INTERRELATION OF PREHISTORIC WELLS, GROUNDWATER RESOURCES, AND STATUES ON EASTER ISLAND IMPLY INTRINSIC UNDERSTANDING OF NATURAL LANDSCAPE BY RAPANUI PEOPLE

by

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Approved: ______________________

Terry Hunt, Ph.D.

Commonly overlooked in the numerous narratives of Easter Island's mystery is the most critical resource to human beings: freshwater. Recent field research on the Island focused on sea ramps and puna (archaeological well features) that may have allowed the prehistoric Rapanui people to obtain this essential resource. A drone with a high-resolution camera and a Trimble GPS unit were used to create 3-dimensional reconstructions of the sea ramps and puna; and an extensive on-site survey of the coastline was conducted to identify traces of freshwater at the marine interface. These two data sets were geographically compared with previously mapped locations of moai (statues) and ahu (statue platforms). The puna are found within 50 meters of a moai or ahu presentation. Additionally, in these areas fresh, potable groundwater seeps into the sea. This correlation of puna, potable water, and ahu with moai suggests a connection between resource use and moai placement, challenging previous beliefs that moai were merely 70-ton manifestations of ancestor worship. For a culture that has been previously portrayed as an example of "ecocide," the Rapanui may actually provide a template for the modern world of how to live in equilibrium with the environment and

its resources. In the face of current global resource shortages, including freshwater, their prehistoric population and resource management strategies should not be viewed as a cautionary guide, but as a lesson to avoid our own demise.

Acknowledgements

I would like to thank Dean Terry Hunt for his professional insight to my research and initial assistance sending me to Easter Island with the National Science Foundation. I would also like to express my sincerest gratitude to Professors Eugene Humphrey and Christopher Bone for their support throughout my thesis development, defense, and revisions. A ‘thank you’ also to the lovely Professor Bishop who, with many a cobble-stoned walk, has guided me through a term at Oxford and the other emotional and academic trials and travails of my undergraduate years. And, of course, my family: to my grandpa for passing on a love of precision and cartography, my grandma for every chocolate birthday cake and box of perfect persimmons, my baba and dede for faraway fiddle tunes and Betty Boop teapots, my mother for her work ethic, intelligence, and self-respect that have never made me doubt my own, and my father for reading me the *Encyclopedia of Aquatic Invertebrates* as a baby and planting sunflowers outside my bedroom window so I would wake up thinking everything is beautiful and anything is possible.

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KEY TERMS

Rapa Nui	Native name of Easter Island
Rapanui	Indigenous people of Easter Island
Puna	Prehistoric archaeological feature resembling a slanted stone terrace; debatably a boat ramp or water well
Moai	Giant stone statues of Easter Island created 1250 – 1500 AD, weighing 20 – 90 tons, and standing 8 – 35 feet tall
Ahu	Stone platforms, sometimes with a terrace-patio area, often accompanied by moai

INTRODUCTION

Perusing the Anthropology section shelves of a used book store, the large orange block letters of Jared Diamond's **COLLAPSE** stands out along the bindings of stacks of used novels. These shelves used to be overpopulated by the names of Diamond, Flenley, Bahn, and Routledge among many other speculators of Easter Island's mysterious past. However, a new spine has begun to stand among its predecessors. The work of Dr. Terry Hunt and Dr. Carl Lipo takes an alternative twist from the traditional narrative portraying the Rapanui people as cannibal sculptors whose resource abuse and internal warfare led to their own demise. Hunt and Lipo suggest the Rapanui people were actually well aware of the natural resources on their island and their cultural practices, including statue making, formed around this understanding and connection to the land (Hunt & Lipo, 2012). One of the most limiting resources on the Easter Island was freshwater. Without any permanent running streams, the attainment of this essential element assumed a central role in Rapanui society. Previous work by Hunt and Lipo and the research presented in this paper seeks to define the role of freshwater in prehistoric culture as it relates to resource management and societal development.

