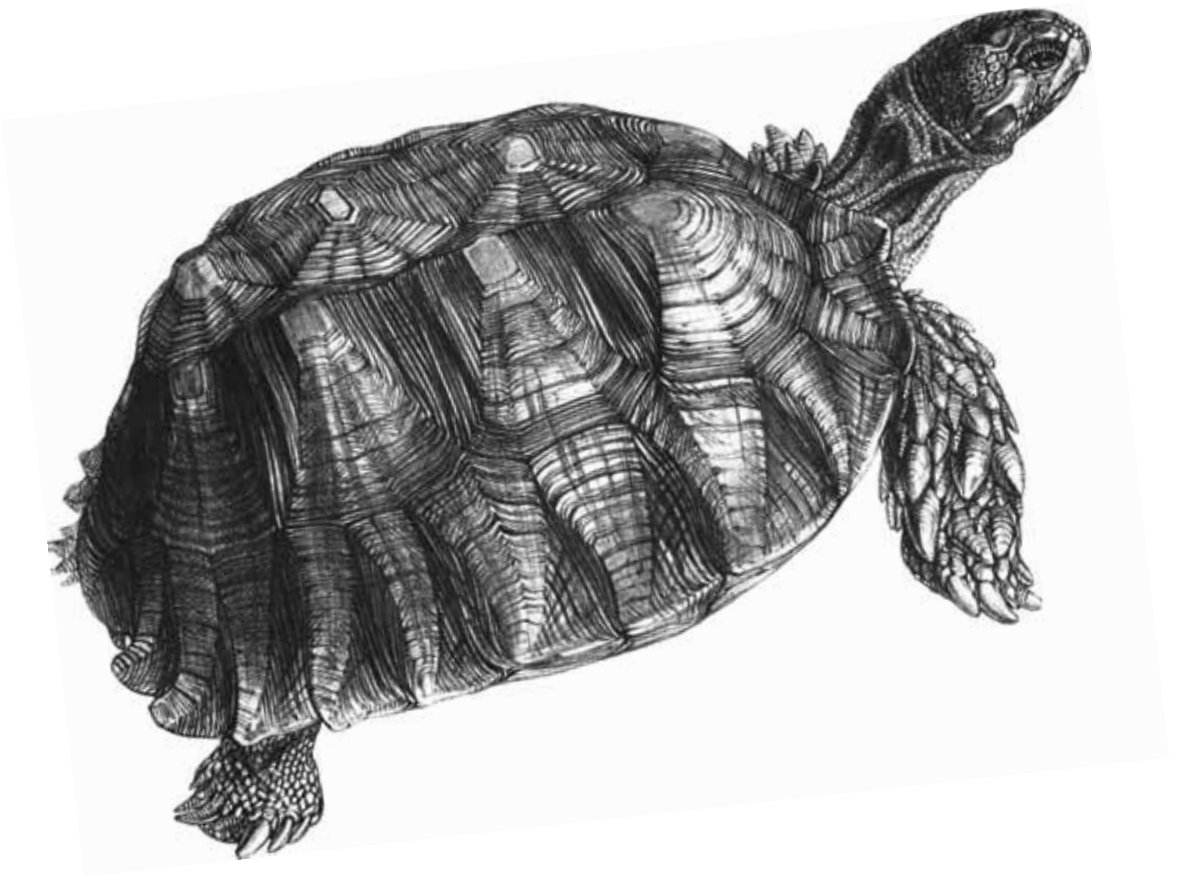


CAN UNWANTED SUBURBAN TORTOISES RESCUE NATIVE HAWAIIAN PLANTS?

by David A. Burney, James O. Juvik, Lida Pigott Burney, and Tomas Diagne



Through a series of coincidences, surplus pet tortoises in Hawaii may end up offering a partial solution to the seemingly insurmountable challenge posed by invasive plants in the Makauwahi Cave Reserve on Kaua'i. This has come about through a serendipitous intersection of events in Africa, the Mascarene Islands, North America, and Hawaii.

