One-Hundred Year Wild Tuatara (*Sphenodon punctatus*) Management Plan for Te Ika-a-Māui, New Zealand

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Executive Summary

Tuataras (*Sphenodon punctatus*) are the only remaining reptiles in the order Rhynchocephalia, endemic to New Zealand. Previously, tuataras existed across the mainland of New Zealand, but now reside on 32 offshore islands in small dispersed populations. Tuataras live in underground burrows, typically with fairy prions (*Pachyptila turtur*) and forage nocturnally on invertebrates, small mammals, and birds. Conservation issues of concern include future populations of invasive rats, competition with conspecific species during nesting – nest evacuations, for example - habitat alteration inducing stochastic plasticity, climate change causing increased male to female sex ratios in populations, and hybridization. This management plan aims to reintroduce and restore wild tuatara populations on the North Island of New Zealand to past populations before the introduction of invasive rats. Objectives reaching this goal include increasing habitat availability by 75%, and increase public cooperation with conservation efforts by at least 50%. To increase habitat availability, a habitat suitability index will be implemented to assess proper habitat for tuataras on the North Island, New Zealand. After suitable habitat has been identified, artificial burrows will be constructed increasing survivorship of tuataras and decreasing parasitism and competitions with fairy prions. To increase cooperation with the public, surveys will be administered to increase ecological knowledge of tuataras. A land use plan will be applied, allowing for public seminars and town meetings to be incorporated into the plan. Seminars and surveys will help identify lowered scientific knowledge of tuataras as well as increasing the public's awareness of conservation needs. The course of actions of this management plan could increase tuatara populations to sustainable levels, back to what they once were in the past of New Zealand.

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Introduction

Tuataras (*Sphenodon punctatus*) are listed as least concern on the International Union for Conservation of Nature Red List. (Hitchmough 2019). The current classification is due to the species surviving in small populations on 32 islands surrounding the mainland of New Zealand (Hitchmough 2019). Major threats tuataras undergo include stochastic plasticity, habitat fragmentation and alteration, and competition (Miller et al. 2012, Grayson et al. 2014, Hitchmough 2019). The current distribution of tuataras is 32 islands surrounding New Zealand inhabiting rocky outcroppings, cliffs, temperate forests and open fields between high tide levels and 722 meters above sea level (Department of Conservation 2001, Hitchmough 2019). Past populations on the mainland of New Zealand were diminished by invasive rat species, leaving only surviving populations of tuataras on the islands (Hitchmough 2019).

Invasive rats in New Zealand are the primary predators and competitors of tuataras (Towns 2009). Invasive rats outcompeted adult tuataras due to similar food resources and higher population sizes (Towns 2009). Tuataras outcompeted by rats experienced decreased overall fitness and body conditions (Towns 2009). Invasive rats prey upon tuatara eggs, hatchlings, and juveniles, indicating tuatara's minimal defense of younger stages (Towns et al. 2007).

Current populations of tuataras are dispersed among islands surrounding the mainland of New Zealand (Hitchmough 2019). Habitat alteration among islands has caused tuataras to be at risk of stochastic plasticity, along with small populations containing inbreeding issues (Department of Conservation 2001, Miller et al. 2012, Grayson et al. 2014, Hitchmough 2019). Tuatara populations on the islands have low distributions and lowered abilities to migrate to differing habitat types due to physical barriers and ecological traps (Grayson et al. 2014).

Natural History

Species Identification

Tuataras look similar to lizards; lizards belong to order Squamata while tuataras belong to order Rhynchocephalia (Fig. 1; Hitchmough 2019). Tuataras are the oldest and only current representative of order Rhynchocephalia (Fig. 1; Miller et al. 2012). Divergence of tuataras from differing reptile orders occurred ~250 million years ago (Miller et al. 2012). The male tuatara averages lengths of 42.69 centimeters and weight of 434.8 grams (Herrel et al. 2010). The female tuatara averages lengths of 34.81 centimeters and weight of 272.7 grams (Herrel et al. 2010). Tuatara in Māori means "peaks on back" due to spiny dorsal crests present on both males and females, being more prominent in males (Fig. 2; Jones and Cree 2012, Grayson et al. 2014). Tuataras come in colorations of light and darker browns and tans, juveniles giving off more coloration patterns that dulls with maturation (Jones and Cree 2012).

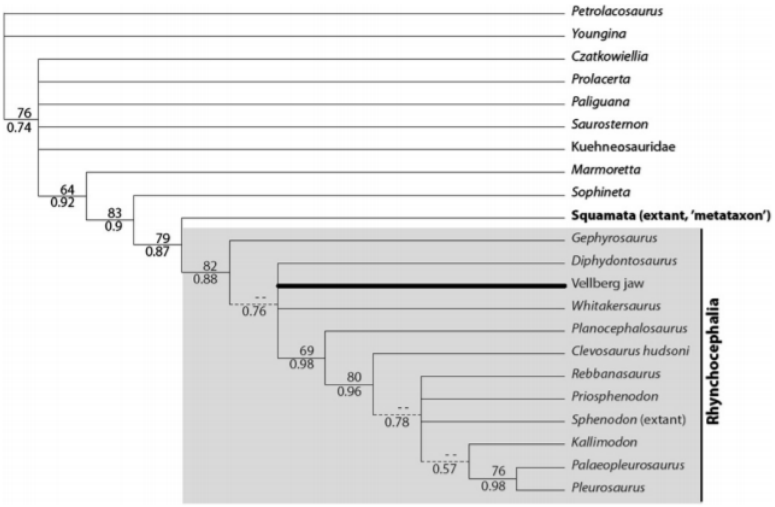

Figure 1: Phylogenetic tree of tuataras and their ancestors in order Rhynchocephalia (shaded) and their relations to other reptiles, such as order Squamata (Jones et al. 2013).

