THE IMPORTANCE OF SCALE IN DETERMINING THE HUMAN POPULATION DISTRIBUTIONS IN THE MARSHALL ISLANDS

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McClatchey, W. and **K. W. Bridges** (Department of Botany, St. John Laboratory 101, University of Hawai‘i at Manoa, Honolulu, Hawai‘i 96822-2279, U.S.A. THE IMPORTANCE OF SCALE IN DETERMINING THE HUMAN POPULATION DISTRIBUTIONS IN THE MARSHALL ISLANDS. Traditional environmental knowledge has been employed by ancient people in the selection of habitation sites in the landscape. In simple terrestrial systems such as Pacific atolls, the apparent patterns of these kinds of decisions may provide insights into the logic that was employed. Based upon ecological analyses at Ailinginae Atoll, Kapingamarangi Atoll and human demographic data from the Republic of Marshall Islands, we have studied two scales of evidence that address the same issue: sustainable human population survival in the Marshall Islands. The scales that were explored are: selection of an islet on which to live at a particular atoll, and distribution of human population levels across a group of islands. We conclude that different factors are impacting the decisions at different scales. Small island effects seem to explain the selection of islets within an atoll while terrestrial land area explains the distribution of the population across the Marshall Islands.

Key Words: Scales, human populations, atoll, Ailinginae Atoll, Marshall Islands, small island effect.

A fundamental element of the survival of ancient human populations was selection of an appropriate site in which to live. There are many reasons why people would elect to reside in a particular site. Some of these reasons are based upon fundamental survival possibilities (e.g., availability of food, water, and shelter). Others are based upon environmental factors (e.g., long-term storm patterns, currents and winds, biological diversity, and physical accessibility). Cultural concerns are also likely to be important (e.g., family unit size, social obligations, warfare, and gender roles). For some peoples living in somewhat uniform environments with plenty of resources this may have been an easy task, but for those living in environments with serious resource limitations, the decision could be one of life or death of their genetic (and cultural) lineage.

Traditional environmental knowledge as studied by ethnobiologists (Cunningham 2001, Merlin et al. 1994, Peters 1996, Prance et al. 1987) has typically focused upon human interactions with specific resources or ecosystems. The logic behind ancient human colonization decisions has not been identified from modern communities however the distribution patterns and colonization histories are, in some cases, known from archaeological, linguistic, and biological evidence. One purpose of the work presented here is the development of hypotheses about the patterns of ancient human selection of environments particularly when they apparently had a choice of sites along a gradient of ecosystem complexity. Of particular interest are decisions about the minimal size of an environment in order for it to be considered viable for long-term human habitation.

Island Biogeography

The situation is different for some other groups of organisms that have been much studied by biogeographers. A principal set of observations used by biogeographers has been natural experiments in colonization ~~in the form~~ of islands. The primary theory developed from this has been "island biogeography" as laid out by MacArthur and Wilson (1967). The theory is based upon observations of species richness along size (very small islands to large land masses) and distance (near to far) gradients and makes predictions of species numbers based upon size (area) of an island and distance from potential sources of species. Generally, the larger the island or the closer to a source of species, the greater the species richness on an island. While the theory has been developed in relatively simple ecosystems, such as those found on small islands, it is also thought to apply in larger and more complex situations, such as continental biomes.

The relationship between species richness and area is widely accepted and used by biologists. However, many problems have been noted in the fundamental theory of island biogeography (Connor & McCoy 1979, Gilbert 1980, Simberloff 1983). One problem is the "small island effect" (Brown & Lomolino 1989). This occurs when species richness on very small islands is determined by stochastic factors and is, therefore, independent of island area. Lomolino (2000) has observed that there is a bias in most surveys and analytical protocols since these disproportionately emphasize large islands and ignore the roles of small islands. Furthermore, he notes that the small islands are better models of patches of habitat that are used in applied ecological and conservation biology studies. He summarizes a number of studies by concluding that "in such cases, community structure may be much more strongly influenced by features other than area, such as natural and anthropogenic disturbance, habitat characteristics within and among patches, patch shape, and degree of isolation." In particular, we are interested in examining the boundary where random factors give way to those that are scalable, such as area.

