for small-scale commercial cultivation of crops such as tomato, cucumber, lettuce, eggplant, carrot, etc.

None of these three possible techniques will introduce salt water into an existing water lens. It seems obvious that this is to be prevented; on the one hand, such action would be contrary to all commonsense – increasing the salinity of the lens is the last thing desired – and, on the other hand, water from above ground level would wash the salt residues from spray into the lens.

Two points require emphasis:

(1) Means are available for increasing natural freshwater stocks. Whether these can be made economically feasible is a matter of testing a full array of methods developed to date, and, perhaps, coming up with others suited to islet structure and resources.

(2) Salt-water irrigation is best done with containers of a sort – an islet which will be devoted entirely to cultivation, troughs, pans, basins (as might be constructed on islet surfaces with cement) or upright columns. Whether enclosures will be of value (for restriction of pests and for increases in temperature and humidity) is also worth testing.

Finally, there is the question of the crops themselves. It does not seem sensible to expect that an atoll will be a viable area to produce extensive commercial crops. Costs will probably not be competitive, there are problems of transportation and distribution and, not least, reliable markets must be available. Production designed to supplement the taste-desire and dietary requirements of atoll people is the goal which should be emphasised.

Hybridisation to meet the specific tolerance levels set by factors important to atoll cultivation could be considered. Such an approach has long been used elsewhere, and would seem to be worth investigation.

Hybridisation, fertiliser requirements, etc, have been the subject of extensive work with temperate crops. Selection itself (from a genetic range within a single species such as guava) has yielded positive benefits. I am convinced that there is much to be done with the crops which have been tended for thousands of years on atolls: numerous varieties and clones of breadfruit, pawpaw, ***Tacca,*** banana, ***Alocasia, Colocasia, Xanthosoma, Pandanus,*** etc, have never been given the opportunity to show what they can do under atoll conditions.

It is quite possible such characteristics as earlier bearing, longer spread of fruiting season, heavier yields, less difficult requirements for water and fertilisers, etc, can be found in some of the varieties of these crops now known from other areas. In more ways than one, this could be a most fruitful area for investigation. □

...marine and terrestrial flora of atolls

by Jan Newhouse

It has been written that "returning to the straightforward pleasures of an earlier way of life, a life . . . close to nature" could perhaps be more satisfying than contending with the "hurly burly of modern existence". This idealistic vision has been nurtured in large part by romanticised portrayals of the South Seas islands: "gleaming crescents" of white sand beach, waters always "turquoise", the ever-present "brightly coloured" fish darting in and out between corals, and the Copernican impossibility of 29.27 evenings with a full moon. Food, of course, is constantly "dropping from the heavens".

What better spot than an atoll for this blessed life, a low coral island where some of the food drops from coconut trees "gracefully arching" over the crescent beaches?

A lot better spots, at least for humans who are first-generation arrivals. As everywhere else, all living things on an atoll are ultimately dependent upon the photosynthetic conversion of radiant to chemical energy. Unlike everywhere else, atoll environments have unique characteristics which can be limiting or inhibiting to the organisms which are capable of making such a conversion.

Some generalities regarding these characteristics, and the organisms themselves, will be covered here. There will be no discussion or reference to:

(1) What is "most important". Is it the coconut tree or perhaps the algae symbiotic with reef-building corals? How about the blue-green algae which fix atmospheric nitrogen? Or maybe the mycorrhiza associated with the roots of some of the land plants?

(2) "Extreme and adverse" conditions. Usually such references reflect a judgment based on what our race considers to be personally

comfortable. Yet organisms found in particular habitats would not be there unless the conditions were within the ranges of tolerable limits for such factors as temperature, salinity, moisture, etc. Most plants (and animals) found under "extreme and adverse" conditions would not survive in our living rooms.

(3) "Micro-distribution", as, for example, on a reef or an islet. Though there is some advantage to thinking in terms of such things as strand plants, understory, colonisers and vegetational associations, Nature does not always co-operate with either our desire to practise reductionism or with our interpretations.