Before we can begin to understand the significance of freshwater in the interpretation of indigenous society, though, we must first understand the context from which it is emerging. Prehistoric Rapanui did not have a written language, and the only primary sources that exist from ancestral people are the indecipherable glyphs on *Rongorongo* tablets. In the absence of an original narrative, speculations from anthropologists like Diamond have gained unprecedented momentum that has led to their domination of bookshelves, and common beliefs of Rapanui society as a cacophony of “chaos and cannibalism” (Diamond, 1995).

The idea and term most proliferated by Diamond’s *Collapse* is “ecocide” (Diamond, 2011). “Ecocide” describes the environmental degradation that occurs when a population recklessly and ignorantly depletes their natural resources, ultimately resulting in their demise (Travis, 2016). This narrative makes the assumption prehistoric people were ignorant of the extent of their resources, or too savage to care. It also implies statues were symbols of power that blinded the population with greed to the point it overshadowed their common sense and was the catalysts of environmental abuse. Hunt and Lipo refute this idea of demise by “ecocide” on multiple fronts including Diamond’s proposed time frame, disregard of varmint predation on palm seeds, creation of warfare events that lack evidence of occurrence, and unconsidered effects of European contact (Hunt & Lipo, 2011: letters). Before Hunt and Lipo began to challenge Diamond’s narrative, though, it had already become a modern “misplaced metaphor” for the world today and subsequent researchers like popular writer Paul Bahn and palynologist John Flenley had added their scientific support to the story (Hunt, 2006: 412).

In Bahn and Flenley’s book *Easter Island, Earth Island (1992),* they promote an hypothesis similar to Diamond’s narrative of demise by “provid[ing] the botanical, ethnological and archaeological evidence that supported the scenario of environmental disaster” (Bahn & Flenley, 2007: 11). Since the early 2000’s, more field research done by Hunt and Lipo has pointed in the opposite direction. However, Bahn & Flenley (2007) dispute new evidence and remain loyal to a “collapse” narrative. While they only mention the relation of freshwater access to settlement locations briefly to challenge Hunt and Lipo, their statement actually becomes a supporting piece of information for Hunt and Lipo's argument that Rapanui people were intrinsically aware of their natural environment; living in careful equilibrium with limited resources. Bahn and Flenley question Hunt and Lipo's dates that suggest "there [were] people at two other locations at the same date" of early settlement, insinuating that this is nonsensical and further indicating the impracticality that these "other locations" were not situated near the calderas, assumed to be "a good supply of fresh water" (Bahn & Flenley, 2007: 12). As I will explain in this paper, the calderas were likely not the best supply of freshwater and people lived in dispersed settlement patterns perhaps in part to avoid contaminating their water resources.

To better understand the relationship of settlement pattern and freshwater sources, I will examine three features previously believed by some to be forms of boat ramps. These three features (1) sea ramps, (2) ramps with patio areas, and (3) *puna* wells have always been known to the native Rapanui people to be sources of freshwater as their name, "puna," means "spring" in Rapanui. However, realizing their true function as freshwater catchment systems should correct some misunderstanding of Rapanui culture, particularly current popular Western narratives of Easter Island and "ecocide." The hydrogeological expertise necessary to design these features required an intimate understanding and respect of their environment by Rapanui society, which is reflected in their settlement patterns, ceremonial statues, and daily lives.

This paper is broken up into OBSERVATIONS that will establish characteristics of sea ramps, ramps with patio areas, and *puna* wells. The METHODS section describes how these features were documented as well as the details of a freshwater survey conducted around the Island to add support to the association of these features with freshwater. RESULTS provide models of features and maps of freshwater seeps, and the DISCUSSION examines the connection between the three features, freshwater seeps, and correlation with cultural monuments to infer the importance of freshwater on prehistoric Rapanui society and culture.

OBSERVATIONS

When beginning to examine these features, a few distinct traits became clear that allowed for differentiation into three categories: those that were simply ramps (leading entirely into the ocean at high tide), those with patio-like areas, and those with seawalls – which we designate the full title of *puna*. The function and distinction of these three types of feature (sea ramps, patio areas, and true *puna* with seawalls) will be deliberated in the DISCUSSION section. However, they share similar characteristics, described below.