We were part of a research expedition to Ailinginae Atoll in the Northern Marshall Islands in June, 2002. This is an atoll with a lagoon approximately 25 km long and 6.5 km wide (Bridges and McClatchey 2004). Our primary tasks were to document the richness of terrestrial vascular plant species and to collect baseline data on species densities and distributions on each of the islets in the atoll. We conducted our work using the lens of biogeographers thoroughly steeped in the theory of island biogeography with predictions that the largest islets would have the greatest species richness. As we analyzed our data we began to realize that we had stumbled upon an example of the “small island effect” wherein unusual factors such as islet shape played a more important role than size in determination of species richness. Figure 1 illustrates our findings that the species richness of an islet is strongly predicted by the shape (R^2=0.715), with round islets having more species while narrower islets have fewer. Plots based on the area of an islet did not predict the richness (R^2=.103, P>0.05).

The expedition was not only concerned with examinations of the vegetation but also with trying to identify evidence of past human habitation. Marshall Island colleagues from adjacent, inhabited, Rongelap Atoll had assured us that Ailinginae Atoll had never been permanently inhabited (supported by past census data). We wondered why people would not have inhabited the atoll and how it might be different from other atolls in the region. Ethnobotanical interviews at Rongelap Atoll had led us to see the common flora of the atolls as very useful and readily modified by people for human benefit. Although the plants we encountered at Ailinginae Atoll included the same useful species that dominated at Rongelap Atoll, it was also clear, based upon the minimal presence or absence of some plants, that people had not done much modification of Ailinginae Atoll (Bridges & McClatchey 2004).

Ailinginae Atoll

Ailinginae Atoll consists of 25 low (1-3 meters high) islets. The uninhabited atoll is located between two permanently inhabited atolls, Bikini and Rongelap, with Rongelap being closer. Ailinginae Atoll has traditionally been occupied for brief periods of time by populations from Rongelap Atoll who used it as an additional resource gathering area. Elders we interviewed from Rongelap Atoll indicated that it was a moderately good source for turtle eggs, fish, crabs, and other marine resources but that the lagoon is too rough for most uses. As with many islands of the tropical Pacific, colonial powers in the 1800s and early 1900s attempted to convert native vegetation into coconut plantations that could be periodically visited and harvested, but otherwise ignored most of the time.

Since Ailinginae Atoll is proximate to US military activities at Bikini Atoll, it has not only been uninhabited but has also had no access by humans for the last fifty years. This presents an unusual situation found in few places: a significantly large area that has had no human interference for a period of 50 years or more. Because we realized that we were to be working in an atoll that was readily accessible but uninhabited we expanded our study of the vegetation in order to locate evidence of former human activities and develop hypotheses about scale relationships involving suitability for human habitation.

Transects and/or inventories (Bridges & McClatchey 2004) were conducted on the eight largest islets: Sifo, Mogiri, Enibuk, Eniuetakku, Ribinouri, Kuobuen, Ucchuwanen and

Knox. Eleven species were found on each of the seven islets: *Boerhaavia tetandra*, *Cordia subcordata*, *Fleurya ruderalis*, *Guettardia speciosa*, *Lepturus repens*, *Microsorium scolopendrium*, *Microsorium scolopendrium*, *Pemphis acidula*, *Pisonia grandis*, *Scaevola frutescens*, *Suriana maritima*, and *Tournefortia argentea*. *Cassytha filiformis*, *Ipomoea alba*, and *Morinda citrifolia* were each only lacking from one islet. *Cassytha* and *Ipomoea* were patchy in their distributions whereas *Microsorium* and *Morinda*, if present, were more widely distributed on an islet. *Boerhaavia diffusa, Portulaca lutea*, and *Triumfetta procumbens* are all herbaceous species that were only sporadically encountered, although on a majority of the islets. These could have been overlooked in transects or inventories because of their size and rarity. Conversely, *Cocos nucifera* and *Pandanus tectorius* are conspicuous species that were not found on each islet but were also unlikely to be missed if present. The remaining species were much less common: *Calophyllum inophyllum*, *Clerodendron inerme*, *Digitaria pruriens*, *Fimbrostylis cyanosa*, *Ochrosia parviflora*, *Soulamea amara*, *Tacca leontopetaloides*, *Terminalia litoralis*, *Thuarea involuta*, and *Wollastonia biflora*. This flora is unremarkable, being quite similar to that found at other atolls in the Northern Marshall Islands (Taylor 1950, Thomas et al. 1989)