Unique characteristics separating tuataras from other reptiles include their dentary orientation and an organ on the cranium known as a "partial eye" (Gorniak et al. 1982, Jones and

Cree 2012). The dentary orientation of tuataras are conical shaped teeth on the lower section of the jaw while the upper jaw has two rows of stout-bladed teeth (Gorniak et al. 1982, Jones and Cree 2012). This orientation of teeth allows for tuataras to crush and slice food while manipulating prey items in the mouth (Gorniak et al. 1982, Jones and Cree 2012). The organ on their head is connected to their brains which includes components that are retina and lens-like (Jones and Cree 2012). The organ is small and covered by scales, but it is light sensitive, no evidence indicating that this "third-eye" can produce anything complicated, such as picking up on movements or the formation of images (Jones and Cree 2012). This organ may be a part of tuatara temperature regulation involving circadian rhythms including basking and regulating homing behaviors (Jones and Cree 2012).

Figure 2: The larger male tuatara (top) and the smaller female tuatara (bottom), male showing more prominent spiny dorsal crest than female (Grayson et al. 2014).

Breeding

Tuataras are long-lived, individuals reaching up to 70 years old with sexual maturity occurring around 15 to 20 years of age (Fig 3; Grayson et al. 2014). Male tuataras undergo a reproductive cycle characterized by continuous sexual activity (Saint Girons and Newman 1987).

Due to the continuous reproductive cycle, spermatogenesis is uninterrupted, slowing during winter months (Saint Girons and Newman 1987). Male tuataras have similar reproductive cycles to lizards of New Zealand, but marked differently from all known cycles of reptiles (Saint Girons and Newman 1987). Female tuataras will mate from January to March during a nesting year while eggs are carried by females until the next spring (Newman et al. 1994). Females nest in colonies, which they return to at least twice and migrate to when nesting years occur (Refsnider et al. 2010, Refsnider et al. 2013). Females show no preference over shaded or unshaded locations, whereas nesting site females use loose soil with low vegetation densities (Refsnider et al. 2010). Females nest around every 4 years on average, causing frequencies of clutch sizes to be low (Fig 3; Newman et al. 1994). Low egg production frequencies correlated to egg shell deposition and slowed vitellogeneses rates (Newman et al. 1994). For Lady Alice Island females, clutch sizes range from 5-13 eggs and for Stephens Island females, clutch sizes range from 1-18 eggs (Newman et al. 1994). Higher temperatures cause there to be an abundance of male tuataras than female tuataras (Grayson et al. 2014). In reptiles, the larger sex will hatch frequently with increasing temperatures and since male tuataras are larger, they hatch more often (Grayson et al. 2014). Due to rising temperatures caused by climate change, this poses incoming threats to future populations of tuataras.

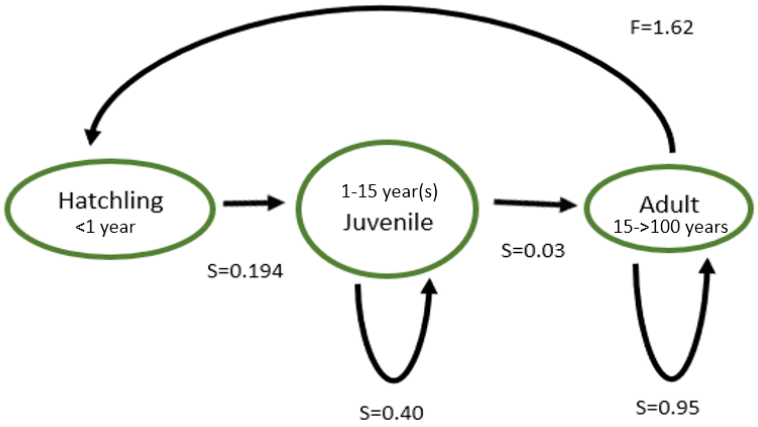

Figure 3: Wild tuatara stage life-cycle model with survival and fecundity rates. Survival separated into stage transitions and probability of surviving in the current stage.

Diet and Foraging

Tuataras are selective and prey upon a variety of small animals and large insects (Walls 1981). The diet of tuataras is different amongst habitat types and the conditions of the environment around them (Walls 1981). Invertebrates make up 74 % of the tuataras diet, 54% being insects - primarily beetles - while the remaining 20% makes up other invertebrates (Walls 1981). Invertebrates contribute 71% in adult males, occurring primarily in the spring, and 33-35% in adult females (Fraser 1933). Invertebrates in the diet of juveniles is 54-70%, no difference among seasons (Fraser 1933). Vertebrates consumed by tuataras are small birds and reptiles, which along with animal parts make up 11% of the total diet (Walls 1981). Seabirds and reptiles are ≤10% of male diets during summer and spring, vertebrates absent in female diets (Fraser 1933). Seabirds contribute 1% to juvenile diets, no reptiles found (Fraser 1933). Plant and inorganic material consumed by tuataras make up 16% of the total diet (Walls 1981). Females consume up to 63% inorganic and plant material during autumn, no difference in male diet among seasons (Fraser 1933). Darkling beetles (*Mimopeus opaculus*), a common dietary invertebrate, make up 1-14% of male diets and ≤15% of female diets (Fraser 1933, Walls 1981).

Vertebrate species such as skinks, geckos, and seabirds are abundant in areas where tuataras can be found (Walls 1981). Vertebrate species make up the smallest percentage of the total diet is due to prey mobility (Walls 1981). Tuataras and seabirds burrow together, which would give tuataras a plentiful food source, but the seabirds are volatile and tenacious, even for large males (Walls 1981).

Active foraging of tuataras occurs at night, between dusk and midnight (Walls 1981). Foraging occurs across the understory, and depending on season, there is a difference in activity (Walls 1981). During the winter, tuatara foraging activity is low, on warmer evenings tuataras will emerge from their burrows (Walls 1981). Individual tuataras, depending on temperature and weather conditions, actively move across the understory during the day (Walls 1981). Prey mobility causes issues while foraging. (Walls 1981). Tuataras possess fleshy tongues, allowing them to manipulate prey items (Gorniak et al. 1982). Mobile prey items too large to be manipulated in the mouth are killed via jaw strength (Walls 1981, Gorniak et al. 1982). Subduing prey via biting is followed by sliding their teeth in the bottom jaw between their two rows on the upper jaw - an action crushing and cutting prey items, known as prolinear sliding (Gorniak et al. 1982). This foraging action is accomplished by the dentary rows sliding between the maxillary and palatine rows, similar to the foraging molar pattern observed in mammals (Gorniak et al. 1982).