Each sea ramp, patio ramp, or *puna* well takes advantage of the landscape's natural curvature down to the ocean's edge. The ramp (sea ramp, patio ramp, or *puna* well ramp) exaggerates the natural **slope** between 10 – 20 degrees, making each *puna* feature angled 15 – 30 degrees towards the sea (**Figure 1**). The measurement of slope taken today may vary from the original angle when the ramp was built due to natural degradation of the land over time. The ramps size ranges from 5 – 15 meters in width**,** and 5 – 10 meters in length.

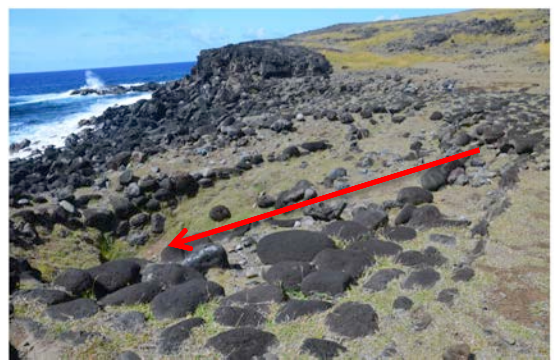


Figure 1 *Sea Ramp at Papa Vaka* the ramp has disintegrated but where the increased slope cuts into the hillside is still evident.

Size, too, is susceptible to natural degradation and alteration by human activity since the sea ramp, patio, or *puna* was originally installed (**Figure 2**).

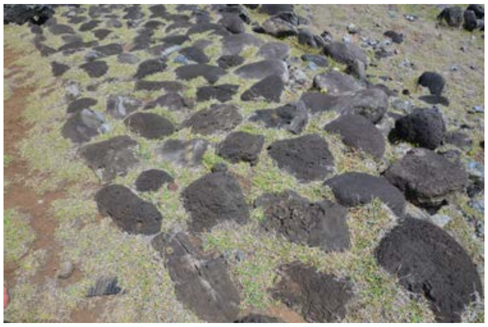


Figure 2 *Sea Ramp at Papa Vaka* the bottom has dropped off due to natural disintegration and likely human disturbance.

Shape and the pattern rocks are placed adds additional similarity between features. The individual stones that comprise the ramp (regardless of sea ramp, patio, or *puna*) are flat with rounded edges and roughly rectangular in shape. Sometimes, they appear to be organized in a pattern of concentric circles, radiating away from the oceans edge. Particularly in the patio areas, this pattern becomes clear (**Figure 3**). The rocks used to form a wall at the base of several *puna* (a seawall) are smaller, more angular, and stacked together in layers (**Figure 4**).

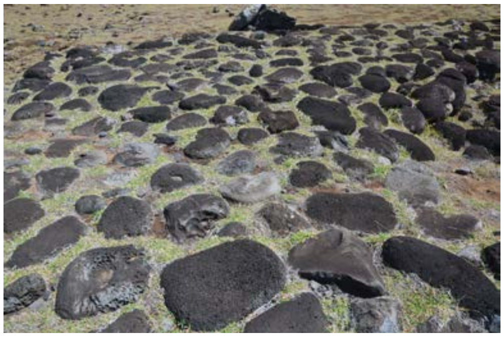


Figure 3 *Puna at Akahanga* shows flat stones, forming a concentric pattern away from the ocean located to the right of this image when taken.

Figure 4 *Puna at La Perouse* thin, oblong, angular stones are stacked in layers to form a wall up to 1.5 meters high.

The section of seawall shown above in **Figure 4** was a part of the *puna* at

Figure 5 *Puna at Wildhorse* the seawall stands at the base of ramp. About 2 meters of land extends from the top of the puna to the ocean, depending on the tide.

Wildhorse (**Figure 5**). Similar walls existed at Hanga Tetenga and La Perouse. This wall is at the base of the sea ramp and stands up to 1.5 meters high, parallel to the ocean. Green plants grew from the wall, and in the bottom corner we found standing freshwater.

Another commonality of sea ramps, patio areas, and *puna* wells was the geologic material. The stones that compose each sea ramp, patio area, and *puna* well are predominately **basalt** (**Figure 6**). Streaks of **red scoria** (**Figure 7**) were also present at a number of the sites. Below the grass and other debris that have built up around the *puna* stones over the years, **bedrock** appears.