(4) "Rarity". As often as not, this is either a function of insufficient investigation or because an organism lives in a habitat far removed from our own. For example, the lists of flora found on Kapingamarangi, Takapoto and Mururoa are far more complete than those from Etal, Kili and Napuka, simply because the former three atolls have been more thoroughly investigated. I was present in 1968 when a dredge-haul between the Galapagos Islands and the coast of Ecuador brought up thousands of a "rare" species of fish, previously described from three known specimens.

Other things being equal, the diversity index of organisms found on an atoll is closely related to the atoll's proximity to sources of biota and/or the extent of human influence.

Though there are a few exceptions (notably Aldabra and Laysan) endemism is, in sharp contrast with high islands, essentially non-existent. This is to be expected; the surface features we see today are certainly no more than 8000 years old. Moreover, islets can be lost or constructed overnight by storms.

Despite the fact that almost all atolls present the same general aspect to an untrained observer, the specific constituents making up the flora may be quite different, much as the rainforests of Sri Lanka and the Andes have very little, yet a great deal, in common.

Although marine and terrestrial flora will be considered separately, there is no such sharp division on an atoll. Some of the blue-green algae found above the high tide level are suspected ecophenes of those in the marine communities, benthic organisms on the reef are partially dependent on leeched nutrients from the islets, and pre-human terrestrial materials were totally derived from the sea.

As interpreted here, the algae have five roles:

(1) Phytoplanktonic and benthic species are, of course, the primary producers at the base of all marine food chains and webs. Nutrients are limiting to the development of large standing crops, and, for this reason, they are fewer than on reefs of nearby high islands or comparable continental shores.

Sargassum is unknown, and ***Ulva*** is only found in quantity around the outfall of centrally discharged sewage. Growth of the benthos is usually greatest at reef margins and around passes.
Moreover, lagoons of atolls which have no pass have fewer species and biomass than those which are open to the ocean. Pools on seaward reef flats are particularly devoid of lush growth; because of tidal fluctuation, the range of water temperature in these pools can vary as much as 32^{0} Celsius within a period of six hours.

(2) Algae are responsible for three different kinds of construction. ***Porolithon onkodes*** of the algal ridge is the stabiliser of seaward reef margins, binding together the organisms with calcareous skeletons in such a way that a common front is presented to the breaking waves. It has been hypothesised that diurnal changes in the P/R ratio for blue-green algae are responsible for pH conditions which bring about the cementation of materials (sand and gravel) above the high tide level.

Finally, all calcareous algae contribute to the structure of the atoll. Segmented and thin crustose forms make only minor contributions, but major ones are made by ***Porolithon*** and ***Goniolithon*** to reefs and islets, and by ***Halimeda*** fragments to the bottoms of lagoons.

(3) Destruction related to algae occurs in two ways. Some solution of carbonates can be attributed to the phenomenon of pH shift mentioned above. However, grazing by molluscs and herbivorous fish on the microscopic algae which invest previously cemented materials (e.g., beachrock) is a greater destructive force on substrates which are either strictly marine or are subject to salt-water spray.

(4) Hermatypic, reef building, corals harbour zooxanthellae in their tissues. Though the exact nature of this relationship is not yet completely clear, most investigators feel it is symbiotic; that is, mutually beneficial to both the coral and the algae. The colour of the mantle of the giant clam ***Tridacna*** is also due to zooxanthellae, and it is felt that this also is a symbiotic relationship.

(5) Some blue-green algae (e.g., ***Nostoc***) fix atmospheric nitrogen, and, aside from the droppings and debris left by birds, this is probably the major source of N for atoll plants.

One role not listed above is that of economic mainstay, though this does not mean that such a possibility has been overlooked. Some ill-advised attempts were made to introduce ***Eucheuma*** to Rangiroa and Kaukura in the Tuamotus. Although it should have been obvious that the low nutrient content of atoll waters would not support ***Eucheuma*** "farms", there was some danger that local conditions (such as effluent from the Rangiroa villages) might have led to a degree of success. If this latter case had prevailed, it is probable that the entire reef ecosystems would have been altered, thus affecting crustacean and fish populations on which the human communities are dependent.