Mueller-Dombois and Fosberg (1998) have stated that “No record remains of the original Marshall Islands vegetation.” However, there is good reason to believe that the flora of Ailinginae Atoll is close to the original, particularly after avoiding fifty years of human contact. The vegetation profile varies from low shrubs and grasses to a 20-25 meter high closed canopy forest. Generally, the tallest vegetation is found in the interior of an islet. In two cases, at Sifo and Knox, we identified the presence of a former garden. Figure 2 illustrates a garden that was crossed by a randomly placed transect on Sifo. Within the zone of *Cocos nucifera* trees were also found *Pandanus tectorius* trees with edible fruit and *Tacca leontopetaloides* plants with edible rhizomes. Most other transects had only native vegetation or native vegetation inter-planted with coconuts during the colonial era. Analysis of these transects is being published elsewhere.

Researchers have implied that the presence of a lens and the area of an islet are critical for human habitation (Hathaway 1953). Although our work has not explored the distribution of water, it is likely that the presence of tall trees in the interior of an islet is an indicator of a freshwater lens below. The issue of a lens and the relationship that this has with human selection of habitation sites occurs at the scale of decisions made within an atoll system. In the case of Ailinginae Atoll, we identified the presence of small gardens, probably associated with short-term habitation sites on the islets of Knox and Sifo. These islets were the roundest, implying that human selection within an atoll was made directly or indirectly based upon islet shape, a result parallel to our finding the highest species richness in islets of this shape. At this level, it is important to keep in mind that people spend most of their time on a single islet, yet are free to periodically visit other islets.

Although we are trying to examine both plants and people, we are aware that they are very different. When we examine the plants of the Marshall Islands, we are using concepts of species richness, whereas with people there is only one species and we have the concept of demography. What is interesting is that the plants and the people hold the same area in common. At a fine scale of examination the people and the plants occupy different physical space, however at the higher scale, they exist in the same area. Unlike people who migrate between atolls during a lifetime, plant breeding systems are such that most reproduction is due to interactions at the islet or atoll scale. The demographics of human populations require that we examine this differently than the plants of the same area.

For the work presented here, we elected to explore the higher scale of human settlement decisions in the Marshall Islands, examining the limitations that might be imposed by atoll environments. At this level, it is important to keep in mind that for the populations of humans in the Marshall Islands, the oceans are not major barriers, but rather are highways between "oasis." The Marshallese are famous ocean navigators and voyaging between atolls was likely quite common. This has caused us to consider the communities of the Marshall Islands to have functioned as a single population. In the process of exploring this we have asked questions about the carrying capacity of the Marshall Islands as a whole and what past population levels imply.

Methods

The methods described below were intended to address the following questions:

> 1. Can we use an ecosystem assessment to identify the features humans might have used for selection of sites in which to live?
>
> 2. If this kind of ecosystem assessment is predictive, can it be used to predict human activities in more complex environments?

The methods were designed to provide information that is comparable with that generated at Kapinginamaringi Atoll by Niering (1963) yet also address a range of other questions (e.g., species richness studies are being published elsewhere).

Marshall Islands population and atoll size data were gathered from a tabular data report by Bryan (1971). This publication provides human population sizes for several years; we used the 1935 data in our analyses. Bryan has also provided data for the total land and lagoon areas. Bryan's listing includes the estimated sizes for all islets in each of the atolls. We adapted these data by summing the areas of an atoll's islets that had an area of 26 ha (0.1 square miles) or larger. If an atoll consisted only of islets smaller than this criterion, then the size of the largest islet was used.

Population trends for the Marshall Islands were obtained for the World-Wide Web database maintained by Spennemann (2000).

Results & Discussion

The population of the Marshall Islands has been estimated and measured many times over the last 150 years (see Spennemann 2000 for a synopsis). The population was relatively stabile between 1850 and 1950, however rapidly increased after the conclusion of the Pacific War and has continued to rise over the last 50 years (Figure 3). During the last 50 years, there has been a great increase in the mobility of people into and out of the Marshall Islands. Many plants, animals, and ideas have been introduced. Probably most important has been the increase in external food subsidies that could be used to support a larger population. We assume that the population level between 1850 and 1950 was at or below the carrying capacity and that because of the cohesiveness of the population across the islands, the populations at each individual atoll were also at or near carrying capacity exclusively using indigenous resources.

