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Invading the Pacific: Biological and Cultural Dimensions of Invasive Species in the Pacific Region

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HUMAN EXPANSION throughout the Pacific region has brought about the crossing of geographical and cultural borders. In many instances this has resulted in economic benefits. However, there are costs which are difficult to estimate and often the effects on the environment are overlooked. These effects include habitat loss, climate change, air and water pollution and over-population.[2] Despite increasing awareness of such environmental issues, actual action to prevent or manage these effects is still less than sufficient. This mimics the current global situation where 'there are virtually no landscapes anywhere on the globe that have not been modified and affected, at least in part, by human actions.'[3] Perhaps the greatest threat to the natural environment is that of invasive species.[4] An invasive species is an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity. Invasive species are a subset of introduced (alien or exotic) species: species which have been transported artificially by humans across borders which otherwise prevented their dispersal. Approximate estimates suggest perhaps 10% of these introduced species become invasive,[5] though the number can vary greatly (and unpredictably). The effects of invasive species are especially catastrophic on oceanic islands, where endemic species can behave naïvely to unfamiliar new species.[6] It is therefore not surprising that invasive species are rapidly coming to the forefront of ecological science and management as the key threat to biological diversity.[7] It is clear that human colonisation and development, as facilitators of species transportation across natural borders, are together contributing factors to this biological devastation. However, this relationship between biology and culture also unites their evolution on islands. Island cultures uniquely evolved around the geography and biology found in each island group.

The variety in scale of the threats and impacts of invasive species can be illustrated by three case studies (the extinction of New Zealand's avifauna by introduced mammals; introduced weeds in Hawaii, and red imported fire ants (*Solenopsis invicta*) invading the Pacific). Although many introductions have taken place throughout the history of the Pacific region, the key to managing new invasions is the prevention of invasions across further geographical borders, though this can only be done when incorporating cultural considerations.

Before discussing the effects of invasive species on the Pacific environment, it is necessary to provide an historic context to the ecology and culture of the Pacific Islands, what is known as 'historical ecology'. The following is by no means intended to be an exhaustive review of Pacific historical ecology, which is provided elsewhere.[8]

The geological origins of the Pacific Islands date back at least 100 million years, from the breakup of Pangea. Here the islands of the Pacific first appeared from the Shatsky Rise between the separation of the Indo-Australian and Pacific plates. These islands were variously colonised by natural dispersal across oceanic barriers (vicariance) and *in situ* speciation. Due to the clustered nature of oceanic ridges and common volcanic activity both around and within the Pacific Rim, island groups were formed. The 'Pacific Basin' itself covers virtually half the globe, and is circumscribed by the 'ring of fire' extending from Tierra del Fuego along the western edges of continental South and North America, Alaska, Kamchatka, Japan and the Philippine and Indonesian archipelagos to New Guinea, New Caledonia and New Zealand (Fig. 1). It contains approximately 25,000 islands totaling over half a million square kilometres of land.

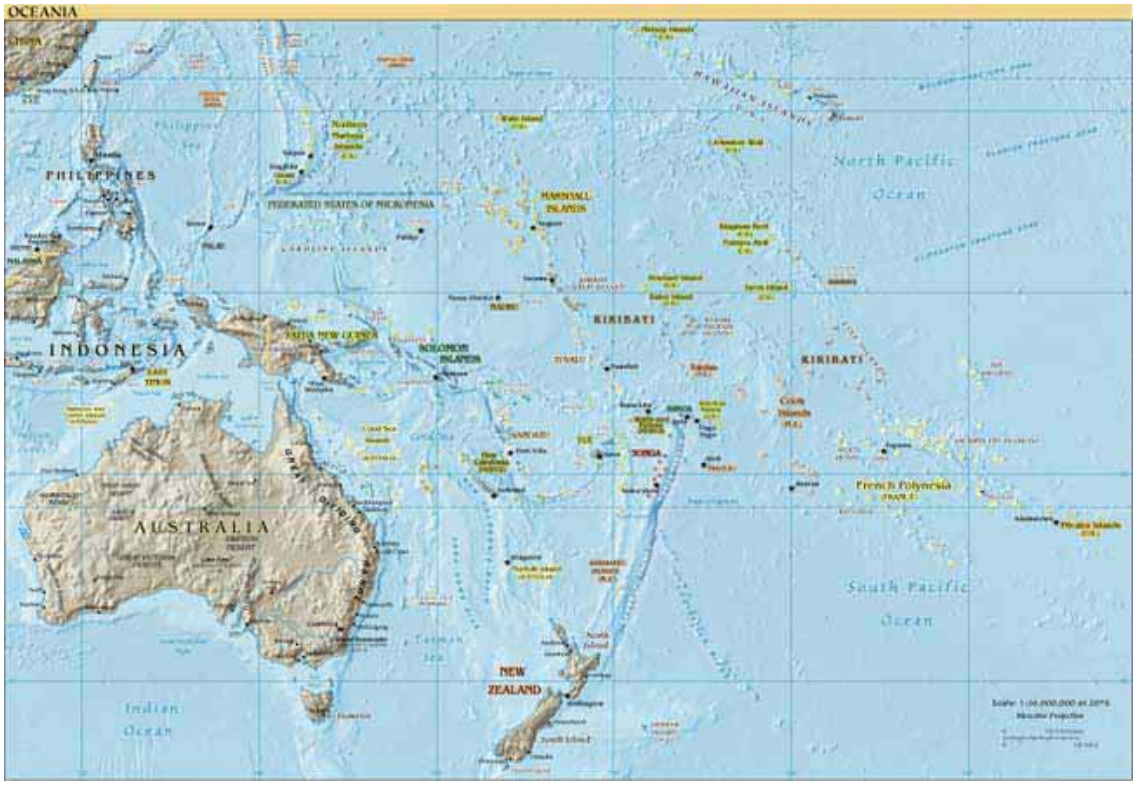

Figure 1: Oceania and its islands[9]

