrane. The columns were spun for 2 minutes at 15,000rpm and the flow through and collection tube were discarded. The DNeasy™ column was transferred to a new 1.5ml microfuge tube and 50µl of heated buffer AE (65°C) was applied to the column membrane. The columns were incubated for 5 minutes at room temperature and then centrifuged for 1 minute at 8000rpm. The column was transferred to a new 1.5ml microfuge tube, 50µl of heated buffer AE again applied to the column and following incubation at room temperature for 5 minutes, the column was again centrifuged at 8000rpm for 1 minute. This allowed collection of all available DNA while not diluting the first elution. The concentration of the samples was determined as before and the samples stored at -20°C until use.

5.2.6 PCR Reaction

RAPD analysis was chosen as the PCR technique as it was considered the most tecnologically simple and cost effective technique. In addition it has been more widely applied to studies of rare species than the more recently developed techniques of AFLP and ISSR, for which many of the technical weaknesses have not yet been uncovered.

RAPD reactions were made to a total reaction volume of 50µl, containing PCR Buffer x10 [10mM Tris-HCl (pH 9.0), 50mM KCl], 3mM $MgCl_2$, 200µM each of dATP, dCTP, dGTP and dTTP, 2 units of Taq polymerase, 0.5µM primer (see below), and 1µl of total DNA (the

mass of DNA in 1µl varied slightly). Reactions were made up over ice and spun for 1 minute at 10,000 rpm before being overlaid with 25µl of mineral oil. Reactions were carried out using a Perkin-Elmer 480 Thermal Cycler (40 cycles of 94°C for 1 minute, 36°C for 2 minutes and 72°C for 2 minutes, followed by 1 cycle of 72°C for 5 minutes).

PCR amplification products were initially viewed on a 1.5% agarose gel (14 x 11 cm) stained with ethidium bromide, run in 1 x TBE Buffer at 110 volts for 1 hour in a Horizon® 11.14 gel rig. If the reaction was successful, with no contamination, they were then run on a 2% agarose gel (27 x 19.5 cm) stained with ethidium bromide, run in 1 x TBE at 80 volts for 5 hours in a Flowgen 06170 gel rig. A 1 Kb DNA ladder (GibcoBRL) with a banding pattern of known fragment size was run in the first and last lanes, in order to aid with the scoring of bands between gels. Gels were examined on an ultra violet transilluminator and photographed using a Kodak Digital Science DC120 Zoom Digital Camera. Images were imported into Kodak Digital Science ID 2.0.2 image analysis package and printed using an Apple Laser writer.

5.2.7 Primer screening

Primers from Operon Technologies 10-mer kits A, B and C were screened using samples from the three selected species, *Angiopteris chauliodonta*, *Coprosma benefica* and *Lastreopsis* cf *pacifica*. Primers that showed unequivocal banding with polymorphism were selected for each species.

5.2.8 Band Scoring

Presence of bands was scored by eye from the printed photographs, and converted into a 1/0 matrix. Only uneqivocal bands were scored, with weak and spurious bands not being included. Computer based scoring was not considered consistent enough.

5.2.9 Data analysis

To assess the overall distribution of diversity within and between populations for each species several measures were used. This was done because there is little consensus in the literature as to how population variation using RAPD-PCR should be analysed and presented.

Initially UPGMA cluster analyses were employed to obtain dendrograms for the populations being assessed (see section 4.2.7). Input matrices used were Nei's (1978) unbiased genetic distance, which allows for small sample size (Nei 1987). UPGMA was used over other methods (eg Neighbor-joining, Dollo parsimony) as it more accurately portrayed the relationships between individuals. This has also been noted by other authors (Ayres & Ryan 1997; Dowe *et al.* 1997; Stewart & Porter 1995), who recommend it for use with studies of rare and endangered species.

Similarly, ordination of the data was carried out using the technique of Nonmetric Multidimensional Scaling (NMDS) using the Sørensen coefficient as the distance measure

(see section 3.1.2 & 4.2.7), and a Monte Carlo test of 100 runs. Multivariate analyses in general allow for a derivation of the natural groupings among individuals, and NMDS in particular complements the clusiter analysis by allowing an assessment of the robustness of the groups obtained (Ayres & Ryan 1997). NMDS using 2 unrotated axes gave the lowest stress values for both the *Angiopteris* and *Coprosma* data sets, while 2 rotated axes gave the lowest stress for the *Lastreopsis* cf *pacifica* data set.

In addition to the graphical analysis, several other quantitative estimates of diversity were measured, as outlined in the introduction. These were Percentage polymorphic loci, Shannon Index of Phenotypic diversity, Nei's (1973) gene diversity statistics, and F-statistics. Three F-statistics were measured for comparison, Wrights (1931), Weir and Cockerham (1984) and Lynch and Milligan (1994).

NMDS was calculated using PC-ORD ver. 3.2, and graphs were drawn using MS Excel 2000. Percentage polymorphic loci, Shannon Index of Phenotypic diversity and Nei's (1978) genetic distance were calculated using POPGENE ver.1.31. (Yeh & Boyle 1997). UPGMA dendrograms and input matrices were also calculated using POPGENE. Wrights (1931), Weir and Cockerham (1984) and Lynch and Milligan (1994) F-statistics were calculated using RAPDFST 4.0.1 (Black 1997).

5.3 Results

5.3.1 Conservation assessment of flora

All indigenous and endemic species were evaluated both for their threat status on Pitcairn, and their IUCN status for both their distribution on Pitcairn Island and for their global distributions. IUCN Red data categories were assigned based on the criteria from IUCN (1994), which are summarised in section 5.1.2. The categories for each species, with the criteria used to determine the categories in square brackets, and estimation of the proportion of the world distribution found in the Pitcairn Islands, are presented below. The habitats in which the species occur, threats to the species and in and ex-situ conservation measures are also presented. TCD refers to the Trinity College Botanic Gardens in which seed and spore collections are in cultivation and storage. Only species in the top 50 ranked by threat score, or which had a risk threat category (EX, CR, EN, VU) for either their Pitcairn or World distributions are presented here, alphabetially by family as in section 2.3.3. A summary table of categories for all species including those with a low risk status is presented in Appendix 5, with a ranked list for all species in Appendix 6.

DICOTYLEDONAE

Apocynaceae

Alyxia scandens Roem. & Schult. (Ind)
Threat score: 8
Pitcairn category: VU [D]
World category: LR [nt]
Number of plants on Pitcairn: <1000 (proportion of world population: <1%)
Habitat requirements: prefers shaded coastal cliff and scrub communities, especially around Tautama.
Threats: encroachment of invasive scrub, lack of bird dispersal agent.
In-situ conservation measures: propagate seed for planting in potentially restored woodland areas
Ex-situ conservation measures: no specific measures needed

Cerbera manghas L. (Ind)
Threat score: 8.6
Pitcairn category: VU [D1]
World Category: LR [lc]
Number of plants on Pitcairn: <1000 (proportion of world population: <1%)
Habitat requirements: found in open mixed woodland, steep slopes and on woodland edges, mainly around Tedside.
Threats: encroachment of invasive woodland, ridge erosion.

In-situ conservation measures: propagate seed for planting in potentially restored woodland areas

Ex-situ conservation measures: no specific measures needed

Asteraceae

Bidens mathewsii Sherff (End)

Threat score: 8.6

Pitcairn category: VU [D1]

World Category: VU [D1, D2]

Number of plants on Pitcairn: <1000 (proportion of world population: 100%)

Habitat requirements: occurs in shaded cliff and scrub communities, especially in southern coastal areas.

Threats: encroachment of invasive scrub.

In-situ conservation measures: encourage increased use as ornamental on Pitcairn

Ex-situ conservation measures: in cultivation in TCD

Boraginaceae

Argusia argentea L.f. (Ind)

Threat score: 17.8

Pitcairn category: CR [B1, D]

World Category: LR [lc]

Number of plants on Pitcairn: <10 (proportion of world population: <1%)

Habitat requirements: coastal communities.

Threats: erosion of coastal areas, invasion of coastal areas by *Cocos nucifera* and *Crinum asiaticum*

In-situ conservation measures: Monitor population (individual), no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat; Not threatened on Henderson Island or Oeno atoll

Brassicaceae

Lepidium bidentatum Montin (Ind)

Threat score: 13.8

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: coastal rocky communities

Threats: erosion of coastal areas, invasion by *Carpobrotus edulis*

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: not threatened on Henderson Island or Oeno atoll

Capparidaceae

Capparis cordifolia Lam. (Ind)

Threat score: not assigned

Pitcairn category: EX/CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: ? (proportion of world population: <1%)

Habitat requirements: coastal rocky communities

Threats: erosion of coastal areas, invasion of coastal areas by *Cocos nucifera* and *Crinum asiaticum*

In-situ conservation measures: relocate

Ex-situ conservation measures: no specific measures needed

Notes: Last seen 1922 by Whitney Expedition; little suitable habitat; not threatened on Henderson Island

Convolvulaceae

Ipomoea littoralis Blume (Ind)

Threat score: 13.8

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, invasion of coastal areas by *Cocos nucifera* and *Crinum asiaticum*

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat

Ipomoea macrantha Roem. & Schult. (Ind)

Threat score: 16

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, invasion of coastal areas by *Cocos nucifera* and *Crinum asiaticum*

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat

Ipomoea pes-caprae L. (Ind)

Threat score: 10.3

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, invasion of coastal areas by *Cocos nucifera* and *Crinum asiaticum*

In-situ conservation measures: search for extant individuals, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat

Euphorbiaceae

Chamaesyce sparrmannii (Boiss.) Hurus. (Ind)

Threat score: 3.6

Pitcairn category: LR [lc]

World Category: VU [D2]

Number of plants on Pitcairn: 1000+ (proportion of world population: c.10% on Pitcairn, c.85% on Henderson)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, spread of invasive species in coastal areas.

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: not threatened on Henderson Island, only other site is the Marotiri rocks

Glochidion comitum Florence (End)

Threat score: 11.3 (inferred from *G. pitcairnense*)

Pitcairn category: CR [D]

World Category: CR [D]

Number of plants on Pitcairn: <50 (proportion of world population: 100%)

Habitat requirements: unknown, probably native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as timber

In-situ conservation measures: Relocate and propagated from cuttings and seed

Ex-situ conservation measures: Propagate specimen in TCD; collect seed for storage in TCD

Notes: Last seen 1991; refind, survey population and collect seed; genus subject of genetic study in TCD

Glochidion pitcairnense (F.Br.) H.St.John (Ind)

Threat score: 7.9

Pitcairn category: VU [A1(d), D]

World Category: VU [A1(d), D1, D2]

Number of plants on Pitcairn: <500 (proportion of world population: 100% on Pitcairn & Henderson)

Habitat requirements: all native woodland communities, and open disturbed scrub

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as timber

In-situ conservation measures: Propagate seed for planting in potentially restored woodland areas

Ex-situ conservation measures: Successfully propagated in TCD; seed collection in TCD genebank

Notes: Genus subject of detailed genetic study in TCD; not threatened on Henderson Island and appears to be regenerating on Pitcairn.

Flacourtiaceae

Homalium taypau H.St.John (End)

Threat score: 8.1

Pitcairn category: LR [nt]

World Category: VU [D2]

Number of plants on Pitcairn: 1000+ (proportion of world population: 100%)

Habitat requirements: all native woodland communities, where it is commonly the dominant canopy tree.

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as timber

In-situ conservation measures: Propagate cuttings in nursery for planting in potentially restored woodland areas

Ex-situ conservation measures: collect seed if seen, propagate and store in TCD

Notes: Detailed study of reproductive biology urgently needed

Xylosma suaveolens (J.R.Forst. & G.Forst.) G.Forst. (Ind)

Threat score: 10.6

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: margins of native woodland communities, especially on steep slopes

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent

In-situ conservation measures: Propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: Seed collection in propagation and storage in TCD; 85% germination from seed, roots easily from cuttings

Notes: Study needed to determine relationships of subspecies in Pacific region; dioecious; vulnerable on Henderson Island

Goodeniaceae

Scaevola sericea Vahl (Ind)

Threat score: 10.8

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, spread of invasive species in coastal areas.

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat; Not threatened on Henderson Island or Oeno atoll

Haloragaceae

Haloragis sp. (End?)

Threat score: 9.3

Pitcairn category: EN [D]

World Category: EN [D]

Number of plants on Pitcairn: <250 (proportion of world population: unknown, 100% if endemic)

Habitat requirements: occurs in shaded cliff and scrub communities, especially in southern coastal areas.

Threats: encroachment of invasive scrub.

In-situ conservation measures: Carry out detailed survey of populations; propagate from seed and cuttings in island nursery

Ex-situ conservation measures: Collect seed for propagation and storage in TCD

Notes: Determine species identity

Hernandiaceae

Hernandia sonora L. (Ind)

Threat score: 12.5

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: native mixed woodland communities, especially in the base of humid valleys

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as timber

In-situ conservation measures: propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: no specific measures needed

Notes: study needed to determine relationships of species in Pacific region

Leguminosae

Caesalpinia major (Medik.) Dandy & Exell (Ind)

Threat score: 9.5

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: margins of native *Homalium taypau* woodland

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Not threatened on Henderson Island

Lythraceae

Pemphis acidula J.R.Forst. & G.Forst. (Ind)

Threat score: not assigned

Pitcairn category: EX/CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: ? (proportion of world population: <1%)

Habitat requirements: coastal communities

Threats: erosion of coastal areas, spread of invasive species in coastal areas.

In-situ conservation measures: no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Last seen by Quayle 1922; little suitable habitat on Pitcairn; Not threatened on Henderson Island

Malvaceae

Abutilon pitcairnense Fosberg (End)

Threat score: not assigned

Pitcairn category: EX/CR [A1(c-e), B2(a-e), C1, C2, D]

World Category: EX/CR [A1(c-e), B2(a-e), C1, C2, D]

Number of plants on Pitcairn: (proportion of world population: 100%)

Habitat requirements: unknown, probably native woodland communities

Threats: unknown, probably spread of invasive species

In-situ conservation measures: relocate if possible

Ex-situ conservation measures: if relocated, propagate immediately

Notes: Last seen 1955 by I. T. Twyford; last collected 1934 by H. St. John 1934

Hibiscus australense Fosberg (Ind)

Threat score: 10.9

Pitcairn category: EN [D]

World Category: DD

Number of plants on Pitcairn: <250 (proportion of world population: ?<10%)

Habitat requirements: ridge communities, especially near the coast

Threats: spread of invasive species, especially grasses on dry ridges

In-situ conservation measures: carry out detailed survey of populations; propagate from seed and cuttings

Ex-situ conservation measures: collect seed for propagation and storage in TCD

Notes: accurately determine Polynesian distribution; may be more threatened

Menispermaceae

Cocculus ferrandianus Gaudich (Ind)

Threat score: 8.2

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <100 (proportion of world population: <1%)

Habitat requirements: coastal rocky communities, although may have occurred farther inland in the past, as closely related species are found on inland cliffs in Rarotonga.

Threats: erosion of coastal areas, spread of invasive species in coastal areas, lack of a bird dispersal agent.

In-situ conservation measures: Propagate from cuttings on Pitcairn for planting in suitable areas

Ex-situ conservation measures: no specific measures, make seed collection if seed is seen

Notes: Never seen in flower or seed, so identity of species uncertain

Myrsinaceae

Myrsine aff. *niauensis* (End)

Threat score: not assigned

Pitcairn category: EX/CR [D]

World Category: EX/CR [B2(a-e), D]

Number of plants on Pitcairn: (proportion of world population: 100%)

Habitat requirements: unknown, probably native woodland communities

Threats: unknown, probably spread of invasive woodland communities, lack of a bird dispersal agent.

In-situ conservation measures: relocate if possible

Ex-situ conservation measures: if relocated, propagate immediately

Notes: Collection made in 1898 islander R. Young, and in 1830 by A. Matthews

Myrtaceae

Metrosideros collina (J.R.Forst. & G.Forst.) A.Gray. (Ind)

Threat score: 8.4

Pitcairn category: LR [lc]

World Category: LR [lc]

Number of plants on Pitcairn: 1000+ (proportion of world population: <1%)

Habitat requirements: native woodland communities in which it is commonly the dominant canopy tree, especially at higher altitudes; shrub form also found on eroding slopes

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: Propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: No specific measures needed

Nyctaginaceae

Pisonia umbellifera (J.R.Forst. & G.Forst.) Seem. (Ind)

Threat score: 13.3

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: native mixed woodland communities, especially in the base of humid valleys

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent as the sticky fruits are large

In-situ conservation measures: Propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: No specific measures needed

Notes: Rare in undisturbed woodland

Oleaceae

Jasminum didymum G.Forst. (Ind)

Threat score: 15

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: native *Metrosideros collina* woodland

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as an ornamental
In-situ conservation measures: Encourage increased, but sustainable use as ornamental on Pitcairn (ie from cuttings rather than wild collections)
Ex-situ conservation measures: make seed collection for storage if possible
Notes: Not seen in fruit

Piperaceae

Peperomia pitcairnensis (Lauterb.) C.DC (End)
Threat score: 6
Pitcairn category: EN [D]
World Category: EN [D]
Number of plants on Pitcairn: <250 (proportion of world population: 100%)
Habitat requirements: native mixed and *Metrosideros collina* woodland communities
Threats: clearance of native woodland, encroachment of invasive woodland
In-situ conservation measures: propagate on Pitcairn; grows easily from cuttings and seed.
Ex-situ conservation measures: successfully propagated at TCD
Notes: Genus subject of detailed genetic study in TCD

Peperomia rapensis F.Br. (Ind)
Threat score: 7.6
Pitcairn category: EN [D]
World Category: VU [D2]
Number of plants on Pitcairn: <250 (proportion of world population: c.20%)
Habitat requirements: native mixed and *Metrosideros collina* woodland communities
Threats: clearance of native woodland, encroachment of invasive woodland
In-situ conservation measures: Propagate on Pitcairn
Ex-situ conservation measures: Propagation protocol developed in TCD - seed has short viability after collection
Notes: Genus subject of detailed genetic study in TCD

Peperomia sp. (End)
Threat score: 10.7
Pitcairn category: CR [C2(b)]
World Category: CR [C2(b)]
Number of plants on Pitcairn: <250 (proportion of world population: 100% if endemic)
Habitat requirements: damp, south facing coastal cliffs
Threats: encroachment of invasive species, coastal erosion
In-situ conservation measures: propagate on Pitcairn
Ex-situ conservation measures: successfully propagated in TCD, from both seed and cuttings.

Notes: Genus subject of detailed genetic study in TCD

Primulaceae

Samolus repens Pers. (Ind)

Threat score: 9.7

Pitcairn category: EN [D]

World Category: LR [nt]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: occurs in shaded cliff and scrub communities, especially in southern coastal areas.

Threats: encroachment of invasive scrub.

In-situ conservation measures: carry out detailed survey of populations; propagate from seed and cuttings

Ex-situ conservation measures: collect seed for propagation and storage in TCD

Notes: accurately determine species identity

Rosaceae

Osteomeles anthyllidifolia (Sm.) Lindl. (Ind)

Threat score: 17.3

Pitcairn category: CR [D]

World Category: DD

Number of plants on Pitcairn: <10 (proportion of world population: <1%)

Habitat requirements: cliffs and rock faces in coastal areas

Threats: erosion of cliffs and ridges, lack of bird dispersal agent, exploitation as an ornamental

In-situ conservation measures: propagate if possible; to date unsuccessful either from seed or cuttings

Ex-situ conservation measures: collect seed for storage and propagation in TCD

Notes: assess worldwide population

Rubiaceae

Coprosma benefica W.R.B.Oliv. (End)

Threat score: 15.5

Pitcairn category: CR [A1(c-e), A2, B1, B2(a-e), C1, C2, D]

World Category: CR [A1(c-e), A2, B1, B2(a-e), C1, C2, D]

Number of plants on Pitcairn: <50; only 12 individuals found in 1997 despite careful searches (proportion of world population: 100%)

Habitat requirements: currently found in degraded scrub, probably used to occur at margins of native woodland communities.

Threats: clearance of native woodland, encroachment of invasive species, lack of bird dispersal agent

In-situ conservation measures: propagate all individuals from cuttings and seed

Ex-situ conservation measures: propagate and store seed in TCD

Notes: detailed assessment of genetic variation in population in section 5.4.3

Cyclophyllum barbatum (G.Forst.) N.Hallé & Florence (Ind)

Threat score: 9.8

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: native mixed woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as an ornamental (Christmas tree)

In-situ conservation measures: propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: in cultivation in TCD

Notes: not threatened on Henderson Island

Guettarda speciosa L. (Ind)

Threat score: 11.2

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: native mixed woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: Propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: no specific measures needed

Notes: not threatened on Henderson Island

Psydrax odorata (G.Forst.) A.C.Sm. & S.P.Darwin (Ind)

Threat score: 12.1

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: margins of native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent, exploitation as an ornamental (Christmas tree)

In-situ conservation measures: Propagate seed and cuttings for planting in potentially restored woodland areas

Ex-situ conservation measures: no specific measures needed

Notes: trial translocation of 235 seed from Jack Willems to Faute Valley initiated in 1997; Not threatened on Henderson Island

Ulmaceae

Celtis pacifica G.Planch. (Ind)

Threat score: 15.8

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50; only one individual found in 1997 (proportion of world population: <5%)

Habitat requirements: native mixed woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland, lack of bird dispersal agent

In-situ conservation measures: propagate from cuttings on Pitcairn for planting in potentially restored woodland areas

Ex-situ conservation measures: no specific measures needed

Notes: Not seen in seed; single individual known from Pitcairn; Not threatened on Henderson Island

Urticaceae

Pilea sancti-johannis Florence (Ind)

Threat score: 11

Pitcairn category: CR [D]

World Category: CR [D]

Number of plants on Pitcairn: <50 (proportion of world population: 0.5)

Habitat requirements: cliffs and rock faces

Threats: erosion of cliff and ridge habitats

In-situ conservation measures: propagate on Pitcairn and introduce to further areas

Ex-situ conservation measures: successfully propagated at TCD

Notes: distribution restricted to Pitcairn and Gambier Islands

MONOCOTYLEDONAE

Liliaceae

Dianella intermedia Endl. (Ind)

Threat score: 12.2

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: coastal rocky communities, although may have occurred farther inland in the past, as on other Polynesia islands.

Threats: erosion of coastal areas, spread of invasive species in coastal areas, lack of a bird dispersal agent.

In-situ conservation measures: Monitor populations; translocate to other areas

Ex-situ conservation measures: Seed in storage in TCD

Notes: Common on other Polynesian islands; vulnerable on Henderson Island

Poaceae

Cenchrus calyculatus Cav. (Ind)

Threat score: 11.8

Pitcairn category: CR [D]

World Category: VU [A2(c)]

Number of plants on Pitcairn: <20 (proportion of world population: <1%)

Habitat requirements: coastal rocky communities

Threats: erosion of coastal areas, spread of invasive species in coastal areas

In-situ conservation measures: collect seed and relocate to protected coastal area

Ex-situ conservation measures: no specific measures needed

Notes: species is declining across Polynesia, and is extinct in many of its former localities (Whistler 1992)

Lepturus repens (G.Forst.) R.Br. (Ind)

Threat score: 8.9

Pitcairn category: EN [D]

World Category: LR [lc]

Number of plants on Pitcairn: <250 (proportion of world population: <1%)

Habitat requirements: coastal rocky communities

Threats: erosion of coastal areas, spread of invasive species in coastal areas

In-situ conservation measures: Monitor populations, no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Little suitable habitat; Not threatened on Henderson Island or Oeno atoll

PTERIDOPHYTA

Adiantaceae

Adiantum hispidulum Sw. (Ind)

Threat score: 9.6

Pitcairn category: VU [D]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: native woodland, especially about the roots of *Homalium taypau* and in rock crevices

Threats: spread of invasive woodland communities.

In-situ conservation measures: encourage increased sustainable use as ornamental on Pitcairn (ie from cuttings and spores rather then wild collections)

Ex-situ conservation measures: successfully propagated at TCD; spore collection in TCD genebank

Notes: islanders suggest it was previously more widespread across the island

Aspidiaceae

Arachnoides aristata (G.Forst.) Tindale (Ind)

Threat score: 9.2

Pitcairn category: LR (lc)

World Category: LR (lc)

Number of plants on Pitcairn: 5000+ (proportion of world population: <1%)

Habitat requirements: native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: propagate from spores for planting into areas cleared of invasive species

Ex-situ conservation measures: no specific measures needed

Ctenitis cumingii Holttum (End)

Threat score: 10.4

Pitcairn category: EN [D]

World Category: EN [D]

Number of plants on Pitcairn: <250 (proportion of world population: 100%)

Habitat requirements: native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: carry out detailed survey of populations; propagate from spores

Ex-situ conservation measures: successfully propagated at TCD

Lastreopsis cf. *pacifica* (Ind)

Threat score: 15.2

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: currently found in *Syzygium jambos* woodland, probably previously found in native woodland communities

Threats: Browns Water is at risk from erosion

In-situ conservation measures: propagate from spores for population reinforcement

Ex-situ conservation measures: in cultivation in TCD

Notes: detailed genetic assessment of population in section 5.4.4

Athyriaceae

Diplazium harpeodes T.Moore (Ind)

Threat score: 14

Pitcairn category: CR [D]

World Category: LR [lc]

Number of plants on Pitcairn: <50 (proportion of world population: <1%)

Habitat requirements: native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: propagate on Pitcairn and reinforce existing populations

Ex-situ conservation measures: successfully propagated in TCD

Notes: 29 individuals known from 6 populations

Cyatheaceae

Cyathea medullaris (G.Forst.) Sw. (Ind)

Threat score: 10.4

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: both native and non-native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland, exploitation of trunks for carvings

In-situ conservation measures: propagate spores for planting in potentially restored woodland areas

Ex-situ conservation measures: spore collection in cultivation and storage in TCD

Hymenophyllaceae

Trichomanes endlicherianum C.Presl (Ind)

Threat score: 8.6

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: damp rocks in native and non-native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: monitor populations, no specific measures needed

Ex-situ conservation measures: in cultivation in TCD, no specific measures needed

Trichomanes tahitense Nadeaud (Ind)

Threat score: 8.5

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: damp rocks in native and non-native woodland communities
Threats: clearance of native woodland, encroachment of invasive woodland
In-situ conservation measures: Monitor populations, no specific measures needed
Ex-situ conservation measures: no specific measures needed

Marattiaceae

Angiopteris chauliodonta Copel. (End)
Threat score: 13.4
Pitcairn category: CR [A1(c-e), B1, B2(a-e), C2]
World Category: CR [A1(c-e), B1, B2(a-e), C2]
Number of plants on Pitcairn: <250 (proportion of world population: 100%)
Habitat requirements: both native and non-native woodland communities
Threats: clearance of native woodland, encroachment of invasive woodland, erosion in Browns Water, exploitation of fronds for bedding
In-situ conservation measures: propagate for reinforcement of population and planting in potentially restored woodland areas
Ex-situ conservation measures: in propagation in TCD
Notes: detailed population genetic study of this species in section 5.4.2.