Habitat

Elevations tuataras are found range from just above high tide levels to 722 meters above sea level (Department of Conservation 2001, Hitchmough 2019). The islands where tuataras are extant are bound by cliffs (Hitchmough 2019). Tuataras live in areas dominated by forest and shrublands, while also living in artificial areas due to habitat fragmentation and alteration

(Hitchmough 2019). The forest type that tuataras inhabit is temperate, with dominant vegetation differing depending if the forest is in the northern islands or the Cook Strait islands (Hitchmough 2019). The plant mahoe (*Melicytus ramiflorus*) is the dominant vegetation in both the north and Cook Strait Islands (Hitchmough 2019). Taupata (*Coprosma repens*) is common forest cover, which are wind-shorn and low (Markwell 1997, Hitchmough 2019). Tuataras also commonly inhabit flax bushes (*Phormium tenax*) (Hitchmough 2019). Other common forest cover is mahoe, kohekohe (*Dysoxylum spectabile*), and pigeonwood (*Hedycarya arborea*) (Markwell 1997). Uncommon forest is kawakawa (*Macropiper excelsum*), nettle (*Urtica ferox*), and nighshade (*Solanum nigrum*) (Markwell 1997). Common cover in pastures, grasslands, and shrubs is wild oats (*Avena sterilis*), ryegrass (*Lolium perenne*), silver tussock (*Poa cita*), tuapata, and *Hebe urvillea* (Markwell 1997). Bare rocks and low-lying shrubs comprise cliffside cover (Markwell 1997). Altered habitat that tuataras frequent is farmlands, specifically sheep pastures (Hitchmough 2019). Altered habitat increases deficiencies in cover and invertebrate populations, caused by agriculture and logging (Quinn et al. 2004, Hitchmough 2019).

Tuataras are highly territorial, similar to many lizard species in order Squamata, the closest relatives to order Rhynchocephalia (Moore et al. 2009). Territorial behavior is observed in male to male competitions and in females by nest guarding (Moore et al. 2009, Refsnider et al. 2009). Large males have increased chances of defending their territories from others, holding areas dense with females (Moore et al 2009). Males fight off others that attempt to enter their territory, by winning against aggressors they succeed in guarding females (Moore et al. 2009). Females are territorial of nests and offsoring (Refsnider et al. 2009). Females become social when they migrate to rookeries where they nest colonially with other females (Refsnider et al. 2013). Rookeries are not a part of tuatara home ranges (Moore et al. 2009, Refsnider et al. 2013).

Specific resource selection of tuataras indicated by burrowing habits (Moore et al. 2010). Tuataras "share" burrows they inhabit with fairy prions (*Pachyptila turtur*) - a species of seabird (Mulder and Keall 2001). Burrows, complex or not, are resources that both tuataras and fairy prions use and compete for (Corkery 2012). Tuataras use these burrows as nesting sites and cover (Towns et al. 2006, Refsnider et al. 2009, Corkery 2012, Corkery et al. 2014). The interaction between tuataras and fairy prions is parasitic (Corkery 2012). Tuataras use fairy prion burrows for cover and are easy opportunities for predation of hatchlings (Corkery 2012). When tuataras are present, the time an adult fairy prion will spend interacting with its young in the burrow is halved (Corkery 2012). This reduces the fitness of the growing chicks and the adult fairy prions (Corkery 2012). Competition between tuataras and fairy prions is likely due to burrows being limited resources for both species (Corkery 2012).

Thermoregulatory Requirements

Tuataras are cold-blooded and must use external means to regulate body temperatures and unlike most in class Reptilia tuataras can remain active at low temperatures (Saint Girons et al. 1980). Low temperature activity of tuataras has been viewed at 7ºC (Saint Girons et al. 1980). Tuataras withstand lower temperatures because they are primarily nocturnal, though they will emerge from burrows during the day (Saint Girons et. al. 1980). Tuataras forage for prey items at night and regulate their body temperatures during the day (Saint Girons et al. 1980, Walls 1981). Tuataras regulate body temperatures at burrow entrances and will move into open areas to bask if burrows are shaded (Saint Girons et al. 1980). Evidence for the body temperature means of tuataras in shaded forests was 17ºC, with a standard error of 0.5ºC, to 24.6ºC, with a standard error of 1.1ºC, in open locations (Saint Girons et al. 1980). Tuataras shift behavior of selecting habitat depending on humidity of the environment (Corkery et al. 2014). When humidity levels

are high a tuatara will spend more time out of their burrows (Corkery et al. 2014). Tuataras utilize open, warm areas of the understory to regulate body temperatures (Corkery et al. 2014). At night, tuataras commonly move along warmer sections of the ground while foraging, allowing them to regulate body temperatures efficiently (Corkery et al. 2014). When the environment is humid, tuataras are less likely to select warmer sections of the understory (Corkery et al. 2014). However humid conditions increase the length of time tuataras remain out of their burrows (Corkery et al. 2014).

Distribution

Tuataras are endemic to New Zealand (Hitchmough 2019). Fossil records on the mainland, the North and South Islands (Fig. 4), have shown subfossil remains of tuataras that were lost around 800 years following colonization (Hay et al. 2010, Hitchmough 2019). Subfossil remains indicate that up until the 1700s, they were widespread across New Zealand (Hay et al. 2010, Hitchmough 2019). Today, natural populations of tuataras can be found on 32 islands (Fig. 4), while in the last century, tuatara populations have been lost from 10 islands offshore of New Zealand (Hitchmough 2019). Islands where tuatara populations can be found are northeast of the North Island on Poor Knights Islands, 35º28’S, extending to the Cook Strait on the North Brother Island, 41º07’S (Hitchmough 2019). Stephens Island, an island within the Cook Strait, has one of the largest occurring populations of tuataras (Mulder and Keall 2001). Due to having one of the largest populations, Stephens Island has become the location of high conservation efforts for the tuatara. (Mulder and Keall 2001).