In the past the islands have been arbitrarily geographically classified into three groups – Micronesia, Melanesia and Polynesia. This definition is now widely considered as not properly recognising the pattern of their colonisation, and instead 'Near' and 'Remote' Oceania are now considered more appropriate. Nevertheless reference to the colloquial term 'Polynesia' is retained here, which equates approximately to Remote Oceania. Remote Oceania is most emphasised here due to its relative isolation and recent colonisation, which have together led to its distinct cultural and conservation values being most distinct.[10] Polynesia itself can be considered the triangle demarcated by Hawaii in the north, New Zealand to the southwest and Easter Island to the east. No other region contains so many isolated landforms, amongst such a vast amount of ocean. Because of this isolation each of these island groups is biologically and culturally unique and precious, but equally as

vulnerable in these respects.[11] As an example of this uniqueness we can consider the case of the honeyeater family of birds (Meliphagidae), with over 160 species in the Pacific. The original ancestor species most likely originated through Papua New Guinea and dispersed across the Pacific, radiating into the variety of forms that are now (or until recently were) seen across the Pacific as endemic, insular species. As an example of their vulnerability consider that all five species of Hawaiian honeyeaters (Drepaniidae) are now extinct, and a further sixteen species are threatened elsewhere in the Pacific.[12]

Approximately 35,000 years ago 'Near Oceania' was colonised along the Bismarck and Solomon Archipelagos. Little exploration followed until around 3300 years ago, when the Lapita people began moving into 'Remote Oceania', reaching Samoa and Tonga around 3100 years ago.[13] For the first time technology was applied to the (unnatural) transport of resources, rather than voyaging to find (natural) resources. Predominantly expanding from the South East of Asia, island colonies were gradually established, which evolved culturally over time as the flora and fauna had done. Unfortunately this colonisation initiated the decline in biological diversity. Primitive development saw the loss of habitat and harvesting of the indigenous biota as well as the introduction of alien species. Animals introduced across Remote Oceania included the Polynesian rat (Pacific rat (kiore), *Rattus exulans*), jungle fowl (*Gallus gallus*), pig (*Sus scrofa*) and dog (*Canis familaris*),[14] as well as limited dispersal of *Rattus praetor*. [15] Together these began to reduce the biodiversity that had evolved on these islands. The oldest and most infamous example is the Polynesian rat, also used as an indicator of island colonisation[16] (although not without debate).[17] Only recently has the full extent of the impacts of Polynesian rats on island fauna begun to be acknowledged.[18] As the initial invaders on many islands, before any record of indigenous biodiversity was made, their effects went largely unnoticed. Even if humans did finally notice, the rats would usually remove the last individuals swiftly thereafter.[19] Overall human arrival on central Pacific islands was an event with dramatic consequences for ecosystems characterised by a biota lacking defenses against humans (and the portmanteau[20] biota these new two-legged vertebrates carried with them).[21] As new environments were discovered, it would become necessary for the colonising people to adopt various strategies of resource use in order to persist. As an example of this, resource use on islands can be readily divided into two types. Where water could be controlled, agricultural intensification would follow. Where water could not be controlled, it was necessary to utilise shifting cultivation. These mutually exclusive uses often led to conflict, and would require strong leadership to emerge, such as the case in Hawaii.[22] Hence this led to both biological and cultural adaptation on the islands. Furthermore this illustrates that ecology and economics were not mutually exclusive to the indigenous people. Ultimately the environment depended on the practices of the people, although until even recently this was still argued.[23]

With a move towards more sustainable practices, different levels of equilibrium were reached on islands,[24] depending on both the time since colonisation (relative intactness of the ecosystems, related to isolation) and the practices adopted by the indigenous people. On islands that had received less intense human contact, the biota remained largely intact. In other cases, massive biodiversity loss occurred. The worst case was that of the ill-fated Easter Island (Rapa Nui), where complete

ecological and cultural collapse took place. Although originally colonised as early as 1600BP, the settlement and initial development stage dated from 400AD, where the population may have reached levels around 10,000 people. At this time Easter Island was characterised by a rich culture, including the characteristic erection of hundreds of stone figureheads. Around 800AD habitat loss of the rich palm forests becomes apparent in the pollen records, and by 1400-1500 no trees were found on the island.[25] Following this loss of biological resources, the culture turned upon itself, with clan wars followed by cannibalism. The Spanish appropriated the island in the 1770s, and this was followed by outbreaks of disease and slave trading in the 1860s, which further reduced the population to only 110 people by the late 1800s.[26] What remained was a relic of the past cultural and biological diversity that had existed.