Ophioglossaceae

Ophioglossum nudicaule L. (Ind)
Threat score: 10.5
Pitcairn category: EN [D]
World Category: LR [lc]
Number of plants on Pitcairn: <250 (proportion of world population: <1%)
Habitat requirements: ridges and eroding slopes, especially on damp flushes
Threats: spread of invasive species, erosion of habitat
In-situ conservation measures: monitor populations, no specific measures needed
Ex-situ conservation measures: no specific measures needed

Ophioglossum reticulatum L. (Ind)
Threat score: 10.5
Pitcairn category: EN [D]
World Category: LR [lc]
Number of plants on Pitcairn: <250 (proportion of world population: <1%)
Habitat requirements: ridges and eroding slopes, especially on damp flushes
Threats: spread of invasive species, erosion of habitat
In-situ conservation measures: monitor populations, no specific measures needed
Ex-situ conservation measures: no specific measures needed, in cultivation in TCD

Polypodiaceae

Phymatosorus commutatus (Blume) Pic.Serm. (Ind)

Threat score: 9.1

Pitcairn category: VU [D]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: margins of both native and non-native woodland communities

Threats: clearance of native woodland, encroachment of invasive woodland

In-situ conservation measures: Propagate spores for planting in areas cleared of invasive species

Ex-situ conservation measures: in cultivation in TCD, no specific measures needed

Phymatosorus powellii (Baker) Pic.Serm. (Ind)

Threat score: 11.1

Pitcairn category: VU [D]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <5%)

Habitat requirements: native woodland communities and fernlands

Threats: clearance of native woodland, encroachment of invasive woodland, erosion of fernlands

In-situ conservation measures: Propagate spores for planting in areas cleared of invasives

Ex-situ conservation measures: no specific measures needed

Pteridaceae

Acrostichum aureum L. (Ind)

Threat score: not assigned

Pitcairn category: EX/CR

World Category: LR [nt]

Number of plants on Pitcairn: 0 (proportion of world population: 0%)

Habitat requirements: saltmarsh and swamp, no suitable habitat on Pitcairn

Threats: unknown

In-situ conservation measures: no specific measures needed

Ex-situ conservation measures: no specific measures needed

Notes: Observed by Bennett 1834, doubtful record as no suitable habitat

Vittariaceae

Vittaria elongata Sw. (Ind)

Threat score: 8.3

Pitcairn category: VU [D1]

World Category: LR [lc]

Number of plants on Pitcairn: <1000 (proportion of world population: <1%)

Habitat requirements: damp rocks in native woodland communities
Threats: clearance of native woodland, encroachment of invasive woodland
In-situ conservation measures: monitor populations, no specific measures needed
Ex-situ conservation measures: no specific measures needed

LYCOPHYTA

Lycopodiaceae

Lycopodium cernuum L. (Ind)
Threat score: 10
Pitcairn category: LR [lc]
World Category: LR [lc]
Number of plants on Pitcairn: 1000+ (proportion of world population: <1%)
Habitat requirements: eroding slopes, roadsides, fernlands
Threats: severe erosion, encroachment of invasive scrub
In-situ conservation measures: monitor populations, no specific measures needed
Ex-situ conservation measures: no specific measures needed

In general there is overall agreement between the threat score and the IUCN category for the threat on Pitcairn. Anomalies include *Ipomoea macrantha*, ranked 17th by the IUCN criteria, but ranked 3rd by the threat score. This is due to the fact that the threat score considers the threat status of the species' habitat, in this case easily accessible at the main landing point on the island, as well as the species potential for exploitation, in this case large attractive flowers, factors which are not considered by the IUCN analysis. The top 4 species in the threat scores are all represented by single individuals on Pitcairn. Another anomaly is shown by *Pilea sancti-johannis* which, with a threat number of only 11.04, was assigned Critically Endangered by the IUCN categories, while *Phymatosorus powellii* with a slightly higher threat score of 11.05 was only classified as Vulnerable. This is probably because *Pilea sancti-johannis* exists in small numbers on a small area of very remote cliffs, while the *Phymatosorus powellii* is more widespread but occurs in easily reached locations and has some potential for exploitation. Similarly, *Lycopodium cernuum* and *Metrosideros collina* are both Low Risk under IUCN criteria, but here receive a threat score higher than many Endangered and Vulnerable species, due to the vulnerability of their habitats. Threat scores could not be calculated for extinct taxa, as data on their habitat and distribution were unknown.

Table 5.1 of the number of species in each IUCN category, shows that 63% of the indigenous flora received an IUCN threat category based on their Pitcairn distribution, and 22.2% of the flora is globally threatened. Table 5.2 shows that there are two endemic species extinct on Pitcairn, *Abutilon pitcairnense* and *Myrsine* aff. *niauensis*, and table 5.1 shows that these are extinct for their world distributional status. The three other species that fall into the extinct category for their Pitcairn distributional status are all widespread

across the Pacific region and, in the cases of *Acrostichum aureum* and *Pemphis acidula*, may be mistaken records from other islands, there being little or no suitable habitat on Pitcairn. All 12 of the endemic species are globally threatened, although this is due to the fact that the IUCN red list criteria take total world distributional area into consideration when assigning categories. To combat this, separate Pitcairn categories that ignored this criterion were assigned to all species. However, only one endemic, the widespread tree *Homalium taypau*, fell in to the low risk category, even with the revised criteria.

Table 5.1 - Number of species in each IUCN Red data threat category for the Pitcairn Island native flora, and also based on the world distributions of Pitcairn species. Percentage of total flora is in brackets after the number of species.

Threat Category	Pitcairn Status	World Status
Extinct	5 (6.2%)	2 (2.5%)
Critically Endangered	16 (19.8%)	5 (6.2%)
Endangered	17 (21%)	4 (4.9%)
Vulnerable	13 (15.9%)	7 (8.64%)
Low Risk	31 (38.3%)	63 (77.8%)

Table 5.2 - Number of endemic species in each IUCN Red data threat categories, based on the species global distributions.

Threat Category	Endemic species
Extinct	2
Critically Endangered	4
Endangered	3
Vulnerable	2

In addition to the endemic species there are a number of species with limited distributions which fall into IUCN threat categories: the distribution of *Glochidion pitcairnense* (vulnerable) is limited to the Pitcairn group; *Pilea sancti-johannis* (critically endangered, with more than half its population on Pitcairn), is limited to Pitcairn and the Gambier Islands; *Hibiscus australense* and *Peperomia rapensis* (both vulnerable) are limited to Pitcairn and the Austral Islands; *Chamaesyche sparmannii* (vulnerable) is limited to Henderson, Pitcairn and Marotiri rocks, with an estimated 95% of the total population of the species in the Pitcairn Group. Other Pitcairn species restricted to Polynesia are *Celtis pacifica*, *Xylosma suaveolens* and *Trichomanes tahitense*. *Lastreopsis* cf. *pacifica*, one of the new records for the island, is also found only in Polynesia, and has a threat category of low risk for its world distribution. However, the specimens from Pitcairn differ somewhat from the original description of the species, and this may be a new species, in which case it would fall into the critically endangered category for both its Pitcairn and World distributions.

5.3.2 Selection of species for more detailed study

Three species were selected for more detailed study. *Angiopteris chauliodonta* and *Coprosma benefica* were chosen as they both are endemic and both fall into the critically endangered category. *Lastreopsis* cf. *pacifica* was chosen as it is a new record for the island, is critically endangered, in a highly threatened habitat, and also may be an endemic

species. At the time of collecting it was unclear as to the identity of the taxon, but it was clearly highly threatened on the island. The other two critically endangered endemic species, *Glochidion comitum* and *Peperomia sp.*, were not chosen as they are currently part of a detailed phylogenetic study of the genera in the Polynesian region (Una Bradley pers. comm.).

5.3.3 *Angiopteris chauliodonta*

Population survey

Angiopteris chauliodonta, endemic to Pitcairn, was represented by 6 populations, the location and distribution of which are mapped in figure 5.1, with population information in table 5.3. The plants occured in a range of woodland habitats, but mostly in woodland heavily invaded with *Syzygium jambos*. Fertile plants account for only 19.0% of the total of 774 plants recorded on the island, although one population, High Point 1, had 41.9% fertile plants. Plants less then 1 metre in size account for 63.8% of the total. Plants under 2 metres were never found to be fertile, but only 31% of plants over 2 metres in size were sterile.

The Faute Valley population comprised no fertile individuals, and Garnets Ridge only had one small fertile individual. The Foutu population had 80% fertile individuals, but this was combined with virtually no evidence of juvenile individuals. The populations at High Point have the most balanced demographic structure, with few large individuals, but with individuals in all size classes, both fertile and sterile (or juvenile). The Browns Water population had a very large number of small, sterile individuals, with only a 12% occurrence of fertile plants. However, there was evidence that many plants have become reduced in size, with many plants having stipules (leaf bases) from much larger fronds persisting, suggesting that some individuals were at least larger and perhaps fertile in the past.

Table 5.3. - Distribution and population details for *Angiopteris chauliodonta* on Pitcairn Island. Sterile and fertile individuals are divided into size classes.

Location	Sterile (m)						Fertile (m)				Totals	
	≤0.1	≤0.5	≤1	≤1.5	≤2	≤3	≤2	≤3	≤4	>4	Overall	Fertile
Faute Valley	1	1	2	1	2	2					9	0
Garnets Ridge		5			7		1				13	1 (7.69%)
Foutu		2	3				5	5	5	5	25	20 (80%)
High Point 1	31	66	34	10	17		79	31	4		272	114 (41.9%)
Brown's Water	111	152	86	56	24	14		4	4	4	455	12 (2.64%)
Total	**143**	**226**	**125**	**67**	**50**	**16**	**85**	**40**	**13**	**9**	**774**	**147 (19.0%)**
% of total	**18.4**	**29.2**	**16.1**	**8.7**	**6.5**	**2.1**	**11.0**	**5.2**	**1.7**	**1.2**		

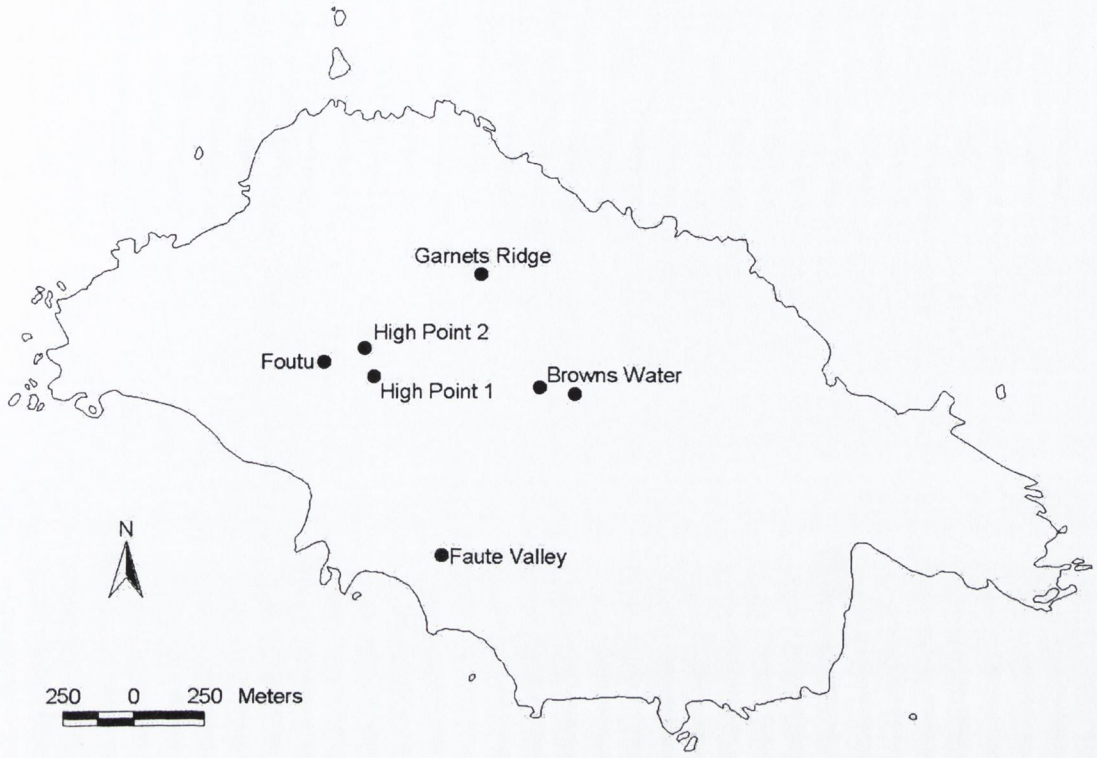


Figure 5.1 - Map to show the distribution of *Angiopteris chauliodonta* on Pitcairn island. Locations are those used as populations in the data analysis.

RAPD Primer Screening

Five RAPD primers were selected as showing the largest number of clear, polymorphic bands for *Angiopteris* spp (table 5.4). Operon OPA primer kit contained all of the primers eventually selected. Not all samples collected underwent PCR successfully, and so were removed from the analysis. Of a total of 30 samples collected from Pitcairn, 25 were used, and of 18 collected from the Society islands, 17 were used. 53 scorable bands were found for *Angiopteris chauliodonta*, with a further 13 being found for the Society Islands *Angiopteris* spp.

Table 5.4 - Sequences of primers and number of loci generated with *Angiopteris* spp.

Primer	Sequence	Fragment size range	No. loci (Pitcairn)	No. loci (All)
OPA 02	TGCCGAGCTG	280-1630 bp	11	12
OPA 03	AGTCAGCCAC	300-1190 bp	8	10
OPA 04	AATCGGGCTG	260-860 bp	11	14
OPA 09	GGGTAACGCC	290-1900 bp	11	14
OPA 10	GTGATCGCAG	290-1170 bp	12	16
Totals			53	66

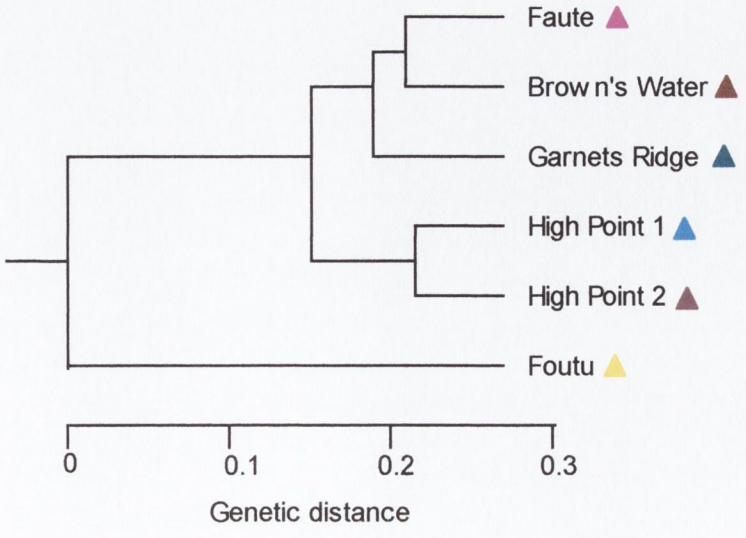
DNA Data analysis

Genetic distance was calculated between all individuals and between each population (table 5.5). The genetic distances plotted onto a UPGMA dendrogram (figure 5.2) show that High Point populations 1 and 2 are the most closely related, with the lowest genetic distance (0.0494), while the Foutu and the Faute Valley populations are the most distant (0.3377). The distinctness of the Foutu population is due to the fact that this population contains the only exclusive band in the data set, and also is represented by only 4 individuals. The similarity between the two most geographically distant populations at Faute Valley and Garnets Ridge (0.616) may be an artifact of sample size, as the Faute population is only represented by 2 individuals and the Garnets ridge populations by 3 individuals. A low sample number would mean that only the most common bands are most likely being represented by these populations. A UPGMA dendrogram drawn to represent the relationships between the individuals distinguishes the individuals from the Society Islands as expected (figure 5.3). There is considerable overlap between the Pitcairnese populations with no distinct populations emerging.

Table 5.5 - Nei's unbiased measure of genetic distance (Nei 1978).

	Faute	**Foutu**	**High Point 1**	**High Point 2**	**Browns Water**	**Garnets Ridge**
Faute	****					
Foutu	0.3377	****				
High Point 1	0.1016	0.2169	****			
High Point 2	0.1289	0.2170	0.0494	****		
Browns Water	0.0692	0.2793	0.0781	0.0839	****	
Garnets Ridge	0.0616	0.2903	0.1414	0.1753	0.0800	****

Figure 5.2 – UPGMA dendrogram based on Nei's (1978) genetic distance (see table 5.5)



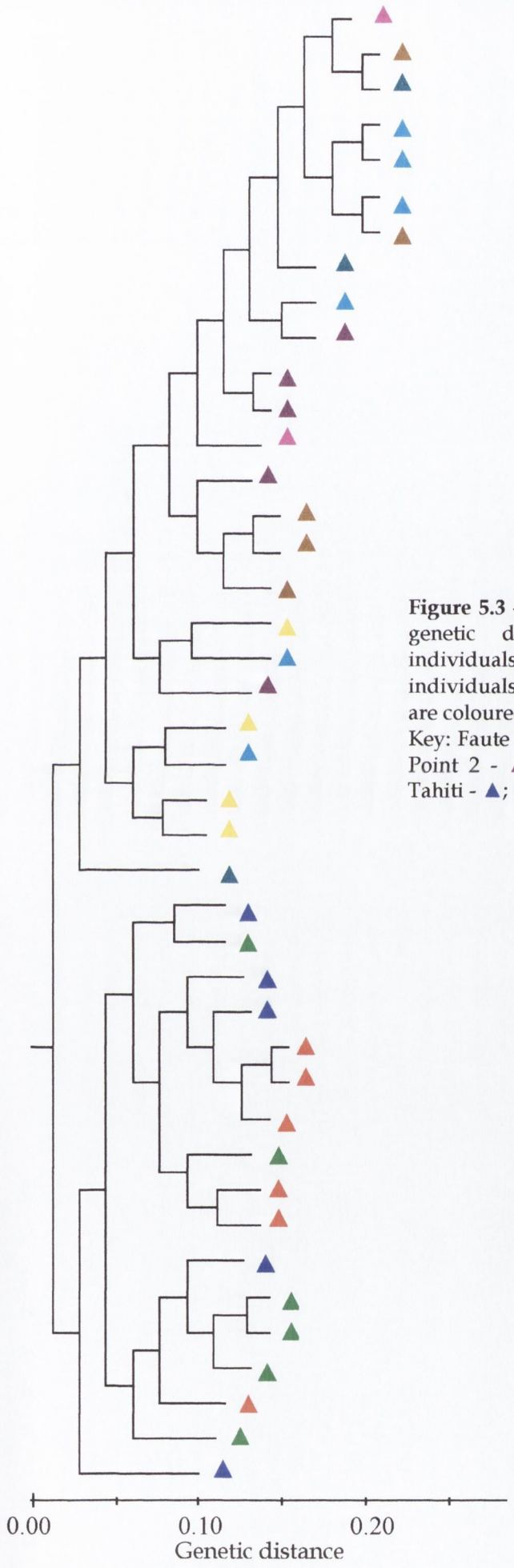


Figure 5.3 – UPGMA dendrogram based on Nei's (1978) genetic distance for the *Angiopteris chauliodonta* individuals from Pitcairn and the *Angiopteris sp.* individuals from Tahiti, Huahine & Moorea. Individuals are coloured according to population.
Key: Faute Valley - ▲; Foutu - ▲; High Point 1 - ▲; High Point 2 - ▲; Brown's Water - ▲; Garnets Ridge - ▲; Tahiti - ▲; Huahine - ▲; Moorea - ▲.

In order to graphically represent the relationships within the populations from Pitcairn an NMDS analysis was carried out, using 2 unrotated dimensions to ensure the lowest stress levels (26.48). The analysis was robust with p values of less than 0.01 for both dimensions for 100 runs using a Monte Carlo test (table 5.6). The results (figure 5.6) show a similar pattern to the UPGMA dendrogram, with the Foutu population ordinating with high values for both dimension one and dimension 2, and the other populations ordinating with low dimension 1 and dimension 2 values. The other populations, however overlap and are not distinctly seperated.

Table 5.6 – Stress and 'p' values for NMDS of 2 axes unrotated for *Angiopteris chauliodonta*

	Stress	p
Dimension 1	26.48	0.0100
Dimension 2	15.75	0.0100

p = proportion of randomised Monte Carlo test runs with stress ≤ observed stress (ie p = (1 + no. permutations ≤ observed) / (1 + no. permutations)

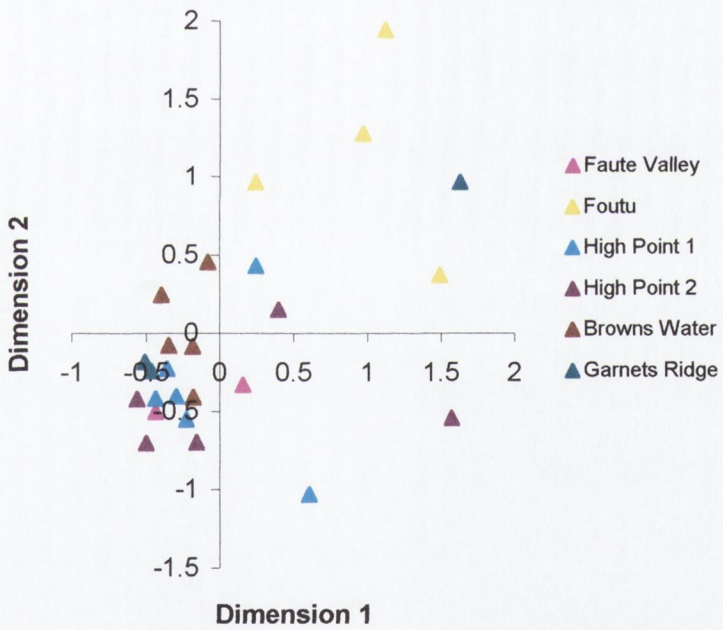


Figure 5.4 – NMDS for *Angiopteris chauliodonta* using 2 unrotated dimensions.

Analysis of the RAPD loci data showed low levels of diversity within the individual populations on Pitcairn island, compared to the within population variation from the Society island samples (tables 5.7 & 5.8). In the Pitcairn samples, the highest levels of within population diversity were found in the High Point 1 and 2 populations, and the lowest in the Faute Valley population. This was consistent in all the quantitative diversity estimates calculated: % polymorphic loci, Shannon diversity index and Nei's gene diversity statistics (table 5.5). The Society island populations showed the highest diversity in the Moorea samples, and the lowest in the Huahine samples. Again this was consistent with all the diversity estimates used.

Between population diversity could only be tested for the Pitcairn island population, as only one population was sampled from each of the Society islands. Total observed diversity (H_T) was divided into within population diversity (H_S) and between population diversity (D_{ST}), with H_S (0.154) being higher than D_{ST} (0.116) (table 5.7).

Table 5.7 - Summary population diversity statistics for *Angiopteris chauliodonta*.

Location			Faute	Foutu	High Point 1	High Point 2	Browns Water	Garnets Ridge	All Pitcairn
Sample size			2	4	6	5	5	3	25
% Polymorphic loci		%	21.21	33.33	46.97	46.97	36.36	40.91	72.73
Shannon diversity index		I_S	0.128	0.182	0.296	0.277	0.203	0.257	0.400
Gene diversity Stats (Nei 1973, 1987)	Total observed diversity	H_T	0.088	0.122	0.207	0.190	0.138	0.180	0.270
	Within pop diversity	H_S							0.154
	Between pop diversity	D_{ST}							0.116
	Gene diversity between pops	G_{ST}							0.429
	Gene diversity within pop	$1-G_{ST}$							0.571

Table 5.8 - Summary diversity statistics for Society Islands populations of *Angiopteris* spp.*

Location		Tahiti	Huahine	Moorea
Sample size		5	6	6
% Polymorphic loci	%	57.58	43.94	68.18
Shannon diversity index	I_S	0.342	0.232	0.423
Gene diversity Stats (Nei 1973, 1987)	H_T	0.235	0.155	0.295

* - the samples were not determined to species level.

Three separate F-statistics were calculated for the Pitcairn population of *Angiopteris chauliodonta* (table 5.9). All values showed significant levels of genetic divergence (F_{ST}) among populations, and high levels of gene flow (N_M) between populations, but the Weir and Cockerham (1984) F_{ST} was lowest and the least significant (p=0.0025). Weir and Cockerham (1984) is the most relevant F_{ST} measure for the data set presented here as it takes into consideration the sample size and population number and thus gives a better estimate for rare species.

Table 5.9 - Calculated F-statistics for *Angiopteris chauliodonta*

F-statistic	F_{ST}	N_M	χ^2
Wrights (1931)	0.404	0.4	20.2***
Weir & Cockerham (1984)	0.368	0.4	18.4**
Lynch & Milligan (1994)	0.426	0.3	21.3***

The significance of the calculated χ^2 was tested using 5 degrees of freedom

** $p = 0.0025$

*** $p \leq 0.001$

5.3.4 *Coprosma benefica*

Population survey

Coprosma benefica was represented on Pitcairn by one population spread over an area of only 500m², with 12 individuals in total. The plants occur in a range of habitats in scrub and at woodland margins. As the species was dioecious, the sex of each plant was noted, but in some cases it could not be determined as no flowers or fruit were seen on some immature individuals. 7 plants were confirmed to be female, 1 male and 4 could not be determined. The location and distribution of the individual trees is mapped on figure 5.5, with population information in table 5.10.

Table 5.10. - Distribution and population details for *Coprosma benefica* on Pitcairn Island, the number in brackets after the collection number refers to the numbers used for figure 5.7.

Collection	Sex	Location	Description
97-649 (1)	Female	Isaac's Valley, left of road	Mature tree, to 3m
97-650 (2)	Female	Isaac's Valley, left of road	Young tree
97-651 (3)	Female	McCoy's Valley, south of road	Multistemmed to 2.5 m, one fruiting; probably damaged during road operations and re-grown
97-652 (4)	?	McCoy's Valley, south of road	Immature tree to 2.5m, damaged by fallen banana
97-653 (5)	?	McCoy's Valley, south of road	Immature tree 1.5m
97-654 (6)	Female	McCoy's Valley, south of road	Mature tree to 7m; blown over in storm in August, regenerating from base and 2m by Sept 2
97-655 (7)	Male	Matt's shed, north side of road	Mature tree, to 5m
97-656 (8)	?	Taro Ground, E of radio station	Shrub to 3m
97-657 (9)	?	Taro Ground, NE of radio station	
97-708 (10)	Female	Taro Ground, N of radio station	Shrub to 2.5m, fruiting
97-889 (11)	Female	Taro Ground, E of radio station	Shrub to 3m, next to a *Cerbera manghas* and the radio aerial mast line
97-890 (12)	Female	Taro Ground, E of radio station	Shrub to 2.5m

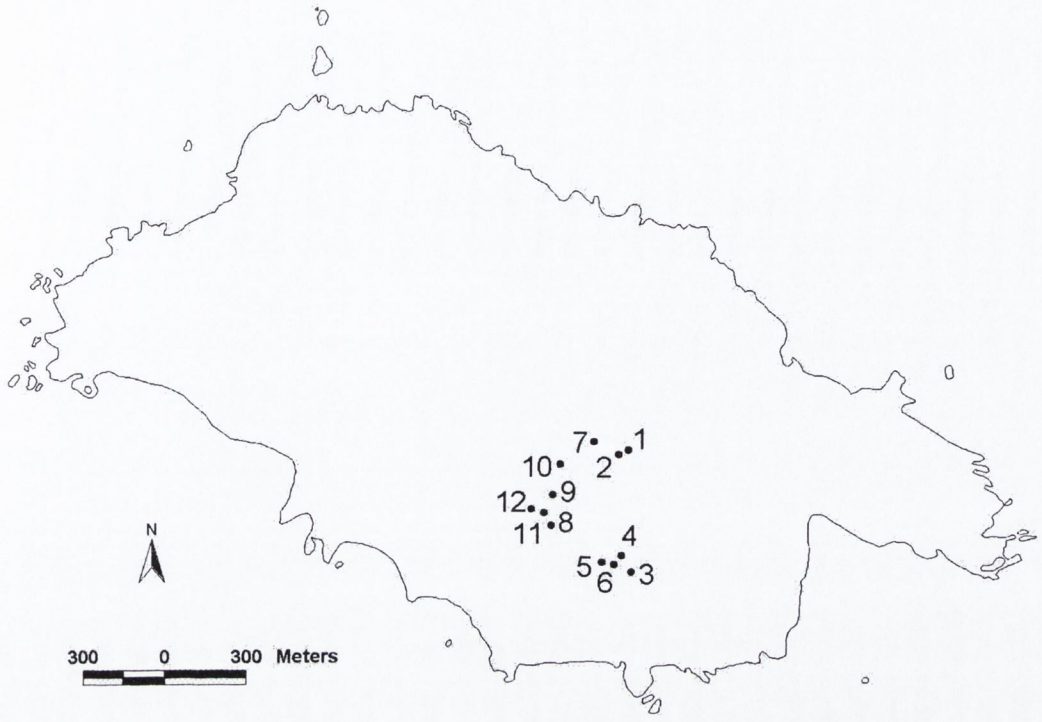


Figure 5.5 - Map to show the distribution of *Coprosma benefica* on Pitcairn Island.