We have used the 1935 population data as an estimate of the intrinsic carrying capacity of the Marshall Islands: 9191 people. If this is correct, then the current population (estimated in 2000 to be approximately 65,000) far exceeds the carrying capacity and can only be maintained through substantial external subsidies.

Kapingamarangi Atoll

Studies of islands in the Central and Western Pacific provided data for development of the theory of Island Biogeography. One of these studies (Niering 1963) was an ecological analysis of Kapingamarangi Atoll in the Caroline Islands. This very isolated atoll is inhabited by Polynesians earning their living on very small islets with a total land area of only 112 hectares. The islets of Kapingamarangi Atoll vary from 0.012 to 32.2 hectares with terrestrial vascular plant species varying from 5 to 61. The study is one of the few that has quantitatively measured plant species richness on islets of an isolated Pacific Atoll. Niering measured the area of each islet and its species richness and found a relationship between the number of species and the size of the islet.

The fact that Kapingamarangi Atoll is inhabited and probably has been so for hundreds of years is an indication that it is an acceptable human environment. Niering (1963) reported that the people of the atoll primarily live on two adjacent islets, Werua (41.4 hectares) and Touhou (3.7 hectares). The rest of the 33 islets surveyed are not permanently inhabited but are visited periodically for resources. It is interesting to note that the largest islet, Hare (32.2 hectares) is not inhabited. Hare is a long and narrow islet that is more than 6 times as long as it is wide. The two inhabited islands are each about as long as wide and Werua is almost twice as wide as Hare. At Kapingamarangi

Atoll, people are inhabiting the widest islet. Niering (1963) proposed that the population of Kapingamarangi Atoll was in equilibrium with the environment and that under the conditions of the atoll, it could support a stable population of about 450 people. He calculated, based on the population of 426 at the time, that 0.26 hectares of terrestrial area would be needed to support each person.

A similar land-use pattern as that observed at Kapingamarangi Atoll can be seen in other atolls throughout the tropical Pacific. One or a few islets serve as habitation sites and other islets function as resource pantries. For instance in the Marshall Islands, Hatheway (1953) reported that at Arno Atoll most people live in villages along the lagoon shores of the wider islands, noting that "islands less than 600 feet wide and stony lands were for the most part uninhabited."

Although Kapingamarangi Atoll is not in the Marshall Islands, it is nearby, with largely the same flora as is typical of the Marshall Islands. Kapingamarangi Atoll differs from the typical Marshall Islands in being much more isolated from its nearest neighbors (therefore the atoll must provide all human needs, rather than the needs being met across a range of atolls as is suggested for the Marshall Islands.) Niering's prediction implies a carrying capacity for atolls such as the Marshall Islands that seems to be much higher than the situation that was found prior to the 1950s. Figure 4 illustrates this point. The dashed line is a predicted carrying capacity for atolls of a variety of sizes based upon Niering's prediction. The solid line is a regression based upon the total area of 27 atolls and 5 low islands in the Marshall Islands. Note that the population data for Jaluit Atoll has not been included because of the atoll's early role as a German colonial center of trade and the likelihood that the population reported in the 1800s was already heavily supported by external subsidies. The remaining atolls and islands have a surprisingly tight prediction (R^2=0.6996) of population based upon total land area. It is interesting that the data supports a linear model. This relationship, which requires 0.534 hectares of terrestrial area to support each person, predicts far fewer people on the same land area than was given by Niering.

Based upon our examination of islets at Ailinginae Atoll, we thought that the prediction of the land area might be improved by considering only the area of the larger islets. The size of the habitable islets from Ailinginae Atoll was ~26 hectares. We reanalyzed the Marshall Islands data by considering this area as our lowest size for selection of islets (a minimal area for habitation). In a few cases, inhabited atolls included only islets smaller than 26 hectares, so the largest islet was used for the calculation. While the relationship was maintained when we excluded small islets, the relationship had the same explanation of deviations from the mean population (R^2= 0.6987). Therefore, at the scale of the groups of atolls, there does not seem any reason to focus upon only the potentially inhabited islets.