Generally however, cultural practices were based on 'traditional ecological knowledge' (TEK), whereby practical ecological knowledge learnt by previous generations both from their homelands and then *in situ* could be employed in managing the environment.[27] Usually these cultural practices manifested themselves as forms of limits over both the times and places where resource use could occur. Integration with the environment was ultimately essential to avoid catastrophe, 'for in transforming their island environments, indigenous peoples also were compelled to change their technologies, economics, societies, and even ideologies.'[28] Other examples of cultural integration include the use of species as environmental indicators, such as certain seabirds for the proximity of land, or the presence of large schools of fish.[29] Without external (Western) pressure for primary resources, habitat loss was generally restricted to coastal village areas.

Colonisation occurred in two waves in the Pacific – Polynesian discovery, followed by European colonisation.[30] Western discovery of the Pacific Islands and their culture occurred in the mid to late 1700s by voyagers such as Captain James Cook. These Europeans arrived with 'Western' views of biological management, which predominantly divorced man and nature. The increased levels of trade both within island groups and between islands saw the rate of biological invasions increase by many degrees of magnitude. Following sealers and whalers, Dutch, Spanish, French and British immigrants began to colonise many islands. These Europeans brought new technologies, and a much faster rate of change than the Pacific had ever seen. Rapid population growth, new technologies and the introduction of many more exotic species challenged the fragile biological and cultural equilibriums that had been established following Polynesian settlement. The general shape of diversity curves for both biology and culture during the two waves of colonisation can be illustrated graphically (Figure 2). Initially as people colonised and a distinctive culture was established, cultural diversity increased. Although the cultures were intimately linked with the biology, this increase in cultural diversity was inadvertently correlated with a decline in biological diversity. The natural biogeographic borders that had generated biological and cultural diversity were further transcended following Western colonisation. Cultural diversity, which had peaked before Western colonisation, then began to decline. Biological diversity, which had usually stabilised, then suffered a second collapse. Biological and cultural diversity were now tightly coupled and both subject to Western elements. From this it follows that to conserve biological diversity it has now also become necessary to conserve cultural diversity.

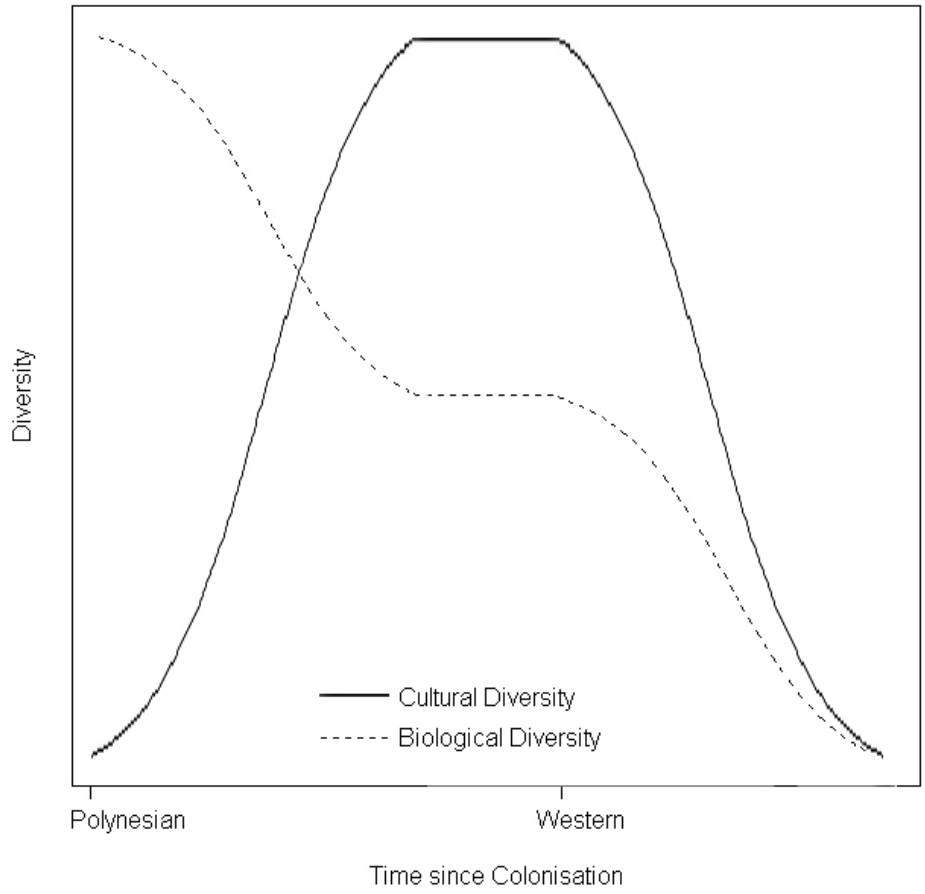

Figure 2: Biological and cultural diversity: Hypothetical diversity indice curves