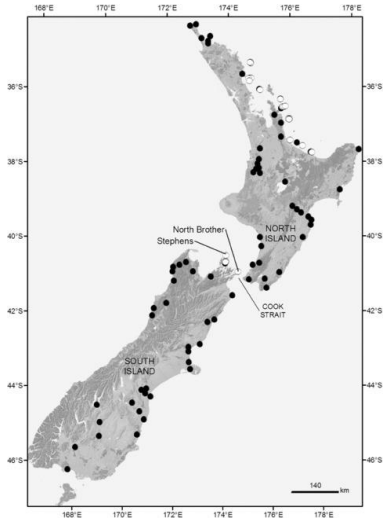

Figure 4: Locations on New Zealand's mainland where subfossil remains of tuataras have been found, indicating how widespread the species once was (Miller et al. 2012).

Islands housing tuataras are small, making the growth of populations difficult (Miller et al. 2012). The latitudinal range now is 6º, which is around 30% of their original range before humans began living on New Zealand (Miller et al. 2012). Current distributions and elevational ranges are restricted, putting tuataras at increased risks of extinction (Miller et al. 2012). Limiting geographical ranges and low genetic variations between populations increases stochasticity (Fig 5; Miller et al. 2012).

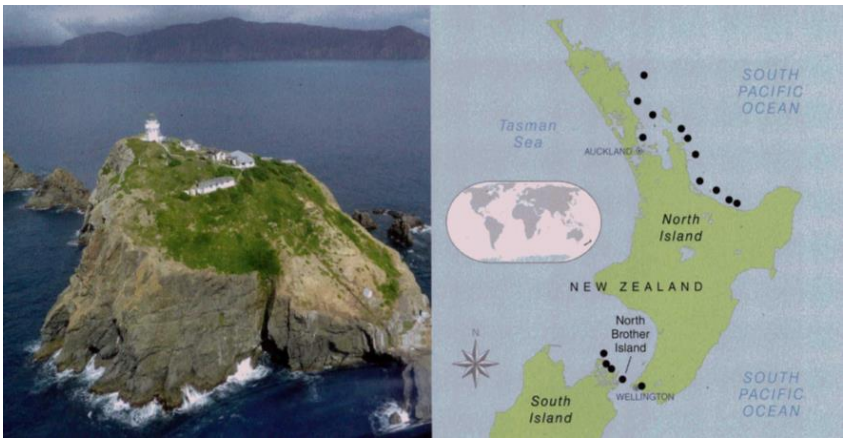

Figure 5: Extant locations where tuataras are found, Poor Knights Islands to the North Brother Island (Right). North Brother Island as an example showing little range geographically on most islands (Left) (Grayson et al. 2014a).

Islands, such as Stephens Island, have dense populations of tuataras (Grayson et al. 2014a). These populations are high for the islands they inhabit, although these densities would be considered low on the mainland. These populations are undergoing genetic and geographic stochasticity, causing future issues (Miller et al. 2012, Grayson et al. 2014a). Geographic isolation reduces opportunities for tuatara migration to other islands of the mainland (Grayson et al. 2014a). Issues will worsen as climate change effects both tuataras and the biodiversity of New Zealand in the future (Grayson et al. 2014a, Lundquist et al. 2011).

Threats and Defenses

Invasive rat populations arriving with settlers was the primary threat to tuataras (Grayson et al. 2014, Hitchmough 2019). Rat species causing the primary decline of tuataras was Polynesian rats (*Rattus exulans*) (Fig. 6; Department of Conservation 2001, Hitchmough 2019). Rats secondarily contributing to the decline were Norway rats (*Rattus norvegicus*) and black rats (*Rattus rattus*) (Department of Conservation 2001, Hitchmough 2019). Feral cats pose conservation issues since cats feed on tuataras and their primary prey items (Fitzgerald et al. 1991). Feral cats have decreased tuataras and other wildlife species by predation and out competition (Veitch 2001). Habitat loss due to colonization impacted populations of tuataras (Moore et al. 2007, Hitchmough 2019). Stephens Island has been observed for their population of tuataras, which have suffered from habitat alteration (Moore et al. 2007). Examining tuataras indicates no signs of decline from habitat alteration, but observing tuatara populations around a half a century ago shows evident fitness (Moore et al. 2007). Past habitat alteration on Stephens Island caused tuatara populations to become density dependent (Moore et al. 2007). The native forests, with more than 80% being cleared for farmland in the 1920s was part of habitat alteration (Moore et al. 2007). Minor threats include their capture and use in illegal pet trades

(Department of Conservation 2001, Hitchmough 2019). Past indicators of poachers show success in tuatara capture, although there is no presence in the illegal pet trade (Hitchmough 2019).

Figure 6: The Polynesian rat, known to the Maori as koire, is the primary invasive rat species competing with adults and preying upon eggs and juveniles.

Tuataras nest guard, an uncommon behavior among reptiles (Refsnider et al. 2009). 56% of females display nest guarding behaviors during nesting seasons (Refsnider et al. 2009). Nest survivorship on rat-free islands is 76.7% (Refsnider et al. 2009). Islands where invasive rats and native tuataras are found occupying together show low nest survivability for tuataras (Refsnider et al. 2009). On islands that are rat-free, female tuataras defend their nests against conspecific females (Refsnider et al. 2009). Female tuataras attempt to enter other nests, forcing residents to evacuate - primarily nests that are unguarded (Refsnider et al. 2009). 25% of nests are evacuated by females during nesting seasons (Refsnider et al. 2009).