RAPD Primer Screening

Only three primers were found to show any polymorphic bands for *Coprosma benefica* (table 5.11). In total only 31 scorable bands were found. Operon OPA primer kit contained all of the primers eventually selected.

Table 5.11 - Sequences of primers and number of loci generated with *Coprosma benefica*

Primer	Sequence	Fragment size range	No. loci
OPA 08	GTGACGTAGG	290-1410 bp	9
OPA 09	GGGTAACGCC	520-1860 bp	11
OPA 10	GTGATCGCAG	290-1220 bp	11
Totals			31

DNA Data analysis

Genetic distance was calculated between each of the individuals on the island (table 5.12), to see which individuals were most closely related. As no individuals had an identical banding pattern, there were no clones present in the population. The greatest distance was found between individuals 97-649 and equally 97-652 and 97-889 (0.2942). The least distance is 0.0198, between individuals 97-653 and 654, between 97-654 and 97-708 and between 97-889 and 97-890. A UPGMA dendrogram is presented in figure 5.6 to illustrate these relationships.

Table 5.12 - Nei's unbiased measure of genetic distance (Nei 1978)

	97-649	97-650	97-651	97-652	97-653	97-654	97-655	97-656	97-657	97-708	97-889	97-890
97-649	****											
97-650	0.2683	****										
97-651	0.2429	0.1942	****									
97-652	0.2942	0.0606	0.1706	****								
97-653	0.2183	0.0400	0.1942	0.0606	****							
97-654	0.2429	0.0198	0.1706	0.0400	0.0198	****						
97-655	0.2429	0.1476	0.0817	0.1706	0.1476	0.1252	****					
97-656	0.1476	0.1032	0.1252	0.1252	0.1032	0.0817	0.1252	****				
97-657	0.1942	0.1032	0.0817	0.1252	0.1032	0.0817	0.0817	0.0400	****			
97-708	0.2183	0.0400	0.1476	0.0606	0.0400	0.0198	0.1032	0.0606	0.0606	****		
97-889	0.2942	0.0606	0.1706	0.0817	0.1032	0.0817	0.1706	0.1706	0.1706	0.1032	****	
98-890	0.2683	0.0817	0.1476	0.1032	0.1252	0.1032	0.1476	0.1476	0.1476	0.1252	0.0198	****

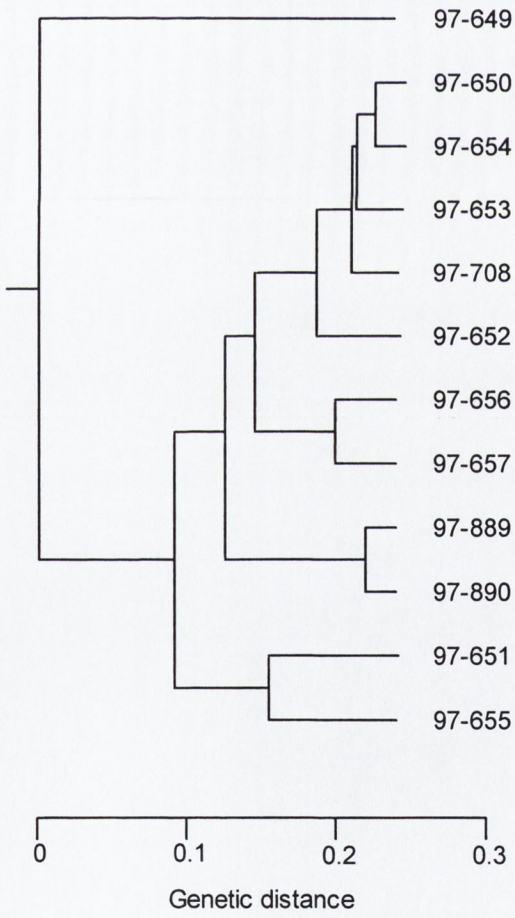


Figure 5.6 – UPGMA dendrogram based on Nei's (1978) genetic distance (see table 5.12)

A NMDS was carried out using the RAPD loci, and the resulting graph is shown in figure 5.7. Again the lowest stress values were obtained when using 2 unrotated dimensions (18.41), and the analysis was robust (p=0.01) when subjected to a Monte Carlo test (table 5.13). Individual 97-649 again ordinates distantly to the other individuals in the

population, with 97-651 and 97-655 also separating out. Other individuals form a cluster around the origin.

Table 5.13 - Stress and 'p' values for NMDS of 2 axes unrotated for *Coprosma benefica*

	Stress	p
Dimension 1	18.41	0.0100
Dimension 2	10.54	0.0100

p = proportion of randomised runs with stress ≤ observed stress (ie p = (1 + no. permutations ≤ observed) / (1 + no. permutations)

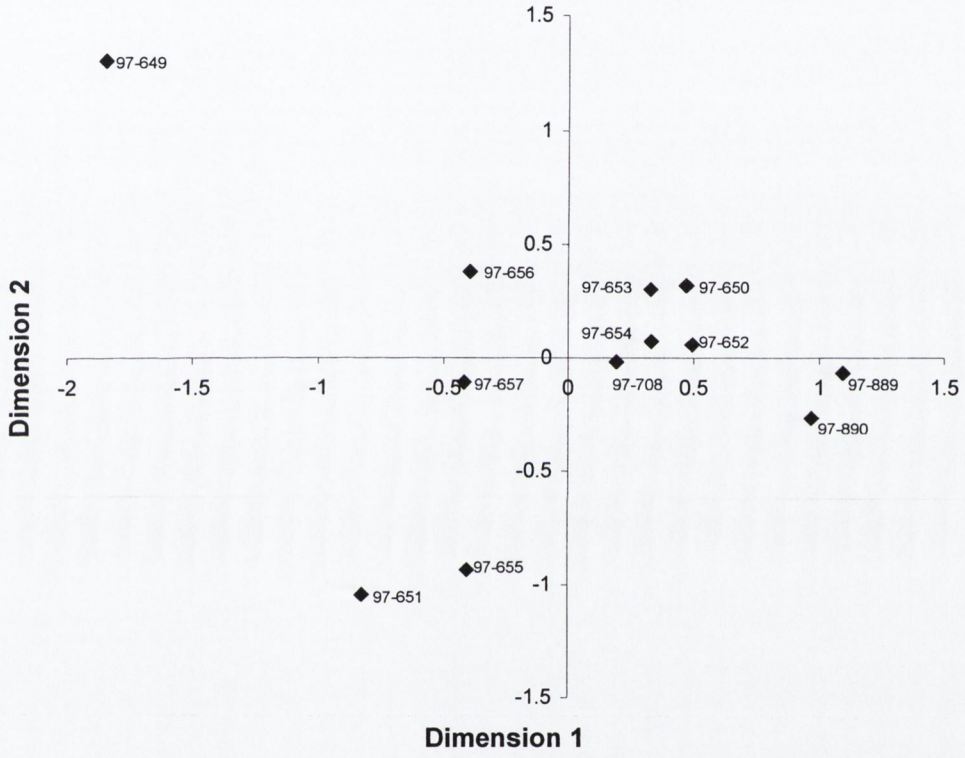


Figure 5.7 - NMDS for *Coprosma benefica* using 2 unrotated dimensions.

Statistical analysis of the *Coprosma benefica* RAPD data also showed a low population variation using all distance measures (table 5.14), % polymorphic loci (37.25%), Shannon diversity index (0.168) and Nei's (1978) total observed diversity (0.107). No between population calculations, or F-statistics could be calculated as there is effectively only one population on the island. Thus Nei's (1978) total diversity is equal to the within population diversity co-efficient. Gene diversity within population has a value of 1 (1-G_{ST}).

Table 5.14 - Summary diversity statistics for Pitcairn population of *Coprosma benefica*

Sample size			12
% Polymorphic loci		%	37.25
Shannon diversity index		I_S	0.168
Gene diversity Stats (Nei 1973, 1987)	Total observed diversity	H_T	0.107
	Within pop diversity	H_S	0.107
	Between pop diversity	D_{ST}	0
	Gene diversity between pops	G_{ST}	0
	Gene diversity within pop	$1-G_{ST}$	1

5.3.5 *Lastreopsis* cf *pacifica*

Population survey

As with *Coprosma benefica*, *Lastreopsis* cf *pacifica* is represented by only one population on Pitcairn, with one additional individual sterile plant being found at a distance of less than 500 metres, but in a neighbouring valley (figure 5.8; table 5.15). The main population was found under a *Syzygium jambos* canopy, with the bulk of the plants on a rock face covering only 10x15m, associated with *Trichomanes enderlichianum*. The total area covered by the main population was only 20x60m. The population was comprised of nearly 90% sterile individuals, with only 20 mature, fertile individuals being found. Nearly half of the plants seen (48.1%) were mid-sized and sterile, with 25% juvenile plants. Only a single individual was found downslope despite careful searches for further plants and a second population.

Table 5.15 - Distribution and number of individuals for *Lastreopsis* cf *pacifica* on Pitcairn Island

Location	Sterile			Fertile	Totals
	Juvenile	Mid-sized	Mature	Mature	Overall
Browns Water	49	91	28	20	188
Pulau	0	0	1	0	1
Total	49	91	29	20	189
% of total	25.9%	48.1%	15.3%	10.6%	

Figure 5.8 - Map to show the distribution of *Lastreopsis* cf *pacifica* on Pitcairn Island.

RAPD Primer Screening

Six primers were found to show the largest number of clear, polymorphic bands for *Lastreopsis* cf. *pacifica*, giving 70 scorable bands in total (table 5.16). All of the primers used were from Operon kit B. Of 40 individuals collected only 27 were used in the analysis, as not all gave strong enough banding patterns for accurate scoring.

Table 5.16 - Sequences of primers and number of loci generated with *Lastreopsis* cf *pacifica*

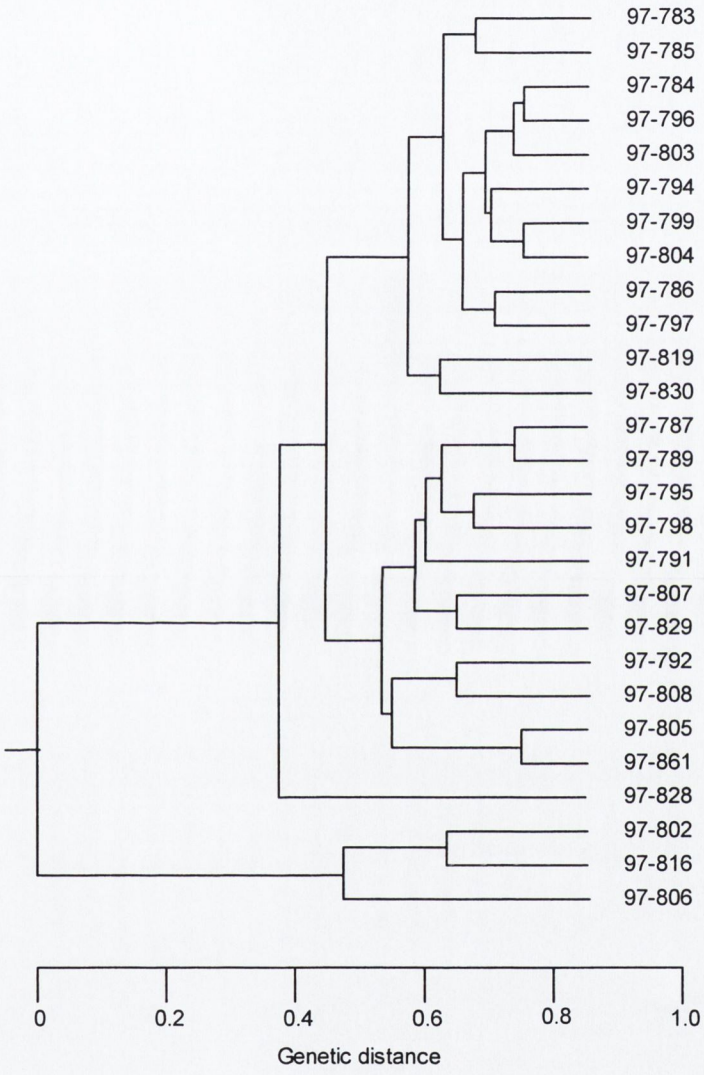
Primer	Sequence	Fragment size range	No. loci
OPB 01	GTTTCGCTCC	250-1490 bp	13
OPB 02	TGATCCCTGG	390-1180 bp	5
OPB 03	CATCCCCCTG	220-2020 bp	10
OPB 04	GGACTGGAGT	280-1430 bp	16
OPB 05	TGCGCCCTTC	260-1090 bp	11
OPB 08	GTCCACACGG	160-2220 bp	15
Totals			70

DNA Data analysis

A matrix to show the genetic distance between individuals in the population was calculated using Nei's unbiased measure and is shown in table 5.17. The genetic distance between the individuals varied widely, from a minimum distance of 0.0597 between individuals 97-784 and 97-796, to a maximum of 1.2384 between individuals 97-784 and 97-806. The mean distance was high at 0.4099, with 39.6% of the distances between 0 and 0.3, 38.2% of the distances between 0.3 and 0.5, and 22.2% of the distances over 0.5. A

UPGMA dendrogram using these genetic distances is shown in figure 5.9 to graphically represent the relationships between the individuals. The dendrogram suggests some structure in the population with distinct groupings forming, but with large distances between some individuals.

Figure 5.9 - UPGMA dendrogram based on Nei's (1978) genetic distance (see table 5.17)



As for the two previous species, *Angiopteris chauliodonta* and *Coprosma benefica*, NMDS was carried out to spatially arrange the distribution between the individuals, and a rotated 2 dimensional analysis was found to give the lowest stress values (table 5.18; figure 5.10). A Monte Carlo analysis of 100 runs was carried out and the stress values were found to be consistent. Most of the individuals cluster with higher dimension 1, but with widespread dimension 2 values. Three individuals cluster with very low dimension 1 values (97-802, 97-806, 97-816), similar to the cluster at the lower end of the UPGMA dendrogram.

Table 5.17 - Nei's unbiased measure of genetic distance (Nei 1978) calculated for *Lastreopsis* cf. *pacifica* on Pitcairn Island

	97-783	97-784	97-785	97-786	97-787	97-789	97-791	97-792	97-794	97-795	97-796	97-797	97-798	97-799	97-802	97-803	97-804	97-805	97-806	97-807	97-808	97-816	97-819	97-828	97-829	97-830	97-861
97-783	****																										
97-784	0.1911	****																									
97-785	0.1398	0.1737	****																								
97-786	0.1911	0.1911	0.2451	****																							
97-787	0.4274	0.3840	0.6506	0.3023	****																						
97-789	0.4499	0.4055	0.6232	0.3629	0.0752	****																					
97-791	0.3423	0.3423	0.4055	0.2638	0.2638	0.2088	****																				
97-792	0.4499	0.4055	0.6232	0.4055	0.2088	0.1566	0.3221	****																			
97-794	0.1566	0.1232	0.1398	0.1911	0.4274	0.4055	0.3840	0.4055	****																		
97-795	0.3023	0.3423	0.4499	0.3023	0.1911	0.1737	0.1566	0.3221	0.3423	****																	
97-796	0.1911	0.0597	0.1737	0.1911	0.3840	0.4055	0.3423	0.4499	0.1232	0.3423	****																
97-797	0.1737	0.1070	0.1232	0.1070	0.4499	0.4729	0.2829	0.5205	0.1737	0.3221	0.1070	****															
97-798	0.2451	0.2088	0.3840	0.3221	0.1737	0.1911	0.2088	0.3023	0.2829	0.1398	0.2451	0.3023	****														
97-799	0.1398	0.1070	0.1232	0.1737	0.4499	0.4274	0.2829	0.4274	0.1398	0.3221	0.1070	0.0910	0.3023	****													
97-802	0.8001	0.9383	0.9760	0.8001	0.5205	0.5452	0.6788	0.4499	0.8001	0.6788	0.9383	1.0561	0.5965	0.9019	****												
97-803	0.1566	0.0910	0.2088	0.1566	0.3423	0.3629	0.3423	0.3629	0.0910	0.3023	0.0597	0.1398	0.2829	0.1398	0.8668	****											
97-804	0.1398	0.1070	0.1232	0.2088	0.4499	0.4274	0.3629	0.4274	0.0752	0.2829	0.1070	0.1232	0.2638	0.0597	0.9019	0.1070	****										
97-805	0.3423	0.3423	0.4055	0.3423	0.2268	0.1737	0.3023	0.2088	0.2638	0.2638	0.3423	0.4055	0.2451	0.3221	0.5205	0.3023	0.3221	****									
97-806	0.9019	1.2384	1.0152	1.0561	0.7684	0.7376	0.7077	0.6788	1.0561	0.7684	1.1431	1.1896	0.8001	1.0152	0.3629	1.1431	1.0986	0.7684	****								
97-807	0.2268	0.2268	0.3221	0.1911	0.2638	0.2451	0.2268	0.3221	0.1911	0.1911	0.1911	0.2451	0.2088	0.1737	0.6788	0.1566	0.1737	0.2268	0.9019	****							
97-808	0.4499	0.4499	0.5705	0.3629	0.2088	0.1566	0.2451	0.1566	0.4499	0.2451	0.4964	0.4729	0.2638	0.4274	0.4055	0.4499	0.4729	0.2451	0.5705	0.3221	****						
97-816	0.7684	1.0561	1.0152	0.9019	0.5965	0.6232	0.7077	0.5205	0.9019	0.7684	0.9760	1.0986	0.6788	0.9383	0.1737	0.9760	1.0152	0.5965	0.3023	0.7077	0.5205	****					
97-819	0.2829	0.2829	0.3840	0.2451	0.3221	0.3423	0.4055	0.3423	0.2088	0.3629	0.2829	0.3423	0.3840	0.2268	0.7077	0.2088	0.2268	0.2829	1.0152	0.1737	0.3840	0.7376	****				
97-828	0.4055	0.4499	0.3423	0.4055	0.4964	0.5205	0.5452	0.4274	0.3629	0.4964	0.4499	0.4729	0.4729	0.3840	0.5452	0.4499	0.3423	0.3221	0.5705	0.4055	0.4729	0.6232	0.4729	****			
97-829	0.3840	0.2638	0.4499	0.3023	0.1911	0.1737	0.3023	0.2451	0.2638	0.2268	0.2638	0.3629	0.2088	0.2829	0.6232	0.2638	0.2829	0.1911	0.8329	0.1566	0.2829	0.7077	0.2829	0.3629	****		
97-830	0.2088	0.2088	0.2638	0.2088	0.3629	0.3423	0.3221	0.4274	0.1398	0.3221	0.1737	0.2638	0.3023	0.2268	0.7684	0.1737	0.2268	0.3221	1.0986	0.2088	0.3840	0.8001	0.1911	0.5205	0.2451	****	
97-861	0.3840	0.4274	0.4055	0.3840	0.3023	0.2451	0.3840	0.2451	0.3023	0.3423	0.3840	0.4499	0.3221	0.3629	0.5205	0.3423	0.3629	0.0597	0.9019	0.2638	0.3221	0.6506	0.3221	0.3629	0.2638	0.3629	****

Table 5.18 - Stress and 'p' values for NMDS of 2 axes rotated for *Lastreopsis* cf *pacifica*

	Stress	p
Dimension 1	14.43	0.0100
Dimension 2	11.42	0.0100

p = proportion of randomised runs with stress ≤ observed stress (ie p = (1 + no. permutations ≤ observed) / (1 + no. permutations

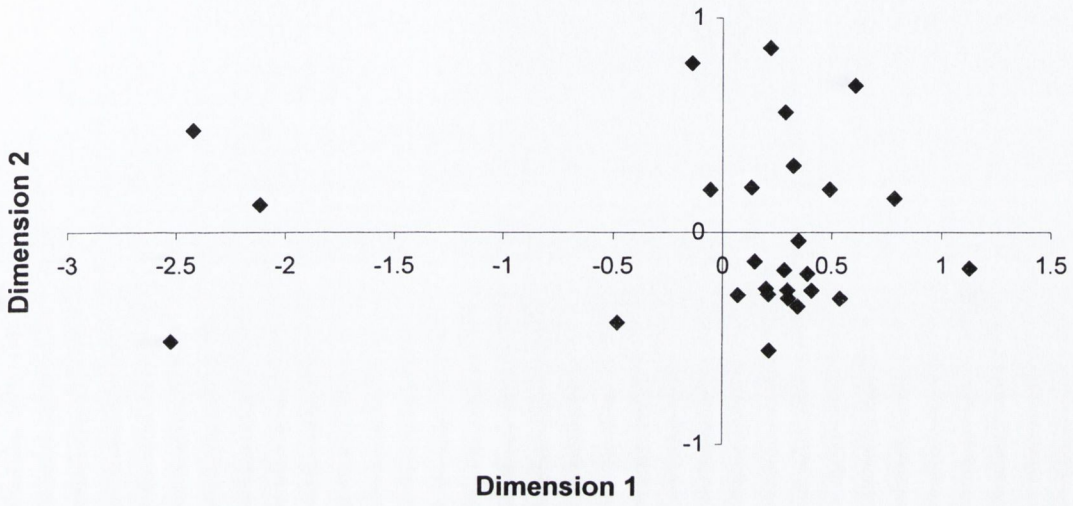


Figure 5.11 - NMDS for *Lastreopsis* cf *pacifica* using 2 rotated dimensions.

Statistical analysis of the RAPD loci showed more diversity than was found in either of the other two species (table 5.19). As with the Nei's (1978) genetic distance values, the % polymorphic loci (98.55%), Shannon diversity index (0.458), and Nei's (1973) total observed diversity (0.297) were all high, higher even than the *Angiopteris* spp. values for the Society islands. No between population calculations, or F-statistics could be calculated as there was effectively only one population on the island.

Table 5.19 - Summary diversity statistics for Pitcairn population of *Lastreopsis* cf *pacifica*

Sample size			27
% Polymorphic loci		%	98.55
Shannon diversity index		I_S	0.458
Gene diversity Stats (Nei 1973, 1987)	Total observed diversity	H_T	0.297
	Within pop diversity	H_S	0.297
	Between pop diversity	D_{ST}	0
	Gene diversity between pops	G_{ST}	0
	Gene diversity within pop	$1-G_{ST}$	1

5.4 Discussion

5.4.1 Species conservation

Assessment of the entire Pitcairn flora using IUCN categories allowed the prioritisation of species for conservation. *In* and *ex-situ* conservation needs, along with their levels of urgency, could then be allocated on a species by species basis. The aim therefore was to compile priority species lists that would be useful both for conservation efforts on Pitcairn, and for internationally recognised conventions. Hence the assessment using both the threat score for Pitcairn and the IUCN Red data categories or the species global distributions.

While the IUCN categories for Pitcairn and the threat scores gave similar results, the threat score gives a truer reflection of the overall extinction threat on Pitcairn, as it took habitat threats and exploitation into consideration. Generally, the most threatened taxa on Pitcairn are those that occur in very small and geographically restricted populations.

Abutilon pitcairnense and *Myrsine* aff. *niauensis* are two endemic but probably extinct species. Detailed searches were carried out on the island for these two species but they were not relocated. Gothesson (1997) mentions some uncorroborated but reliable comparatively recent sightings, notably Twyford of *Abutilon pitcairnense* in 1955 and Lintott of *Myrsine* aff. *niauensis* (reported as *Bumelia sp.*) in 1957. Further searches should continue on any subsequent botanical visits to the island. Other extinct species (*Pemphis acidula, Capparis cordifolia, Acrostichum aureum*) are widespread species and may be either mistaken records for the island, or due to the transient nature of the species have never become fully established. In any case further botanical visits to the island should look for these species.

Of the five species which have critically endangered status for both their Pitcairn and world distribution, two (*Coprosma benefica* & *Angiopteris chauliodonta*) are the subject of more detailed analysis in this chapter, two (*Peperomia sp.* & *Pilea sancti-johannis*) are successfully in cultivation in TCD, and one (*Glochidion comitum*) was not recovered during the most recent botanical visit to Pitcairn in 1997. This latter species, *Glochidion comitum*, should be refound as a matter of priority on any further visits to Pitcairn, the population assessed and propagated. A further 10 species have a critically endangered status for Pitcairn, but low risk status for their world distributions. The populations of these species should be closely monitored and in several cases the separate populations should be propagated. While these species are not threatened by extinction worldwide, they contribute towards the biodiversity and maintenance of the natural habitats on Pitcairn.

Hibiscus australense is an example of a species for which the world distributional information is deficient, and therefore it is difficult to determine the global conservation status and IUCN category. On Pitcairn the species is endangered and based on its global

distribution, which is limited to Pitcairn and the Austral Islands, the world status is vulnerable. A survey of the species distribution in the Australs may show it to be also be threatened there, and make it deserving of endangered status. A further species, *Peperomia rapensis*, is also confined to Pitcairn and the Austral Islands, with endangered status on Pitcairn and vulnerable status for its worldwide distribution. Seed from the Austral Islands (collected in 2000) is germinating in TCD, but propagation of samples from Pitcairn were unsuccessful, probably due to loss of viability during transit from Pitcairn.

All of the other species which qualify as Endangered for both their Pitcairn and global IUCN categories are endemic species, two of which have been successfully propagated at TCD (*Ctenitis cumingii* & *Peperomia pitcairnensis*) and the other of which still requires detailed taxonomic study to determine its identity (*Haloragis sp.*). Detailed population surveys should also be carried out for these species. 10 species are endangered on Pitcairn, but fall into the low risk category for their world distribution. No specific measures are needed for conserving these species, although the populations should be monitored, and the propagation of these species would be beneficial for reintroduction into cleared areas. Vulnerable species similarly require no specific conservation measures, but their propagation would be advantageous.

While the assigning of both a Pitcairn Island and a World Red data status helped to overcome problems presented by the IUCN 'area of occupancy' criteria and aided in prioritising conservation needs for Pitcairn, the world distribution is the status that should be presented in the IUCN searchable database and in the international forum. Endemic species such as *Homalium taypau* are not necessarily threatened at the Pitcairn level, but the fact that they occur in such a small area means they require at least regular monitoring, to protect against the populations reduction or extirpation due to stochastic effects.

Comparison with the IUCN categories for other islands, shows that Pitcairn has a comparable ratio of threatened species. Pitcairn has 22.2% of its species globally threatened, nearby Rapa has 25% and the Society group of Islands have 23% (Florence 1997a). Only 12% of the Marquesas flora is threatened (in need of urgent reassessment), but Mauritius has 50% of its flora threatened, including 8.9% of the flora of 900 species being now extinct (Page *et al.* 1995).