With the ensuing accelerated development and globalisation brought about by Western society came increased pressure on the environment for resource availability, in the forms of both land area and natural commodities. Island economies struggled to meet these demands and, following marginalisation and exploitation, were subsequently forced to intensify and specialise their production.[31] Confounding this dilemma is that Western society commonly attempts to dominate its environment, and island systems are much more susceptible to poor conservation practice. A common symptom of these widespread phenomena is the increase in acute species invasions currently taking place. These invasions can have very localised and devastating effects on components of ecosystem structure. Specific examples from the Pacific include fruit-flies (*Bactrocera* spp.) invading Nauru, with immediate effects on fruit production and community consumption[32] and the invasion of Laysan Island by the introduced grass southern sandbur (*Cenchrus echinatus*), which seriously affected burrows of the threatened Laysan albatross (*Diomedea immutabilis*) during nesting.[33] The case of introduced goats and pigs on Sarigan Island in the Northern Marianas highlights the complex modification of ecosystems that can occur from multiple invasions.[34] The removal of the introduced mammals releases introduced weeds from herbivory, and a new suite of invasive species becomes dominant, as was observed on Round Island in Mauritius. More often than not these species arrive as a result of increased trade and movement

between islands. A particular period of high rates of invasion was World War II and the period immediately following it (1940-1960s). The American military wished to establish a strong presence in the Pacific, and inadvertently transported species with them.[35] The best documented example is the invasion of Guam by the brown tree snake (*Boiga irregularis*). Believed to have arrived in the cargo hold or wheel lofts of military aircraft, this species is now regarded as the single cause for the extinction of nine out of eleven of Guam's native terrestrial bird species, and extinction in the wild of one of the two remaining species.[36] Similar large-scale military movements and activities have generated biological invasions throughout the Pacific.[37]

Less tractable marine invasion (freshwater and oceanic) similarly occurs throughout the Pacific, and indeed the world.[38] The effects are no less severe on the environment. Ballast waters provide an ideal medium for the transfer of species, being concealed, and periodically uploaded and flushed. Although species invasion can be addressed by means of land quarantine at borders, the proliferation of international treaties has meant that ships harbouring species can move freely throughout the Pacific Ocean. Although the number of documented marine invasions may currently be low, this can in large part be attributed to the lack of documentation, and the confounding 'cryptography' of the species involved.[39] The impacts of all invasive species are similarly far-reaching in that they include effects on human health,[40] and effects on economies.[41] Biological diversity is not alone in being devastated by the effects of invasive species, introduced as a consequence of human colonisation.

Three case studies illustrate the variety in scale of the threats and impacts of invasion throughout the Pacific. New Zealand's avifauna and its devastation by introduced mammals over the last 1,000 years provides an historical context, mirrored across the Pacific. Hawaii's flora and introduced weeds highlight the intensity and magnitude of plant invasions, while the recent escalating invasion of the Pacific by red imported fire ants (*Solenopsis invicta*) highlights an immediate threat which requires appropriate and decisive action before it is too late.

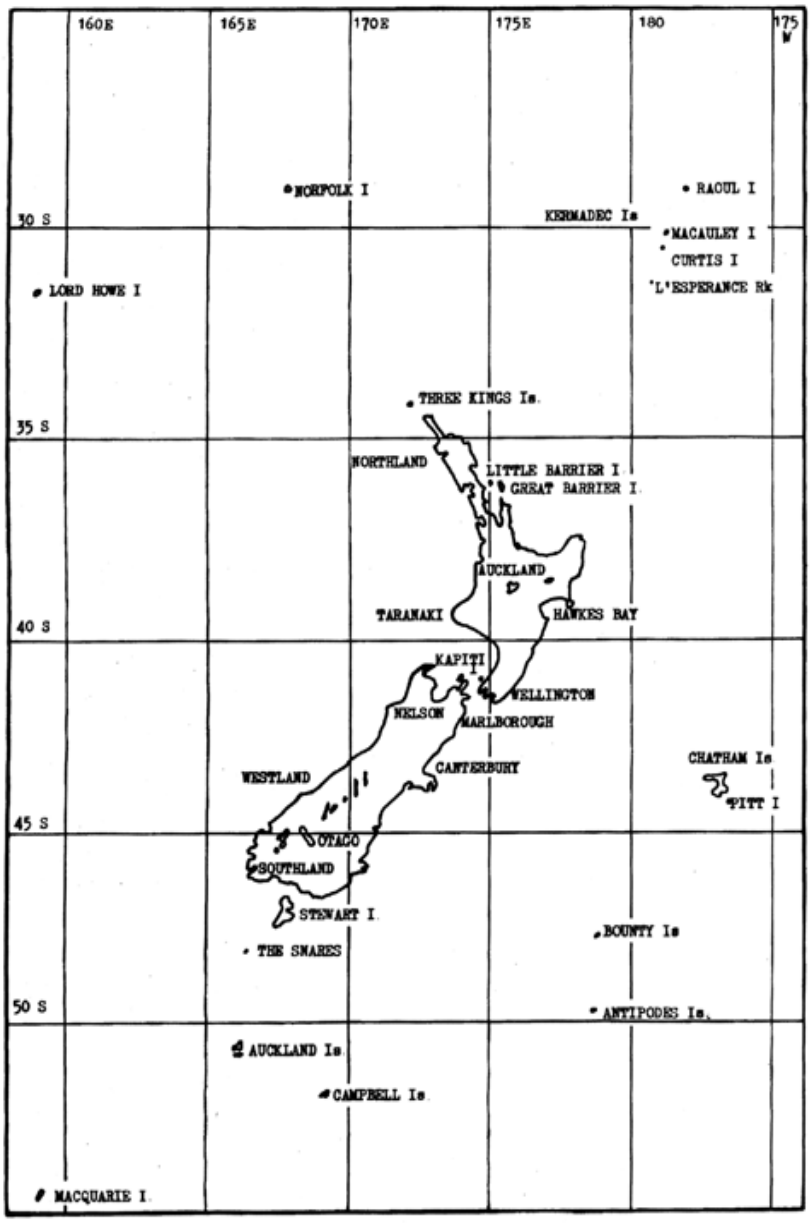

Figure 3: New Zealand Islands

New Zealand's Avifauna and Introduced Mammals

New Zealand separated from the Gondwana land mass early, around 80 million years ago. This occurred before the radiation of mammals, and so New Zealand's indigenous biota (birds, reptiles, insects and flora) evolved in the absence of terrestrial mammals. This had profound effects on the diversity and radiation of species within the New Zealand archipelago. The radiation saw niches that elsewhere would have been occupied by mammals, instead filled by birds, lizards and invertebrates.