Basalt is an igneous rock that forms as the magma from a volcanic eruption cools. This fine-grained rock is the most common rock of the eastern Pacific islands on the oceanic plate, characterized by its dark color and range of porosity (Strickler, 1997). Easter Island basalt has a "rather high total porosity" compared to basalts found over most of the rest of the world. Porosity, in geological terms, is the fraction of total

Figure 6 *Basalt*

Figure 7 *Red Scoria*

volume to pore space (Humphrey, 2016: personal communication). Additionally, what makes the Easter Island basalt special is that these pores are connected by tiny fractures as a result of consecutive volcanic eruptions (Humphrey, 2016: personal communication). The nature of these interconnected pores makes the rock permeable. While basalt porosity has been studied predominately for its role in the construction of moai statues, it could also be observed as a hydrological feature of the Island (Gioncada, 2010). Basalt on Easter Island also contains comparatively high levels of iron, which allows it to oxidize faster and adopt the reddish hue seen in much of the rock strewn about and on top of some moai's heads (Bonatti, 1977). Traces of red scoria also mark a number of the puna areas. Red Scoria is an "extremely vesicular basaltic lava" that, as the description suggests, begins as a common basalt, but the iron oxidizes during the eruption, turning it red (Jones, 2016).

Another geologic similarity is the **bedrock** beneath at least portions of these ramps and *puna* features. Slabs and formations provide a surface for the rectangular *puna* stones to sit upon, and eventually the spaces between them fills with smaller particles and grass, which root these stones to the hardened slab. The bedrock may appear impermeable in comparison to the vesicular basalt and scoria but tiny cracks still allow it to conduct water to the ramp stones, which with their high porosity act as storage space for the water. Large bedrock formations left in organic shapes from when the lava flow met the cold ocean and solidified, act as sidewalls at a number of the features.

At the base of a number of these features without a seawall, a stretch of smaller rocks, gravel, and sand, extends to the ocean's edge at low tide. While the distance from the base of the bedrock to the sea changes with the tides, at low tide it can reach up to two meters from the stone toes of the sea ramp to the water. High tide touches the bottom few rows of rectangular rocks, leaving sea foam in their crevasses. Particularly at Te Pito Kura, more commonly known to tourists as the ‘Navel of the World,’ this sandy area was sufficiently expansive for a family to sit and eat lunch – as I saw once, the adults stretching their feet into the ocean while the children looked for shells in the sand at the ramps base.

Location is another similarity. All sea ramps, patio areas, and puna wells are found within a maximum of three meters from the ocean, measuring from the base of the ramp to the tideline at low tide. At high tide the waves come right up to the bottom of the ramp. They often are in proximity to modern wells used by native people. The modern well, shown in Figure 8, is constructed with stones from the original sea ramp. Makeshift hoses lead back to animal troughs. Buckets, water bottles, and cups are also often found near the pumps. As will be discussed later, these features are usually found within 15 – 20 meters of a moai and sometimes ahu platform. The size of these features seems to reflect the magnitude of the moai and accompanying ahu (Zeferjahn, 2015: poster).

Figure 8 *Sea Ramp at Modern Well* the modern construction is perched on top of the remnants of a puna ramp.

METHODS

FRESHWATER CATCHMENT FEATURES

After locating a sea ramp, ramp with patio, or *puna* well, and noting the initial observations given above, I used a Nikon Camera to capture 300 – 800 photos per feature. More complex *puna* with seawalls required more photos than sea ramp and patio features. The camera was held overhead to capture the maximum amount of area as I walked in a grid-like pattern over the feature, taking pictures continuously, to make sure the feature was captured by every angle. For features that were larger, more complex, or next to a cliff I had used a Phantom 2 quadcopter. Flying from 3-9 meters elevation, it took photos every 3 seconds from an iPhone 4 strapped to its underside. These photos were then uploaded to Agisoft Photoscan – a photographical software that knits images together. A Trimble GPS unit was used to collect exact locations of sea ramps, patio area, and *puna*. The resulting models can be rotated, flipped, even turned inside out. From these models, more accurate measurements such as slope and depth can be made than would have been possible in the rocky terrain of the field. ArcMap/ArcGIS was also useful to depict the data. After plotting the GIS coordinates from the Trimble, ArcMap enabled us to examine the sea ramps, patio areas, and *puna* in the greater context of their natural landscape and proximity to other archaeological features.