There are a number of factors that are important in explaining the approximately 30% of the remaining variability. One of these must be the stochastic element of population change. In addition, several obvious variables would seem to contribute to the relationship between the demographic pattern and atoll area including rainfall, size of the freshwater lens at each atoll, species richness at each atoll, and availability of marine resources (particularly fish) at and near each atoll. We have not explored all of the possible contributing factors since our goal was to look at the higher scale and to see if we could explain the general pattern. We recognize that data such as has been produced for Palau (Johannes 1981) would be useful in searching for important details.

We examined the general rainfall pattern in the Marshall Islands to see if it had any influence on the relationship between population size and land area. The country has distinctly dryer atolls in the north and wetter atolls in the south (Mueller-Dombois & Fosberg 1998). There was no evidence that this difference added to the predictability of our relationship. Rainfall may operate through water availability in supporting crops that are salt-water intolerant (Hatheway 1953). Also, wetter atolls have greater plant species richness (Mueller-Dombois & Fosberg 1998). Our data, however, don't have the detail to examine the possible relationships.

Plant species richness in the Marshall Islands is not uniform. Northern atolls, that are also drier, have much lower numbers of species than do the southern atolls (National Biodiversity Team 2000). While the plant species richness correlates well with rainfall level, the influence of this factor on the human population demographics is not known.

Conclusions

Niering's (1963) parting comments about the Kapingamarangi Atoll could equally apply to the Marshall Islanders, "The atoll is an essentially self-sufficient microcosm in which man is a key component in balance with his environment." We may never be able to reconstruct the perspectives of ancient Marshallese colonists nor the means by which they managed the suite of atoll resources to obtain a level of balance with their environment. However, we can see that in the atoll environments where terrestrial resources are very limited, people survived. Our world is faced with many kinds of problems. One lesson that we can potentially learn from the ancient Marshall Islanders is how to survive within limited means and how to sustainably maintain our population.

We would like to see the same sort of analysis that we have conducted applied to other Pacific Island groups. We also think that other aspects should be studied in more detail, such as measurement of area or volume of marine resources that could be used.

In conclusion, we feel that we have illustrated that at fine scales (decisions within an atoll), the shape of an islet is an important feature, however at higher scales (decisions within an island group), the shape of an islet is not very important, but rather the size is important. This kind of observation may also hold true for other kinds of human selected environments that are fragmented, patchy, or otherwise isolated. For example, decisions at fine scales (e.g., family farms) depend very much on localized variables such as shape, but decisions at the higher scale (e.g., community resource management) depend upon more global phenomenon. If the Marshall Islands are to serve as a model, then it would seem that both kinds of decisions must be used and not perceived as in conflict but as complementary.

Acknowledgments

Mayor James Matayoshi, John Fysh, and the Rongelap Atoll Local Government proposed the idea of this research and made it happen. We would like to thank the members of our field research team: Jodi Stevens, Jon Stevens, and Carrie Harrington, for their hard work and focus in gathering part of the data presented here. Funding for this research was provided, in part, by the U.S. Department of the Interior and the U.S. National Institutes of Health.

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Figure 1. Plant-Island Shape Relationship *at Ailinginae Atoll* (after Bridges & McClatchey 2004)