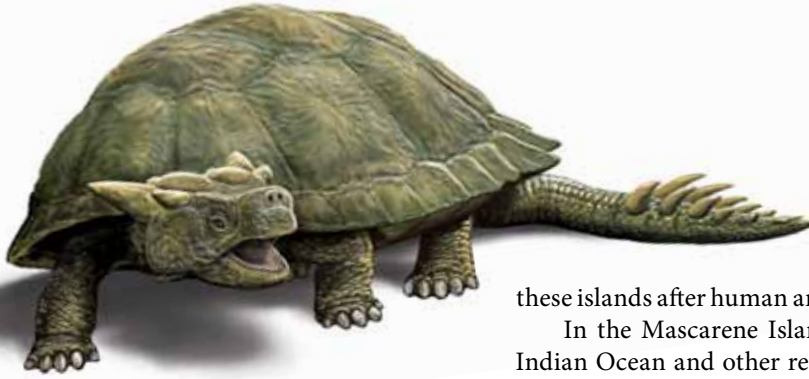
The remote Hawaiian Islands were beyond the reach of naturally dispersing island tortoises, but the niches were apparently still there. Giant flightless ducks and geese evolved on these islands with tortoise-like beaks and other adaptations as terrestrial “meso-herbivores.” Dating of these remarkable fossil remains shows that they went extinct soon after the arrival of Polynesians at the beginning of the last millennium leaving the niches for large native herbivores entirely empty. Other native birds, including important plant pollinators, and some plant species have also suffered extinction in recent centuries.

This trend accelerated after European settlement with the introduction of many invasive alien plants and the establishment of feral ungulate populations such as sheep, goats, cattle, and European swine, as well as other insidious invasives such as deer, rats, mongoose, feral house cats, and even mosquitoes, which transmit avian malaria to a poorly resistant native avifauna.

With its remaining native ecosystems continuing to lose species to extinction and contracting in area through urban development and degradation by invasive species impacts, Hawaii has become a global poster child for endangered species and “novel ecosystems.” Novel ecosystems are biological communities intentionally or unintentionally manipulated and/or engineered by humans. In a recent article titled “*The New Normal*,” Emma Marris posits that ecologists and conservationists are reluctantly accepting that we live in human controlled ecosystems where the traditional dichotomy between “alien” and “pristine” has become substantially blurred. Further, Marris states that ecosystem management objectives are confounded because many functionally important native species are already extinct and many established invasive plants and animals are likely here to stay. Managing such systems to optimize the preservation of local biodiversity along with

ecosystem services and a complex mix of often conflicting stakeholder interests clearly requires new paradigms and new tools.

Lacking any native mammalian herbivores, the majority of the over 1,000 native Hawaiian plant species on the islands have been widely regarded in the literature as singularly lacking in defensive mechanisms, such as spines and toxins, against large “toothsome” herbivores. However, evidence suggests that plants on the world’s most remote islands, lacking native mammalian herbivores — the “Toothless Islands” so to speak — may have developed some defenses against the birds and/or reptiles with whom they co-evolved. Studies by Helen James and David Burney of *coprolites*, (fossil dung pellets), of one of the big extinct flightless ducks of Maui showed that they ate the terrestrial understory plants, even ferns and such, in Hawaii’s primeval paradise. Some plants there, such as the dominant dry-forest koa trees and several of the strange and beautiful *Cyanea* species, exhibit strong *heterophylly* — different, presumably less palatable leaves near the ground, changing to larger and more succulent foliage above the likely upper reach of browsing animals. Many native Hawaiian plants are closely related to species in the South Pacific islands that undoubtedly co-evolved with the giant horned *Meiolania* tortoises that went extinct on many of



GRAPHICS BY CARL BUELL

The extinct, giant horned-tortoises of the family Meiolaniidae (top) exhibited a Gondwana distribution from the Cretaceous of Argentina to the late Pleistocene of Australia and Anthropocene of Melanesia, including Fiji and New Caledonia. Recent discoveries in Vanuatu of subfossil Meiolaniid tortoises in a comparatively recent Proto-Polynesian (*Lapita*) cultural context (2,700 yr BP) reinforce a pattern of Melanesian megafaunal extinctions congruent with the early human settlement chronology in the region. This extinction pattern closely replicates similar ones for Caribbean tortoises (*Chelonoidis* sp.) over the past 500 to 5,000 years, extinctions which likewise match with the dates of initial Amerindian settlement. In the Hawaiian Islands, too remote for natural tortoise colonization, a large flightless duck, the “tortoise-billed” *moa nalo* (bottom) evolved to fill this grazing herbivore niche. Its extinction also coincided with the arrival of the first Polynesian settlers almost a millennium ago. The ghosts of recently extinct giant tortoises and large flightless birds lurk in the ecological and evolutionary background for many oceanic islands of the world and we argue there are living proxy species potentially available to fill these lacunae and restore some semblance of appropriate native ecosystem structure and function.

these islands after human arrival in recent millennia.

In the Mascarene Islands of the southwestern Indian Ocean and other remote island areas, floras that had to defend themselves against giant birds and tortoises also show strong heterophylly, as well as saplings with tough flexible stems and often a purplish color on the lowermost leaves that may indicate the presence of certain defensive chemicals to discourage the toothless beaks of non-mammalian vertebrate herbivores. Research scientists such as Christine Griffiths have shown through careful experimentation that tortoises are highly beneficial to native Mascarene plants. They play at least three major roles: 1) controlling undergrowth, particularly competing non-native plants; 2) cycling nutrients in their dung; and 3) promoting the dispersal and germination of rare native plant seeds by ingesting the fruits.