Initially only two mammal species (kiore, *Rattus exulans* and kuri, *Canis familiaris*) journeyed with the original Maori colonists. During Maori occupation the usual haunts of island exploitation occurred: habitat loss, harvesting and the introduction of species, the latter generally identified as the main causal factor in the decline and extinction of species.[42] Mammals hunt by smell, but because New Zealand's avifauna (indeed all its biota) had evolved in the absence of mammals, this method of hunting was unfamiliar, whereas freezing when under threat from other

sight-hunting species had always been an evolutionary selected defence. This left the avifauna vulnerable to predation, particularly in the case of flightless birds,[43] a common phenomenon of island species.[44] In total at least 32 bird species are known to have become extinct in this time,[45] the kiore responsible for some of these,[46] human exploitation for others.[47] Given time, as had occurred on other Pacific Islands, the societies adapted to the landscape. In the South Island of New Zealand, where permanent agriculture was not possible, the indigenous people shifted to a nomadic hunting culture.[48] 'Rahui' and 'tapu' were initiated,[49] whereby land could be protected from resource gathering until it was replenished (using TEK as a guideline), or made permanently off-limits for spiritual reasons (such as highest points which were viewed as departure points for spirits). Both served to protect biologically valuable areas using cultural means. Similar practices also occur in the Cook Islands (Raratonga). Gradually the environment stabilised following the first colonisation of New Zealand.

The arrival of Europeans at the beginning of the nineteenth century saw an explosion in the number of terrestrial mammals, with some 53 different species being introduced, 25 of which successfully established.[50] In only 200 years most of these mammals have expanded their distributions across the entire New Zealand archipelago, although there have been some areas where only recent range expansion has occurred. These species were introduced for a variety of reasons, including labour, sport, pets, biological control and accidental transportation.[51] Introduced rodents arrived in the sequence *Rattus exulans*, *R. norvegicus*, *Mus musculus* and *R. rattus*.[52] Other particularly devastating mammals included the stoat and feral cat.[53] The deleterious effects of these invasions are best illustrated on islands which otherwise harboured unique species.[54] The 1963 irruption of rats on the Big South Cape Islands saw three bird species go extinct, while cats on Little Barrier Island (Hauturu) continually plagued conservation work and required massive eradication effort in the early 1980s. Stoats have recently received considerable attention directed towards mainland control and eradication on offshore islands.[55] Following the invasion of these mammal species, a further nine bird species went extinct, thus to date a total of at least 41 species, or 40% of New Zealand's land and freshwater birds, have gone extinct.[56] In addition to these are those many species which are currently considered threatened or endangered, either with reduced ranges or restricted to offshore island (predator free) nature reserves. In total over 50% of New Zealand's avifauna has been 'seriously' affected by introduced mammals and the effects of introduced mammals on New Zealand's avifauna can be considered nothing less than catastrophic.

Hawaiian Flora and Introduced Weeds

The Hawaiian islands originated from volcanic activity, and are characterised as one of the most remote Polynesian island groups, with a total land area of approximately 16,642km^2. The islands were once so culturally unique that it was suggested they had instead been colonised from South America. As illustrated earlier by Hawaiian honeycreeper radiation, their biology was similarly as unique, including geological diversity which led to a massive diversification of plant life. Captain James Cook first sighted the Hawaiian islands in 1778. Like New Zealand, Hawaii had no endemic mammals except bats. The introduction of mammals to Hawaii thus had similarly

devastating effects as has occurred in New Zealand, however such effects have already been discussed. Entering the twentieth century, Hawaii became the 'gateway to the Pacific' – a tourist destination, military base and trade extension of North America. Underlying all this was the constant introduction of alien plant species to Hawaii. Even before Western occupation, it has been estimated that human inhabitants had extensively altered almost 80% of the vegetation of lowland Hawaiian islands.[57]