Invasive rats affect tuatara health and fitness. Invasive rats prey upon the tuatara eggs and juveniles (Newman 1988, Towns 2009). Invasive rats prey upon juveniles due to their sizes since adults become too large to kill (Newman 1988). Evidence of rat attacks show juvenile tuataras with tails, digits, and flesh from their abdominal wall missing (Newman et al. 1988). Invasive rat

predation upon juveniles is due to decreased mobility and size compared to adults (Towns et al. 2007, Towns 2009). Evidence occurred when invasive rats were removed from an island where tuataras are extant, after almost 200 years of being an island invasive (Towns et al. 2007). Islands where rats were removed showed dramatic increases in body conditions of adult tuataras with raised proportions of juveniles in tuatara populations (Towns et al. 2007). Diets of both invasive rats and tuataras are similar, rats outcompeting tuataras due to larger population sizes (Towns 2009). Competition over similar resources and large populations of invasive rats causes fitness of tuataras to decline, including overall body condition (Towns 2009). Interactions indicate tuataras have little defenses against the invasive rats (Towns et al. 2007, Towns 2009)

Climate change among New Zealand has been observed and future impacts show signs of increasing affects (Lundquist et al. 2011). Predictions of future emissions causing increasing air temperatures by 2.1ºC by 2090 (Lundquist et al. 2011). Sea levels are projected to rise between ranges of 0.18 to 0.59 meters by 2100, likely pushing tuataras up from elevation range of high tide level to 722 meters above sea level (Department of Conservation 2001, Lundquist et al. 2011, Hitchmough 2019). Coastal habitats and associated biota will be impacted by rising sea levels and storms intensity causing naturally occurring surges and higher tides (Lundquist et al. 2011). Disturbances among communities of aquatic and terrestrial environments will rise, indicated by increasing storm intensities (Lundquist et al. 2011).

Conservation Needs

Ecological

Tuatara habitat is dispersed, only true wild populations are found on the islands in which they now reside (Hitchmough 2019). Tuataras primarily display risks of stochastic genetics due

to fragmented populations (Department of Conservation 2001, Miller et al. 2012, Grayson et al. 2014a, Hitchmough 2019). Altered habitats cause fragmentation increasing the likelihood of genetic stochasticity (Moore et al. 2007, Hitchmough 2019). Tuataras on islands with low distribution opportunities are restricted in their abilities to migrate to other islands or elevations (Grayson et al. 2014a).

Tuataras compete for food with invasive rats, primarily Polynesian rats (Towns 2009). Rats are opportunistic and consume almost any food item, outcompeting tuataras (Towns 2009). Tuataras were New Zealand's top predator and primary consumer before invasive rat introductions (Walls 1981, Daugherty and Cree 1990, Towns 2009, Miskelly 2015). Rats target juveniles as food resources (Newman 1988, Towns 2009). Fairy prions and tuataras compete over the usage of burrows, the relationship being parasitic (Corkery 2012). See in Walls 1997, the relationship between tuataras and fairy prions is an aggressive one that favors tuataras. Tuataras halve the time adult fairy prions spend in the burrows with their young (Corkery 2012). Tuataras gain cover and food resources, young seabirds, while fairy prions receive no benefits in fitness from the relationship (Corkery 2012). When tuataras are present success and survivorship of seabirds is cut to 35% instead of 60% (Markwell 1997). If this management plan focuses solely on tuatara survival without the consideration of fairy prion survivability and success, then management efforts become counterproductive (Corkery 2012).

Tuataras reach sexual maturity when juveniles transition into adults, posing issues for managing future populations (Fig. 3; Grayson et al. 2014). Sexually mature males have the capacity to reproduce at any time of the year due to constant spermatogenesis, but females do not mate until the January to March (Saint Girons and Newman 1987, Newman et al. 1994). Female tuataras only mate if it is a nesting year, making reproduction uncommon (Newman et al. 1994).

After mating, females carry eggs until the following spring before she nests and lays the eggs indicating increased mortality rates (Newman et al. 1994). After laying, females nest guard against conspecific evacuations and predators (Towns 1988, Refsnider et al. 2009). Females nest socially in rookeries increasing probabilities of nest evacuations (Refsnider et al. 2009, Refsnider et al. 2010, Refsnider et al. 2013).

Climate change will affect the male-female sex ratio of eggs. Increased temperatures cause sex ratio of eggs to be primarily male (Fig 7; Grayson et al. 2014). Temperature-dependent determination of sex is indicated by size, and in orders of class Repilia the larger sex is the female (Fig 7; Grayson et al. 2014). Tuataras are unique among class Reptilia because higher temperatures produce males (Fig 7; Grayson et al. 2014). Rising temperatures associated with climate change increases male to female sex ratios, posing future threats for populations (Grayson et al. 2014).

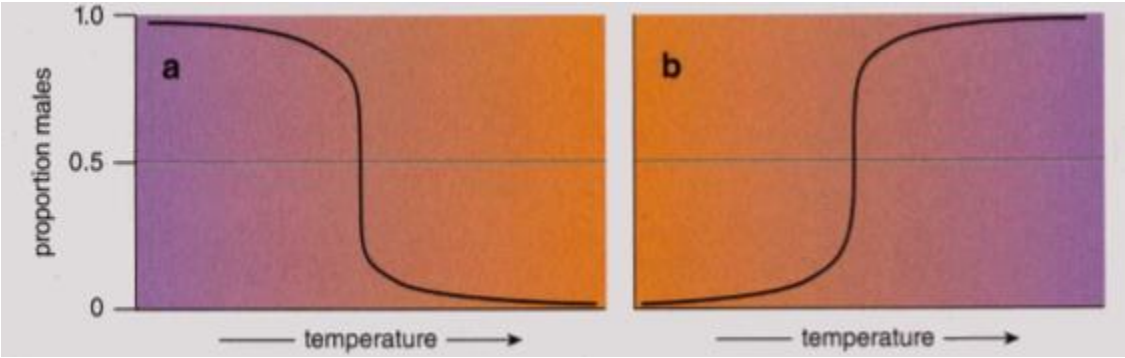

Figure 7: Graph (a) indicates increased temperatures that will produce more females, in orders Crocodilia, Testudines and Squamata, though it is undetermined if snakes are temperature dependent. Graph (b) indicates that increased temperatures produce more males, in the order Rhynchocephalia (Grayson et al. 2014a).