Biologist and entrepreneur Owen Griffiths, owner of several nature preserves on Mauritius, Rodrigues, and Madagascar, has demonstrated through two decades of landscape management with tortoises that they quite reliably crop down invasive weeds introduced from the continents, and generally have less or even no preference at all in native plants of remote islands with their presumed defenses against “tortoise attack.” On tiny and remote Rodrigues Island 650 km east of Mauritius, Griffiths’ private-sector conservation venture, the François Leguat Giant Tortoise and Cave Reserve, has reintroduced over 130,000 rare native plants to a securely fenced 19 ha landscape previously degraded by goats and other livestock. Most of the weeding is done by two alien, but non-invasive, species of tortoises. Scientists believe they are ecologically similar to the two now-extinct *Cylindraspis* tortoises species first described by colonist François Leguat in the late 17th century.

The current “tortoise-based land management” results are astounding. Over 1,000 introduced Aldabra Tortoises (*Aldabrachelys gigantea*) and Madagascar Radiated Tortoises (*Astrochelys radiata*) keep the place looking as if a whole crew of expert horticulturists were cutting the grass and pulling the weeds and thus promoting native forest regeneration.



PHOTOGRAPH BY LIDA PIGOTT BURNLEY

The arrival of tortoises to Makauwahi Cave Reserve has added a whole new dimension of interpretive opportunities and native plant restoration experiments there. Kids playing on the nearby beach, most of whom have already visited the site's remarkable fossil and archaeological digs and perhaps helped plant native trees on previous visits, have a whole new reason to come and learn (above). The first big Sulcata from Hilo, Hawaii, (below) received a traditional Hawaiian greeting.



PHOTOGRAPH BY LIDA PIGOTT BURNLEY

MAKAUWAHI CAVE RESERVE: WHERE PAST AND FUTURE MEET

Meanwhile, back on the sub-arid south coast of Kaua'i, there is also a place with a vaguely similar theme: the Makauwahi Cave Reserve. For two decades, scientists have excavated the rich fossil site in the cave's central sinkhole, recovering literally millions of fossils and thousands of human artifacts. This has allowed them to trace the environmental history of the last 10,000 years on the island. In the book *Back to the Future in the Caves of Kaua'i: A Scientist's Adventures in the Dark*, David Burney muses that large flightless ducks and geese — *moa nalo*, Hawaiian for the "lost fowl" — must have been important shapers of the landscape. As *keystone species* in ecological terminology, they may have grazed the forest understory as tortoises have been well-documented to do on other remote islands, or the giant ratite birds called *moa* in the Maori language did on New Zealand.

A compelling indirect clue that tortoise grazing might benefit native Hawaiian plants was noticed by the Burneys at the François Leguat Reserve on Rodrigues. In a strange twist, over the past century, at least two native Hawaiian plants have somehow become established as "invasive aliens" on Rodrigues, a grass and small shrub, and are found in the Rodrigues tortoise grazing paddocks where they appeared to be largely avoided by the tortoises. This was the first inkling that these Hawaiian species perhaps possessed some chemical or physical defenses that carried over from past co-evolution with the *moa nalo* to also protect them from tortoises?

At Makauwahi Cave on Kauai's south shore, the Burneys have a lease from Grove Farm Company on abandoned farmland and limestone mine spoil areas that, two decades ago, were almost devoid of native plants. With the help of thousands of volunteers and local school children, almost 6000 native plants have been established on the seven ha site, focusing on the reintroduction of native plant species that were predominant in the nearby cave's recent fossil record. Many of these species now reproduce on their own. Although the resulting "living museum" is beautifully maintained by staff and volunteers, non-native and highly invasive weeds introduced to Hawaii from the tropical continental areas of the world keep the workers on a desperate treadmill of weed control, struggling with mowers, weed whackers, and shovels to stem the tide of the green invasion.