5.4.2 *Angiopteris chauliodonta*

Angiopteris Hoffmann (Marattiaceae) is a widespread genus of giant ferns with bipinnate fronds up to 4m in length, occurring from Madagascar across South East Asia and Polynesia, and North to Japan. The taxonomy of the genus is debated with some authorities retaining only one species, *A. evecta*, in the genus while others allowing up to 200 (Copeland 1947; Verdoorn 1938). *Angiopteris* is distinguished from *Marattia* as having

rounded sporangia arranged in two rows (normally of 5-7 sporangia), while in *Marattia* the sporangia are fused into a single linear synangium (Copeland 1947). *Angiopteris* is distinguished from *Archangeopteris* by being bipinnate and large in size (Copeland 1947).

Angiopteris chauliodonta Copel. (plate 5.1) is endemic to Pitcairn although the type specimen of *A. longifolia* is also attributed to Pitcairn (Copeland 1938). *A. longifolia* is in fact confined to the Society Islands, the Cook Islands and Rapa, and the species was probably described from Tahitian material, mistakenly labelled as having been collected from Pitcairn (Copeland 1938)(labelled as collected in 1830, but as it was published by Hooker in 1830, it was probably actually collected in 1825 on Captain Beecheys voyage to the Pacific). *A. chauliodonta* differs in having broad, sterile apices of the pinnules, with sharp, narrow, incurved teeth at their bases (Copeland 1938).

Little is known about the breeding biology of *Angiopteris sp.*, or about the life cycle of individuals within the genus. In addition no literature was found relating to the population dynamics of species within the genus or in closely related genera. *Angiopteris sp.*, however, reproduce both sexually by spores and vegetatively by means of the large fleshy stipules found at the base of the frond (plate 5.2). The gametophytes are large and long lived, and although they are supposed to be obligate mycorrhizal (Hepden 1960), they were successfully germinated on sterilised compost in TCD.

Previous botanical surveys on Pitcairn had found only two populations of *Angiopteris chauliodonta* on Pitcairn, one from Garnets Ridge, and one from the hills above Adamstown (probably the Browns Water population)(St. John 1987; Waldren *et al.* 1995b). This survey has increased the number of populations to 6, with reasonably certainty that no further large populations will be found, as the island was thoroughly searched.

No individuals had identical RAPD banding patterns, suggesting no clones were sampled, something which can be a problem when sampling from vegetatively reproducing species. In addition, being able to distinguish all individuals suggests that adequate numbers of primers were analysed, thereby increasing the validity of the results.

The species shows hierarchy in the amount of variability, with smaller populations not necessarily having less variation. The high levels of genetic diversity in the two High Point populations may be explained by their large size, high number of fertile individuals and spread of individuals in all size classes, as well as their proximity to each other which increases the effective population size and the chances of gene flow between the populations. The lowest levels of diversity in Faute Valley could be explained by the population's remoteness (700m to nearest populations at Browns Water and High Point) and very small size (only 9 individuals). High levels of diversity in the Garnets Ridge population, even though the population is small, may relate to its proximity to the Browns Water and High Point populations. This is backed up by the NMDS analysis of the populations, in that the Garnets Ridge population overlaps with the High Point and

Browns Water populations on the resulting ordination (figure 5.6). The levels of genetic variation suggest that the Garnets Ridge population may be a remnant of an originally larger population, or be a newly expanding population, but considering its location in an area threatened by severe erosion it is more likely that it is a remnant of a once larger population.

The Brown's Water population is the largest on the island, but one that is at risk from erosion and road widening. There is evidence that the population was once larger, perhaps not in actual plant numbers, but rather in the size of the plants. This is evidenced in the presence of stipules, or the persistent leaf bases, that would have held much larger fronds than are currently on some of the plants. The reduction in the size of the population has also been noted by islanders who used to collect fronds from this site (B. Christian pers comm). This population, however, still shows the highest levels of regeneration of any population on the island.

The Foutu population is the most distinct population. This population occurs close to the High Point populations, but is separated from them by a major ridge and dense cloud forest. This dense vegetation surrounding the population may reduce gene flow from this population to the others. The genetic distance between the Foutu and the Faute populations was 0.3377 (table 5.5), and while this is substantially higher than other genetic distances in the populations (0.0494 - 0.2903), it is lower than genetic distances between populations in other species. For example in *Hordeum spontaneum* populations from Israel genetic distances between populations of up to 0.393 have been recorded (Dawson *et al.* 1993).

The populations from Moorea and Tahiti had higher levels of genetic variation than in the populations from Pitcairn, with the population from Huahine having more variation than three of the six populations. This can be explained by the much larger sizes of the populations that these *Angiopteris* sp. samples were collected from, the larger number of populations and their proximity, as well as the fact that these species occur in a wider range of habitats than *Angiopteris chauliodonta* (they are also found on the margins of fernlands and grasslands), and thus the higher levels of genetic plasticity found in these species.

Within-population diversity for the Pitcairn populations was 57.1% of the total diversity found, which is comparable to values found in *Hordeum spontaneum* (Dawson *et al.* 1993). *Grevillea scapigera* (Proteaceae), a rare shrub from Australia, has within-population variation at 86.95%, although the species is spread over a larger area (Rossetto *et al.* 1995). Similarly, Ayres & Ryan (1997) studied the genetic variation in *Wyethia reticulata* (Asteraceae), a rare endemic plant from California, and found most of the genetic variation to be within-population, as flowering is reliant on fire events, thus reducing the chance of gene flow between populations.

Plate 5.1 - *Angiopteris chauliodonta* stand on Pitcairn Island.

Plate 5.2 – Fleshy 'stipule' of *Angiopteris chauliodonta,* resulting at the leaf base of dead fronds. These 'stipules' can vegetatively reproduce.

The F_{ST} and N_M values from this study were similar across the three different measures of calculation, but as in Apostol *et. al* (1996) the Weir and Cockerham value was lower for F_{ST} and higher for N_M. The other measures tend to overestimate F_{ST} and underestimate N_M for small populations sizes, whereas Weir and Cockerham takes sample size into consideration. The F_{ST} values were higher than in the *Wyethia reticulata* study (Ayres & Ryan 1997), (F_{ST}=0.368 for *Angiopteris chauliodonta*, as opposed to F_{ST} =0.25 for *Wyethia reticulata*).

The large amount of genetic variation between populations in comparison to other studies, coupled with the high level of gene flow in the species (estimated from the effective migration rate, N_M), suggests that the population of *Angiopteris chauliodonta* are actively interbreeding. Realistically, it may be artificial to consider the species to be divided into populations, when the total area covered by the species, and the distance between the populations is so small.

The reported decline in *Angiopteris chauliodonta* on Pitcairn is due to several factors. In the past the species covered large areas, and fronds were cut for their scent and as bedding (B. Christian pers comm). More recently plants have also been collected as ornamentals (C. Warren pers comm). Invasion of the taxons' natural habitat by both *Lantana camara* (High Point, Foutu, Garnets Ridge, Faute Valley) and the spread of *Syzygium jambos* trees (Browns Water, High Point) probably account for most of the reduction in populations. *Lantana camara* spreads in canopy openings preventing regeneration of other species, and while *Syzygium jambos* provides dark and humid conditions, it also causes erosion by eliminating the ground flora, hence failing to properly bind the soil (especially problematic in Browns Water). It has been documented that slow growing pteridophytes are badly affected by invasive species while more weedy pteridophytes may actually benefit (Given 1993). Natural erosion, exacerbated by anthropogenic activities, threatens the Garnets Ridge population, which is precariously located on the edge of the Hollow, a large area of bare eroding soil. The Faute Valley populations, however, even though located in a remote valley is probably the population most at risk, as the population is small, with a low genetic variation and no fertile individuals.

Angiopteris chauliodonta requires both *in* and *ex-situ* conservation actions. In 1997 a trial translocation of 40 stipules from Browns Water, High Point and Foutu were planted into Jack Willems Valley. The site was chosen as it had appropriate protected and inaccessible habitat, but was visible from a road. The islanders had expressed an interest in having the species more widespread as an ornamental. A trial reinforcement of the Faute Valley population was carried out by planting 9 stipules from the population's 2 largest individuals farther up the gully in a less invaded area. Now that information is available about the distribution of genetic variation within the population, further translocations and population reinforcements can be carried out, mixing genotypes appropriately. The aim is to minimise inbreeding and maximise genetic variability, so individuals from the

most diverse populations (ie High Point and Garnets Ridge) should be mixed with and translocated into the less diverse populations (ie Faute Valley and Foutu).

5.4.3 *Coprosma benefica*

Coprosma Forster (Rubiaceae) is a genus of trees and shrubs that occurs from Australia, across the Pacific islands to South America, with centres of diversity in New Zealand and Hawaii (Heads 1996). The genus is commonly dioecious, with fruits that are bird-dispersed (Lee *et al.* 1994).

No quantitative survey of *Coprosma benefica* (plate 5.3) on Pitcairn had previously been carried out. The first record of the species from 1831 had no associated location information. Subsequent collections in 1934 included samples from Adamstown, Parlver Valley, Down Rope, Outer Valley and Middle Hill (St. John 1987). Despite careful searching, no individuals were located in any of these sites, although the Outer Valley and Middle Hill collections may be the Radio Station and McCoy's Valley individuals, with locality names confused (easily done on Pitcairn, where every small piece of land has a different name).

As with *Angiopteris chauliodonta,* the number of primers used distinguished all genotypes, and the lack of identical banding patterns suggested no clones were present in the population. This also suggested that *Coprosma benefica* is not apomictic, as has been proposed for some Pacific island *Coprosma* spp. (M. Khein, pers com to S. Waldren). Individuals that are located closest together are not necessarily most closely genetically related, which suggests gene flow throughout the population. However, the genetic distances between individuals were also low (0.0198 to 0.2942) compared to the *Lastreopsis* cf *pacifica* population also studied (0.0597 to 1.2384). Thus while individual 97-649 seems from the UPGMA dendrogram (figure 5.6) and the NMDS ordination (figure 5.7) to be very distant to the other individuals in the population, it is in fact not very distant with distance values ranging from 0.1476 to 0.2942.

The population genetic diversity was also very low compared with the other species presented here (H_T = 0.107 in *Coprosma benefica,* 0.270 in *Angiopteris chauliodonta* and 0.297 in *Lastreopsis* cf *pacifica;* I_S = 0.168 in *Coprosma benefica,* 0.400 in *Angiopteris chauliodonta* and 0.458 in *Lastreopsis* cf *pacifica*). Comparison with other studies of rare endemic species that only occur in a single population show, however, that the level of genetic diversity in *Coprosma benefica* is not low. No RAPD variation was found in 29 individuals (all extant individuals) of *Limonium cavanillesii* (Plumbaginaceae) (Palacios & Gonzalez-Candelas 1997), and three populations (containing all 31 extant individuals) of *Metrosideros bartlettii* (Myrtaceae) showed only slightly higher levels of diversity with AFLP (H_T = 0.18)(Drummond *et al.* 2000). Long lived perennials tend to have higher genetic diversity than short-lived species (Hamrick *et al.* 1979), which may explain why *Limonium cavanillescii* showed the lowest levels of variation.

Coprosma benefica may never have had very high population numbers on Pitcairn due to geographical and biological criteria, a feature noted for the closely related genus *Psychotria* (Batianoff and Burgess 1993; in Mauchamp *et al* 1998). However, the very small population currently on Pitcairn has probably derived from a vast reduction of an originally more widespread population. The main factor that has caused the species decline, and pushed it to near extinction, is almost certainly the eradication of frugivorous birds from the island. In order to germinate successfully the seed has to be ingested and passed through the gut of a bird, and thus there are no young individuals. The timescale of the decline of the population is unknown, as are the ages of the individual trees located on the island. Therefore it is difficult to tell if the effects of inbreeding depression are already seen, or at what stage in the future they will be expressed. The low genetic variation within population is an indication that some effect is already apparent.

Coprosma benefica is also threatened from a plan to build an airstrip on the island. The island is at present being surveyed to find a suitable site for the airstrip if the plan goes ahead. The only two parts of the island that have a long enough flat area are Aute Valley and the Radio Station area. Both of these areas are near to the sites of the mature plants.

Coprosma benefica can be propagated easily from cuttings, but shows low seed viability after drying. Soaking seeds with vinegar prior to planting may mimic the effect of ingestion and aid in germinating fresh seed which should be collected and planted from all maternal parents. Immediate vegetative duplication of all available individuals for translocation to a protected site is a priority, with a stock also being stored in the island nursery. A stock of plants in the nursery will ensure against further genetic erosion in the population. The destruction of the largest individual during a storm in 1997 indicates the stochastic threats to the small population. Ideally 4 duplicates of each individual should be translocated, to ensure that total genetic variation accounted for, as recommended by Page *et al.* (1995). Fresh seed should also be transported to TCD for *ex-situ* conservation both in the gene bank and in the living collection. Once grown-on, propagated plants should be made available to other institutions.

Genetic comparisons with populations of *Coprosma rapensis* from Rapa and Mangareva would help to determine if the levels of variation found on Pitcairn are consistent to closely related species, or if the population on Pitcairn is suffering from inbreeding or even the Allee effect (where the levels of genetic variation within the population get to such low levels, and the age and size structure becomes so unbalanced that normal sexual reproduction cannot occur; Hunter 1995). In this case, and if the species are closely related, a controlled breeding programme between *C. benefica* and *C. rapensis* might be necessary.

Plate 5.3 – *Coprosma benefica* flowers and leaf from Pitcairn Island. A female flower is shown on the left, while a male flower and a leaf is shown on the right.

Plate 5.4 – *Lastreopsis* cf. *pacifica* from Pitcairn Island.

5.4.4 *Lastreopsis* cf *pacifica*

Lastreopsis cf. *pacifica* (plate 5.4) was a new record for Pitcairn, identified for the first time in 1997. The species was collected previously in 1991, but misidentified as the endemic species *Ctenitis cumingii* (Florence *et al.* 1995). *Ctenitis cumingii* is a larger species with a more widespread distribution on Pitcairn.

As in *Angiopteris chauliodonta*, there is a very low effective population size in *Lastreopsis* cf. *pacifica*, with only 20 fertile individuals being recorded out of a total population of 189. No individuals showed an identical banding pattern, indicating no clones were present in the population, and while some individuals were closely related (genetic distance of 0.0597), others had genetic distances higher than in the other two species tested (genetic distance up to 1.2384). Genetic diversity measurements were similarly high, with total observed diversity higher than in the other two species. Narrowly endemic species typically have less than half the genetic diversity of widespread species, with regionally distributed species having intermediate values (Hamrick *et al.* 1991). This may explain why the single population of *Lastreopsis* cf *pacifica* has higher genetic diversities than *Coprosma benefica*, or even the more widespread *Angiopteris chauliodonta*.

If a decline in the population of *Lastreopsis* cf *pacifica* on Pitcairn has occurred it is almost certainly due to the spread of invasive species. The Browns Water site is invaded by *Syzygium jambos* and may be subject to soil erosion. Originally the population may have been continuous between Browns Water and Pulau under a canopy of native tree species, but the area is now open floored forest dominated by the trees *Syzygium jambos* and *Mangifera indica*. Another scenario is that the species is a recent coloniser of Pitcairn, which would explain why the first record of the species was found in 1991, even though the location where it is found is a relatively well botanised area, easily accessible from and close to the village at Adamstown.

The spores of *Lastreopsis* cf. *pacifica* germinate readily, and as there is a high level of genetic variation in the population, a large mixed spore collection should be collected and planted in the island nursery. Several suitable sites for translocation can be identified in some of the more remote valleys and new populations created using spores and propagated plants. In addition the population in Brown's Water should be remonitored and perhaps reinforced, as should the population in Pulau. If suitable habitat can be identified in between these existing populations a reintroduction of a population should be carried out to provide a mechanism by which gene flow can occur between these populations. A priority for *Lastreopsis* cf *pacifica* is also the exact determination of the Pitcairn plants to species level, and if it is a new species. Even if it is not a distinct species, a stock of plants in the nursery will provide plants to be translocated into areas cleared of invasive species.

5.4.5 Usefulness of genetic fingerprinting in this study

Genetic fingerprinting techniques were used in this study to give a simple estimate of the genetic variation within and between the populations of the three species under detailed study. This technique may give different estimates of variation than would other techniques, but variation was found in all species and the money saved from costlier methods (such as AFLP) can be better used in implementing conservation plans.

The results of the analysis are what might be expected. The endemic species (*Angiopteris chauliodonta* & *Coprosma benefica*) were found to have less genetic diversity than the potentially more widely distributed, or recent founder species (*Lastreopsis* cf. *pacifica*)(as stated in Frankham 1997, Hamrick *et al.* 1991), and the smaller populations had reduced genetic variation probably due to random genetic drift and inbreeding (as stated in Hartl & Clark 1997). Comparison of the data presented here with other population studies of rare plant species is difficult, as often no genetic variation was found (Dowe *et al.* 1997; Palacios & Gonzalez-Candelas 1997), or no quantification of genetic variation was calculated (Stewart & Porter 1995).

However, even though the results found were those expected, knowledge of the relationships between populations enable recovery plans to be targeted at mixing diverse populations with less diverse populations to maximise variation (ie *Angiopteris chauliodonta*). For species with single populations knowledge of the level of genetic diversity allows taxa to be proioritised based on the likelihood of extinction is due to loss in genetic variability. If a species has high variability, it is more likely to be threatened by loss in suitable habitat, and thus there is more chance of successful conservation. Genetic diversity in a species cannot be recovered once it is lost, but suitable habitats can at least be reconstructed if necessary.

5.4.6 Concluding remarks

A high percentage (63%) of the flora of Pitcairn is threatened locally, while nearly a quarter of the taxa (22.2%) are globally threatened. Most of these species require immediate *in* and *ex-situ* conservation actions to be initiated, while all need regular monitoring to combat against massive losses due to stochastic effects. Knowledge of the genetic diversity within the three species that were studied in detail (*Angiopteris chauliodonta, Coprosma benefica* and *Lastreopsis* cf. *pacifica*), allows a more scientific assessment of the species conservation needs and as this information is now known prior to the establishment of conservation programmes for these species, it allows more detailed monitoring of the relative success of such programmes. Ideally this information would be known for all threatened species on the island, but as there is a large number (51) and a diverse range of species threatened on Pitcairn this is not possible with the technology and manpower available. An assessment for the 18 globally threatened species would be more feasible, and as tissue samples for all of the endemic species were

collected in 1997, it is not an unreasonable goal (with the exception of the two extinct species, *Abutilon pitcairnense* & *Myrsine* aff. *niauensis*). While only three of these species are covered here, a further five (*Glochidion pitcairnense, G. comitum, Peperomia pitcairnensis, P. rapensis* & *P. sp. nov.*) are the subject of a research project in TCD.

Chapter 6 : Discussion

6.1 Introduction

The aims of this thesis were to provide the baseline information and data from which a conservation plan for the flora and vegetation of Pitcairn Island could be most effectively developed. In order to do this a complete floristic and vegetation survey was necessary, in addition to a compilation of information relating to the distribution of the flora and vegetation in the context of the Pacific island floras. Only once this information was obtained could the conservation status of the islands taxa be determined, and conservation actions for each species be developed.

The flora of Pitcairn Island consisted of 81 native species, of which 30 are pteridophytes, and 250 introduced species. Eleven of the native species were endemic to Pitcairn, although two of these 11 are probably now extinct. Of the introduced species over 40% have been introduced for cultivation. Non-native species were found right across the island, but native species still dominate in the remoter valleys on the south of the island.

The vegetation of Pitcairn was found to consist of 14 vegetation communities: 4 coastal communities, 6 woodland communities, 2 fernland communities and 2 scrub communities. These were found to be equivalent to the Pacific biomes of plantation forest (*Syzygium jambos* forest on Pitcairn), montane rainforest, lowland rainforest, cloud forest, scrub, savanna, fernland and strand habitats. Most of these vegetation types contained high numbers of non-native species, but in cases where there are a high number of native species, the dominant species was often an introduced taxon (eg *Syzygium jambos* woodland contained 87.9% native species, but the dominant taxon, *Syzygium jambos* is non-native).

The combination of plant taxa found on Pitcairn Island and the other islands in the Pitcairn group are closely related to the taxa found in the Austral group of islands to the west of Pitcairn, which are in turn derived from the flora of the Indo-Malesian region of the Pacific. There was no relationship between the Pitcairn flora and that of the Americas. Distance from source and habitat availability are the two factors that determine floristic composition (incorporating factors such as island type and altitude). Strand species were most likely to be sea dispersed while inland species are more likely to be wind or bird dispersed. The number of seeds dispersed in a single event was generally likely to be one, but in most cases more then one propagule will be dispersed at a time, as a bird will eat more then one fruit, or more then one propagule may adhere to a passing carrier. In some cases wind dispersed species will also be dispersed by adherence, as their tiny seeds or spores may become adhered to a birds feet in mud. This study shows that plant distributions on islands are a complex phenomenon, and agrees with the conclusions of van Balgooy (1996), that plant distributions are not only influenced by historical factors

(distribution of ancestral species, geology), but also by ecological factors (climate, competition, dispersal).

An initial conservation assessment of the flora showed that 63% of the native flora was threatened on Pitcairn, while 22% was globally threatened, based on the species IUCN categories. For most species immediate *in* and *ex-situ* conservation activities are recommended. On Pitcairn the problem was not simply the loss of species, but also the loss of habitats and the genetic diversity within the species. As information is available from the vegetation study as to which habitats the rare species occur in, it is possible to identify those that are necessary for the conservation of the rare species, and indeed which habitats are at themselves at risk. It is futile to conserve the species present and their genetic variation if the habitat in which they occur is being destroyed (Haig 1998), or indeed if the habitats in which they thrive are unknown and thus the species are being placed in unsuitable habitats. Long-term goals for successful conservation involve the detailed knowledge of both the species requirements, and the interactions in the ecosystems in which they occur.

Assessing the genetic diversity within species is a more complex matter. Here three species have been studied in further detail using the technique of RAPD's, and this has proved useful in producing conservation protocols for these species based on more robust scientific data than the simple threat scores. However, in situations where obtaining detailed genetic information is not feasible, taxa should be ranked according to their degree of endangerment, not simply so that resources can be allocated most effectively, but also so that actions are taken in an appropriate timescale before major reductions in populations, or extinction occurs. In addition small populations are fundamental evolutionary elements that may be the basis for founder effects and allopatric speciation, evolutionary processes that give birth to new species, and this justifies efforts for their protection (Mauchamp *et al.* 1998).

6.2 Threats to the native flora and vegetation

The threats to the native flora and conservation problems on Pitcairn are similar to those of most habited Pacific Islands, as discussed in chapter 1.

Alien species

A large number of species (c. 250) have been introduced to Pitcairn, both accidentally and intentionally. Some have become widespread and troublesome, and include both animals (e.g. rats, mice, wasps, ants and fruit flies) and plants (e.g. *Lantana camara, Sorghum sudanense*). The number of introductions appears to have increased with time, and the problems associated with these species have become acute only over the past five decades. The pace of introductions does not appear to have decreased in recent years despite a growing awareness of the problems caused by introduced species, and a large number of the species listed in Cronk & Fuller (1995) as invasive in the Pacific region are now on the island.

The threats to the native biodiversity are mainly due to widespread alien species (e.g. *Lantana camara, Canna indica*) or the as yet poorly dispersed species (e.g. *Crinum asiaticum, Carpobrotus edulis, Leucaena leucocephala*) which are not considered by Pitcairners to be a problem. The islanders are more concerned with more typical agricultural weeds (e.g. *Bidens pilosa, Euphorbia peplus*) and the spread of *Syzygium jambos*. This latter species is poorly dispersed but it does readily spread in the vicinity of mature trees to eventually form monospecific stands. Large parts of the island above Adamstown are dominated by these stands, which contain few native species; where these stands occur on steep slopes, the lack of ground flora results in soil erosion. Similarly there are virtually no areas of the coast that contain as many native as invasive species, and no areas where some level of invasion has not occurred. *Lantana camara* is known to be responsible for the extinction of at least one species in the Galápagos islands (Mauchamp *et al.* 1998). Allelopathic compounds produced in the roots and shoots, copious seed production year round, and an ability to spread vegetatively contribute to the success of *Lantana camara* as an invader (Cronk & Fuller 1995). *Psidium guajava* also has the potential to be a serious threat for the future (Mauchamp *et al.* 1998).

The invasive species problem is largely due to historical clearance of land for vegetable gardens when the island was more densely populated, and as the gardens were abandoned they became covered by non-native grasses and shrubs. This accounts for all the remaining areas of native forest being concentrated in the more remote and steeper valleys.

Loss of native species

A very serious threat to the flora of Pitcairn is the lack of a frugivorous bird. 22 species from Pitcairn Island are dispersed through ingestion by a bird, and a further 9 are

dispersed by means of adherence mechanisms (see Chapter 4 for further detail). In some cases germination does not occur until the fleshy coat has been removed, so birds are not simply required for dispersal but also the subsequent establishment of a seedling. Eleven of the 17 species from Pitcairn with a threatened status for their world distribution require bird dispersal, including the probably extinct species *Myrsine* aff. *niauensis* and the critically endangered species *Coprosma benefica* and *Glochidion comitum*. In addition a whole suite of native species (19) are being threatened in their Pitcairn distributions by the lack of a bird disperser including *Celtis pacifica, Cocculus ferrandianus, Xylosma suaveolens, Psydrax odoratum* and *Cyclophyllum barbatum*.

Coprosma benefica is also at risk from the plan to build an airstrip on the island. The island is at present being surveyed to find a suitable site for the airstrip if the plan goes ahead. The only two parts of the island that have suitable sites are Aute Valley and the Radio Station area. Both of these areas are the sites of the majority of the mature *Coprosma benefica* plants. These areas have, however, very few other important species, and so measures could be taken to move these plants and introduce them into other areas. The contruction of an airstip would be of massive social and economic benefit to the island community.

Erosion

Erosion is also a major problem on Pitcairn and is exacerbated by the use of a bulldozer, which is not really suited to the tasks for which it is used (e.g. clearing roads, clearing gardens). Indeed most of the islands roadways have been simply bulldozed forming channels up to 1.5m deep with exposed soil on either side. No provision is made for water drainage in the construction of the roads, which are simply re-bulldozed following storms. Other causes are the clearing of bush on steep slopes, and in part to goat grazing on exposed ridges. While some erosion in inevitable on high islands due to climatic effects and landslides, it is clear that the current excessive erosion threatens the native plant species and communities, and also the gardens of the islanders. In 1997 following storms, a wide band of muddy discoloured sea was clearly visible surrounding the island.

Other threats

Due to its small size, rugged landscape and small population, Pitcairn has been spared from some of the destructive human induced changes that have affected other islands (eg coconut & sugar cane plantations, over-fishing, commercial logging, pollution other than that linked to erosion). However, the increased economic reliance on cultivated fruits for drying may have major effects on the native flora and vegetation, and will lead to increased erosion as less suitable sites on slopes are cleared for gardens.

Pitcairn is out of the line of cyclones and so avoids regular major climatic disturbances. However as sea surface temperatures increase due to global warming, and cyclones become more common, Pitcairn may become increasingly affected by these factors.

Similarly tourism has not yet affected Pitcairn, but is a constant threat, especially with the current vogue for 'adventure' holidays, and interests that have been expressed by a New Zealand conglomerate for the development of massive hotel ventures on the Pitcairn group of islands.

Genetic erosion and inbreeding effects are undoubtedly proceeding in the native plant species, but this is a feature virtually impossible to detect or measure except with detailed genetic analyses.