To confirm the function of these features as freshwater catchment systems, we conducted an additional freshwater survey at the marine interface to identify freshwater seeps and see if they corresponded to the sea ramps, ramps with patio areas, and *puna* locations. The methods for this survey are also included below:

FRESHWATER SURVEY

The initial approach to collecting our data was to fasten conductivity and temperature sensors with GPS units to boogie boards and tow them behind sea kayaks around the Island during low tide. The sensors and GPS units were tested in a sheltered cove at Hanga Roa, and performed optimally. After taking the kayaks into the open ocean though, it became clear this would not be a successful method. Even in the sheltered bay of Tongariki, the kayaks could not get close enough to the shore to detect freshwater without risking being smashed on rocks covered in sea urchins. Alternatively, we decided to take the measurements manually by hiking along the coast and stopping every 6 – 8 meters to test the ocean conductivity and temperature using a thermometer, conductivity meter, GPS unit to record coordinates. This method actually proved better than kayaking because it allowed us to make more detailed observations of the surroundings features on land. However, hiking and measuring was extremely time consuming – often taking an hour to cover just a quarter mile of coast because the terrain was so steep and jagged. Frequently, we had to wait between wave sets to get accurate readings. This time requirement constrained us to only collecting measurements of the north and south shores. We were also restricted by the tides.

Measurements had to be taken at low tide to ensure our sensors were detecting freshwater seeps coming out of the island at points below the high tide line. At high tide, waves quickly obscured any traces of freshwater. The necessity of taking measurements at low tide limited us to a two-hour window (one hour before and one hour after low tide) that only occurred once or twice during the daylight. On a few days, we were only able to collect data during one low tide window.

While taking these precautions assured we had excellent salinity readings, our temperature measurements were inconsistent due to the variability of water depth where we were able to collect data. Sometimes the water had been sitting n the shallows or pooling on bedrock after the tide receded, giving it time to warm before we measured it. Other times, the only places we could find between craggy boulders to stoop and safely take measurements were constantly being overturned by the waves, or in the shadow of the cliffs, making the readings cooler. For this reason, while there seemed to be an overall trend in low temperatures that corresponded to low salinity, temperature data will be left out of the DISCUSSION and only shown briefly in RESULTS.

RESULTS

FRESHWATER CATCHMENT FEATURES

Sea Ramp: *the ramp alone extends into the ocean at high tide*

Ramp with Patio: *the sea ramp is accompanied with a patio-like area composed of flat smooth stones in a roughly concentric pattern*

Puna Well: *the sea ramp ends in a sea wall that prevents direct access to the ocean from the ramp; freshwater often found in the deepest corner*

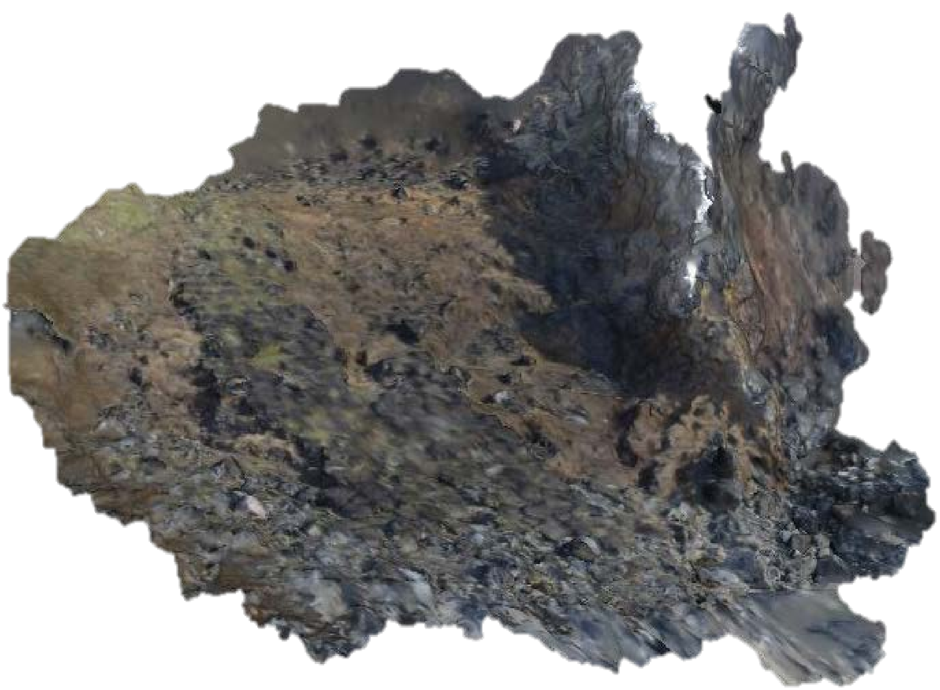
A tabulated summary of freshwater catchment features is given below, as well as models constructed from the photos taken at four of the sites, and the results of our water survey.