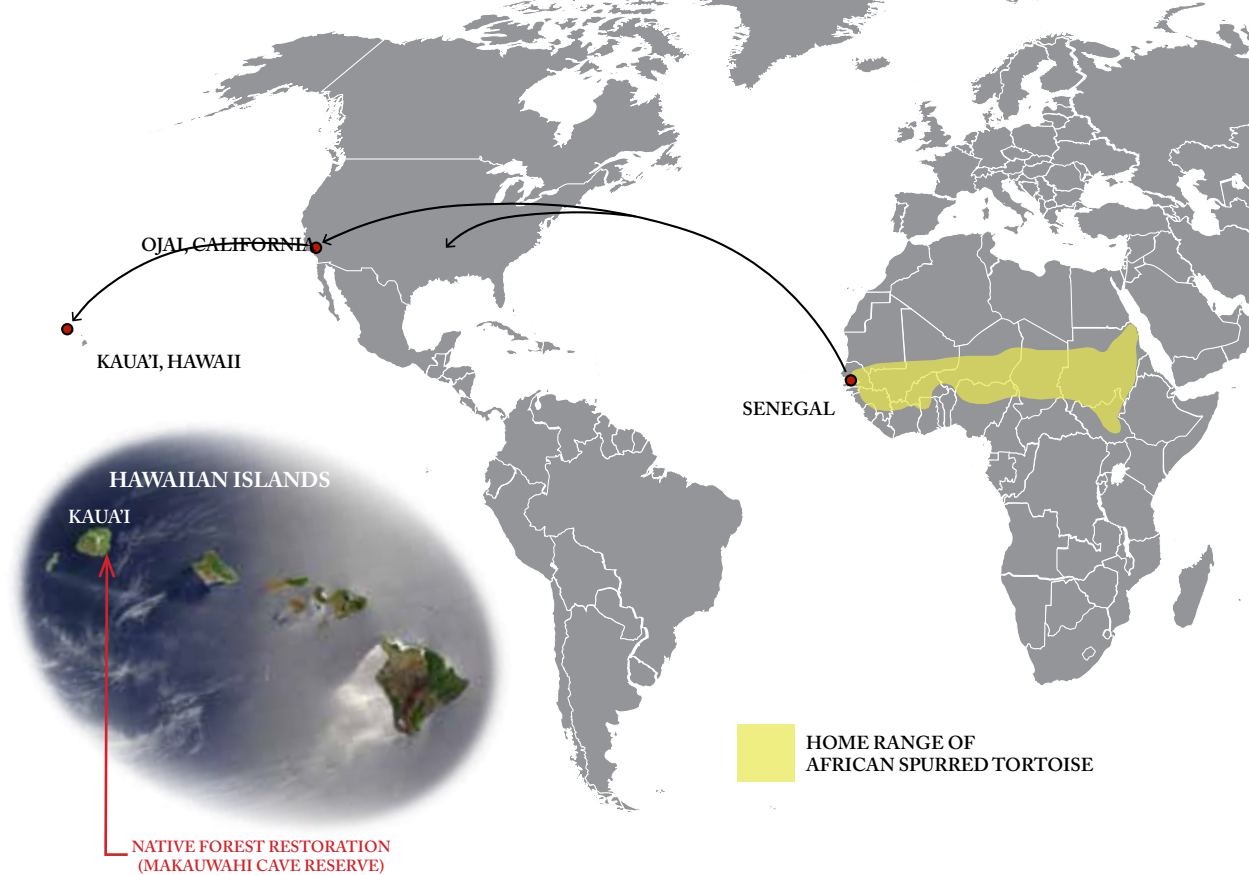
In the summer of 2011, reserve managers decided it was time to try the "Indian Ocean solution," and get some tortoises to help. Aldabra Tortoises, however, are quite expensive, and shipping from the US mainland or from Owen Griffiths' excellent breeding facilities on Mauritius halfway around the world was beyond the small non-profit's budget.

Co-author and Professor at University of Hawaii — Hilo, Dr. James Juvik, Hawaii's tortoise expert, had a possible solution: the large African Spurred Tortoise, better known to enthusiasts as the Sulcata Tortoise (*Centrochelys sulcata*), is abundantly available, even free for "adoption," in Hawaii, California and other states. Labeled the "suburban time bomb" because they are purchased as cute tiny pets that grow up and become long-lived giants and ultimately a burden to their loving owners, Sulcata are often offered up for adoption. For most suburbanites, 50 to 100 kg of tortoise is just too much to look after. So it was decided, at the Makauwahi Cave Reserve, that the logical first step in making a systematic scientific test of giant tortoises as landscape managers in Hawaii would be to enlist the aid of this super-abundant, cheap, and hardy African species. Although yet another "alien" species, this tortoise meets the important criterion of not being "invasive."

Land tortoises, unlike aquatic turtles that can disappear under water, have never been documented to become invasive anywhere in the world, although they have been widely reintroduced to Indian Ocean islands, at Charles Darwin's suggestion, since 1874. Several kinds of land tortoises are popular pets throughout the world, and to our knowledge none have ever created a problem for any ecosystem. Quite the contrary, large tortoises were once abundant on most continents and oceanic islands until the arrival of humans drove almost all of these species to extinction. It has been proven over and over again that it is relatively easy to get rid of tortoises in contrast to mosquitoes, mongoose, rats, cats, and deer, if for some reason you don't want them around. With respect to Kaua'i, whether they would show a similar preference for weeds over the established native trees, shrubs, and groundcovers was a question readily answered only by controlled scientific field testing.