6.3 Integrated conservation for the flora and vegetation

In chapter 5 the conservation needs for individual threatened species were identified. In most cases this related to monitoring of populations and the *ex-situ* cultivation of individuals for reintroduction to areas cleared of invasive species. *In-situ* conservation is time consuming and expensive for individual species, but is more feasible if carried out through the preservation of intact ecosystems, so ensuring the well-being and survival of the plant species they contain, and the maintenance of the essential they support (Synge 1979). The identification of reserve areas for priority conservation will allow this species and habitat based conservation to be carried out in tandem.

6.3.1 Location of potential reserve sites

When identifying reserve areas it is important to conserve both areas rich in endemics, but also other ecosystems not necessarily diverse but housing large assemblages of species or ecological phenomena. This also allows migrations between areas containing important species. Thus the geography of the species needing protection is central to the development of conservation strategies (Abbitt *et al.* 2000).

The use of the technique of complementarity allows the efficient identification of priority areas for conservation. The technique involves the use of taxic weighting and not just species richness (Vane-Wright *et al.* 1991). A step wise procedure is taken whereby the most diverse area is identified, and the species and habitats therein noted. The second area chosen in this situation is not necessarily the second most diverse region, but rather the region which holds the largest number of species and habitats that are not protected by the first area. Ideally this process is continued until all of the taxa in question are protected. In addition it is useful to note the population sizes of the species being protected, to make sure that they would be viable in the long term.

Figures 6.1 & 6.2 show the distribution of threatened species on Pitcairn. Figure 6.3 & 6.4 show the locations of 'hotspots of native diversity' and 'hotspots of endangerment' respectively. The fact that some of the areas identified as 'hotspots of diversity' and 'hotspots of endangerment' overlap shows that native diversity has been pushed to the margins of its original distribution. For both the global and Pitcairn IUCN status' there is a clear concentration of rare species in the Tautama area to the south of the island, and around the highest point in the south-west. Similarly there is a concentration of hotspots along the south coast and notably around Tautama.

Tautama is reasonably inaccessible, and rarely visited by islanders, even though it covers a substantial area and houses several different vegetation communities. It is also a historically important site, thought to be one of the original Polynesian settlements and a regionally important Polynesian quarry (Weisler 1995). All of these factors make Tautama

an ideal area in which to locate a potential nature reserve area, and indeed this has been suggested previously (Waldren *et al.* 1999a).

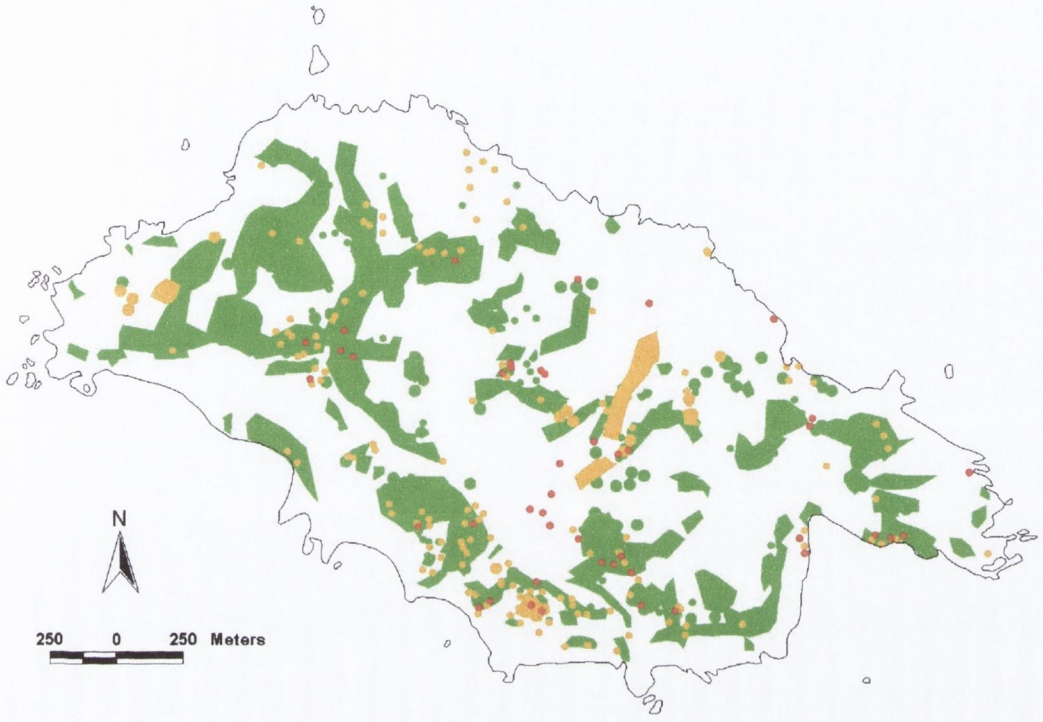


Figure 6.1 - Distribution of locally threatened species on Pitcairn island, using the IUCN Red data categories. Maps show the Pitcairn IUCN threat status. Key: red = critically endangered species; orange = endangered species; green = vulnerable species.

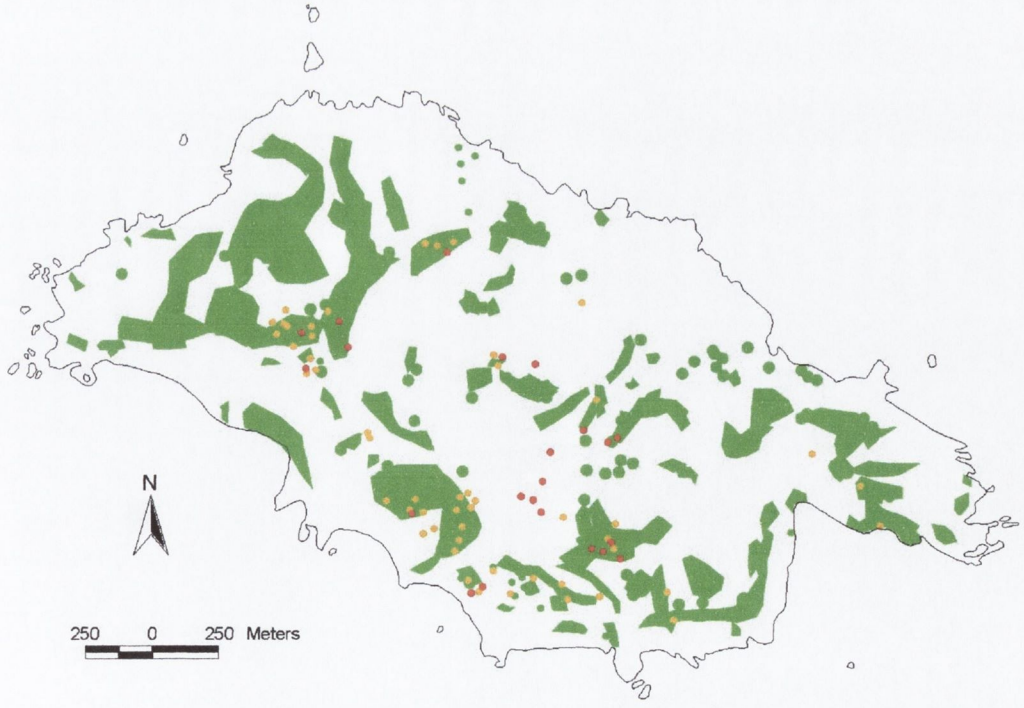


Figure 6.2 - Distribution of globally threatened species on Pitcairn island, using the IUCN Red data categories. Maps show the global IUCN threat status. Key: red = critically endangered species; orange = endangered species; green = vulnerable species.

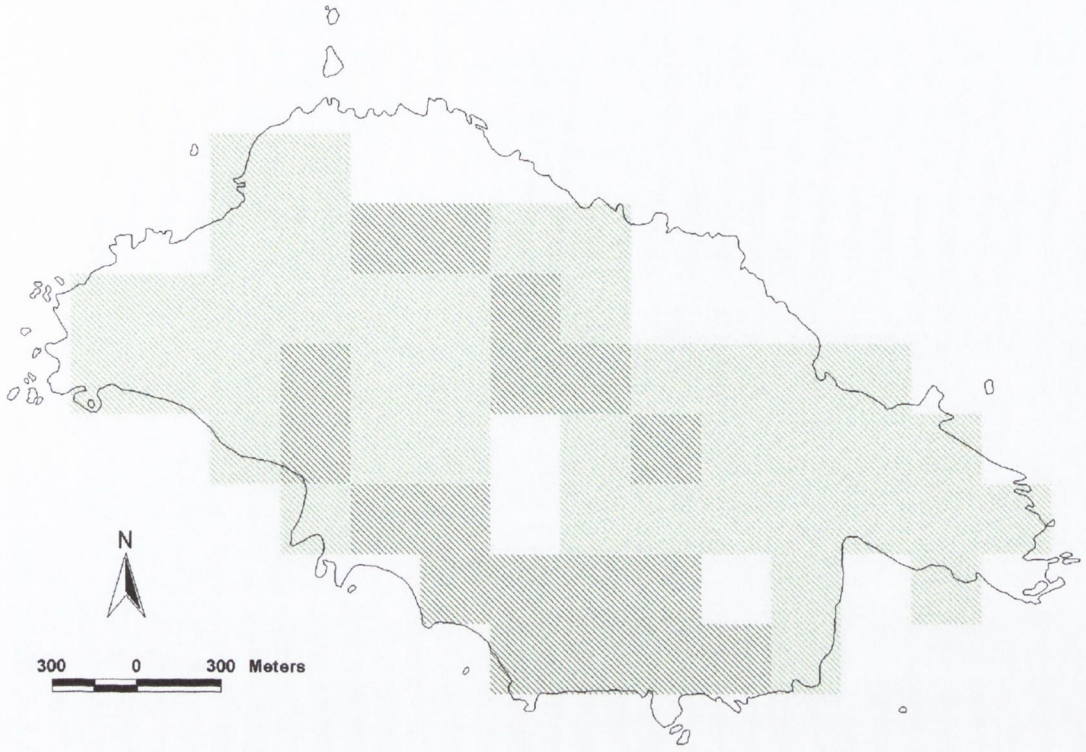


Figure 6.3 - Map of Pitcairn to show the locations of 'hotspots of native diversity'. Light green squares have 12-23 native species, while the dark green squares have 24-36 native species.

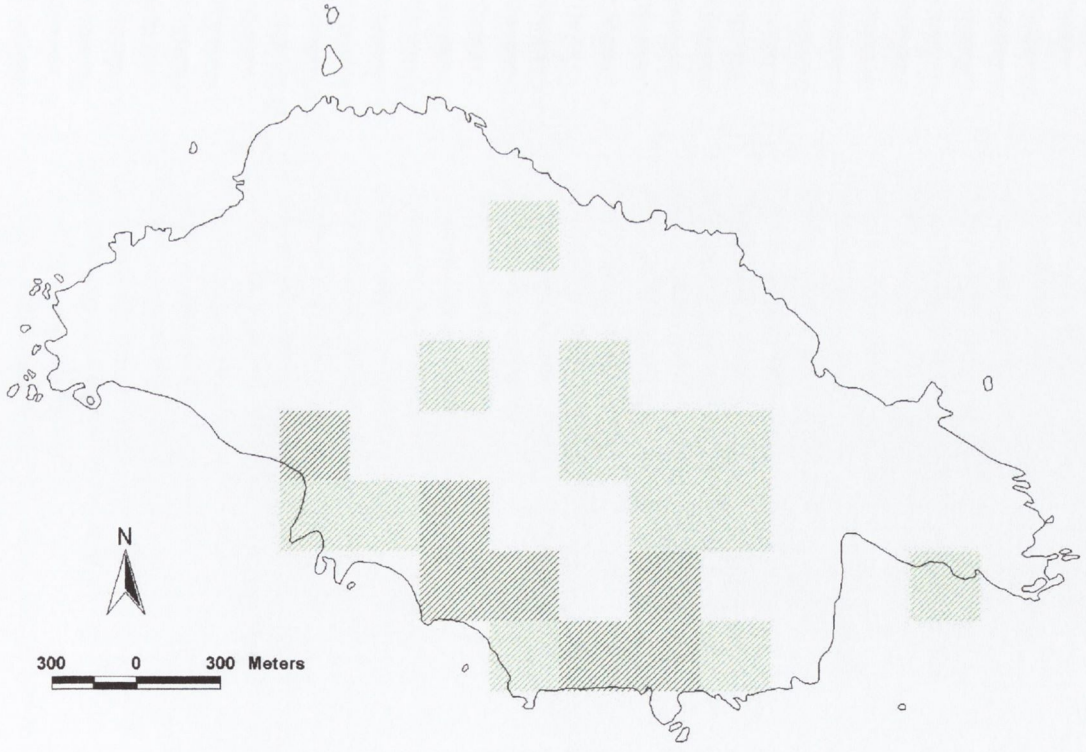


Figure 6.4 - Map of Pitcairn to show the locations of 'hotspots of endangerment'. Light green squares have 5-10 threatened species, while the dark green squares have 11-15 threatened species. In all cases the squares with the most threatened species correspond to those with high numbers of native species in figure 6.3.

The Tautama area from the surrounding ridges and cliffs down to the sea, would protect 23 species listed as threatened on Pitcairn, and 8 of the native habitat types. 9 of these species are globally threatened. As this area comprises a natural physiographic unit from ridge crest to coast with natural edge barriers, protecting this area as a reserve would avoid problems caused by edge effects (table 1.2). However, while the site would protect a high number of species, several of these (eg *Diplazium harpeodes*) are in very small numbers and do not represent viable populations. Figure 6.5 shows the locations of the remaining threatened species once those which have populations within the Tautama reserve are removed.

The next step, therefore, is to identify another area that can be conserved, that would add more of the threatened species, as well as improving the populations of species already conserved in the Tautama area. Adjacent to Tautama are Faute, Outer and Ginser Valleys, a reserve area which also contains 23 threatened species, 4 of which are not found in the Tautama reserve, and 7 habitats, 2 of which are not found in the Tautama reserve. However, while there are many species here, most of them are in small non-viable populations (eg one individual of *Diplazium harpeodes* & the smallest population of *Angiopteris chauliodonta*). As with Tautama, the area is remote and rarely visited or used by islanders.

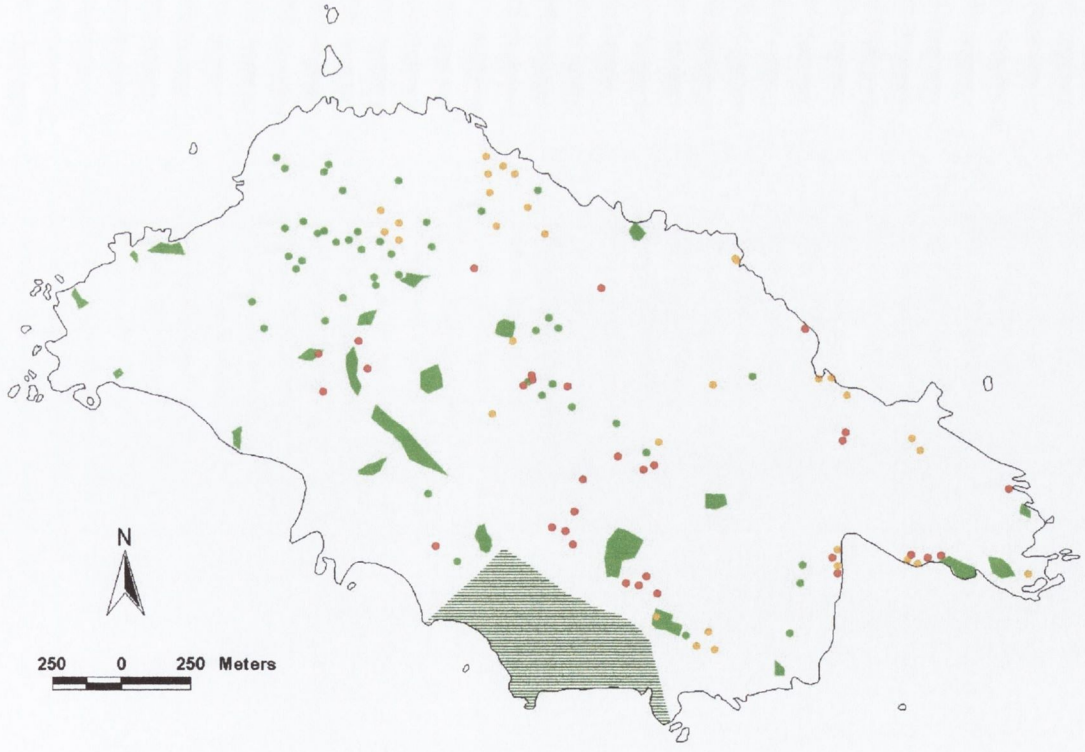


Figure 6.5 - Distribution of threatened species on Pitcairn island, following the removal of species that are represented in the Tautama reserve area. Maps show the Pitcairn IUCN threat status. Key: red = CR species; orange = EN species; green = VU species; shaded = Tautama reserve.

Another suitable site is the area running along either side of Big Ridge and Parlver Ridge, incorporating Foutu and the inaccessible Ginser Valley, down to the sea. This area holds 19 threatened species, 11 of which are globally threatened species, and 4 of which are not in the Tautama reserve. In addition 8 of the species in common with Tautama have larger populations here than in the Tautama area. The Big Ridge area represents 7 habitats, 1 of which is not found in the Tautama reserve. Even though this area has fewer threatened species and habitats than the Faute Valley area, it would be more appropriate as a second reserve area due to the fact that the populations of species present are larger and therefore more viable in the long term. In addition the Big Ridge area would provide suitable habitats for reintroduction of several of the other rare species (eg *Coprosma benefica*). Figure 6.6 shows the locations of the remaining threatened species following the removal of those which have populations within the Tautama or Big Ridge reserve areas.

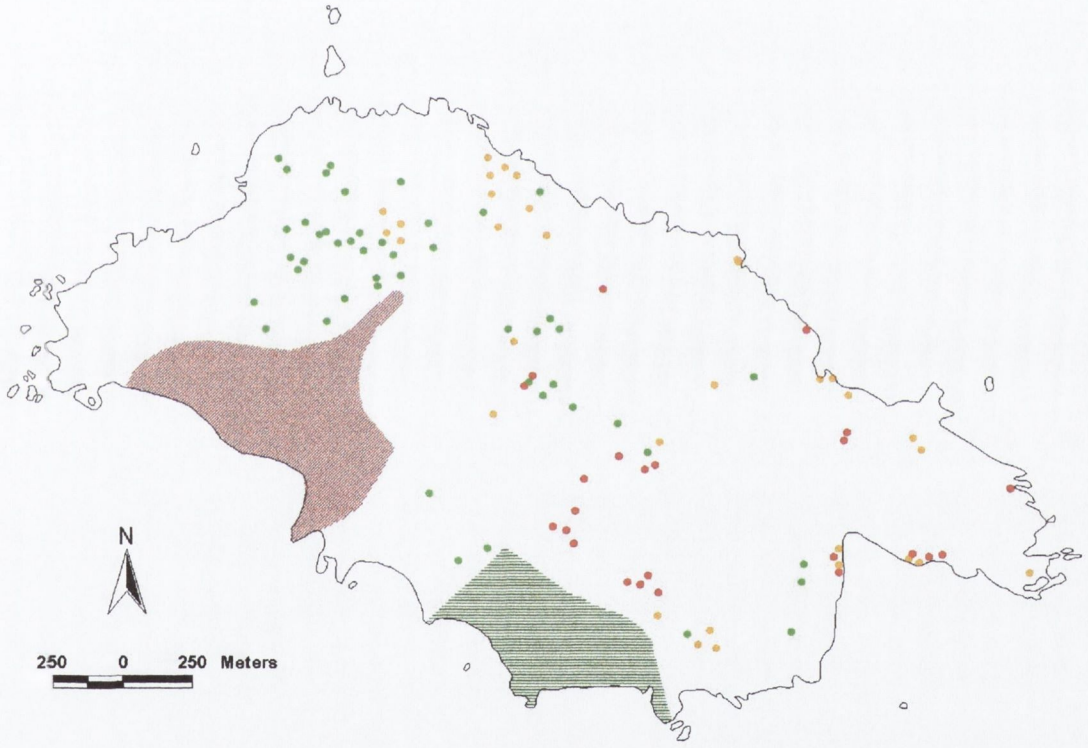


Figure 6.6 – Distribution of threatened species on Pitcairn island, following the removal of species that are represented in the Tautama and Big Ridge reserve areas. Maps show the Pitcairn IUCN threat status. Key: red = CR species; orange = EN species; green = VU species; green shaded area = Tautama reserve; pink shaded area = Big Ridge reserve area.

This Big Ridge reserve area (pink area in figure 6.6) is a less than ideal shape for a reserve area, with the elongated extension to the north dramatically increasing the boundary area and thus increasing the edge to core ratio. However, this extension runs along a major ridge, and holds the potential site for many of the endangered species to be translocated or reintroduced to (in particular *Coprosma benefica*). In addition the area surrounding this elongated extension is native *Pandanus tectorius*, *Homalium taypau* and *Metrosideros collina* woodland, and will provide a secure buffer zone to the ridge reserve area, thus reducing

the edge effects. The boundary to the south of the main area of reserve is a ridge, and the boundary to the north is buffered by *Homalium taypau* woodland.

A further small reserve area at the coastal site of Down Rope houses 7 threatened species, 4 of which are not found in the other 2 reserve areas, and 2 of which have larger populations than in either of the other reserve areas. 2 habitats are represented here, both of which are also found in the Tautama and Big Ridge areas. The potential reserve area is bounded on all sides by cliff and forms a natural physiographic unit on its own. The population of *Hibiscus australense* that occurs at Down Rope is however small and probably not viable in the long term. Reinforcement of this population with individuals from the only other, but larger, population at Christians Cave would improve the likelihood of its survival. Down Rope has also been previously suggested as a cultural reserve area due to the presence of Polynesian petroglyphs on the cliffs beside the beach (Waldren *et al.* 1999a). Figure 6.7 shows the locations of the remaining threatened species following the removal of those which have populations within the Tautama, Big Ridge or Down Rope reserve areas. Figure 6.8 shows this same map for the species that are globally threatened.

Allocating these three areas as reserves will protect all of the native habitat types, as well as 31 species threatened on Pitcairn, and all except two of the globally threatened species, *Coprosma benefica* and *Cenchrus calyculatus*. *C. benefica* currently occurs in highly degraded habitats, but there is a record from Parlver Ridge in 1934 (St. John 1987), so reintroduction of this species to the Big Ridge reserve may prove feasible. *Cenchrus calyculatus* occurs in coastal scrub habitats and populations could be introduced to the Down Rope and Tautama reserves.

13 species remain that are threatened on Pitcairn, and lie outside of the suggested protected areas. At least three of these species, *Argusia argentea, Ipomoea macrantha* and *Scaevola sericea*, are rare due to the limited habitat available to them on Pitcairn. As they are all coastal species, populations could be established in the Down Rope reserve if desired. The other remaining species present more complex problems, and have to be addressed on an individual basis:

- *Adiantum hispidulum* - occurs in *Homalium taypau* woodland in Faute Valley beside Tautama, and may even occur on the cliff at Tautama. It could potentially be also introduced to the *Homalium taypau* woodland in Tautama. It would be less likely to survive in the cloud forest of the Big Ridge reserve.
- *Caesalpinia major* - occurs at woodland edges and in open degraded scrub habitats. Is likely to persist in its current location without any particular measures, and is not of much concern.

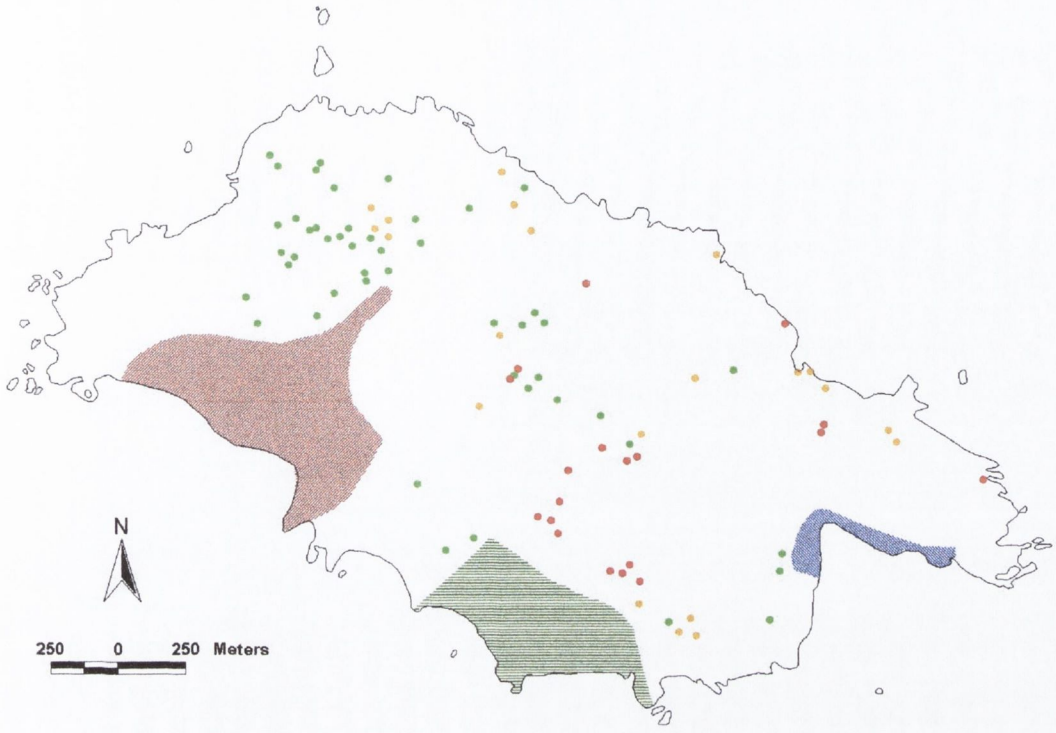


Figure 6.7 - Distribution of threatened species on Pitcairn island, following the removal of species that are represented in the Tautama, Big Ridge and Down Rope reserves. Maps show the Pitcairn IUCN threat status. Key: red = CR species; orange = EN species; green = VU species; green shaded = Tautama reserve; pink shaded = Big Ridge reserve; blue shaded = Down Rope reserve.

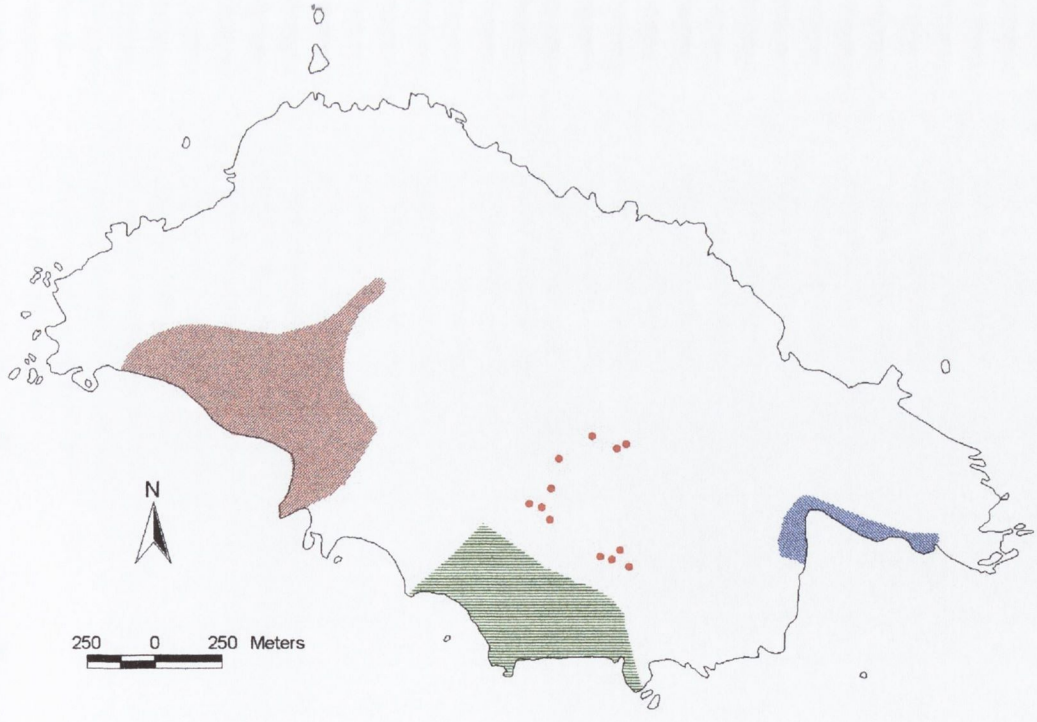


Figure 6.8 - Distribution of threatened species on Pitcairn island, following the removal of species that are represented in the Tautama and Big Ridge reserve areas. Maps show the Global IUCN threat status. Key: red = CR species; green shaded = Tautama reserve; pink shaded = Big Ridge reserve area; blue shaded = Down Rope reserve area.