Table 1: Water Catchment Feature Characteristics

Feature	Type	Ahu (m)	Moai	Petroglyphs	Slope (°)	Material	Notes
Papa Vaka	Sea Ramp	5	None	Yes 60 m	30 - 40	Basalt, gravel, bedrock, sand	Natural drainage area, may have been a patio area before disturbance
Akahanga	Puna with Patio Area	40	None	None	10 - 20	Basalt, smaller rubble-like rock, bedrock sidewall formation	Natural outlet, circular patio area, longer rocks appear to create an outline for the patio; patio slopes into ramp that leads into actual well with inland wall; stones of this wall appear to be arranged in a columnar fashion
Wildhorse	Puna	6	None	Yes 80 m	10 – 20	Basalt	Seawall approx. 2 m high, larger rocks at base of ramp packed tightly, freshwater in bottom corner, green plants growing from wall

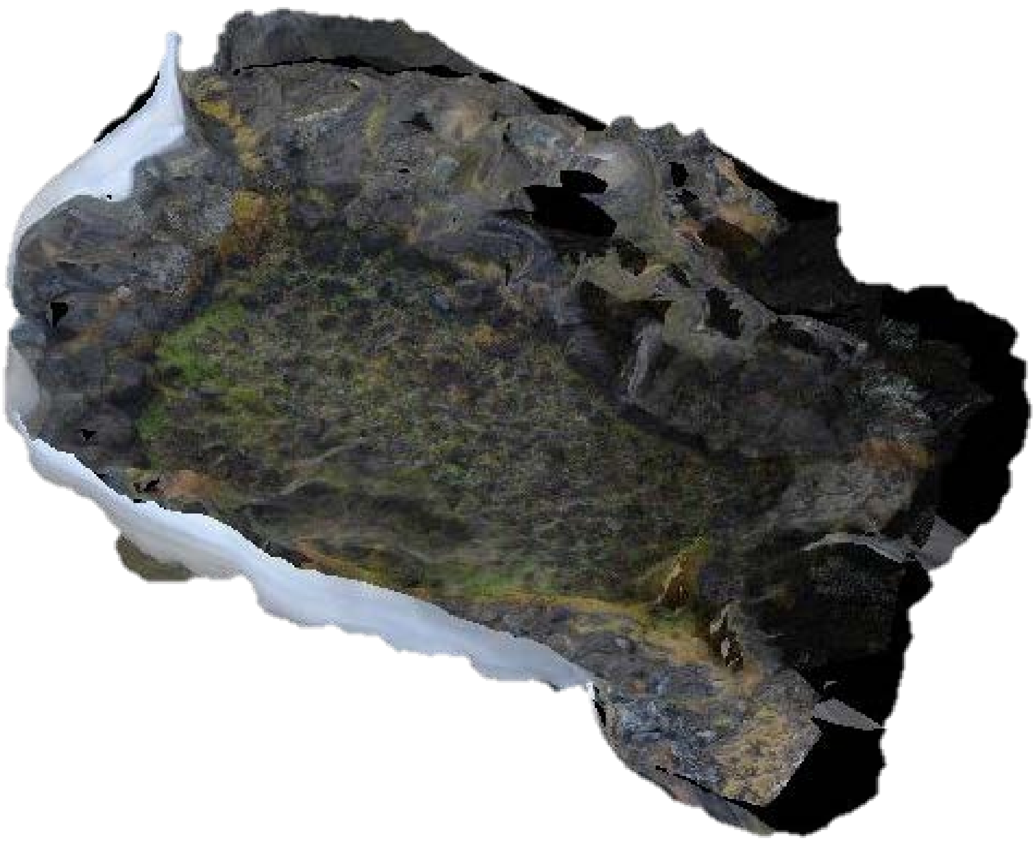
Navel of the World	Sea Ramp	30	Yes	None	30	Basalt, sand, bedrock formations	Organized in arched pattern, radiating away from the waer, comparatively large and well constructed
Hange Tetenga	Sea Ramp	9	Yes	None	25 – 30	Basalt, red scoria, bedrock formations	Indentations left in the ground that are approximately the size of the stones in the ramp, water lines left in clay between existing set stones.
La Perouse	Puna	9	None	None	10 – 15	Basalt, scoria	1 seawall, 2 side walls leading from top of ramp to, freshwater in deepest corner, green plants growing from the seawall
Modern Well	Sea Ramp	30	None	None	10	Basalt, smaller rocks, soil	Modern well with hose leading to animal trough situated on top of upper ramp, stones from ramp appeared to be used in the construction of the well
Indentation Well	Bedrock Formation	5	Yes	None	No ramp	Bedrock, basalt stones inside	Approx. 2-3 meters in diameter by 3-3.5 meters long and up to .75 meters deep, green plants grew through the base, it filled slightly with rain
Tongariki	Sea Ramp	65	Yes	None	10	Basalt, built on sand, dirt, and bedrock	The largest ramp recorded, the face of an older style moai was embedded in the ramp, rocks collectively larger