THE LAST CONTINENTAL GIANT: AFRICA'S SULCATA

Against all odds, only a single continental giant tortoise among dozens of extinct sister species has survived the human diaspora of the past 50 millennia, and ironically it resides near the very



The global reach of *Sulcata*, from Senegal to Hawaii in the 1970s and now back again to Hawaii 40 years later in a new ecological proxy role. Over this period the pet *Sulcata* population has mushroomed in the US while in the species' sub-Saharan native range tortoise densities have plunged.

SATELLITE IMAGE BY NASA TERRA SATELLITE

heartland of East African human evolution. Perhaps co-evolution with human ancestors that were only gradually increasing in lethal capabilities gave the species the time and savvy to adapt and strategize for survival in the face of this new and clever predator. The *Sulcata* must have had a few other things going for it to avoid the fate of its lost giant kin — being flipped over on the campfire and cooked in their own pot-like shells. *Sulcata* inhabits sub-desert grassland and thorn-scrub along the margins of the Sahara, where early hunter-gatherer populations would have been sparse and had to carefully weigh the caloric energy cost-benefit of digging tortoises from their deep burrows or waiting around for their occasional above-burrow appearance.

In the mid-seventh century, *Sulcata* caught a lucky break from their sympatric human inhabitants when Islam exploded out of Arabia and across North Africa. Nomads and trans-Sahara trade routes extended this religious diffusion rapidly southward into the Sahel range of *Sulcata* by the ninth and tenth centuries. With Islam came *Sharia* Law with strict food taboos as to what is permissible, *halaal*, and forbidden, *haraam*. Along with the obvious,

pork and alcohol, ugly creatures of the ground like snakes, lizards and tortoises were *haraam*. This serendipitous religious conversion carried *Sulcata* survival safely through more than a millennium and into the 21st century. By now, however, the human population of the Sahel has multiplied manifold and hunter-gatherers have been replaced by a much higher density of pastoralists with their domesticated flocks of goats and sheep. The resulting overgrazing and encroaching desertification presents challenges for both people and tortoises in the region. Drought, poverty, and famine can sometimes overwhelm traditional religious strictures, and no *Sharia* Law is violated by collecting tortoises for export to distant global pet markets.

By the end of the last century in Senegal, on the western end of the *Sulcata* range, tortoise populations had become dangerously depleted and restricted to the northeast Ferlo region of the country. In the 1990s, local Senegalese conservationist and co-author Tomas Diagne took up the *Sulcata* conservation cause along with that of other indigenous turtle species. A “Tortoise Village” was then created, modeled on a French counterpart

developed by Bernard Devaux. Located about 20 miles outside the capital city of Dakar, the village pursues multiple objectives including environmental and conservation education for both locals and foreign tourists, a rescue center for confiscated animals, and a captive breeding facility to replenish wild populations. An “SOS Sulcata” field research program complements this effort. Over the past decade, village conservation education programs within the Sulcata’s remaining habitat, and release and monitoring (radio tracking) of captive raised and confiscated tortoises into protected reserves has produced positive results and demonstrates the potential for more widespread restoration of this species in Senegal and perhaps across the Sahel.

“SULCATIZATION” AND A HISTORY OF SULCATA IN THE US PET TRADE 1965 - PRESENT

In mid-September 2011, James O. Juvik was in his back yard in Hilo, Hawaii, slowly coaxing a 80 kg Sulcata tortoise into a very large pet carrier bound for David and Lida Pigott Burney on Kaua’i. Even with fresh papaya as the lure, progress was slow, giving Juvik a moment to contemplate an amazing convergence of tortoises, time, and space. Almost exactly forty years earlier to the day in 1971, a wooden crate had arrived from France at the Hilo Airport customs shed. The contents were two 30 to 35 cm long sub-adult Sulcata — perhaps the first bona fide pair ever imported into the US — destined

to become the founder stock for a pet tortoise craze that would sweep across the suburban backyards of Sunbelt America over the next forty years.

Earlier in the 1960s, one or two lone Sulcata had surfaced among the tortoise *aficionados* of southern California. Perhaps the very first was an animal brought back from an African expedition by Paquita Machris, a renowned big game hunter, conservationist, and Los Angeles philanthropist, whose quarry ranged the gamut from four-ton African elephants to Greenland narwhals, the unicorn whales, that would ultimately fill the stuffed animal dioramas of the LA County Museum. Fortunately, and more in the tradition of famous animal collector Frank Buck, this tortoise had been brought back alive. The beautiful and robust blond to yellow shell with deeply chiseled annual growth rings, and its apparent rarity, harking from an exotic and little known home range along the southern margins of the Sahara, created an immediate buzz in the greater Los Angeles tortoise-keeping community.