- *Cerbera manghas* - occurs in mixed woodland and ridge slopes at Tedside, and just falls outside of the area covered by the Big Ridge reserve. If deemed necessary at a later date, populations could be established within the boundaries of the Big Ridge Reserve, and introduced to the ridge slopes of the Tautama reserve. Currently the population is actively regenerating in available natural woodland.

- *Lastreopsis* cf. *pacifica* - as discussed previously (section 5.4.4) the population of this species is in a very precarious habitat at Brown's Water. Brown's Water has been previously suggested as a reserve area due its high native biodiversity, and the fact that the site is an important watershed. However a major trackway runs along the side of the valley, and erosion of landslides on to the populations of *L. pacifica* are likely. Introduction of a population into suitable damp shaded gullys in Tautama would establish a population within a reserve and away from the potential threats presented at Brown's Water, although monitoring and steps to protect the Brown's Water population should also be taken. The hydrological importance of Brown's Water should be emphasised in support of its conservation.

- *Lepidium bidentatum* - this species was only seen at one location although it probably is more common on some of the inaccessible coastal cliffs. If a seed source is found a population could potentially be established at Down Rope, but this is not currently necessary.

- *Ophioglossum reticulatum* & *O. nudicaule* - these two species occur in damp flushes on ridges and eroding slopes. Populations in the Hollow are at risk from erosion, but other populations, such as those at Long Ridge and Christians Cave may benefit from a certain amount of goat trampling and erosion. The population of *O. nudicaule* in the remote Toonina Valley is unlikely to be at risk. Propagation and cultivation of these species are probably too difficult to be feasible, and so the existing populations should be monitored.

- *Osteomeles anthyllidifolia* - only a single individual of this species remains on Pitcairn in a relatively protected site at Ships Landing point. If propagation of the species is successful, individuals could potentially be introduced to the cliffs at Tautama.

- *Psydrax odorata* - individuals of this species produce copious amounts of seed on Pitcairn, which could be established along Big Ridge or along the ridges at Tautama. This species could also be cultivated around and near Adamstown for use as a timber and 'Christmas tree' resource.

- *Trichomanes tahitense* - this species is found in Faute Valley next to Tautama, and in Browns Water. Cultivation or translocation of a population of the plant would prove almost impossible due to the nature of *Trichomanes* spp. as being slow

growing, difficult to establish from spores and having very particular microhabitat requirements. There is however a strong possibility that the species may occur in Tautama but was overlooked in 1997. Introduction of cuttings into the same habitat as the *Lastreopsis* cf. *pacifica* in Tautama could be attempted, but other than this little can be done except to monitor existing populations and carefully search Tautama in the hopes of finding an already established population.

6.3.2 Further conservation needs

Control of threats

Once the appropriate reserve areas have been identified, the next priority would be to control potential threats to the native taxa and habitats. The main threat has been identified as invasive species and so the priority will be to eradicate invasive species which have limited population sizes, and to prevent the further spread of *Syzygium jambos* into remaining native forest.

The control and removal of *Syzygium jambos* should not be undertaken until the highly invasive *Lantana camara* has been controlled, or until alternative land uses have been initiated. Removal of *Syzygium jambos* should start uphill, as this should reduce reinfestation as the seeds are more likely to spread downhill, and in areas where it as yet is not a major problem (e.g. Faute Valley, where *Syzygium jambos* only occurs in one small area). Several methods are currently being tested to kill the cut stumps, including painting with Tordon™ herbicide or crude oil. Cutting of large individuals results in a dense cover of seedlings forming on the ground, so clearance of areas will require several years of commitment in any single area. Revegetating cleared areas with vigorous native species may reduce the *Syzygium jambos* regrowth, however, the soil seedbank of *Syzygium jambos* may persist for many years (P. Bingelli pers com.).

Control of *Lantana camara* is a more complex problem and will probably require biological control which is being investigated (P. Bingelli, pers com.). Partially successful control of *Lantana camara* has been achieved by means of introduced insect biological control in Hawaii and the Galápagos Islands, but it is still a major pest (Cronk 1997; Schofield 1989). It was also successfully eradicated through clearing by hand in parts of the Galápagos National Park in 1995 (Mauchamp *et al.* 1998). The persistence of some *Lantana camara* populations is probably due to the fact that many different varieties and cultivars have been introduced to most areas, some of which show more resistance to the biological control agents (P. Bingelli pers com.).

Other species identified in section 2.4.1 which have potential to become invasive should also be eradicated or controlled where possible. *Leucaena leucocephala* and *Psidium cattleianum* currently exist in small enough numbers that they could be simply removed by hand. *Psidium guajava* presents a more complex problem as it is widely used by the islanders for fruit. Clearance of the species could be carried out from remote areas where

the islanders do not collect the fruits. This species may also have been spread by the islands Polynesian rat (*Rattus exulans*) population, and recent attempts to eradicate the rat may also serve to control the plants spread. *Passiflora* spp. are a major invader, the spread of which may also be aided by the Polynesian rat. However, the eradication of all *Passiflora* spp. would meet with too much opposition from the islanders and would in any case be unfair to them, so potential eradications should be limited to those species perceived to be pests by the islanders themselves. The spread of these species to other islands in the group is a major threat, notably to the World Heritage Site of Henderson Island where a single *Passiflora maliformis* plant was found in 1991. The recently introduced *Carpobrotus edulis* is currently only found at St. Pauls, but it was impossible to determine in 1997 how extensively it had spread down the cliff. Visible and accessible individuals of this species should be removed, and if necessary (ie if it can be determined that it has spread extensively on the St. Pauls cliffs) further control measures should be investigated. *Carprobrotus edulis* was originally introduced to St. Pauls to control erosion, and is an example of an introduced control agent becoming a pest itself.

The IUCN guidelines for the prevention of biodiversity loss caused by invasive species target better education and awareness, improved laws and greater management capacity, backed by capable customs and quarantine systems, to be the factors necessary for prevention of the arrival of alien invasive species onto islands (Species Survival Commission/IUCN 2000a). There is certainly a need for better education and awareness on Pitcairn in relation to invasive species. For example there is little point in trying to control *Lantana camara* until the islanders have been educated that it is not beneficial to the soil, as they currently think.

Erosion problems can only really be tackled with specialist advice. Erosion has been identified by the islanders as a cause for concern, and the recent introduction of *Carpobrotus edulis* at St. Pauls was an attempt to control erosion at the site. Plantings of native species in areas such as this would be more appropriate, notably *Pandanus tectorius*, native pteridophytes such as *Dicranopteris linearis* and *Phymatosorus scolopendria*, and native bryophytes such as *Trematodon latinervis*, and *Campylopus sp.* which are already successfully binding and protecting some areas from erosion. A proposed airstrip on the island's only flat ground would displace the islanders gardens to the steeper slopes, and thus potentially increase erosion. Careful planning and relocation of gardens will have to be undertaken if the airstrip is to go ahead. A proposal to build a surfaced road from Adamstown to Bounty Bay, down the so called 'Hill of Difficulty', one of the steepest and most severely eroding slopes, has recently been accepted although the start date for the project has not yet been confirmed. A consequence of this however, is the necessity to build a quarry on the island. The location of the quarry site will impact on native vegetation, although finance is now being included in the project to restore the area after

the building works have been completed. It is also important that further erosion is prevented where possible when clearing invasive species.

After invasive species and erosion the lack of a frugivorous bird is probably the largest conservation problem affecting Pitcairn Island. There is no available information as to what species were present (although a *Ducula sp.* is likely to have been present, M. Brooke pers comm 2001), or as to when these birds became extinct, but while some became extinct during the Polynesian occupation, others were wiped out more recently as they were a pest on fruit crops (T. Christian pers com; G. Wragg pers com). Trial reintroductions of birds to islands are being considered in the Cook Islands (G. McCormack pers com.), and this is something that could be considered for the future if it is successful elsewhere. The introduction of a fruit dove population (eg the Henderson fruit dove *Ptilinopus insularis;* or another endangered Polynesian *Ducula sp.* or *Ptilinopus sp.;* M. Brooke pers comm 2001) to the Tautama reserve would help to disperse and thus conserve 19 of the native species, 11 of which are threatened.

The effects of goat trampling and browsing has been successfully constrained on some of the Galápagos Islands through the culling of goat populations and the fencing off of areas with threatened populations of species (Schofield 1989). Fencing of goats on Pitcairn has been attempted in the past, but with little success, and there is a lack of support from the islanders for an initiative such as this.

Ex-situ conservation

Future conservation measures on Pitcairn will be primarily *in-situ* by means of protecting species in reserves. This is the ideal method for species recovery, but it is not always possible, and may leave a population threatened by stochastic effects if the numbers are very low. In chapter 5 additional *ex-situ* conservation measures necessary to ensure the long-term survival of some rarer species were identified. *Ex-situ* therefore will be most important for the protection of species whose habitat has been irreversibly damaged, or whose numbers are very low. These ex-situ activities identified two main institutions as necessary for their success, the Pitcairn Island Department of Conservation, and TCD.

Ex-situ conservation that would be undertaken on Pitcairn includes the propagation of rare plant taxa in order that individuals can be planted into native populations to increase the numbers in the populations, and also to provide individuals that can be used to reintroduce populations to areas where the species were previously found, or where they can be more successfully protected. In TCD the purpose of the *ex-situ* activities would be very different, and would provide backup measures for the activities being undertaken on Pitcairn. This would be mainly in the form of a stored seed-bank collection for rare taxa, and living collections of individuals to be used for research purposes. Separate recovery plans would be drawn up for each species, as different species have differing conservation needs. Plant reintroduction techniques are still only experimental, but are becoming more

popular as accepted tools for increasingly more sophisticated conservation regimes (Maunder 1992). They are especially important for species in areas at risk of habitat destruction, and those that have critically low numbers (<50), and thus may be ultimately necessary for many of the taxa identified as threatened for Pitcairn.

The propagation of highly threatened native species so that populations can be reintroduced into protected areas and areas cleared of invasive species is the main priority for *ex-situ* conservation. In particular species such as *Coprosma benefica* will not survive unless new habitat is found for them, because the plants currently occur in such degraded areas. Species recovery programmes in general will aim to increase the numbers of rare species in areas that are relatively undisturbed and unused by the islanders, while monitoring and maintaining populations of keystone and other native species already present. It is possible to identify the areas suitable for reintroduction of threatened species as information is available from Chapter 4 as to what vegetation communities are present in the different areas, and as quadrats were deliberately taken to include rare species their habitat preferences are known.

Propagation will be undertaken for more than just threatened native species, but also for non-threatened species that can be introduced to areas as they are cleared of invasive species. These species will serve to bind the substrate and prevent the reinvasion of non-native species, thus preparing the areas for planting of the rarer taxa. Examples of appropriate species are *Nephrolepis* spp., *Phymatosorus* spp., *Davallia solida* and *Dicranopteris linearis*.

As well as reserve areas it is possible to locate areas to be used for exploitation and cultivation. Restored areas would be especially suitable for mixed planting of native species along-side fruit and timber trees. Some areas may be found to be completely unsuited to native plantings and these could be identified for tree or crop plantation areas. A stock of these fruit and timber trees could also be propagated on Pitcairn for use as necessary. Suitable and preferred taxa can be identified following discussions with the islanders, which will ensure that they are involved at all levels of the conservation and restoration process, and ensure that the conservation activities do not impinge on their activities but rather provide a sustainable future for them.

Following discussions in 1997, the Island Council secured funding to establish a small nursery on Pitcairn. This will act as a source of material to revegetate cleared areas, provide the necessary propagated material of local plant resources, and provide the facilities needed for the Conservation Officer to undertake species recovery work. Clearly, there will be a need for on-going advice and consultation, but the Conservation Officer has already attended a period of training at the Royal Botanic Gardens, Kew, and we are hopeful that future scientific visits to Pitcairn can substantially contribute to the operations of the nursery. The provision of this nursery is an example of close co-

operation between a small local community and outside scientific advisors, and this co-operative approach as an essential means of forwarding conservation objectives while providing empowerment of local communities.

In the British Overseas Development Authorities report on biological diversity in developing countries and overseas territories, endemic species and threatened habitats were identified as priorities for conservation (Flint 1991). In addition the wider objective of any biodiversity expenditure within aid programmes should be to maximise the conservation and use of biodiversity in order to provide sustainable social and economic benefits to developing countries (Flint 1991). Thus the British Authorities, who oversee Pitcairn Island acknowledge that there is an international obligation to protect the biodiversity of Pitcairn Island and the associated islands in the group. The Pitcairn group is also included in the province defined as priority for the establishment of protected areas in the World Conservation Strategy (IUCN 1980).

6.3.3 Feasibility of successful practical conservation on Pitcairn

Setting conservation priorities and management objectives is futile if practical matters such as local involvement and land ownership issues are not addressed, and practitioners do not understand the human factors involved (Wright & Lees 1996). In particular, allowance has to be made for any infrastructural developments that would be of benefit to the local communities, and partnerships have to be encouraged between local communities and their scientific advisers. Legislation and development plans should allow for both sustainable development and conservation to co-occur.

On Pitcairn Island there are several local issues which need to be addressed before conservation activities can be implemented. Land ownership on the island is by inheritance, as is traditional in most Pacific island communities. This leads to a situation where an individual islander will own small, widely scattered plots of land and even individual trees, across the whole island. In addition many non-resident islanders own land which is left unmanaged. The unmanaged land is in many cases reverting to invasive *Lantana camara* scrubland or *Sorghum sudanense* savanna. There is currently no land tax applied to non-resident land owners and so there is no finance available to improve these plots. Land ownership issues are currently being addressed by the island council, and it has been suggested that areas be set aside as nature reserves to be owned and managed by the island council. The three reserve areas suggested here are on unused land in remote areas, and as such should not come up against major opposition.

Proposed developments have been noted where relevant throughout the text, and the main developments currently under discussion are the provision of an airstrip, a paved road at the 'Hill of Difficulty' and a holiday resort development. All of these developments will require environmental impact assessments to be undertaken prior to construction work. The road construction work will, however, require the further

development of a quarry site, a crusher and potentially the digging of a borehole. The airstrip, road development, crusher and quarry site have all been discussed at length and appropriate sites have been identified. In addition finance has been set aside in the development budgets for environmental reconstruction following the construction work. A desalinisation plant has been suggested as an alternative to the digging of a borehole, as a borehole would affect the groundwater of the island, and as fresh water is not readily available on the island at any time, a desalinisation unit would be of benefit to the islanders following the construction work. The holiday resort development is a recent proposal, and as such has not yet been fully discussed either by the Island Council or their advisors. This kind of development will require a large number of environmental, economic and social issues to be addressed, and is beyond the scope of this discussion.

Funding for conservation activities is difficult to obtain under any circumstances, and Pitcairn Island is no different. As discussed in section 1.4.5, a part-time Conservation Officer has been appointed, and the officer has attended a training course in the Royal Botanic Gardens, Kew. This is a government funded position, but the associated nursery that has been set up will require continued external funding. Further manual, technical and scientific assistance is required on site and this will require a small expedition to the island in the near future. Again funding will have to be sought for this, but as this expedition could be run when visiting the island to carry out environmental impact assessments for the proposed developments, costs can be kept to a minimum.

The rat eradication project which was carried in 1997 and again in 1998 was unsuccessful. Further minor attempts have been made, and while the rat population is depleted, there is potential for the original rat population numbers to be achieved again. Another large scale rat eradication project has been suggested, and much of the plant conservation implementation will rely on the success of eradication. This is because the islands rat population is probably one of the main dispersers of invasive species, such as *Psidium* spp., *Passiflora* spp., *Lantana camara* and *Syzygium jambos*.

A further factor that needs to be addressed is the fact that Pitcairn Island itself has no biodiversity plan. Following the designation of Henderson Island as a World Heritage Site, a full management plan for the island was drawn up, but this has never been done for Pitcairn. The compilation of a biodiversity and sustainable development plan in line with the Convention on Biological Diversity (CBD) would be timely, as it would serve to address development, land ownership and conservation issues, as well as set out guidelines to which further developments would be subjected. If the delimitation of reserve areas is to be a success, proper management guidelines and funded full-time government officer positions will have to introduced in tandem.

6.4 Implications for Pacific island conservation

The study presented here could be used as a base model from which to initiate the baseline data collection and conservation activities for other larger islands in the Pacific. This study presents a step by step approach for a simple island ecosystem, but one that could be expanded to suit other islands with more diverse species and habitats. The Pitcairn island group is interesting as it shows a range of habitat types with varying levels of human disturbance in a biogeographically remote location. Similarly as the Pitcairn group contains all of the island types it provides a good model of species distributions in a simplified unit. The group exhibits the differences between species a poor remote atoll (Ducie), a less remote and less species poor atoll (Oeno), a makatea island (Henderson) and a high island (Pitcairn). Threats to the native biodiversity for all of these island and substrate types differ, as do the conservation priorities. Combining this detailed study of Pitcairn with the detailed studies made on Henderson and Oeno in 1991, means that a conservation assessment for the whole island group can now be made, and priorities set.

As Pitcairn is a small island, with a now well studied flora, for which species distributions are reasonably accurately known, it is possible to make informed conservation management decisions. However for larger islands this is not always the case. In addition the survey of Pitcairn took place in conjunction with a rat eradication project, for which a grid of trails covering the whole island was cut. This provided the opportunity to visit otherwise inaccessible parts of the island. The possibility of coinciding island surveys with other larger scientific expeditions must be considered during the preliminary stages of planning, so that trail cutting and other tasks do not curtail the time spent on gathering scientific data.

In the study presented here it was found that 'hotspots of diversity' overlapped with 'hotspots of endangerment' making the selection of areas for reserves to be a relatively straight forward task. However this will not always be the case, and for many islands rarity and diversity may not be coincident. In cases such as these, and in cases where larger islands and data sets are utilised, the technique of complementarity can still be used, but by employing a statistical procedure such as that available in the WORLDMAP computer package (Natural History Museum 1994-2001).

The Polynesian region is described as a high-priority area for conservation of biodiversity, because of its high level of endemism and also high level of threat to both species and their habitats (Mittermeier *et al.* 1998; Olson & Dinerstein 1998). On many of the Polynesian islands this is primarily due to introduced species, and there is good evidence that biological invasions contribute substantially to species extinction (Vitousek *et al.* 1997). This study showed that Polynesian islands with high percentages of endemism also have the highest invasive species indices, a fact which has major implications for conservation activities in the region.

6.5 Concluding remarks

It is important to promote sustainable conservation in conjunction with development, to ensure a future income and standard of living for the islanders. Now over one third of the native-born Pitcairners live away from the island, with most of them settling in New Zealand. The population has dropped from a maximum of 200 to now being only 38 permanent people. A major factor in the depopulation of the island is poverty, with most of the islanders reliant on the sale of carvings to make a living. Government positions are part-time and poorly paid, and as such they are not taken seriously by the islanders who hold them. This is also true of the Conservation Officer position, on which much of the objectives of this thesis rely. It would certainly be helpful to have more full-time paid conservation related positions held by the islanders, but it would be also beneficial to have more full-time government paid position in other areas of the island community. Unless the islanders are given the motivation to take local government and environmental issues more seriously they will potentially lose out on obtaining potential funding and subsidies that could be available to them.

Now that the baseline data has been collected it will take little effort to continue conservation work on Pitcairn. It is important this is carried out soon to prevent further environmental degradation as is common on other islands (Bahn & Flenley 1992; Mauchamp *et al.* 1998; Page *et al.* 1995; Zizka 1991). Too often after the initial survey work is done the actual implementation of conservation objectives is not carried out due to a lack of funding and interest. In a country such as Pitcairn with a depauperate but interesting and internationally important flora, the potential loss of any species should be sufficient to warrant an active conservation policy, at least in establishing population monitoring of the remaining populations.

The development of reserve areas around Tautama, Big Ridge and Down Rope would provide protective refuges for most of the islands threatened species, as well as providing suitable habitat into which other rare species could be introduced. As Tautama and Down Rope are remote, inaccessible and rarely visited by islanders, and the area around Big Ridge is used mainly for nature walks, the segregation of these areas as reserves would not restrict the day to day life of the islanders, and would enhance these areas of natural beauty.

Pitcairn Island has a small but now well studied flora. The distribution of vascular plants across the island is now known in detail, the status and threats to the flora have been assessed, and the patterns of vegetation communities have been described, and probably in greater detail then for any other Polynesian island. The provision of these baseline floristic and vegetation community data enables objective conservation priorities to be set: these priorities are essential in a remote location such as Pitcairn, which has limited financial and manpower resources available for conservation activities. Further study of

the ecological interactions and processes involved in the relatively simple Pitcairn vascular flora are now required, as this should be of benefit in understanding these processes on other, more complex and biologically diverse islands elsewhere in the Pacific.

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Appendix 1 - List of introduced species found on Pitcairn Island.

Family	Genus	Species	Status	Local Name
Acanthaceae	*Thunbergia*	*alata*	Cul	
Agavaceae	*Agave*	*americana*	Nat	
Agavaceae	*Cordyline*	*fruticosa*	Pol	Ti; Tee; Tee-plant; Raw-tee; Ou-tee; Rauti
Aizoaceae	*Carpobrotus*	*edulis*	Nat	Ice plant
Amaranthaceae	*Achyranthus*	*aspera*	Pol	Crocus stuff
Amaranthaceae	*Alternanthera*	*brasiliana*	Nat	
Amaranthaceae	*Amaranthus*	*viridis*	Adv	
Amaranthaceae	*Celosia*	*argentea*	Cul	Cock comb
Amaranthaceae	*Gomphrena*	*globosa*	Cul	
Amaryllidaceae	*Clivia*	*miniata*	Cul	
Amaryllidaceae	*Crinum*	*asiaticum*	Cul	
Amaryllidaceae	*Eurycles*	*amboinensis*	Cul	
Amaryllidaceae	*Hippeastrum*	*x hortorum*	Nat	Christmas Lily
Amaryllidaceae	*Zephyranthes*	*candida*	Cul	
Anacardiaceae	*Mangifera*	*indica*	Cul	Mango-Herbert; Mango
Anacardiaceae	*Spondias*	*dulcis*	Pol	Vhe tree
Annonaceae	*Annona*	*cherimola*	Cul	Shere
Annonaceae	*Annona*	*reticulata*	Cul	Custard apple
Annonaceae	*Annona*	*squamosa*	Cul	Snow-fruit
Apiaceae	*Apium*	*graveolens*	Cul	Celery
Apiaceae	*Apium*	*leptophyllum*	Adv	
Apiaceae	*Daucus*	*carota*	Cul	Carrot
Apiaceae	*Petroselenium*	*crispum*	Cul	Parsley
Apocynaceae	*Allamanda*	*cathartica*	Cul	Pu-pu
Apocynaceae	*Catharanthus*	*roseus*	Cul	Hilda-flower
Apocynaceae	*Nerium*	*oleander*	Cul	Oleander; Mountain Rose; Holiandah
Apocynaceae	*Plumeria*	*rubra*	Cul	Frangi-panni
Apocynaceae	*Stephanotis*	*floribunda*	Cul	Stiffen-o-his
Apocynaceae	*Vinca*	*minor*	Cul	Binii flower
Araceae	*Alocasia*	*macrorrhiza*	Pol	Ape; Appai; Yappa; Egyptian lily
Araceae	*Colocasia*	*esculenta*	Pol	Water taro; Dry land taro; Black tale; Red tale
Araceae	*Monstera*	*deliciosa*	Cul	
Araliaceae	*Polyscias*	*guilfoylei*	Cul	Mock Coffee
Asteraceae	*Adenostemma*	*lavenia*	Adv	White stuff
Asteraceae	*Arctotis*	*stoechadifolia*	Cul	African daisy
Asteraceae	*Bidens*	*pilosa*	Adv	Broom stuff; Broom stick
Asteraceae	*Calendula*	*officinalis*	Cul	Calendula
Asteraceae	*Centaurea*	*cyanus*	Cul	Corn flower

continued

Family	Genus	Species	Status	Local Name
Asteraceae	*Chrysanthemum*	*x morifolium*	Cul	
Asteraceae	*Conyza*	*bonariensis*	Adv	
Asteraceae	*Gaillardia*	*aristata x pulchella*	Cul	
Asteraceae	*Gerbera*	*jamesonii*	Cul	
Asteraceae	*Helichrysum*	*bracteatum*	Cul	Knob everlasting
Asteraceae	*Lactuca*	*sativa*	Cul	Lettuce
Asteraceae	*Leucanthemum*	*vulgare*	Cul	
Asteraceae	*Sigesbeckia*	*orientalis*	Adv	Nightshade
Asteraceae	*Sonchus*	*oleraceus*	Adv	White stuff
Asteraceae	*Synedrella*	*nodiflora*	Adv	
Asteraceae	*Tagetes*	*patula*	Adv	Marigold
Asteraceae	*Taraxacum*	*officinale*	Adv	Knacker food
Asteraceae	*Vernonia*	*cinerea*	Adv	
Barringtoniaceae	*Barringtonia*	*asiatica*	Pol	Utu; Big seed
Basellaceae	*Boussingaultia*	*gracilis*	Cul	Madeira vine
Begoniaceae	*Begonia*	*sp.*	Cul	
Boraginaceae	*Cordia*	*subcordata*	Pol	Toa
Brassicaceae	*Brassica*	*juncea*	Cul	Mustard
Brassicaceae	*Brassica*	*oleracea*	Cul	Biini Cabbage
Brassicaceae	*Brassica*	*rapa*	Cul	Turnip
Brassicaceae	*Coronopus*	*didymus*	Adv	
Brassicaceae	*Lobularia*	*maritima*	Cul	
Brassicaceae	*Matthiola*	*incana*	Cul	
Brassicaceae	*Nasturtium*	*sarmentosum*	Cul	
Brassicaceae	*Raphanus*	*sativus*	Cul	Radish
Bromeliaceae	*Ananas*	*comosus*	Cul	Pineapple
Cactaceae	*Epiphyllum*	*sp.*	Cul	
Cactaceae	*Opuntia*	*ficus-indica*	Nat	
Cannaceae	*Canna*	*indica*	Nat	Indian Shot
Cannaceae	*Canna*	*sp. cult.*	Cul	Indian Shot
Caprifoliaceae	*Lonicera*	*japonica*	Cul	
Caricaceae	*Carica*	*papaya*	Nat	Papaw; Jack-fruit; Papaya
Caryophyllaceae	*Cerastium*	*vulgatum*	Adv	Winter weed
Caryophyllaceae	*Dianthus*	*chinensis*	Cul	
Caryophyllaceae	*Stellaria*	*media*	Adv	Chickweed
Casuarinaceae	*Casuarina*	*equisetifolia*	Cul	Ironwood
Chenopodiaceae	*Beta*	*vulgaris*	Cul	Red beet
Chenopodiaceae	*Spinacia*	*oleraceae*	Cul	Spinach