Sociocultural and Economic

In New Zealand, tuataras are known to have significant cultural influence, especially to the Māori (Ramstad et al. 2007). Tuatara in Māori means “peaks on back” (Jones and Cree 2012,

Grayson et al. 2014). In Māori tradition, tuataras represented guardians warning of either calamities or death, acting as social controls (Ramstad et al. 2007). Adversely, tuataras were bad omens or knowledgeable beings (Ramstad et al. 2007). Traditional and cultural knowledge of tuataras is well known among New Zealand (Ramstad et al. 2007). Tuataras have many myths, legends, but known cultural information outweighs ecological knowledge among New Zealand's public (Ramstad et al. 2007). Interviews of ecological knowledge of the public only gave minimal characteristics of tuatara habitats and reproductive cycles (Ramstad et al. 2007). Tuataras are well-known worldwide for being evolutionarily unique, increasing public knowledge with current information would increase conservation efforts.

Economics effecting tuataras on environmental levels is agriculture and logging (Quinn et al. 2004). Logging and agriculture are primary sources of income for New Zealand, causing habitat fragmentation and alteration (Quinn et al. 2004). Agriculture and logging have caused forests and other sources of cover to reduce from 80% to 30% (Quinn et al. 2004). Large scale deforestation began 160 years ago when colonization of New Zealand occurred, conservation efforts slowing current rates (Quinn et al. 2004). 94% of New Zealand's deforestation was caused by agriculture while the remaining 6% was caused by logging (Quinn et al. 2007). Today the agriculture and logging efforts of New Zealand are causing tuatara populations on smaller islands to become more genetically stochastic due to a low range of distribution and less opportunities for cover (Quinn et al. 2004, Grayson et al. 2014).

Legal

In Appendix 1 of CITES (Convention on International Trade in Endangered Species) tuataras are among the most endangered (Gray 1842, Hitchmough 2019, CITES). Species in Appendix 1 are considered the most endangered flora and fauna, more than Appendices 2 and 3

(CITES). Tuataras are among Appendix 1, banned from any sorts of international trading, unless the purpose of the trading is for scientific reasons and not for commercial needs and wants (CITES). Tuataras are listed under Annex A of the EU Wildlife Trades and Regulations, the highest priority among the other four Annexes to be monitored (EU Wildlife Trades and Regulations). All Appendix 1 species of CITES are found on Annex A listing, along with few Appendix 2 and 3 species (EU Wildlife Trades and Regulations). Tuataras are listed as a high priority species with a decreasing population, but no quotas or suspensions are discussed in CITES (Gray 1842, Hitchmough 2019). The tuatara, on the IUCN RedList, is stated to have 55,000 mature individuals in New Zealand with an overall unknown population trend due to low monitoring efforts (Hitchmough 2019). The IUCN RedList indicates the tuatara is a species of least concern (Hitchmough 2019).

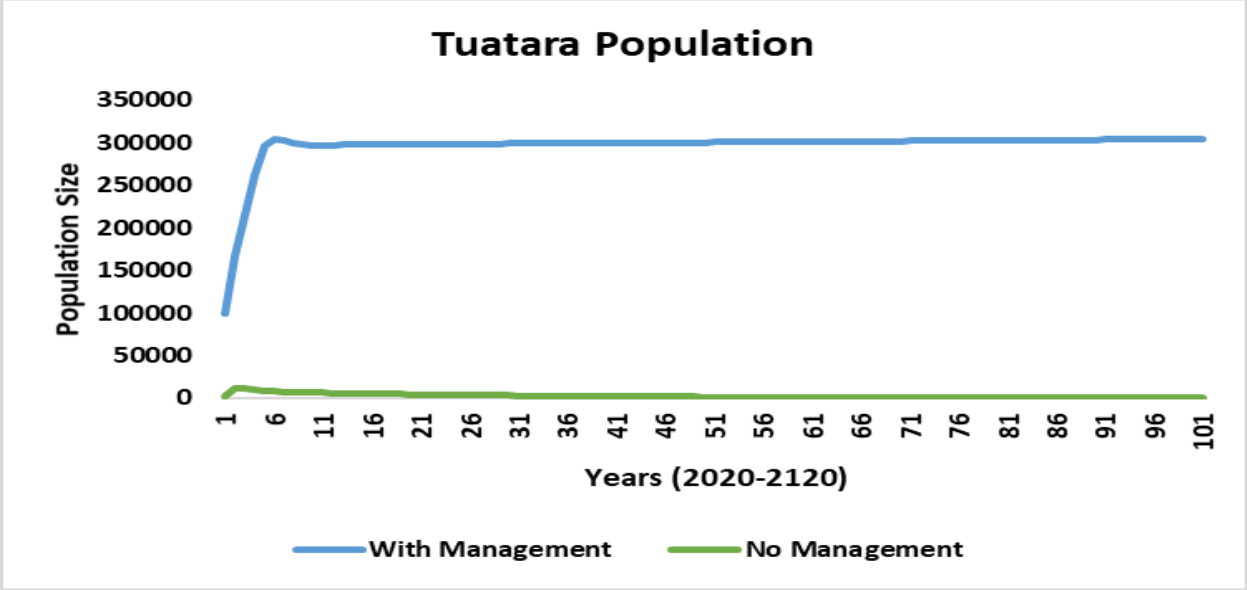

Figure 8: Wild tuatara (Sphenodon punctatus) population trends over one-hundred years on North Island, New Zealand with or without management actions.