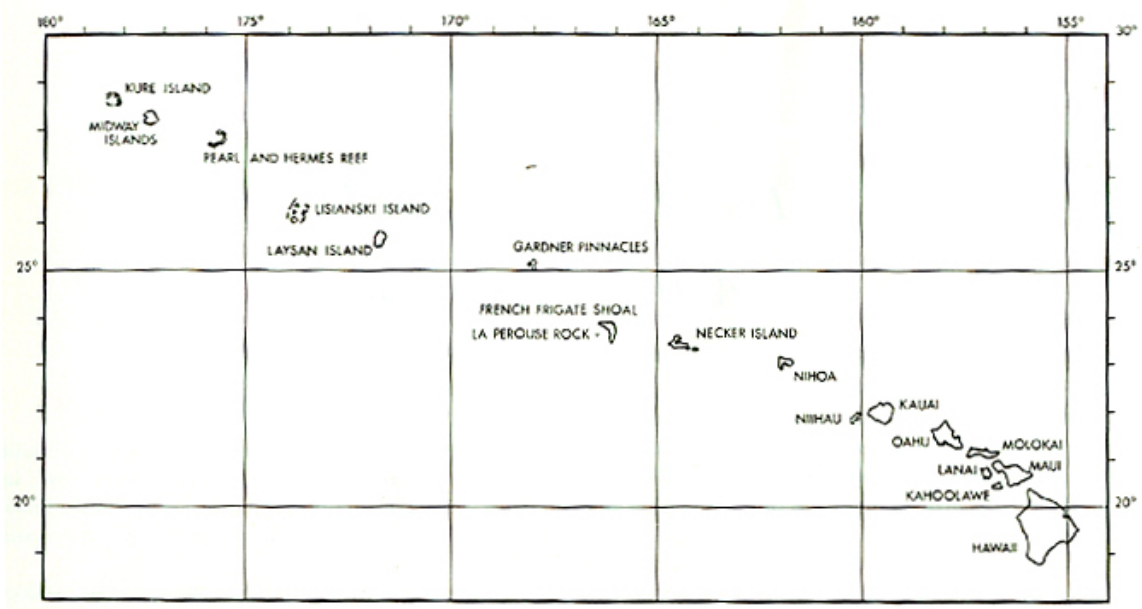

Figure 4. Hawaiian Islands

The majority (approximately 70%) of Hawaii's plant invasions have occurred as a result of the ornamental plant trade. Although not all plants become invasive, it is very difficult to typify the characteristics of those that do,[58] though three properties that are generally (but not exclusively) shared between invasive plants are: 1) animal or wind dispersed propagules (seeds/spores); 2) rapid growth rates, and 3) high fecundity (reproduction).

Together, these traits allow plants to reach almost any area, establish and grow rapidly, followed by massive reproduction to reinitiate the cycle. Over an estimated 13,000 exotic plants have been introduced to Hawaii. In a recent review,[59] it was estimated that over 140 of them had become problematic plant species, categorised as 23 dominant invaders, 76 moderate invaders and 41 potential invaders (problematic elsewhere). This equates to approximately 1% of those introduced, although another 200-300 may simply be laying 'dormant'. The effects of invasive weeds on threatened plants can be varied and are usually detrimental.[60] Plants make up the greatest biomass of terrestrial ecosystems, and so alteration of the ecosystem at this level has effects on all other biota.

The extent of impacts is highlighted by one of the worst invasive weeds in Hawaii. The small tree *Miconia calvescens* grows to heights of 15m, with large 80cm purple and green leaves. The tree was first introduced in the early 1960s, although no concern was raised regarding its presence until 1990,[61] despite its reputation as 'the most invasive and damaging of alien plant species to wet forests of Pacific islands'.[62]

This reputation was instituted following its devastating effects in Tahiti where, once it became an ornamental escapee in 1937, dense monocultures became established across the island. Currently 25% of Tahiti is covered by such monospecific stands (although 65% of the island is invaded). Although initially control of the seven established populations seemed feasible (20,000 plants were removed over three years), the discovery of a 150ha fruiting population of over 1000 plants on an inaccessible 500 year old lava flow promptly required a change in management strategy.[63] A shift towards control over eradication, with the emphasis on multi-agency cooperation, became necessary.

The invasive characteristics of *Miconia calvescens* include its ability to germinate in very low light levels, and then to overshadow other canopy plants with its large leaves. Its seeds are dispersed by both birds and (introduced) mammals, and have a seed-bank lifetime of up to four years with 500-1000 germinating plants per square metre. Control work also encourages dispersal through track clearance and via mud on boots. It is expected that invasion throughout Hawaii will be most prolific in the lowland areas of 1800-2000mm rain. Control strategies include hand removal, chemical application (both ground-based and aerial spraying) as well as investigation of potential biological control methods.[64] It is also necessary to incorporate public education and targeting of transportation pathways such as contaminated soil, which to be successful must include working with the indigenous people and their culture.

As an example Hawaii clearly illustrates the effects that unmoderated border passage can have on the environment. Once invasion has occurred agricultural intensification and land disturbance exacerbate the impacts. These border crossings have been occurring since the first Polynesian occupation, and continue still, at an increasingly rapid rate following Western colonisation. The freedom with which species introductions have been allowed to take place has similarly encouraged species establishment and invasion. Without any checks on what species are being allowed in, Hawaii has merely become a biogeographic extension of North America.

Red Imported Fire Ants

History often teaches us valuable lessons, as is evident from the prior two cases. The unmediated introduction of species can have many profound and often cascading effects on natural ecosystems. Extinction is a distinct outcome, and the effort required to eradicate a species once established can be huge. However, the introduction of both mammals and plants ('large organisms') to new locations is now more rigorously monitored by government agencies. What is becoming apparent now is that insects, ants in particular, are also incredibly effective and devastating invaders. Over 147 ant species have been recorded outside their native habitat, with most of these records from the Pacific Islands.[65] The worst of these ant invaders is the red imported fire ant (*Solenopsis invicta*). Red imported fire ants are currently not found on any Pacific Islands, however the threat of invasion by them is almost imminent, as territories around the Pacific Rim gradually become invaded, and incursions into the Pacific begin to be documented.

Before describing the distribution and invasion of red imported fire ants, it is insightful to characterise the species, and why its invasion across borders has been followed by social, agricultural, economic, technological and biological devastation.