continued

Family	Genus	Species	Status	Local Name
Clusiaceae	*Calophyllum*	*inophyllum*	Pol	Tamanu
Combretaceae	*Terminalia*	*catappa*	Pol	Big Mango; Red-leaf tree; Mango
Commelinaceae	*Commelina*	*diffusa*	Adv	Cow grass; Water grass
Commelinaceae	*Zebrina*	*pendula*	Nat	
Convolvulaceae	*Ipomoea*	*batatus*	Pol	Sweet potato; Kumara; Deering; Flat Russell; White Sydney
Convolvulaceae	*Ipomoea*	*brasiliensis*	Cul	Pa'hu'e
Convolvulaceae	*Ipomoea*	*indica*	Nat	
Cucurbitaceae	*Citrullus*	*lanatus*	Cul	Water melon
Cucurbitaceae	*Cucumis*	*melo*	Pol	Melon
Cucurbitaceae	*Cucumis*	*sativus*	Nat	Cucumber
Cucurbitaceae	*Cucurbita*	*cf. maxima*	Cul	Squash
Cucurbitaceae	*Curcubita*	*pepo*	Cul	Pumpkin; Hui
Cucurbitaceae	*Benincasa*	*hispida*	Pol	Calabash; Gourd; Hui
Cucurbitaceae	*Sechium*	*edule*	Cul	Choko
Cyperaceae	*Cyperus*	*javanicus*	Adv	Skinner's shit; Skin-a-shit
Cyperaceae	*Kyllinga*	*brevifolia*	Adv	
Cyperaceae	*Kyllinga*	*nemoralis*	Adv	
Dioscoreaceae	*Dioscorea*	*alata*	Pol	Yam; Arrowroot; Ouhui; Mahoi; Bottleneck
Dioscoreaceae	*Dioscorea*	*bulbifera*	Pol	
Dioscoreaceae	*Dioscorea*	*esculenta*	Cul	Ofalei; Yam; Bottleneck; Palwa?
Dioscoreaceae	*Dioscorea*	*pentaphylla*	Pol	
Ericaceae	*Arbutus*	*unedo*	Cul	Strawberry tree
Ericaceae	*Rhododendron*	*cf. indicum*	Cul	
Euphorbiaceae	*Acalypha*	*wilkesianna*	Cul	Red tree
Euphorbiaceae	*Aleurites*	*moluccana*	Pol	Dudwi; Doodoe; Doodway; Tiaieri; Candlenut
Euphorbiaceae	*Chamaesyce*	*hirta*	Adv	
Euphorbiaceae	*Codiaeum*	*variegatum*	Cul	
Euphorbiaceae	*Euphorbia*	*peplus*	Adv	
Euphorbiaceae	*Euphorbia*	*pulcherrima*	Cul	
Euphorbiaceae	*Manihot*	*esculenta*	Cul	Manioka
Euphorbiaceae	*Phyllanthus*	*amarus*	Nat	Mahamee
Euphorbiaceae	*Ricinus*	*communis*	Nat	Castor oil plant; Casta vine
Geraniaceae	*Pelargonium*	*domesticum*	Cul	Geranium
Gramineae	*Cenchrus*	*echinatus*	Cul	Pilipili; Sticking grass
Gramineae	*Coix*	*lacryma-jobi*	Nat	Job's tears
Gramineae	*Cynodon*	*dactylon*	Adv	
Gramineae	*Digitaria*	*setigera*	Adv	Ladies grass
Gramineae	*Eleusine*	*indica*	Adv	Dog grass; Crow's foot
Gramineae	*Oplismenus*	*compositus*	Cul	Grass from Tonga

continued

Family	Genus	Species	Status	Local Name
Gramineae	*Paspalum*	*orbiculare*	Adv	
Gramineae	*Oplismenus*	*hirtellus*	Adv	
Gramineae	*Paspalum*	*conjugatum*	Adv	Austin grass; Charles Aute grass; Pulau grass
Gramineae	*Saccharum*	*officinarum*	Pol	To; Sugar Cane; Taiti Cane
Gramineae	*Schizostachyum*	*glaucifolium*	Pol	Bamboo
Gramineae	*Setaria*	*verticillata*	Adv	Fox-tail grass
Gramineae	*Sorghum*	*sudanense*	Adv	Broom grass; Broom straw; Alwyn grass
Gramineae	*Sporobolus*	*indicus*	Adv	Cat's tail
Gramineae	*Zea*	*mays*	Cul	Corn
Hydrangeacae	*Hydrangea*	*macrophylla*	Cul	
Iridaceae	*Gladiolus*	*sp.*	Cul	Gladiola
Iridaceae	*Iris*	*sp.*	Cul	
Lamiaceae	*Ballota*	*nigra*	Adv	
Lamiaceae	*Mentha*	*arvensis*	Cul	Mint
Lamiaceae	*Ocimum*	*basilicum*	Adv	Mint; Basil
Lamiaceae	*Salvia*	*officinalis*	Cul	Sage; Henry flower
Lamiaceae	*Salvia*	*splendens*	Cul	
Lauraceae	*Persea*	*americana*	Nat	Alligator pear, Alligator tree; Pear; Alligator
Leguminosae	*Abrus*	*precatorius*	Nat	
Leguminosae	*Adenanthera*	*pavonina*	Nat	Red seed
Leguminosae	*Albizia*	*saman*	Cul	Rain tree
Leguminosae	*Bauhinia*	*monandra*	Nat	Hattie
Leguminosae	*Caesalpinia*	*pulcherrima*	Pol	
Leguminosae	*Cajanus*	*cajan*	Pol	
Leguminosae	*Cassia*	*septentrionalis*	Nat	Dorcas-flower
Leguminosae	*Centrosema*	*pubescens*	Adv	
Leguminosae	*Clitorea*	*ternatea*	Cul	Creeper
Leguminosae	*Delonix*	*regia*	Cul	Henry tree
Leguminosae	*Desmodium*	*tortuosum*	Adv	
Leguminosae	*Erythrina*	*variegata*	Pol	Monkey puzzle
Leguminosae	*Inga*	*edulis*	Cul	Beni-fruit
Leguminosae	*Lablab*	*purpureus*	Nat	Wild bean creeper; Musical bean; Wild bean; Faat Faat
Leguminosae	*Leucaena*	*leucocephala*	Adv	
Leguminosae	*Mucuna*	*gigantea*	Cul	Pohua
Leguminosae	*Phaseolus*	*limensis*	Cul	Lima bean; Big beans
Leguminosae	*Phaseolus*	*vulgaris*	Cul	Hitchie-beans
Leguminosae	*Pisum*	*sativum*	Cul	Peas
Leguminosae	*Pisum*	*vulgaris*	Cul	Red kidney bean; String bean
Leguminosae	*Tephrosia*	*purpurea*	Pol	Bag iron

continued

Family	Genus	Species	Status	Local Name
Leguminosae	*Vigna*	*unguiculata*	Cul	Cow pea
Liliaceae	*Allium*	*ascalonicum*	Cul	Scallion
Liliaceae	*Allium*	*cepa*	Cul	Onion
Liliaceae	*Allium*	*porrum*	Cul	Leek
Liliaceae	*Asparagus*	*setigerus*	Cul	Asparagus
Malvaceae	*Gossypium*	*herbaceum*	Cul	
Malvaceae	*Hibiscus*	*diversifolius*	Pol	Nahue
Malvaceae	*Hibiscus*	*hastatus*	Cul	Red fautu
Malvaceae	*Hibiscus*	*rosa-sinensis*	Pol	Cockscomb
Malvaceae	*Malvastrum*	*coromandelianum*	Adv	
Malvaceae	*Sida*	*rhombifolia*	Adv	Big Jack
Marantaceae	*Maranta*	*arundinacea*	Cul	Arrowroot
Meliaceae	*Melia*	*azadrach*	Cul	Pride of India
Moraceae	*Artocarpus*	*altilis*	Pol	Breadfruit; Bread; 'Uru
Moraceae	*Broussonetia*	*papyrifera*	Pol	Aute
Moraceae	*Ficus*	*carica*	Cul	Fig
Moraceae	*Ficus*	*elastica*	Cul	
Moraceae	*Ficus*	*prolixa*	Pol	Banyan; Big tree
Moraceae	*Morus*	*alba*	Cul	
Musaceae	*Musa*	*troglodytarum*	Pol	Mountain plantain; Fei; Fayee; Cooking banana
Musaceae	*Musa*	*x nana*	Cul	Ha'I; China
Musaceae	*Musa*	*x paradisiaca*	Pol	Banana; Plantain; Meia; Sydney
Myrtaceae	*Eucalyptus*	*sp.*	Cul	
Myrtaceae	*Eugenia*	*uniflora*	Nat	French Cherry; Edmond fruit
Myrtaceae	*Metrosideros*	*excelsa*	Cul	Pohutukawa
Myrtaceae	*Psidium*	*cattleianum*	Nat	
Myrtaceae	*Psidium*	*guajava*	Cul	Guava
Myrtaceae	*Psidium*	*malaccensis*	Nat	Mountain apple
Myrtaceae	*Syzygium*	*jambos*	Nat	Rose apple
Nyctaginaceae	*Bougainvillea*	*spectabilis*	Cul	Bougainvillea
Nyctaginaceae	*Mirabilis*	*jalapa*	Nat	Low red shrub; Low white
Oleaceae	*Jasminum*	*grandiflorum*	Nat	Jassamine; Jasmy
Oleaceae	*Olea*	*europaea*	Cul	Olive tree
Oxalidaceae	*Oxalis*	*bermudiana*	Adv	
Oxalidaceae	*Oxalis*	*corniculata*	Adv	Biampree-creeper
Palmaceae	*Cocos*	*nucifera*	Pol	Cocoa-nut; Coco nut palm; Heari; Palm tree; Cocknut
Palmaceae	*Phoenix*	*dactylifera*	Cul	Date palm
Pandanaceae	*Pandanus*	*inermis*	Cul	Paoiri
Passifloraceae	*Passiflora*	*edulis*	Nat	Passion fruit; Granny bonnet

continued

Family	Genus	Species	Status	Local Name
Passifloraceae	*Passiflora*	*laurifolia*	Nat	
Passifloraceae	*Passiflora*	*maliformis*	Nat	
Passifloraceae	*Passiflora*	*quadrangularis*	Nat	Granadilla; Thornton
Pinaceae	*Pinus*	*caribaea*	Cul	Pine
Piperaceae	*Piper*	*sp.*	Cul	
Plantaginaceae	*Plantago*	*major*	Adv	Canary seed
Polygonaceae	*Antigonon*	*leptopus*	Cul	Love lies bleeding
Polygonaceae	*Coccoloba*	*uvifera*	Cul	Peru tree
Portulacaceae	*Portulaca*	*fosbergii*	Cul	
Proteaceae	*Grevillea*	*robusta*	Cul	
Proteaceae	*Macadamia*	*integrifolia*	Cul	Macadamia
Punicaceae	*Punica*	*granatum*	Cul	Pomegranate
Rosaceae	*Eriobotrya*	*japonica*	Cul	Loquat
Rosaceae	*Fragaria*	*x ananassa*	Nat	Strawberry
Rosaceae	*Malus*	*domestica*	Cul	Apple
Rosaceae	*Prunus*	*armeniaca*	Cul	Apricot
Rosaceae	*Prunus*	*domestica*	Cul	Plum
Rosaceae	*Prunus*	*persica*	Cul	Peach
Rosaceae	*Rosa*	*sp.*	Cul	
Rubiaceae	*Coffea*	*arabica*	Nat	Coffee
Rubiaceae	*Gardenia*	*jasminoides*	Cul	Tiritaini; Tioretaina
Rubiaceae	*Morinda*	*citrifolia*	Pol	Nanu; Nono; Nun-oo; Flower tree
Rutaceae	*Cirus*	*paradisi*	Cul	Grapefruit
Rutaceae	*Citrus*	*aurantifolia*	Cul	Lime
Rutaceae	*Citrus*	*aurantium*	Cul	Sour orange
Rutaceae	*Citrus*	*limonia*	Cul	Rough skinned lemon
Rutaceae	*Citrus*	*reticulata*	Cul	Mandarin orange
Rutaceae	*Citrus*	*sinensis*	Cul	Orange
Sapindaceae	*Cardiospermum*	*halicacabum*	Cul	
Sapindaceae	*Dodonaea*	*viscosa*	Cul	Tea tree
Sapindaceae	*Sapindus*	*saponaria*	Cul	Soap tree
Sapotaceae	*Bumelia*	*lanuginosa*	Cul	
Scrophulariaceae	*Angelonia*	*biflora*	Cul	Depphi
Scrophulariaceae	*Russelia*	*equisetiformis*	Nat	Bell flower
Solanaceae	*Capsicum*	*frutescens*	Cul	
Solanaceae	*Cestrum*	*nocturnum*	Cul	Queen of the night
Solanaceae	*Lycopersicon*	*esculentum*	Nat	Tomato
Solanaceae	*Nicotiana*	*tabacum*	Nat	Tobacco
Solanaceae	*Petunia*	*x hybrida*	Cul	

continued

Family	Genus	Species	Status	Local Name
Solanaceae	*Physalis*	*peruviana*	Cul	Gooseberry; Cape gooseberry; Obra Cabbage
Solanaceae	*Solanum*	*americanum*	Adv	
Solanaceae	*Solanum*	*melongena*	Cul	Eggplant
Solanaceae	*Solanum*	*nigrum*	Cul	Obru; Obrew; Obro; Aubru
Solanaceae	*Solanum*	*tuberosum*	Cul	Irish Tatte; Spod; English Potato
Strelitziaceae	*Strelitzia*	*reginae*	Cul	Bird of paradise flower
Taccaceae	*Tacca*	*leontopetaloides*	Pol	Tahiti arrowroot
Taxaceae	*Araucaria*	*heterophylla*	Cul	Norfolk pine
Tiliaceae	*Corchorus*	*echinatus*	Cul	
Verbenaceae	*Clerodendrum*	*thomsonae*	Cul	Henry flower
Verbenaceae	*Lantana*	*camara*	Nat	Lantana
Verbenaceae	*Verbena*	*bonariensis*	Adv	Wild verbena
Verbenaceae	*Verbena*	*littoralis*	Adv	
Vitaceae	*Vitis*	*vinifera*	Cul	Grape
Zingiberaceae	*Alpinia*	*speciosa*	Cul	Ginsey
Zingiberaceae	*Curcuma*	*longa*	Pol	Yellow ginsy; Tumeric; Djinzi
Zingiberaceae	*Zingiber*	*zerumbet*	Pol	White ginsy; Ginger

Appendix 2 - List of Bryophytes identified from Pitcairn Island.

Collection	Putative identification	Locality	Altitude	Habitat
97-152	*Leucophanella sp.*	Faute Valley	120m	On Metrosideros collina
97-153	*Schiffneriolejeunea sp.*	Faute Valley	120m	On Metrosideros collina
97-154	*Thyridium obtusifolium*	Faute Valley	120m	On Metrosideros collina
97-162	*Campylopodium sp.*	Devils Elbow	260m	On rock face
97-163a	*Campylopodium sp.*	Devils Elbow	260m	On rock face among Dicranopteris and Lycopodium
97-163b	*Jungermannia sp.*	Devils Elbow	260m	On rock face among Dicranopteris and Lycopodium
97-166	*Thyridium obtusifolium*	Below Highest point	280m	On Metrosideros
97-187	*Philonotis st-johni*	Johnny Toonina	200m	Wet rock in stream
97-188	*Macromitrium sp.*	Johnny Toonina	200m	On damp rock with Peperomia blanda
97-189	*???????*	Long Ridge	240m	On rock
97-190a	*Rhacopilum cuspidigerum*	Johnny Toonina	200m	Under Pandanus
97-190b	*Schiffneriolejeunea sp.*	Johnny Toonina	200m	Under Pandanus
97-190c	*??????????*	Johnny Toonina	200m	Under Pandanus
97-190d	*Microlejeunea sp.*	Johnny Toonina	200m	Under Pandanus
97-191	*????????*	Long Ridge	240m	On rock
97-196	*Schiffneriolejeunea sp.*	Johnny Toonina	200m	Wet rock face
97-198	*Thyridium obtusifolium*	Outer Valley	80m	On rock with Trichomanes enderlichianum, T. tahitense & Vittaria elongata
97-199	*Radula sp.*	Outer Valley	80m	On rock with Trichomanes enderlichianum, T. tahitense & Vittaria elongata
97-248	*Neckera sp.*	Tautama	100m	On cliff base beside sea with Peperomia sp. nov.
97-249	*????????*	Tautama	100m	On sea rocks above coast with Apium prostratum
97-250	*Trematodon latinervis*	Tautama	100m	Rocky area beside sea
97-252	*Fissidens sp.*	Issacs Valley	140m	Rocks in mixed woodland
97-253a	*Frullania sp.*	Issacs Valley	140m	Rocks in mixed woodland
97-253b	*Schiffneriolejeunea sp.*	Issacs Valley	140m	Rocks in mixed woodland
97-254	*Schiffneriolejeunea sp.*	Issacs Valley	160m	Rocks in mixed woodland
97-268a	*Schiffneriolejeunea sp.*	Water Valley	80m	On rocks in Homalium woodland
97-268b	*Fissidens sp.*	Water Valley	80m	On rocks in Homalium woodland
97-269a	*Calymperes sp.*	Water Valley	80m	On rocks in Homalium woodland
97-269b	*Schiffneriolejeunea sp.*	Water Valley	80m	On rocks in Homalium woodland
97-270	*Rhacopilum cuspidigerum*	Water Valley	80m	On rocks in Homalium woodland
97-277	*Philonotis sp.*	Pulau	80m	Seepage in rock face
97-278	*Campylopus sp.*	Pulau	80m	Forming cushion, large boulder in Homalium forest

continued

Collection	Putative identification	Locality	Altitude	Habitat
97-306	*Schiffneriolejeunea sp.*	Charles Aute Valley	200m	On Phoenix dactylifera
97-307	*Macromitrium sp.*	Below Ships Landing Point	180m	On Homalium
97-308a	*Trematodon latinervis*	St. Pauls	40m	Bare eroded slope
97-308b	*Campylopus sp.*	St. Pauls	40m	Bare eroded slope
97-308c	*?????????*	St. Pauls	40m	Bare eroded slope
97-309	*Calymperes sp.*	Tautama	80m	On rock in Pandanus grove with Peperomia rapensis
97-310	*Frullania sp.*	Tautama	100m	On Homalium, in Homalium-Pandanus woodland
97-328	*Radula sp.*	Browns Water	180m	Wet rock face
97-329	*Radula sp.*	Browns Water	180m	Wet rock face
97-330	*Schizomitrium sp.*	Browns Water	180m	Wet rock face
97-339a	*Thyridium sp.*	Below Highest point	280m	On tree fern trunk
97-339b	*Macromitrium sp.*	Below Highest point	280m	On tree fern trunk
97-339c	*Schiffneriolejeunea sp.*	Below Highest point	280m	On tree fern trunk
97-368	*Taxithelium falcifolium*	North Beach	5m	On Pisonia in embayment forest
97-376a	*Schiffneriolejeunea sp.*	1km, North-south trail		On Pisonia
97-376b	*Frullania sp.*	1km, North-south trail		On Pisonia
97-376c	*Macromitrium sp.*	1km, North-south trail		On Pisonia
97-592	*Philonotis st-johni*	Deep Valley	120m	In stream at base of valley
97-593	*?????????*	Deep Valley	120m	In stream at base of valley
97-594a	*Syrrhopodon sp.*	Deep Valley	120m	On rock
97-594b	*Schiffneriolejeunea sp.*	Deep Valley	120m	On rock
97-595	*????????*	Water Valley	240m	On large rock
97-631	*Trematodon latinervis*	Hill of Difficulty	60m	On eroded slope
97-699	*Hypopterygium sp.*	Ginger Valley	180m	On shaded rocks in gully
97-856	*Trematodon latinervis*	Hill of Difficulty	100m	Eroding roadside
97-857a	*Campylopus sp.*	The Hollow	240m	Eroded slope with Dicranopteris linearis
97-857b	*Cephalozia sp.*	The Hollow	240m	Eroded slope with Dicranopteris linearis
97-858a	*Jungermannia sp.*	The Hollow	140m	Eroding slope
97-858b	*Campylopodium sp.*	The Hollow	140m	Eroding slope
97-858c	*Schiffneriolejeunea sp.*	The Hollow	140m	Eroding slope

Appendix 3 - Top 100 species for Pitcairn ranked in order of percentage occurrence in a 250m^2 grid of the island. Species are ranked overall, and with a second separate ranking for native and non-native taxa.

Overall rank	Genus	Species	% Ocurrence	Status	Native rank	Non-native rank
1	*Phymatosorus*	*scolopendria*	80.2	Native	1	
2	*Lantana*	*camara*	79.1	Non-native		1
3	*Pandanus*	*tectorius*	75.6	Native	2	
4	*Nephrolepis*	*hirsutula*	74.4	Native	3	
5	*Conyza*	*bonariensis*	68.6	Non-native		2
6	*Oxalis*	*corniculata*	67.4	Non-native		3
7	*Paspalum*	*conjugatum*	64.0	Non-native		4
8	*Commelina*	*diffusa*	62.8	Non-native		5
9	*Homalium*	*taypau*	62.8	Native	4	
10	*Musa*	*sp.*	62.8	Non-native		6
11	*Davallia*	*solida*	61.6	Native	5	
12	*Canna*	*indica*	58.1	Non-native		7
13	*Psidium*	*guajava*	58.1	Non-native		8
14	*Christella*	*parasitica*	57.0	Native	6	
15	*Sorghum*	*sudanense*	57.0	Non-native		9
16	*Glochidion*	*comitum*	50.0	Native	7	
17	*Oplismenus*	*hirtellus*	47.7	Non-native		10
18	*Bidens*	*pilosa*	46.5	Non-native		11
19	*Cordyline*	*fruticosa*	46.5	Non-native		12
20	*Metrosideros*	*collina*	46.5	Native	8	
21	*Nephrolepis*	*biserrata*	46.5	Native	9	
22	*Pyrrosia*	*serpens*	46.5	Native	10	
23	*Syzigium*	*jambos*	46.5	Non-native		13
24	*Apium*	*leptophyllum*	45.3	Non-native		14
25	*Synedrella*	*nodiflora*	45.3	Non-native		15
26	*Taraxacum*	*officinale*	44.2	Non-native		16
27	*Glochidion*	*pitcairnense*	41.9	Native	11	
28	*Plantago*	*major*	41.9	Non-native		17
29	*Sonchus*	*oleraceus*	41.9	Non-native		18
30	*Cocos*	*nucifera*	40.7	Non-native		19
31	*Hibiscus*	*tiliaceus*	40.7	Native	12	
32	*Verbena*	*bonariensis*	40.7	Non-native		20
33	*Pneumatopteris*	*costata*	38.4	Native	13	
34	*Asplenium*	*shuttleworthianum*	37.2	Native	14	
35	*Mariscus*	*javanicus*	34.9	Non-native		21

continued

Overall rank	Genus	Species	% Ocurrence	Status	Native rank	Non-native rank
36	*Psilotum*	*nudum*	34.9	Native	15	
37	*Sida*	*rhombifolia*	34.9	Non-native		22
38	*Aleurites*	*moluccana*	33.7	Non-native		23
39	*Lablab*	*purpureus*	33.7	Non-native		24
40	*Mangifera*	*indica*	32.6	Non-native		25
41	*Morinda*	*myrtifolia*	32.6	Native	16	
42	*Chamaesyce*	*hirta*	30.2	Non-native		26
43	*Loxoscaphe*	*gibberosum*	29.1	Native	17	
44	*Phymatosorus*	*commutatus*	29.1	Native	18	
45	*Cyathea*	*medullaris*	27.9	Native	19	
46	*Doodia*	*media*	27.9	Native	20	
47	*Kyllinga*	*brevifolia*	27.9	Non-native		27
48	*Morinda*	*citrifolia*	27.9	Non-native		28
49	*Dicranopteris*	*linearis*	26.7	Native	21	
50	*Portulaca*	*lutea*	26.7	Native	22	
51	*Taeniophyllum*	*fasciola*	26.7	Native	23	
52	*Arachniodes*	*aristata*	25.6	Native	24	
53	*Bidens*	*mathewsii*	25.6	Native	25	
54	*Setaria*	*veticillata*	25.6	Non-native		29
55	*Peperomia*	*blanda*	25.6	Native	26	
56	*Asplenium*	*obtusatum*	24.4	Native	27	
57	*Hippeastrum*	*x hortorum*	24.4	Non-native		30
58	*Nephrolepis*	*cordifolia*	24.4	Native	28	
59	*Apium*	*prostratum*	23.3	Native	29	
60	*Asplenium*	*nidus*	23.3	Native	30	
61	*Colocasia*	*esculenta*	23.3	Non-native		31
62	*Desmodium*	*tortuosum*	23.3	Non-native		32
63	*Peperomia*	*pitcairnense*	23.3	Native	31	
64	*Lycium*	*sandwichense*	22.1	Native	32	
65	*Persea*	*americana*	22.1	Non-native		33
66	*Phymatosorus*	*powellii*	22.1	Native	33	
67	*Carica*	*papaya*	19.8	Non-native		34
68	*Citrus*	*aurantium*	19.8	Non-native		35
69	*Coix*	*lacryma-jobi*	19.8	Non-native		36
70	*Cyclophyllum*	*barbatum*	19.8	Native	34	
71	*Polyscias*	*guilfoylei*	19.8	Non-native		37
72	*Araucaria*	*heterophylla*	18.6	Non-native		38
73	*Ocimum*	*basilicum*	18.6	Non-native		39

continued

Overall rank	Genus	Species	% Ocurrence	Status	Native rank	Non-native rank
74	*Sesuvium*	*portulacastrum*	18.6	Native	35	
75	*Solanum*	*americanum*	18.6	Non-native		40
76	*Eugenia*	*reinwardtiana*	17.4	Native	36	
77	*Guettarda*	*speciosa*	17.4	Native	37	
78	*Passiflora*	*maliformis*	17.4	Non-native		41
79	*Cerbera*	*manghas*	15.1	Native	38	
80	*Ctenitis*	*sciaphila*	15.1	Native	39	
81	*Thespesia*	*populnea*	15.1	Native	40	
82	*Vittaria*	*elongata*	15.1	Native	41	
83	*Erythrina*	*variegata*	14.0	Non-native		42
84	*Ficus*	*prolixa*	14.0	Non-native		43
85	*Cynodon*	*dactylon*	14.0	Non-native		44
86	*Hernandia*	*sonora*	14.0	Native	42	
87	*Pinus*	*caribaea*	14.0	Non-native		45
88	*Clivia*	*miniata*	12.8	Non-native		46
89	*Ipomoea*	*indica*	12.8	Non-native		47
90	*Paspalum*	*orbiculare*	12.8	Non-native		48
91	*Peperomia*	*rapensis*	12.8	Native	43	
92	*Chamaesyce*	*sparrmannii*	11.6	Native	44	
93	*Kyllinga*	*nemoralis*	11.6	Non-native		49
94	*Malvastrum*	*coromandelianum*	11.6	Non-native		50
95	*Psydrax*	*odorata*	11.6	Native	45	
96	*Vernonia*	*cinerea*	11.6	Non-native		51
97	*Xylosma*	*suaveolens*	11.6	Native	46	
98	*Eleusine*	*indica*	10.5	Non-native		52
99	*Eugenia*	*uniflora*	10.5	Non-native		53
100	*Oxalis*	*bermudiana*	10.5	Non-native		54