Since some atolls (e.g., Minerva of Tonga) have no land above the high tide line, their flora is made up entirely of algae. A few atolls have only bare sand islets, but the majority, by far, are vegetated. This latter group has land areas which range from less than one hectare to over 57,000 hectares on Christmas in the Line Islands.

All land not reached by the high tide – in fact, everything above the growth of organisms on the reef flat, lagoon reef and patch reefs – is either an erosional remnant, because of human intervention, or due to storm action.

Erosional remnants (principally beachrock) are what remain from the latest eustatic drop in ocean level perhaps some 3000 years ago, as well as the results of localised upwelling. The human contribution to land has taken several forms. Johnston Island is the product of dredges and bulldozers, many atolls have piers and fishponds, and some islets (e.g., Touhou of Kapingamarangi) have been partly constructed with human muscle.

However, to anyone who has seen the great gravel and boulder ramparts along seaward shores, or specific deposits which can be attributed to a particular event (the 1906 hurricane which hit northern Takapoto), it is obvious that storm waves have been most responsible for the construction (and destruction) of islets.

The islets which result from storm waves are made up almost entirely of calcareous debris from corals, algae, molluscs and foraminifera. Exceptions to this rule are the small quantities of pumice which occasionally wash ashore, gravel and stones caught in the roots of drifting logs, volcanic soil transported by humans, and basalt artifacts introduced by the aboriginal inhabitants.

Many islets, particularly those which are almost exclusively made up of sand, would be ephemeral if it were not for the binding action of roots. In most cases, these are on plants which arrive by natural agencies, though there are some instances in which humans have made deliberate plantings, as, for example, my own involvement in three attempts to introduce mangroves to Johnston for the purpose of stabilising the shoreline.

Though islets are more often found on the windward than leeward sides of an atoll rim, this is nothing more than a generalisation; storm waves can come from any direction. Rangiroa is so large that waves generated in the lagoon have built islets (one of which is vegetated) on several patch reefs.

As a rule, the average size of fragments making up an islet is progressively smaller from the ocean side to the lagoon shore. This is because most are seaward-derived, and smaller detritus is obviously carried further from the source. Also, since most islets do owe their existence to materials which originated outside the seaward reef margin, they tend to be highest on the ocean side, and gently slope toward the lagoon.

As recently as two decades ago, there were contrasting views on how the land plants originally arrived. On the one hand, there was the belief that atolls are sitting on the tops of peaks of sunken continents, and that their flora of today represents survivors of the continents themselves. On the other hand there was conjecture that agencies such as birds, wind and water currents had been responsible for the original introductions.

Studies (e.g., Funafuti, Mururoa, Eniwetok) have, indeed, confirmed that atolls are constructed on basaltic foundations which have been sinking slowly, but these foundations are the result of isolated volcanic activity, not continental peaks. Also, as has been mentioned above, the land areas of atolls are no more than several thousand years old.

Investigations of recent years, including experimental work, strongly support the supposition that atoll land floras are entirely of casual and deliberate introductions, rather than remnants from sunken continents:

(1) Seeds have been found in the feathers, in mud on the feet and in the wastes of pelagic sea birds.
(2) Some seeds, but more particularly the spores of ferns and mosses, have been "screened" from upper air masses by special devices attached to airplanes for this purpose.
(3) Both flotation capability and viability after prolonged periods of immersion in salt water have been checked for seeds and fruit of many atoll plants. It has been concluded that the initial foothold for a number of plants came about when these parts drifted onto a beach, as well as, possibly, vegetative and reproductive portions which arrived by "rafting" on logs.
(4) Humans have made both intentional and unintentional contributions. The floras found along atoll runways (e.g., Midway, Hao, Wake, Canton, Kwajalein) are remarkably similar, and have some elements found nowhere else on the atolls. It is suspected that a number of these plants first arrived as seeds caught in the external seams of airplanes. When trouser cuffs were fashionable they may have also made a contribution; spores and seeds have been germinated from this source. Deliberate introductions were started hundreds, even thousands, of years ago, and continue to the present day.