When nests are disturbed the ants swarm over any nearby object, delivering multiple painful stings to the intruder which cause burning and itching followed by redness and a pustule that can become infected. An unaware individual can easily sustain dozens of stings in a single encounter, with approximately 1% of people having allergic reactions.[66] This has affected quality of life in invaded areas. They are predators of both insects and crops in invaded areas, and pervasively affect agriculture through machine infestation and damage, reduction of harvesting efficiency and attacks on livestock.[67] Similar damage to infrastructure such as property and electrical equipment is also caused by red imported fire ants.[68] Studies of effects on birds, small mammals, invertebrates and plants are too numerous now to list. Gotelli and Arnett[69] give results of a 2000km transect studying the effects of red imported fire ants on fauna across the United States. Estimates place the cost to Texas alone of red imported fire ant invasion at over $US500 million per year. In contrast to the earlier case studies the diversity of impacts of this contemporary invasive species is considerably wider.

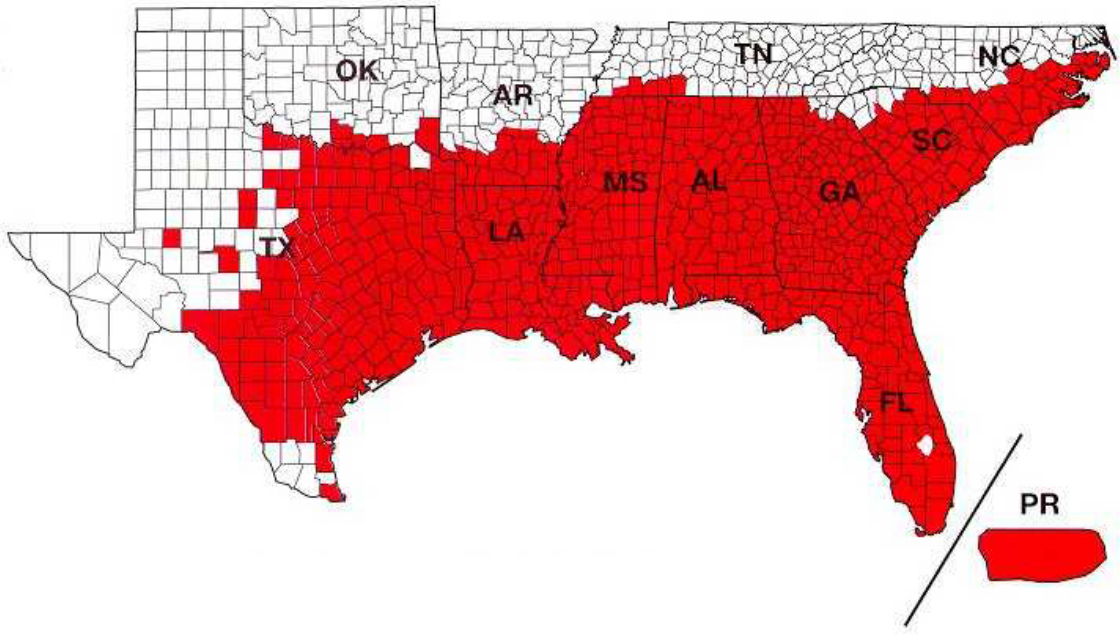

Figure 5. Red imported fire ant infestation pre-1953

The red imported fire ant invasion has been well documented across North America. It first arrived in Mobile, Alabama from its native Central/South America in the 1930s. The culture of free distribution, trade and transport of agricultural and horticultural machinery and products across state boundaries undoubtedly aided in the species' subsequent invasion of other counties and across state borders. It was not until 1958 that the USDA established quarantine procedures to limit the movement of potentially infested material outside of infested zones. The first eleven states to be invaded were located in the south east of the United States, and were invaded before 1953 following range expansion and local transport radiating from Mobile, Alabama (Figure 5). In 1998 red imported fire ants were first detected in California and New

Mexico, bringing the total number of states to thirteen. California, on the westernseaboard, acts as a gate-way to the Pacific (in particular Hawaii) and thus the threat of Pacific invasion has become imminent.

In a parallel to what might occur in the Pacific, red imported fire ants are also invading the Caribbean. Alarmingly this invasion has received very little attention to date. Davis and colleagues[70] list 13 islands that have been invaded by red imported fire ants over the last 20 years. To add more urgency to the matter, in February 2001 red imported fire ants were found in Brisbane, Australia, on the other side of the Pacific. The long-distance pathway through which this occurred has not been identified, and most likely never will be now that the species has widely established. The commendably rapid response by the Australian Government will see $AUS123 million spent over the next five years treating over 40,000ha of possibly infested area. Results of the first year of treatment promisingly saw a 90% kill rate in nests. In March 2001 a single nest was also located in the vicinity of Auckland International Airport, New Zealand. Rapid response saw the nest destroyed and the surrounding area of possible natural dispersal monitored. No sightings following this incursion have been reported, and the species is considered eradicated (a world first, related directly to response time and population size).

Although there has been some success in controlling and eradicating red imported fire ants around the Pacific Rim, the sudden explosion in distribution is a cause for major concern amongst scientists, managers, indigenous people and all other inhabitants of the Pacific. Current projects are modeling the potential range of red imported fire ants should they invade Hawaii, which is identified as the most likely location for first incursion, although all Pacific islands are potentially at risk. Scientists and managers are also working cooperatively to increase quarantine and surveillance measures to intercept red imported fire ant incursions into the Pacific.