Appendix 4 – Spearman's rank correlations for the environmental variables measured for each quadrat

	Coarse	Granular	Hue	Dominant	Value	Chroma	pH	LOI	Aspect	Altitude	Slope	Ratio	Light	Moss cover	Bare Rock	Litter	% Openess	PPFD a direct*	PPFD a diffuse*	PPFD a total*	PPFD b direct*	PPFD b diffuse*	PPFD b total*	DSF	ISF	TSF	RFR
Coarse	****																										
Granular	0.466	****																									
Hue	0.055	0.014	****																								
Dominant spectra	0.098	0.202	0.358	****																							
Value	-0.100	-0.364	0.019	-0.267	****																						
Chroma	-0.197	-0.213	-0.016	0.127	0.222	****																					
pH	0.061	0.016	-0.084	0.023	-0.036	-0.059	****																				
LOI	0.106	0.336	0.051	0.038	-0.787	-0.170	-0.133	****																			
Aspect	-0.342	-0.219	0.060	-0.140	0.146	-0.054	-0.134	-0.135	****																		
Altitude	-0.225	-0.097	0.144	-0.018	-0.214	0.253	-0.448	0.413	0.127	****																	
Slope	0.207	-0.059	-0.035	-0.100	0.094	-0.100	-0.039	-0.059	-0.045	-0.153	****																
Ratio	-0.134	-0.296	-0.154	-0.237	0.612	0.209	0.067	-0.577	0.125	-0.227	-0.028	****															
Light	-0.146	-0.281	-0.016	-0.211	0.432	0.470	0.001	-0.325	0.174	0.088	0.028	0.514	****														
Moss cover	-0.025	0.093	0.149	0.112	-0.054	-0.220	-0.263	0.086	-0.051	0.113	0.200	-0.300	-0.101	****													
Bare Rock	0	-0.207	0.031	-0.008	0.502	-0.022	0.063	-0.659	0.022	-0.483	0.168	0.298	0.190	0.190	****												
Litter	0.098	0.198	0.097	0.188	-0.450	-0.105	-0.100	0.437	0.054	0.333	-0.204	-0.453	-0.372	0.073	-0.576	****											
% Openness	-0.069	-0.285	0.076	-0.265	0.493	0.219	0.010	-0.462	0.169	-0.068	-0.167	0.559	0.591	-0.332	0.257	-0.360	****										
PPFD a direct*	-0.224	-0.095	0.142	-0.018	-0.215	0.257	-0.448	0.414	0.125	1	-0.154	-0.226	0.092	0.111	-0.482	0.331	-0.065	****									
PPFD a diffuse*	-0.184	-0.047	0.086	-0.047	-0.245	0.185	-0.401	0.411	0.104	0.952	-0.170	-0.238	0.047	0.079	-0.479	0.326	-0.062	0.951	****								
PPFD a total*	-0.236	-0.110	0.143	-0.025	-0.210	0.250	-0.460	0.410	0.139	0.995	-0.150	-0.237	0.094	0.136	-0.460	0.320	-0.061	0.995	0.946	****							
PPFD b direct*	-0.001	-0.246	0.096	-0.254	0.465	0.200	0.048	-0.476	0.158	-0.045	-0.218	0.569	0.566	-0.404	0.264	-0.339	0.909	-0.042	-0.029	-0.037	****						
PPFD b diffuse*	-0.076	-0.300	0.076	-0.257	0.522	0.242	-0.021	-0.491	0.212	-0.026	-0.157	0.624	0.621	-0.335	0.243	-0.359	0.958	-0.023	-0.030	-0.019	0.951	****					
PPFD b total*	-0.007	-0.254	0.099	-0.254	0.470	0.204	0.039	-0.478	0.165	-0.044	-0.210	0.581	0.570	-0.399	0.262	-0.343	0.919	-0.041	-0.031	-0.036	0.999	0.962	****				
DSF	0	-0.207	0.126	-0.241	0.432	0.180	0.058	-0.433	0.140	-0.064	-0.258	0.513	0.535	-0.379	0.237	-0.332	0.881	-0.061	-0.051	-0.053	0.942	0.908	0.943	****			
ISF	-0.068	-0.296	0.058	-0.263	0.535	0.234	0.005	-0.512	0.213	-0.068	-0.156	0.636	0.620	-0.342	0.271	-0.369	0.959	-0.065	-0.069	-0.061	0.951	0.998	0.961	0.907	****		
TSF	0.005	-0.253	0.091	-0.242	0.480	0.191	0.059	-0.498	0.159	-0.081	-0.205	0.589	0.568	-0.406	0.279	-0.352	0.918	-0.078	-0.068	-0.073	0.997	0.959	0.998	0.944	0.960	****	
RFR	-0.129	-0.304	0.018	-0.244	0.589	0.160	0.013	-0.565	0.197	-0.227	-0.135	0.783	0.495	-0.321	0.335	-0.434	0.890	-0.224	-0.228	-0.218	0.810	0.882	0.825	0.787	0.887	0.830	****
LAI	0.080	0.330	-0.039	0.255	-0.492	-0.209	0.023	0.469	-0.179	0.066	0.137	-0.551	-0.561	0.340	-0.244	0.314	-0.962	0.064	0.066	0.056	-0.888	-0.935	-0.896	-0.856	-0.936	-0.898	-0.867

Appendix 5 - IUCN categories and threat scores, with relevant criteria, for the Pitcairn Island Flora

Family	Genus	Species	Status	Pitcairn Status	Number on Pitcairn	Basis	World Status	Basis	Proportion on Pitcairn	Population size	Distribution	Attractiveness	Usefulness	Remoteness	Accessibility	Habitat vulnerability	Habitat specificity	Threat Score
Malvaceae	*Abutilon*	*pitcairnense*	End	EX/CR		A1(c-e), B2(a-e), C1, C2, D	EX/CR	A1(c-e), B2(a-e), C1, C2, D	100%									0
Pteridaceae	*Acrostichum*	*aureum*	Ind	EX/CR		A1(c-e), B2(a-e), C1, C2, D	LR	lc	<1%									0
Adiantaceae	*Adiantum*	*hispidulum*	Ind	VU	<1000	D	LR	lc	<1%	1	3.11	1	1	1	0.5	1	1	9.61
Apocynaceae	*Alyxia*	*scandens*	Ind	VU	<1000	D	LR	nt	<1%	1	3.54	0	0	1	0.5	1	1	8.04
Marattiaceae	*Angiopteris*	*chauliodonta*	End	CR	<250	A1(c-e), B1, B2(a-e), C2	CR	A1(c-e), B1, B2(a-e), C2	100%	2	2.85	1	2	1	0.5	2	2	13.35
Apiaceae	*Apium*	*prostratum*	Ind	LR	2000+	nt	LR	lc	<1%	0	1.58	0	1	0	0.5	0	2	5.08
Aspleniaceae	*Arachniodes*	*aristata*	Ind	LR	5000+	lc	LR	lc	<1%	1	1.67	0.5	0	1	1	2	2	9.17
Boraginaceae	*Argusia*	*argentea*	Ind	CR	<20	B1, D	LR	lc	<1%	6	3.84	0.5	2	1	0.5	2	2	17.84
Aspleniaceae	*Asplenium*	*nidus*	Ind	LR	1000+	nt	LR	lc	<1%	0	1.85	1	0	1	0.5	1	0	5.35
Aspleniaceae	*Asplenium*	*obtusatum*	Ind	LR	2000+	nt	LR	lc	<1%	0	1.58	0.5	0	1	0	0	2	5.08
Aspleniaceae	*Asplenium*	*shuttleworthianum*	Ind	LR	5000+	lc	LR	lc	<1%	0	1.05	0.5	0	0	0	0	2	3.55
Asteraceae	*Bidens*	*mathewsii*	End	VU	<1000	D1	VU	D1, D2	100%	1	1.58	0.5	1	1	0.5	2	1	8.58
Leguminosae	*Caesalpinia*	*major*	Ind	VU	<1000	D1	LR	lc	<1%	1	3.54	0	0	2	1	2	0	9.54
Capparidaceae	*Capparis*	*cordifolia*	Ind	EX/CR		D	LR	lc	<1%									0
Ulmaceae	*Celtis*	*pacifica*	Ind	CR	<20	D	LR	lc	<5%	6	3.84	0	1	1	1	2	1	15.84
Gramineae	*Cenchrus*	*calyculatus*	Ind	CR	<20	D	VU	A2(c-)	<1%	4	3.84	0	0	0	1	1	3	12.84
Apocynaceae	*Cerbera*	*manghas*	Ind	VU	<1000	D1	LR	lc	<1%	1	2.6	0.5	2	1	0.5	1	0	8.6
Euphorbiaceae	*Chamaesyce*	*sparrmannii*	Ind	LR	1000+	lc	VU	D2	c.95%	0	2.6	0	0	1	0	0	0	3.6
Thelypteridaceae	*Christella*	*parasitica*	Ind	LR	1000+	lc	LR	lc	<1%	0	0.21	0	0	2	1	3	0	6.21
Menispermaceae	*Cocculus*	*ferrandianus*	Ind	EN	<100	D	LR	lc	<1%	3	3.69	0	0	0	0.5	0	1	8.19
Rubiaceae	*Coprosma*	*benefica*	End	CR	<50	A1(c-e), A2, B1, B2(a-e), C1, C2, D	CR	A1(c-e), A2, B1, B2(a-e), C1, C2, D	100%	5	3.54	0	0	2	1	4	1	16.54
Aspidiaceae	*Ctenitis*	*cumingii*	End	EN	<250	D	EN	D	100%	2	2.37	0.5	0	1	0.5	2	2	10.37
Cyatheaceae	*Cyathea*	*medullaris*	Ind	VU	<1000	D1	LR	lc	<1%	1	1.41	1	1	1	1	2	2	10.41
Rubiaceae	*Cyclophyllum*	*barbatum*	Ind	VU	<1000	D1	LR	lc	<1%	1	2.26	0	2	1	0.5	2	1	9.76
Davalliaceae	*Davallia*	*solida*	Ind	LR	5000+	lc	LR	lc	<1%	0	0.12	0.5	1	2	1	2	0	6.62
Liliaceae	*Dianella*	*intermedia*	Ind	CR	<50	D	LR	lc	<1%	5	3.69	0.5	0	1	0	1	1	12.19
Gleicheniaceae	*Dicranopteris*	*linearis*	Ind	LR	5000+	lc	LR	lc	<1%	0	1.41	0	1	2	1	1	1	7.41
Aspidiaceae	*Diplazium*	*harpeodes*	Ind	CR	<50	D	LR	lc	<1%	4	2.98	0.5	1	1	0.5	2	2	13.98
Blechnaceae	*Doodia*	*media*	Ind	LR	1000+	nt	LR	lc	<1%	0	1.85	0.5	0	1	0.5	1	0	4.85
Myrtaceae	*Eugenia*	*reinwardtiana*	Ind	LR	1000+	nt	LR	lc	<1%	0	2.05	0	1	2	0.5	0	1	6.55
Euphorbiaceae	*Glochidion*	*comitum*	End	CR	<50	D	CR	D	100%	5	0.81	0	2	1	0.5	2	0	11.31
Euphorbiaceae	*Glochidion*	*pitcairnense*	Ind	VU	<1000	A1(d), D	VU	A1(d), D1, D2	100%	2	0.44	0	2	1	0.5	2	0	7.94
Rubiaceae	*Guettarda*	*speciosa*	Ind	EN	<250	D	LR	lc	<1%	3	2.15	1	2	1	0	2	0	11.15
Haloragaceae	*Haloragis*	*sp.*	End ?	EN	<250	D	EN	D	100%	3	3.25	0	0	0	0	1	2	9.25
Hernandiaceae	*Hernandia*	*sonora*	Ind	EN	<250	D	LR	lc	<1%	2	2.49	0	1	2	1	2	2	12.49
Malvaceae	*Hibiscus*	*australense*	Ind	EN	<250	D	DD/VU	D2	<10%	3	3.39	1	0	1	0.5	1	1	10.89

Family	Genus	Species	Status	Pitcairn Status	Number on Pitcairn	Basis	World Status	Basis	Proportion on Pitcairn	Population size	Distribution	Attractiveness	Usefulness	Remoteness	Accessibility	Habitat vulnerability	Habitat specificity	Threat Score
Malvaceae	*Hibiscus*	*tiliaceus*	Ind ?	LR	5000+	lc	LR	lc	<1%	0	0.7	0.5	1	2	1	1	1	7.2
Flacourtiaceae	*Homalium*	*taypau*	End	LR	1000+	nt	VU	D2	100%	0	0.09	0	2	2	1	2	1	8.09
Convolvulaceae	*Ipomoea*	*littoralis*	Ind	CR	<50	D	LR	lc	<1%	4	3.84	1	0	1	1	1	2	13.84
Convolvulaceae	*Ipomoea*	*macrantha*	Ind	EN	<250	D	LR	lc	<1%	4	3.54	0.5	0	2	1	3	2	16.04
Convolvulaceae	*Ipomoea*	*pes-caprae*	Ind	CR	<50	D	LR	lc	<1%	4	3.84	0.5	0	0	0	1	1	10.34
Oleaceae	*Jasminum*	*didymum*	Ind	CR	<50	D	LR	lc	<1%	4	3.54	1	2	0	0.5	3	1	15.04
Aspleniaceae	*Lastreopsis*	*cf. pacifica*	Ind	CR	<50	D	LR	lc	<5%	4	3.69	0	0	2	0.5	4	2	16.19
Brassicaceae	*Lepidium*	*bidentatum*	Ind	CR	<50	D	LR	lc	<1%	4	3.84	0.5	1	1	0.5	1	2	13.84
Poaceae	*Lepturus*	*repens*	Ind	EN	<250	D	LR	lc	<1%	2	3.39	0	0	1	0.5	1	1	8.89
Aspleniaceae	*Loxoscaphe*	*gibberosum*	Ind	LR	1000+	nt	LR	lc	<1%	0	1.26	1	1	0	1	1	1	6.26
Solanaceae	*Lycium*	*sandwichense*	Ind	LR	1000+	nt	LR	lc	<1%	0	1.85	0	0	1	0	1	2	5.85
Lycopodiaceae	*Lycopodium*	*cernuum*	Ind	LR	1000+	lc	LR	lc	<1%	0	3.54	0.5	1	2	1	1	1	10.04
Myrtaceae	*Metrosideros*	*collina*	Ind	LR	2000+	nt	LR	nt	<1%	0	0.44	1	1	2	1	2	1	8.44
Rubiaceae	*Morinda*	*myrtifolia*	Ind	LR	1000+	nt	LR	nt	<1%	0	1.26	0	0	1	1	2	1	6.26
Myrsinaceae	*Myrsine*	*sp. aff. niauensis*	End	EX/CR		D	EX/CR	B2(a-e), D	100%									0
Davalliaceae	*Nephrolepis*	*biserrata*	Ind	LR	1000+	lc	LR	nt	<1%	0	1.67	0	0	1	1	0	1	4.67
Davalliaceae	*Nephrolepis*	*cordifolia*	Ind	LR	1000+	lc	LR	nt	<1%	0	0.44	1	0	1	1	1	1	5.44
Davalliaceae	*Nephrolepis*	*hirsutula*	Ind	LR	5000+	lc	LR	nt	<1%	0	0.01	0.5	0	1	1	0	0	2.51
Ophioglossaceae	*Ophioglossum*	*nudicaule*	Ind	EN	<250	D	LR	lc	<1%	2	3.54	0	0	0	1	2	2	10.54
Ophioglossaceae	*Ophioglossum*	*reticulatum*	Ind	EN	<250	D	LR	lc	<1%	2	3.54	0	0	0	1	2	2	10.54
Rosaceae	*Osteomeles*	*anthyllidifolia*	Ind	CR	<10	D	DD/LR	nt	<1%	6	3.84	1	0	2	0.5	2	2	17.34
Pandanaceae	*Pandanus*	*tectorius*	Ind	LR	2000+	lc	LR	lc	<1%	0	0.03	0.5	1	2	1	0	0	4.53
Lythraceae	*Pemphis*	*acidula*	Ind	EX/CR		D	LR	lc	<1%									0
Piperaceae	*Peperomia*	*blanda*	Ind	LR	5000+	lc	LR	lc	<1%	0	1.58	0.5	0	0	0.5	0	0	2.58
Piperaceae	*Peperomia*	*pitcairnensis*	End	EN	<250	D	EN	D	100%	2	1.95	0.5	0	0	0.5	0	1	5.95
Piperaceae	*Peperomia*	*rapensis*	Ind	EN	<250	D	VU	D2	c.20%	2	2.6	0.5	0	0	0.5	1	1	7.6
Piperaceae	*Peperomia*	*sp.*	End	CR	<250	C2(b)	CR	C2(b)	100%	3	3.69	0.5	0	0	0.5	1	2	10.69
Polypodiaceae	*Phymatosorus*	*commutatus*	Ind	VU	<1000	D	LR	lc	<1%	1	1.58	0.5	1	0	1	2	2	9.08
Polypodiaceae	*Phymatosorus*	*powellii*	Ind	VU	<1000	D	LR	lc	<5%	1	2.05	1	1	1	1	2	2	11.05
Polypodiaceae	*Phymatosorus*	*scolopendria*	Ind	LR	10,000+	lc	LR	lc	<1%	0	0	0	1	2	1	0	0	4
Urticaceae	*Pilea*	*sancti-johannis*	Ind	CR	<50		CR	D	50%	4	3.54	0.5	0	0	0	1	2	11.04
Nyctaginaceae	*Pisonia*	*umbellifera*	Ind	EN	<250	D	LR	lc	<1%	2	3.25	0	1	1	1	3	2	13.25
Thelypteridaceae	*Pneumatopteris*	*costata*	Ind	LR	2000+	lc	LR	lc	<1%	0	1.05	0.5	0	1	1	1	1	5.55
Portulacaceae	*Portulaca*	*lutea*	Ind	LR	5000+	lc	LR	lc	<1%	0	1.33	0.5	0	1	0.5	0	1	4.33
Psilotaceae	*Psilotum*	*nudum*	Ind	LR	2000+	nt	LR	lc	<1%	0	1.19	0.5	0	1	1	1	1	5.69
Rubiaceae	*Psydrax*	*odorata*	Ind	EN	<250	D	LR	lc	<5%	2	2.6	0.5	2	1	1	2	1	12.1
Polypodiaceae	*Pyrrosia*	*serpens*	Ind	LR	2000+	nt	LR	lc	<1%	0	0.61	0	0	2	0.5	0	0	3.11
Primulaceae	*Samolus*	*repens*	End ?	EN	<250	D	EN	D	100%	3	3.69	0	0	0	0	1	2	9.69
Goodeniaceae	*Scaevola*	*sericea*	Ind	EN	<250	D	LR	lc	<1%	4	3.25	0	0	1	0.5	1	1	10.75

Family	Genus	Species	Status	Pitcairn Status	Number on Pitcairn	Basis	World Status	Basis	Proportion on Pitcairn	Population size	Distribution	Attractiveness	Usefulness	Remoteness	Accessibility	Habitat vulnerability	Habitat specificity	Threat Score
Aizoaceae	*Sesuvium*	*portulacastrum*	Ind	LR	2000+	lc	LR	lc	<1%	0	2.05	0	0	1	0.5	0	1	4.55
Orchidaceae	*Taeniophyllum*	*fasciola*	Ind	LR	2000+	lc	LR	lc	<1%	0	1.58	0	0	1	0	0	2	4.58
Malvaceae	*Thespesia*	*populnea*	Ind	LR	2000+	nt	LR	lc	<1%	0	2.6	1	1	2	1	0	0	7.6
Hymenophyllaceae	*Trichomanes*	*endlicherianum*	Ind	VU	<1000	D1	LR	lc	<1%	1	3.11	0	0	1	0.5	1	2	8.61
Hymenophyllaceae	*Trichomanes*	*tahitense*	Ind	VU	<1000	D1	LR	lc	<1%	1	2.98	0	0	1	0.5	1	2	8.48
Vittariaceae	*Vittaria*	*elongata*	Ind	VU	<1000	D1	LR	lc	<1%	1	2.26	0.5	0	1	0.5	1	2	8.26
Flacourtiaceae	*Xylosma*	*suaveolens*	Ind	EN	<250	D	LR	lc	<10%	2	2.6	0	1	0	1	2	2	10.6

Appendix 6 – Threat scores, Pitcairn and World IUCN status for the native Pitcairn speies, ranked in order of threat.

Genus	Species	Status	Pitcairn IUCN Status	World IUCN Status	Threat Score	Pitcairn IUCN Status ranked	World IUCN Status ranked	Threat Score ranked
Argusia	*argentea*	Ind	CR	LR	17.84	1	18	1
Osteomeles	*anthyllidifolia*	Ind	CR	DD/LR	17.34	2	17	2
Ipomoea	*macrantha*	Ind	EN	LR	16.04	17	27	3
Celtis	*pacifica*	Ind	CR	LR	15.84	5	20	4
Coprosma	*benefica*	End	CR	CR	15.54	3	1	5
Lastreopsis	*cf. pacifica*	Ind	CR	LR	15.19	4	19	6
Jasminum	*didymum*	Ind	CR	LR	15.04	6	21	7
Diplazium	*harpeodes*	Ind	CR	LR	13.98	7	22	8
Ipomoea	*littoralis*	Ind	CR	LR	13.84	8	23	9
Lepidium	*bidentatum*	Ind	CR	LR	13.84	9	24	10
Angiopteris	*chauliodonta*	End	CR	CR	13.35	10	2	11
Pisonia	*umbellifera*	Ind	EN	LR	13.25	18	28	12
Hernandia	*sonora*	Ind	EN	LR	12.49	19	29	13
Dianella	*intermedia*	Ind	CR	LR	12.19	12	25	14
Psydrax	*odorata*	Ind	EN	LR	12.1	20	30	15
Cenchrus	*calyculatus*	Ind	CR	VU	11.84	11	11	16
Glochidion	*comitum*	End	CR	CR	11.31	13	3	17
Guettarda	*speciosa*	Ind	EN	LR	11.15	21	31	18
Phymatosorus	*powellii*	Ind	VU	LR	11.05	34	69	19
Pilea	*sancti-johannis*	Ind	CR	CR	11.04	14	4	20
Hibiscus	*australensis*	Ind	EN	DD/VU	10.89	22	10	21
Scaevola	*sericea*	Ind	EN	LR	10.75	23	32	22
Peperomia	*sp.*	End	CR	CR	10.69	15	5	23
Xylosma	*suaveolens*	Ind	EN	LR	10.6	24	33	24
Ophioglossum	*nudicaule*	Ind	EN	LR	10.54	25	34	25
Ophioglossum	*reticulatum*	Ind	EN	LR	10.54	26	35	26
Cyathea	*medullaris*	Ind	VU	LR	10.41	35	70	27
Ctenitis	*cumingii*	End	EN	EN	10.37	27	6	28
Ipomoea	*pes-caprae*	Ind	CR	LR	10.34	16	26	29
Lycopodium	*cernuum*	Ind	LR	LR	10.04	47	40	30
Cyclophyllum	*barbatum*	Ind	VU	LR	9.76	36	71	31
Samolus	*repens*	Ind	EN	EN	9.69	28	7	32
Adiantum	*hispidulum*	Ind	VU	LR	9.61	37	79	33
Caesalpinia	*major*	Ind	VU	LR	9.54	38	72	34
Haloragis	*sp.*	End ?	EN	EN	9.25	29	8	35
Arachniodes	*aristata*	Ind	LR	LR	9.17	48	41	36
Phymatosorus	*commutatus*	Ind	VU	LR	9.08	39	73	37
Lepturus	*repens*	Ind	EN	LR	8.89	30	36	38
Trichomanes	*endlicherianum*	Ind	VU	LR	8.61	40	74	39
Cerbera	*manghas*	Ind	VU	LR	8.6	41	75	40

continued

Genus	Species	Status	Pitcairn IUCN Status	World IUCN Status	Threat Score	Pitcairn IUCN Status ranked	World IUCN Status ranked	Threat Score ranked
Bidens	*mathewsii*	End	VU	VU	8.58	42	15	41
Trichomanes	*tahitense*	Ind	VU	LR	8.48	43	76	42
Metrosideros	*collina*	Ind	LR	LR	8.44	49	42	43
Vittaria	*elongata*	Ind	VU	LR	8.26	44	77	44
Cocculus	*ferrandianus*	Ind	EN	LR	8.19	31	37	45
Homalium	*taypau*	End	LR	VU	8.09	50	13	46
Alyxia	*scandens*	Ind	VU	LR	8.04	45	78	47
Glochidion	*pitcairnense*	Ind	VU	VU	7.94	46	16	48
Thespesia	*populnea*	Ind	LR	LR	7.6	51	43	50
Peperomia	*rapensis*	Ind	EN	VU	7.6	32	12	49
Dicranopteris	*linearis*	Ind	LR	LR	7.41	52	44	51
Hibiscus	*tiliaceus*	Ind ?	LR	LR	7.2	53	45	52
Davallia	*solida*	Ind	LR	LR	6.62	54	46	53
Eugenia	*reinwardtiana*	Ind	LR	LR	6.55	55	47	54
Loxoscaphe	*gibberosum*	Ind	LR	LR	6.26	56	48	55
Morinda	*myrtifolia*	Ind	LR	LR	6.26	57	49	56
Christella	*parasitica*	Ind	LR	LR	6.21	58	50	57
Peperomia	*pitcairnensis*	End	EN	EN	5.95	33	9	58
Lycium	*sandwichense*	Ind	LR	LR	5.85	59	51	59
Psilotum	*nudum*	Ind	LR	LR	5.69	60	52	60
Pneumatopteris	*costata*	Ind	LR	LR	5.55	61	53	61
Nephrolepis	*cordifolia*	Ind	LR	LR	5.44	62	54	62
Asplenium	*nidus*	Ind	LR	LR	5.35	63	55	63
Apium	*prostratum*	Ind	LR	LR	5.08	64	56	64
Asplenium	*obtusatum*	Ind	LR	LR	5.08	65	57	65
Doodia	*media*	Ind	LR	LR	4.85	66	58	66
Nephrolepis	*biserrata*	Ind	LR	LR	4.67	67	59	67
Taeniophyllum	*fasciola*	Ind	LR	LR	4.58	68	60	68
Sesuvium	*portulacastrum*	Ind	LR	LR	4.55	69	61	69
Pandanus	*tectorius*	Ind	LR	LR	4.53	70	62	70
Portulaca	*lutea*	Ind	LR	LR	4.33	71	63	71
Phymatosorus	*scolopendria*	Ind	LR	LR	4	72	64	72
Chamaesyce	*sparrmannii*	Ind	LR	VU	3.6	73	14	73
Asplenium	*shuttleworthianum*	Ind	LR	LR	3.55	74	65	74
Pyrrosia	*serpens*	Ind	LR	LR	3.11	75	66	75
Peperomia	*blanda*	Ind	LR	LR	2.58	76	67	76
Nephrolepis	*hirsutula*	Ind	LR	LR	2.51	77	68	77
Abutilon	*pitcairnense*	End	EX/CR	EX/CR	0	80	80	78
Myrsine	*sp. aff. Niauensis*	End	EX/CR	EX/CR	0	81	81	80
Capparis	*cordifolia*	Ind	EX/CR	LR	0	78	38	79
Pemphis	*acidula*	Ind	EX/CR	LR	0	79	39	81