Juvik’s new Sulcata, on the other hand, did not appear to acclimatize well to the near incessant trade wind showers and high humidity that build daily along the windward Hilo coast. Consequently, after only a short Hawaiian holiday stay, in November 1971 the pair were traded to Bill Zovickian, now one of the country’s most acclaimed tortoise breeders, then living in Connecticut. Also about this time, Wayne Ferrell, a high end exotic reptile dealer at

“SOS Sulcata” supports conservation research and restoration efforts for this species. Rangers and scientists prepare to release confiscated and captive raised animals (with radio-transmitters attached) back into the wild at the Ferlo Faunal Reserve in the Northeast of Senegal. Multi-year studies over the past decade have demonstrated successful repatriation and good survivorship.



PHOTOGRAPH BY TOMAS DIAGNE

the Herpetarium in San Francisco, began to import a few Sulcata. This is where as a teenager, Turtle Conservancy (TC) founder Eric Goode first saw the species and it immediately became a much coveted prize in his youthful tortoise collecting fantasies.

In 1973, Zovickian acquired yet another pair of Sulcata from a nearby Connecticut turtle collector, and by the spring of 1977, these four animals were rapidly reaching adult sizes with carapaces of 40 to 55 cm and weighing 15 to 30 kg. Zovickian tired of carting this group into and out of his heated garage for the New England winters and unseasonably cool spring and summer nights. So that year, he sent the tortoises south to a warmer and more agreeable arid climate at the San Antonio Zoo in Texas.

Over several years beginning in 1979, the first successful US reproduction was achieved at the zoo with over 130 eggs laid and 40 hatchlings produced. Based on a breeding loan agreement, a portion of offspring was returned to Zovickian, who dispersed animals to private collectors and breeders around the country. This domestic source finally allowed Eric Goode to realize his decade-long Sulcata dream, acquiring his first juveniles in 1981. As Eric recalls, “I went to the Bronx Zoo to meet Bill Zovickian and John Behler, and was handed my two hatchlings in a shoe box ... I was so excited to finally acquire a Sulcata, but after a decade they outgrew the confines of my NYC apartment and it felt like I was living with two goats.”

Goode’s and Zovickian’s similar experience of a “too big and truculent to succeed” syndrome were but a harbinger of things to come. A soon-to-be-exponential cascade of cute pet shop tortoises about the size of a baseball was the result, apparently with no accompanying warning label that after little more than a decade of growth these cute pets could transform into indestructible backyard behemoths, of possibly near infinite longevity. In a recent article, even Dave Friend, one of the country’s true Sulcata-philic and operator of the nation’s largest Sulcata rescue center in Ojai, California, has admonished potential Sulcata pet keepers, “Do not hatch Sulcata to sell or add to your collection. There are way too many that need to be rescued and there are not enough homes to accept them.”

Some years ago, TC chief scientist Ross Kiester coined the term *sulcatization* to characterize the general phenomenon of a tortoise species rapidly transitioning from a scarce import to nationwide pet shop saturation within a few decades through captive breeding. The scale of this Sulcata explosion in the US has been breathtaking. One San Diego breeder confided that his substantial Sulcata herd in the early 2000s was a virtual “tortoise mill” producing more than 3,000 eggs per year with high hatchling success. Female Sulcata can produce egg clutches of up to 30 and lay two to three clutches per year. As might be imagined, oversupply has driven hatchling prices down to around \$40 to \$50.



SOURCE: TTTS JOURNAL

Paquita’s Sulcata caught the attention of this discerning young woman at the 1967 Los Angeles Turtle Show. With distinguished herpetologists and zoo curators serving as judges, trophies and ribbons were awarded in different turtle and tortoise categories. With its first appearance a year earlier at the 1966 show, Paquita’s unique pet had easily trounced all competitors to take “Best in Show” honors.

Thus, the progeny of San Antonio's breeding success, with its early Hawaii connection, has inadvertently fueled a surplus of now unwanted backyard tortoises that may well exceed in numbers the remaining diminishing wild population in North Africa. Is there an end game for these fast growing giant pets?

RETURN OF THE MOA NALO, AND MORE

The overarching goal of the Makauwahi Cave Reserve on Kaua'i is to preserve, study, and restore the remarkable limestone cave system and use the discoveries made there to design and carry out innovative conservation strategies. In that spirit, over 100 species of native and Polynesian-introduced plants have been reintroduced to this landscape to mimic to the extent possible the landscape that would have surrounded the site in the earliest stages of human contact. As a small non-profit, the reserve had over 12,000 visitors last year, and can claim 49 dedicated trained adult docents, 37 partner organizations, and a modest funding stream based on government and private grants, visitor donations, and sales of the book about the project.