The red imported fire ant scenario is significant, as it incorporates all the current issues of biological invasions and border crossings. It highlights the contemporary global scope and immediacy of the threat, including the pervasiveness of invasion by such small organisms, and draws together both the ecological and human dimensions of invasive species management. It also shows the magnitude of action that must be taken in response to invasion by an exotic species known to be problematic. By uniting science (research), technology (methods), society (public support) and culture (management of pathways, etc) it can be shown that success can be achieved, but only if all the necessary components are in place. To address these issues a global workshop on red imported fire ants, with emphasis on addressing the Pacific threat, took place in New Zealand during September 2003, organised by the Invasive Species Specialist Group (ISSG) and Cooperative Islands Initiative (CII). The outcome of this was the development of a multi-country inter-agency prevention plan for red imported fire ants in the Pacific region, the first plan of its kind.

Invasions are clearly at the forefront of today's conservation crisis, and they continue to increase in occurrence daily. The key to redressing the effects of invasive species is to adopt a global context. The issue is global in nature, and can only be solved through international co-operation. One of the primary causes of this biological and cultural collapse has been the crossing of biogeographic borders that in the past created and maintained diversity. The previous oceanic barrier present in

the Pacific has gradually been surpassed by the development of more rapid and global transport. The means of restoring diversity is thus to reinstate these biogeographic borders, however this must be done in a way which does not create unrealistic obstacles to economic progress or cultural integration, nor interfere with the 'quality of life' which people have generally come to accept based on the advent of global roaming. The transport of some species was intentional, and this formed an integral part of historical colonisation.[71] In many cases the introduced species are benign in their new environment, with only a fraction becoming invasive.[72] Species transport itself is not the enemy but, given historical context, poor biosecurity in vetting these species is. The principal solution is to monitor arbitrary borders of territories. Conveniently these are synonymous with coastlines in island systems. It is much more cost-effective to prevent invasion than it is to control or eradicate an established population.[73] It is no coincidence that New Zealand, with possibly the most rigorous quarantine and monitoring procedures in the world, is the first (and currently only) country to have eradicated red imported fire ants. This shows how a real investment in border control can produce actual results in incursion prevention.

Model conservation projects are also a successful tool for restoring local diversity.[74] By protecting areas of land, external environmental pressures can be minimised allowing diversity to recover. In the case of islands it is possible to eradicate established invasive species.[75] This subsequently creates more optimal conditions for the biodiversity that was present before invasive species arrived with humans. Although this technique has been practiced very successfully in New Zealand,[76] its adoption has been slower in the Pacific due to complex land tenure practices, where private land ownership (a Western concept) is not appropriate in indigenous cultures[77] and because of cultural integration of some invasive species (e.g. pigs and kiore). To address these issues less stringent 'protected areas' have been created, where cultural use of protected land is allowed, and co-management with indigenous people takes place. This form of practice marks a shift from the Western dominated approach of land preservation and will need to become increasingly common for conservation success to be achieved in the Pacific. Only through recognising the unique association between biological and cultural diversity in a location, can either one be restored.

The key to both successful quarantine and restoration projects is public awareness and support. Without public support, resources will generally not be available and a lack of involvement will prevent long-term success. It has been shown that any attempts to preserve the remaining fragments of Polynesian bird life must consider the importance of involving local people,[78] whose cultures have been entwined with the fates of these birds for hundreds of years. In island communities there must be a commitment to prevent and eradicate introduced species, and then to monitor the pathways through which they arrived, otherwise reinvasion (either accidentally or purposefully) will re-occur. The first step in accomplishing this is to encourage public awareness through education. Firstly, people must be made aware of the threat invasive species pose to both themselves socially and the biological identity of their home. This may require fostering a passion for biological diversity, or drawing links between biological and cultural diversity. For some groups, it may require highlighting the economical benefits of protecting environmental services and other natural resources which the current market-orientated system struggles to

value accurately.[79] The most successful solutions to the environmental problems of the Pacific are currently being built around constructive accommodation of such social, cultural and economic issues.[80] Wittenberg and Cock illustrate the application of these specific goals in working towards successful invasion prevention and environmental restoration in Hawaii.[81] In New Zealand, although the second decline of biological diversity has not yet been halted, the rate of decline is showing signs of slowing. 'Cultural adaptation' in a Western context has occurred through more rigorous control of pathways of invasion into New Zealand. The public in general have similarly become aware of biological issues and invested funds in projects to preserve biological diversity. At the same time, cultural diversity is being revisited, in attempts to revitalise both itself ('Te Reo Maori') and as a tool to manage biological resources (TEK), as was the practice towards the end of the first wave of Polynesian colonisation that saw biological diversity begin to stabilise.

The key to the joint persistence of biological and cultural diversity on islands is protecting environmental services, by encouraging practices more appropriate to the environment, otherwise Easter Island may be a good model for our entire planet.[82] With good planning,[83] it is possible to achieve success in species eradication on islands that might not have always seemed possible.[84] As David Steadman declares, 'In the next few decades it will be fascinating to participate in the interplay of science, culture, economy, and environment in the South Pacific.'[85] Natural and social scientists, planners and policy makers are currently drawn to 'global change' issues,[86] and so there is no better time to incorporate science, technology, society and culture internationally to work towards solving the complex issues of species invasion and environmental degradation.

NOTES

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