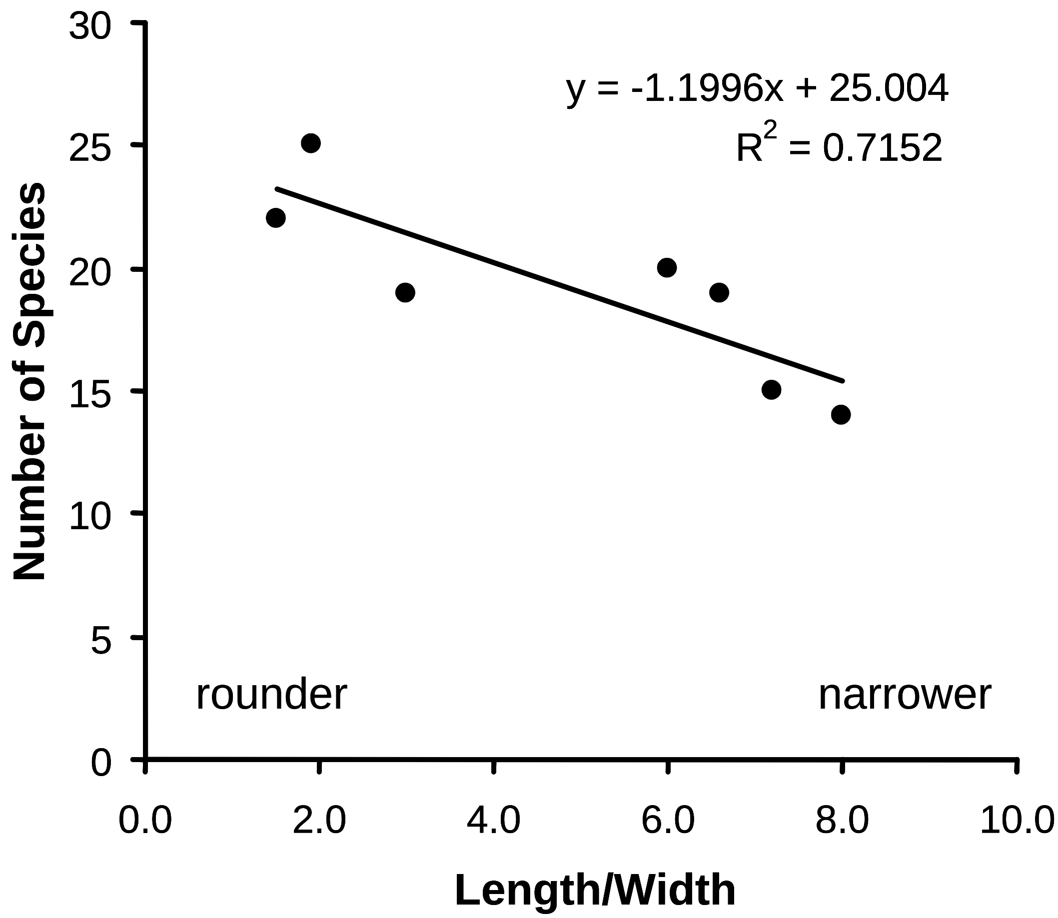

Figure 2. Sifo Islet Transect 2: Major tree species frequency per ten meters of distance between lagoon and ocean (after Bridges & McClatchey 2004)