Model 1: This sea ramp at Papa Vaka took advantage of the natural drainage area. At low tide the base of the ramp just touches the water, at high tide it is submerged.



Model 2: This sea ramp at Hanga Tetenga uses the natural bedrock feature on the right of the ramp to act as a sidewall or maybe like a funnel. While this ramp was more disintegrated than others, indentations of stones left in the ground indicate this sea ramp was once much larger. Rivulets where water flows between the stones during a rain were also imprinted. At low tide there was over 2 meters from the base of the ramp to the ocean's edge.

Model 3: With a complete seawall – this is a true puna, which we dubbed the "Wildhorse Puna" due to the horses we observed drinking from the sea on the other side of the wall. The sea wall is a distinguishing feature of puna from sea ramps or ramps with patio areas. In every case, these puna have had standing freshwater in the right-angled corner, and green plants growing from the sea wall. While this puna only has one side wall leading from the top of the ramp to the sea wall (on the left side of the ramp shown in this image), the puna at La Perouse had two side walls and the puna located near Anakena had one side wall and a bedrock formation on the other side. Eliza Pearce, another University of Oregon undergraduate student, and myself provide scale in the foreground.



Model 4: While the indentation wall was different than a sea ramp, ramp with patio-area, or puna well it is still clearly associated with freshwater catchment. During a quick but heavy rain it was actively collecting water. Bright green grass was growing in the bottom while the vegetation surrounding the indentation was brown and dried. Two smaller moai stood just uphill.

FRESHWATER SURVEY

Salinity: *Dissolved salt concentration in a given volume of water, ranging from 0.0 g/kg in pure freshwater to an average of 35.0 g/kg in the ocean*

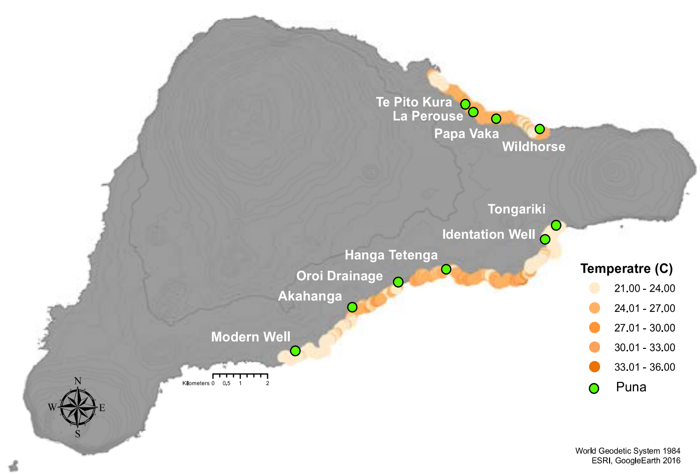
Recorded in k/kg or parts per thousand (ppt)