The number and kinds of seeds and spores which arrive are functions of wind direction and velocity, in both the lower atmosphere and upper stratosphere, the direction and velocity of water currents, the proximity of the atoll to other land masses, including original sources, and the degree of human intervention.

Once seeds have arrived, there are a number of factors which determine whether germination takes place:

(1) Salinity tolerance; in the spray as well as in the ground water.
(2) Fewer niches are available than on high islands. As an example, a fungus parasitic on a specific host may not become established because its host cannot survive atoll conditions.
(3) Although there are a few acidic

pockets in rare accumulations of humus, the pH is almost uniformly high. It ranges from 7.4–7.8 in ground water to 8.3 and above where there is only capillary water.

(4) Soils are made up of one or more of the following: finely ground calcareous materials, bird droppings and decaying vegetable matter. The first impression that soil is sparse is not dispelled on further investigation.

(5) Nutrients are in short supply; this is especially true of iron, nitrogen, phosphorus and potassium.

(6) In theory, an atoll should have some orographic effect, but this was not measurable at Eniwetok, where the most detailed studies were made. Thus, unlike high islands such as Moen, Raiatea and Savai'i, atolls are effectively subject to no more rainfall than their general ocean area. This range is considerable – from an average yearly precipitation of 440 mm for Canton to 3990 mm for Jaluit.
The amount of rainwater which is held by an islet is a function of the islet's shape, size and permeability of the detritus of which it is composed. This fresh water floats on the underlying salt water in what is called a Gyben-Herzberg lens, and tidal fluctuations bring about a constant mixing at the interface.

Given these conditions, the limited land areas, and the random chance on which natural introductions are based, it is not surprising that the number of indigenous species on atolls is considerably less than that found on high islands. The following ratios of indigenous/introduced vascular plants give an indication of this paucity: Arno, 68/57; Kapingamarangi, 38/60; Johnston, 13/41.

The flora of every atoll has been influenced in some way by our race's needs and desires.

The first humans to arrive on an atoll must have had high protein diets for quite some time. Pits had to be dug to the top of the freshwater lens, then well supplied with mulch for the cultivation of taro species. Breadfruit cuttings had to be nurtured carefully, and, at best, coconut plantings (*Cocos* was always introduced) gave no yield for the first eight years. These basic crops were supplemented with, among others, ***Pandanus*** (for food and cordage), ***Hibiscus*** (tapa, cordage and lumber), ***Tacca*** (a carbohydrate much like cornstarch), ***Calophyllum*** (wooden bowls and other artifacts) and ***Musa.***

A major alteration began about 160 years ago when the first coconut plantations were started for the production of copra. Original floras were, essentially, completely wiped out on islet after islet and, in some cases, entire atolls to make way for this commercial venture. Thus, what we think of today as the pristine environment with the "gracefully arching" coconut trees is, in reality, a fairly recent artifact of an economic era.

In essence, the floras of atolls are what we have made of them. □

...an approach to nutrition and health problems in the Tuamotu Islands

by Kim Hien Delebecque, Pierre Delebecque, Bernard Philippe and Jean-Michel Senelart

Introduction

Growing contact with the Western world has radically altered the nutritional habits of the inhabitants of the Tuamotu atolls.

The time has gone when the staple diet of the Tuamotu islanders depended on harvesting coconut palm products, screwpine fruit and arrowroot (***Tacca leontopetaloides***) tubers. The cultivation of taro (***Cyrtosperma chamissonis***), an arduous task formerly carried out in compost pits, has long been abandoned. And although there is still some consumption of breadfruit, bananas and products of fishing and domestic rearing of livestock, which once helped to provide a balanced diet, these products are becoming rarer.

The establishment of permanent links with the outside world, first by sea and then by air, has brought far-reaching changes in the economy and health of the atoll inhabitants. The commercial exploitation of copra and pearl shell, providing a source of income, the increase in the number of paid jobs, the emigration of young adults to Papeete or to the bases of the Pacific Experimentation Centre, and the arrival of Asian traders in the islands to sell canned goods and convenience foods on credit, have all speeded up the abandonment of crop-growing – which is understandable, of course, in view of the poor soils and irregularity of water resources.