Statement of Need

Ecological factors, such as habitat alteration, provide primary reasoning for tuatara management (Quinn et al. 2004, Hitchmough 2019). Impacts due to altered habitats could induce tuataras to forage and nest closer to humans (Walls 1981, Refsnider et al. 2013). Some New Zealand legends depict tuataras as malevolent inadvertently causing uneducated people to inflict harm on individuals (Ramstad et al. 2007, Hitchmough 2019). Protection from uneducated harm via the public can be ensured by incorporating policies from both the Wildlife Act of 1953 (No. 31 of 1953) and the Trade in Endangered Species Act of 1989 (No. 18 of 1989). Habitats must be freed of competition from invasive, rats shown to successfully outcompete tuataras (Towns 2009). Reintroduced wild tuataras are to be monitored to ensure fairy prion burrows remain unparasitized (Corkery 2012). Tuataras parasitizing and lowering the health and fitness of fairy prions populations indicates poor management strategies causing detrimental future effects for seabirds (Corkery 2012). A strategic plan needs to be set in place to ensure proper habitat and monitoring of a wild tuatara population (Figure 8). Along with monitoring populations using a demographic model (Fig. 8), proper habitat will be assessed and protected via acts and policies. Acts protecting vegetation integral to tuatara cover and habitat are the Native Plants Protection Act of 1943 (No. 15 of 1943), the Forest Act of 1949 (No. 19 of 1949), and the Reserves Act of 1977 (No. 66 of 1977). The Forest Act of 1949 (No. 19 of 1949) also provides proper forest management and controlling rates of timber harvesting. A plan ensuring there will be enough resources so future outcompeting of tuataras is minimized, while reducing the parasitizing of seabirds (Corkery 2012). Wilderness areas providing protection for tuataras along with proper resource assessments can be accomplished regarding policies via the Conservation Act of 1987 (No. 65 of 1987) and the Resource Management Act of 1991 (No. 69 of 1991). Plans for climate

change adapted into the management plan to buffer current effects of climate change as much as possible since it is a factor that cannot be simply stopped at this point in time (Grayson et al. 2014a).

Goal: Maintain reintroduced wild tuatara populations on North Island, New Zealand as an umbrella species in one hundred years.

Objective 1- Increasing habitat availability for tuataras by 75% within five to ten years.

Action 1.1: Provide supplemental proportions of artificial burrows for tuataras as proper habitat and cover in managed areas (Corkery 2012). Burrows will be provided within managed forest at random on the North Island of New Zealand (Yahner et al. 1960). Burrows placed at random will be in 10x10 meter quadrats, setting baseline distance of burrows (Markwell 1997). Burrows are to be dug at minimal depth of 20 centimeters and a maximum depth of 200 centimeters form the surface (Markwell 1997). Artificial burrows will comprise of a 20 to 30 gallon tote box that will be the nesting section of the burrow, and the tote will be connected to the surface using a polyethylene draining pipe (Alexander et al. 2005). Totes acting as nesting chambers will be buried along with the draining pipe, allowing for a singular entrance on the surface for the tuataras (Alexander et al. 2005).

Action 1.2: Establishment of burrows will be followed by the management and reintroduction of native flora (Yahner et al. 1960). Rocky outcropping and primary basking opportunities for tuataras will be protected along with retaining woody debris (Yahner et al. 1960). Fallen woody debris allows for suitable foraging opportunities for tuataras as well as cover and basking (Yahner et al 1960). Woody debris will provide tuataras with suitable proportions of invertebrates, primarily beetles, including vertebrates foraging on invertebrates

(Yahner et al. 1960). North Island forests will need management to decrease fragmentation and possibilities of ecological traps (Yahner et al. 1960). Tuatara issues include genetic stochasticity and longevity indicating the issues with ecological traps and fragmentation in unmanaged forests (Yahner et al. 1960). A habitat-suitability index will be applied to the managed wild population. The habitat-suitability index will take the tuatara population and generate a numeric value assessing the capacity of the forest to support the tuataras (Yahner et al. 1960).

No Action: If burrows are not constructed, tuataras will overtake burrows housing fairy prions, causing increased competition among the seabirds and reptiles (Corkery 2012). Burrows allow for decreased competitions among tuataras and fairy prions along with increasing nesting and hatchling success of tuataras (Corkery 2012). If protection of habitat from alteration and fragmentation is not implemented, then tuatara genetics will become more stochastic (Grayson et al. 2014). Decreasing habitat fragmentation will allow for future populations on the North Island to reproduce and survive at a greater rate (Grayson et al. 2014).

Final Course of Action: Action 1.1 will be implemented within fifty years. If action 1.1 fails, action 1.2 will be implemented within twenty-five years and then action 1.1 will then be reimplemented.

Rational: Tuataras are parasites to seabirds and compete for a common resource, burrows (Corkery 2012). Managing tuataras without consideration of other species would affect the survivability and fitness of fairy prions (Corkery 2012). To reduce competition between tuataras and fairy prions, artificial burrows will be created in the natural environment. Artificial burrows will create suitable cover and nesting habitat for tuataras that will be relocated onto the North Island. Testing the suitability of the artificial burrows will be calculated by conducting

tests with radiotracking along with setting camera traps. Radiotracking will indicate the likelihood of tuataras using the artificial burrows.

Assessment Protocol: Proper habitats for tuataras will be assessed through the use of a habitat suitability index before action 1.1 will be put into effect (Yahner et al. 1960). Habitat parameters assessing suitability will be defined by food availability, lack of human disturbance, cover opportunities and distances to rocky outcroppings. Forests and rangelands will be categorized using habitat suitability indices as primary habitat for tuataras (Bleich et al. 1960, Yahner et al. 1960). Action 1.1 will be placed into effect after the habitat suitability index, implicating the use of artificial burrows for future tuatara populations on the North Island within fifty years following the populations population demographics (Fig. 8; Markwell 1997, Alexander et al. 2005). Artificial burrows will be used to house newly populated tuataras while also estimating the total population and their rate of survival throughout the management plan (Fig. 8; Markwell 1997, Alexander et al. 2005). Management for tuataras on the North Island will be considered successful if tuataras congregate to the artificial burrows and produce enough young to continue sustaining the population up to 75% within seventy-five years (Fig 8).

If tuatara populations on the North Island have not increased by 75%, the reasons for the failure of the objective will be identified. Failure due to specific habitat types may lead the management plan to focus on a singular habitat type and a referral of a habitat suitability index (Fig. 8; Yahner et al. 1960). Incorporations of land use planning and cooperation from local funding may need to be increased to provide sufficient habitat for tuataras (Bleich et al. 1960). Tuatara burrows will be checked for depth and size to properly accommodate for both adults, eggs, and hatchlings (Markwell 1997, Alexander et al. 2005). Surveys and checking of possible predation of rats on tuataras will be assessed to protect reintroduced populations (Towns et al.