The Burneys are paleoecologists and conservationists, but also farmers. Their paleoecology research has spanned the globe, from the Americas to Africa, Asia, and Madagascar. They have worked on remote islands in all three tropical oceans, studying how humans and nature have collided on one land mass after another, beginning where humans began in Africa and ending on tiny remote Rodrigues Island, one of the last human colonization events on the planet. So it was perhaps inevitable that Juvik found a

natural ally in the people and the idea of Makauwahi Cave Reserve, a place where scientists are looking for ways to grow large numbers of native Hawaiian plants and restore damaged agricultural landscapes.

The tortoise experiments on Kaua'i began with one, two, then three large Sulcatas and now six, ranging from 12 to 80 kg, all rescued from suburban backyards in Hawaii. The initial study site is on 0.81 ha of abandoned farmland that had been re-planted with native trees and shrubs beginning in late 2005. In July 2011, we began creating securely fenced enclosures for Sulcata. Heavy solid hog panels proved entirely satisfactory, but are an expensive option. On the other hand, ordinary fine-mesh galvanized concrete lathe works splendidly, and can be readily moved to modify the shape or size of an enclosure. Around the entire experiment, we built a very secure tortoise-proof fence of woven hog wire with extra cable reinforcements at ground level to hold large stubborn tortoises. The clay soil is too hard for the Sulcata to burrow under.

All our test animals are males, both because these are typically the only large animals locally available for rescue, and also because this should further allay any fears of accidental reproduction and escape as yet another biological invader. Readers knowledgeable in captive Sulcata husbandry can doubtless offer cautionary tales of the risks of confining large males together in small areas, because of their well known aggressive combat behavior. During the experimental research period, these tortoises are being constantly monitored by student field workers, volunteers, and reserve staff.



PHOTOGRAPH BY TURTLE CONSERVANCY/ERIC V. GOODE



PHOTOGRAPH BY TURTLE CONSERVANCY/MAXIMILIAN S. MAURER

Dave Friend's Sulcata Rescue Center (<http://ojaisulcataproject.org/>) in Ojai, California (left) is at full capacity with more than 70 large animals in residence and a long waiting list for further tortoise donations. Thanks to Dave's cooperation and support from the Andrew Sabin Family Foundation and Eric Goode, unwanted California Sulcata are heading for Hawaii to support a native forest restoration project on the island of Kaua'i. (right) "Our daughter departed home for college years ago and left her childhood pet, (now 100 lbs) 'Timothy' behind. So what are we supposed to do now?"



PHOTOGRAPH BY JAMES O. JUVIK

One of the native reforestation projects on the Makauwahi Cave Reserve has become an experimental facility for evaluating the beneficial effects of tortoise grazing as a weed control alternative to chemicals, mowers, and hand-pulling.

We now have the first of several systematic experiments running, in which about one-quarter of the field is stocked with tortoises, and the other three-quarters is ungrazed. We started the experiment by mowing the tortoise area and adjacent control area first, then introducing the chelonians. Six months into this one-year experiment, the difference is remarkable in that the area lacking tortoises has become completely overgrown with weeds again. We periodically apply scan-sampling techniques to characterize tortoise behavior through the diurnal cycle, and note down which plants they are eating, what growth stage, and for how long. In addition, feeding trials are run where we present samples of native and non-native plant foods in a systematic manner and note tortoises' choices. We also keep notes on the state of the vegetation, and take repeat photographs from designated points in the field.

WHAT WE FOUND

At some stocking rate yet to be determined, perhaps eight large Sulcata per 0.41 ha, it seems possible to control the weeds in this type of reforestation project with only quite minimal input from horticultural technicians. Instead of the laborious mowing, weed whacking, and hand weeding practiced before, we now only need to mow the site once, put the tortoises on it, and leave the job mostly to them. So far only a few alien weeds are not kept at about a five cm height,

even during winter rains, with intense tortoise grazing. Of these, the most prevalent so far is the spiny Sensitive Briar (*Mimosa pudica*), which can be removed by hand weeding. Almost all other invasive non-native plants in the enclosures are eaten with relish. Some grasses are not eaten much when they reach the flowering stage, that is, when tortoise grazing is insufficient to fully suppress the grasses.

Sulcata are definitely “grazers” and not “browsers” in the simple sense that they tend to search downward for food and don't seem to sustain a feeding bout over their normal head height, even though they may taste items higher up. They have an extremely admirable habit of wedging underneath prostrate native shrubs and eating out all the hard-to-reach weed seedlings. What they don't eat, they trample. Their sleeping sites become quite wallowed, and the weeds quickly disappear at the base of these sprawling natives, with no observed harm to the shrub. This generally produces a low “mushroom” shape to these already attractive plants that heightens the naturally landscaped appearance. This look, that might be described as a kind of “Galapagos meets Serengeti” landscape, may well be structurally similar to the lowland landscapes of this area as they might have appeared before human arrival, scoured by hungry meso-herbivores, the giant flightless ducks and geese, or *moa nalo*.