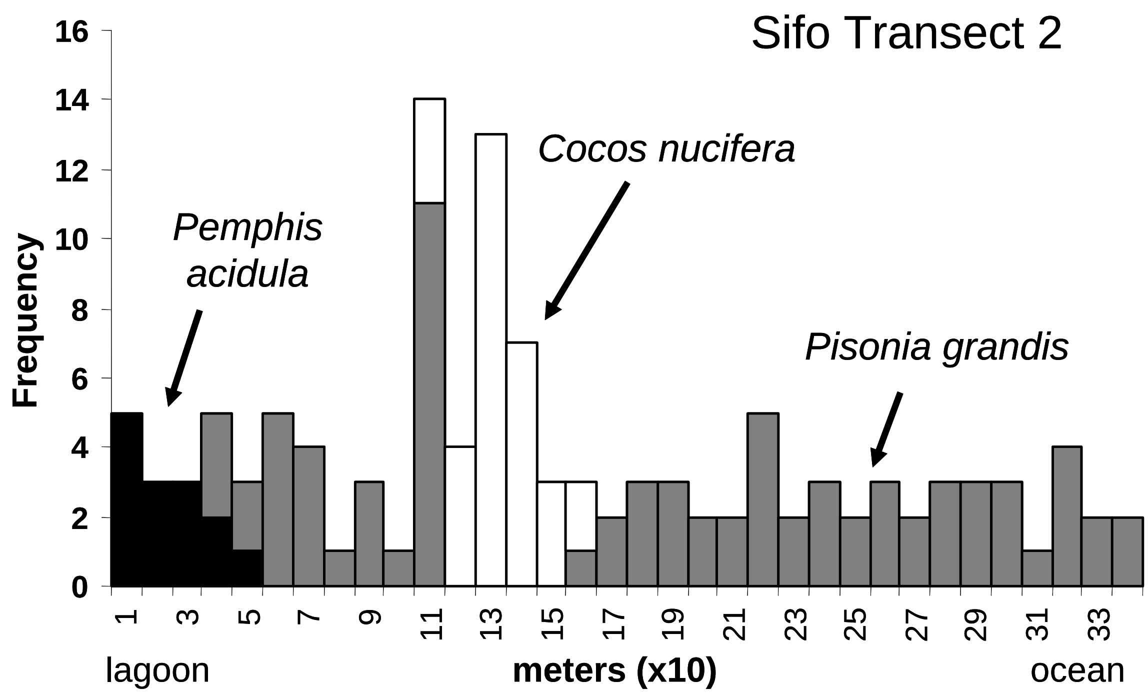

Figure 3. Marshall Islands Population

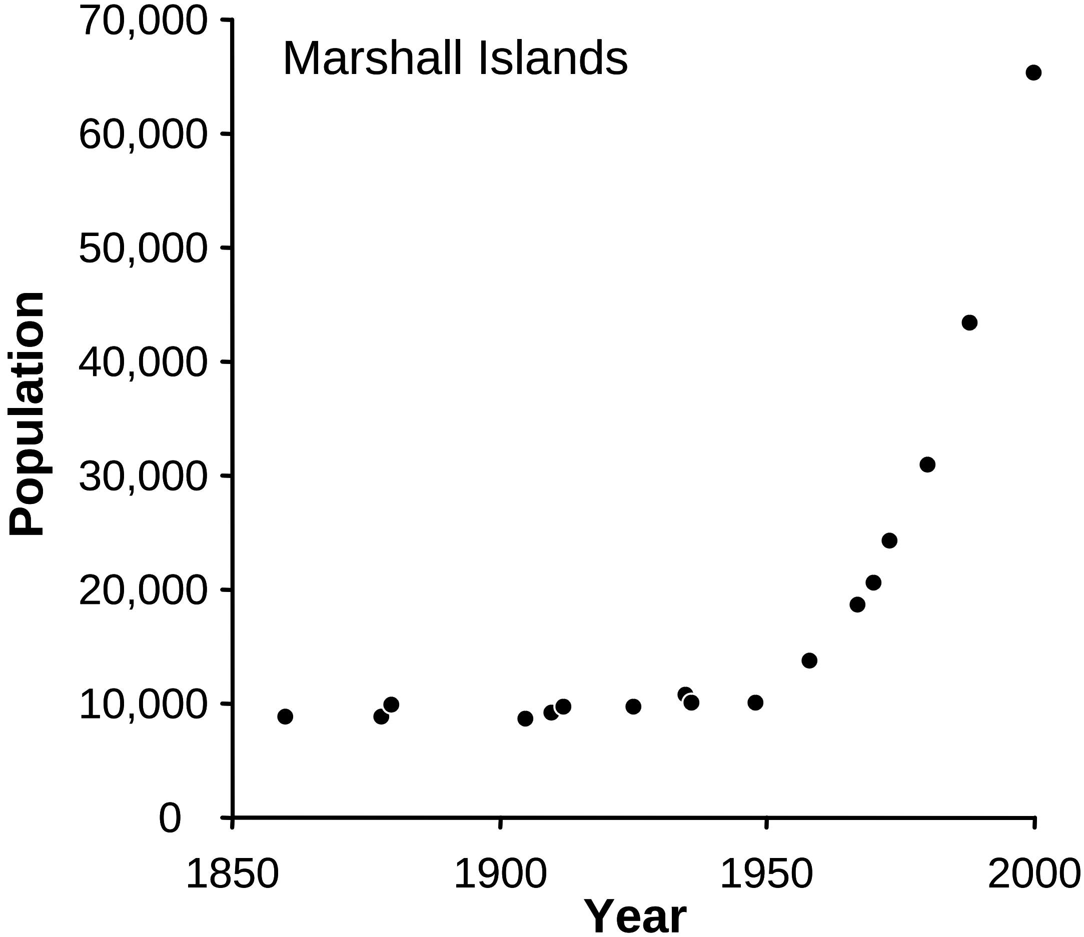

Figure 4. Hypothesized Atoll Carrying Capacity based upon data from the Marshall Islands