2007). If necessary, additional funding may need to be required form donors, local businesses, or the Wildlife Conservation Society.

Objective 2- Increase public cooperation with tuatara conservation efforts by at least 50% within twenty-five years.

Action 2.1: Create a survey to determine the current knowledge that New Zealand's public has on the tuataras (Ramstad et al. 2007). Surveys will be sent out both digitally and physically throughout the North Island, gathering information on public knowledge of tuatara ecology (Ramstad et al. 2007). Survey collection will contain data on the percentage of New Zealand citizens with a basic understanding of tuatara ecology and biology (Ramstad et al. 2007). Surveys will be handed out at seminars and at town meetings that will be held, increasing education on tuataras (Ramstad et al. 2007).

Action 2.2: Surveys and seminars will be additions of a land use plan for the tuatara management project (Ramstad et al. 2007). A land use plan will incorporate a habitat suitability index that will be provided to the public to increase the knowledge of tuatara habitat possibilities on the North Island New Zealand (Bleich et al. 1960, Yahner et al. 1960, Ramstad et al. 2007). Seminars will be held, increasing the knowledge of tuataras as well as involving the public with the creation of the management plans and its future implications (Ramstad et al. 2007). A land use plan will involve the citizens of New Zealand along with scientists within the field (Bleich et al. 1960, Ramstad et al. 2007). The land use plan will prepare a management area where the future population of tuataras will be located while also getting permits and permissions with lawmakers (Bleich et al. 1960, Ramstad et al 2007).

No Action: No precautions taken in increasing the current ecological knowledge of New Zealand's public will result in decreased ecological knowledge of tuataras (Ramstad et al. 2007). Future management actions for tuataras will be less accurate if no action is taken to educate the public of New Zealand on the ecology and biology of tuataras (Ramstad et al. 2007). Land use plans, surveys, and seminars will prevent inaccurate information of tuataras to be spread throughout the North Island, while also respecting the cultural significance the reptile has on the people of New Zealand (Ramstad et al. 2007).

Final Course of Action: Actions 2.1 will be implemented within 1-5 years and action 2.2 will be implemented in years 5-25.

Rational: Culturally, the tuatara is a well-known species on New Zealand, primarily to the Māori (Ramstad et al. 2007). Ecological knowledge of tuataras among the public of New Zealand is lacking (Ramstad et al. 2007.). Through educational processes, the public can be taught the importance of tuataras in the ecosystem. Internet videos, websites, and talks directly with the public can increase education. Creating an interactive map online allowing the public to add photos and locations of located tuataras in the wild would heighten public awareness. The map's instructiveness will create public involvement and work similarly to surveys. Surveys and town meetings provide education and knowledge to the public.

Assessment Protocol: Objective two will be considered successful if local cooperation has increased by 50% within twenty-five years (Fig 8). The public will be interviewed verbally at town meetings and the data will be sent through the use of surveys or undergo visual cooperation (Appendix A). If 50% of the public cooperates and educates themselves on the ecology and biology of tuataras while supporting and contributing to the management plan to the best of their abilities, the plan will be considered successful.

If the objective has not been met, the management team will allow for time to adjust the actions of this objection to accommodate more time with the public of New Zealand. Additional surveys, town meetings, and time with the public will be made to adjust the actions for this objective (Appendix A). If funds for the management plan will not be adequate at the time of the plan, funds from the United States may need to be loaned to the government of New Zealand.

Conclusion

This management plan for the North Island, New Zealand could possibly increase the population size of wild tuataras back to their past populations, while keeping the competition between the tuataras and seabirds to a minimum. Proper habitats should be selected for using a habitat suitability index, followed by providing artificial burrows for both shelter and nesting. New Zealand's public will be educated on the ecology and biology of tuataras, increasing knowledge and allowing for local cooperation of the public. Habitat fragmentation, biased sex ratios, possible future invasive predators, and hybridization are major threats to future wild populations of tuataras. Incoming threats of climate change pose difficult challenges, consequences of failure being the extinction of the tuatara. Success of the plan indicates raising tuataras to self-sustaining populations, similar to those in the past. By mixing both present knowledge and models estimating populations of tuataras, a proper set of actions and assessments were developed to increase tuatara populations. Incorporating the final course of actions within this plan allows for managers to reach the goal of restoring wild tuatara populations to what the once were on the North Island, New Zealand.

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Appendix A

One-Hundred Year Wild Tuatara (*Sphenodon punctatus*) Management Plan for Te Ika-a-Māui, New Zealand

Survey Questions 2020

1. Are you familiar with tuatara (*Sphenodon punctatus*) conservation efforts in New Zealand? (Choose one)
    a. Yes
    b. No
    c. Unsure
2. Have you noticed changes in the numbers of tuataras within the North Island, New Zealand? (Choose one)
    a. Yes, more now than previous years
    b. Yes, fewer now than previous years
    c. No, not any noticeable changes
    d. Unsure
3. Do you believe tuataras (*Sphenodon* punctatus) are an important wildlife species in New Zealand? (Choose one)
    a. Yes
    b. No
    c. Unsure
    d. Other (explain):
4. Are you temporarily or permanently a resident of New Zealand? (Choose one)
    a. Yes
    b. No
    c. Unsure
5. Does the tuatara (*Sphenodon punctatus*) hold any cultural significance to you? (Choose one and describe)
    a. Yes (explain):
    b. No
    c. Unsure
6. Do you know what separates tuataras (*Sphenodon punctatus*) from all other reptiles in class Reptilia? (Choose one and describe)
    a. Yes (explain):
    b. No
    c. Unsure
7. What term best describes your lifestyle? (Choose best answer)
    a. Industrial Worker
    b. Forestry Worker
    c. Agricultural Worker
    d. Wildlife Technician
    e. Other