We have a total of 128 hours of systematic direct field observation using conventional scan sampling of our tortoises' diurnal behavior. We have observed 23.5 hours of feeding behavior, in which twenty species of plants growing in the paddocks were fed upon for at least one sample taken at ten minute intervals for one minute. All plants consumed for a minimum of one minute were non-natives. No native plants were consumed regularly, although two species were occasionally tasted. A native ground-cover species in the test enclosure, *ilie'e* or Leadwort (*Plumbago zeylanica*) was essentially ungrazed and continues to grow within tortoise reach while the non-natives all around them are repeatedly cropped away.

Favorite foods, in terms of our informal preference testing by presenting several cuttings of native and non-native plant materials simultaneously, include the hated invasive vine *mauna loa* (*Canavalia cathartica*) and tender young sprouts of any grasses previously cropped near ground level. *Mauna loa* can climb over young native trees and choke them out. Sulcata attack the plant at all stages with amazing fervor, gulping down four and a half meters or more of a vine stem before taking a break from swallowing. Their dung is almost always very firm and fibrous, as it is supposed to be. When we open a new section, they glut themselves on fresh greens, first eating non-native composites such as the aggressive invader Golden Crownbeard (*Verbesina encelioides*) and sprouting legumes such as *haole koa* (*Leucaena leucocephala*) and Rattle Pod (*Crotalaria*).

WHAT WE WANT TO DO NOW

Now that we feel we have fully mastered the husbandry of our four-legged weed eaters, we are ready to set up more rigorous experiments to tease out the details of this fascinating case of ecological surrogacy. We would like to use our portable fence system to create, inside the main enclosure, a grid of large pens of equal size on land reforested with native trees and shrubs that are competing with very aggressive non-native weeds. All the weeds would be mowed mechanically down to about three cm height, to in effect "reset" the vegetation structurally in the natives' favor. Following proper criteria of experimental design for statistical rigor, we would randomly choose several of the pens as controls, with no large grazers.

On others, we would place large and small Sulcata in various densities and combinations. This would give us insight regarding stocking rates, and size-specific food choice. We would also like to

devote some of the test pens to alternative grazers, such as geese and lambs, alone and in combinations that include tortoises. The vegetation would be assessed for species composition, abundance, and biomass before starting the experiment, and at following intervals of days, weeks, even months. This is classic rangeland management experimental stuff, nothing unusual, except the tortoise part.

If the Makauwahi Cave Reserve can find a way to afford it, we would like to get some other species of tortoises, such as large Aldabras and small Leopard Tortoises (*Stigmochelys pardalis*), to test in our experimental grid. An interesting hypothesis to test would be that larger Aldabra-sized tortoises could help control coarser weeds — perhaps even help clear land overgrown with non-native coarse grasses and shrubs. Similarly, Leopard Tortoises may help us the way Radiata Tortoises help the remarkable restoration projects in the Mascarenes, controlling some otherwise troublesome weeds at the seedling stage.

So much to do, so little time ... for the humans anyway. While our tortoises munch away happily in their ever-growing pasture, with nothing better to do for perhaps half a century or more, the humans involved are busy figuring out how to scale this up. So far, the "crazy" idea of using giant tortoises to control weeds in native reforestation on Kaua'i is working even better than we had ever imagined before our first half-year of field tests began. If this bears out under more intense experimental scrutiny, we will have done more than just tested a hypothesis or two. We will have a breakthrough in native-plant horticulture that may have applications well beyond Makauwahi Cave Reserve. We are already planning several applications ourselves, on larger well-fenced landscapes.

This experimental project represents the unlikely, but fortunate, convergence of solutions to two conservation problems: a surplus of overgrown pens and a need to protect Hawaii's endangered flora from invasive weeds. If surplus Sulcata can work to successfully help restore native forest in Hawaii the concept can ultimately be expanded to other semi-arid islands such as the Bahamas and Turks and Caicos in the Caribbean, where endemic native tortoises were also exterminated only in the last millennium. This in turn should also serve to focus greater international attention on *in situ* conservation of the species in its dwindling sub-Saharan range. Meanwhile, at Makauwahi Cave Reserve visitors can savor a rare commodity in island conservation — real hope for a large scale breakthrough. 🌱

Our tortoises seem happy in their new home, as willing participants in a series of experiments to see if they can control invasive weeds and help save native Hawaiian plants.



PHOTOGRAPH BY LIDA PIGOTT BURNBY