Temperature: *Measure of heat intensity, generally lower in freshwater than sea water, but varies greatly depending on water depth*

Recorded in degrees Celsius (°C)

We collected a total of 1,263 data points each composed of a conductivity measurement, temperature reading, and a longitude and latitude coordinate along the north and south shores. This choropleth map (**MAP 1**) depicts temperature variation recorded in degrees Celsius (°C) of the coastal interface of Easter Island during January 2015. The lighter to darker orange symbolizes cooler to warmer temperatures. The neon green dot represents each sea ramp, patio, and *puna* location identified. As mentioned in the METHODS, depth became too great of an uncontrolled variable affecting our temperature readings. So much so, that they will not be considered in the rest of the DISCUSSION, and shown here for the sake of entirety.

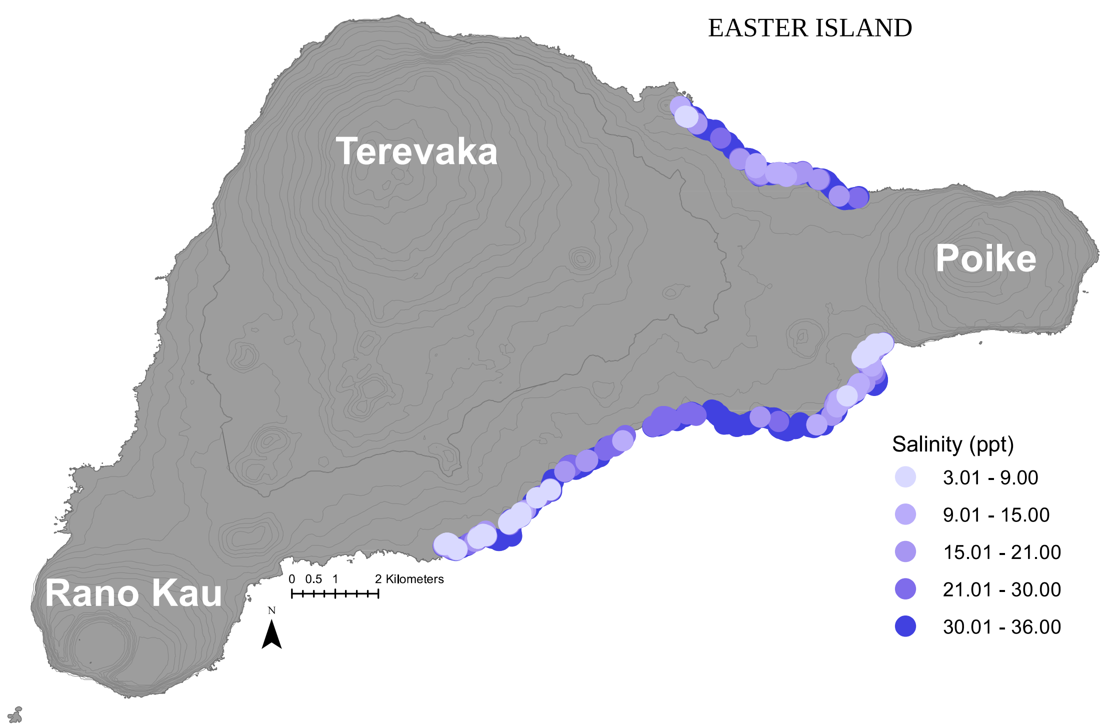
MAP 1: TEMPERATURE (°C) SURVEY of EASTER ISLAND



MAP 1 This choropleth map depicts temperature variation recorded in degrees Celsius (°C) of the coastal interface of Easter Island during January 2015. The lighter to darker orange symbolizes cooler to warmer temperatures. The neon green dot represents the different location puna were identified.

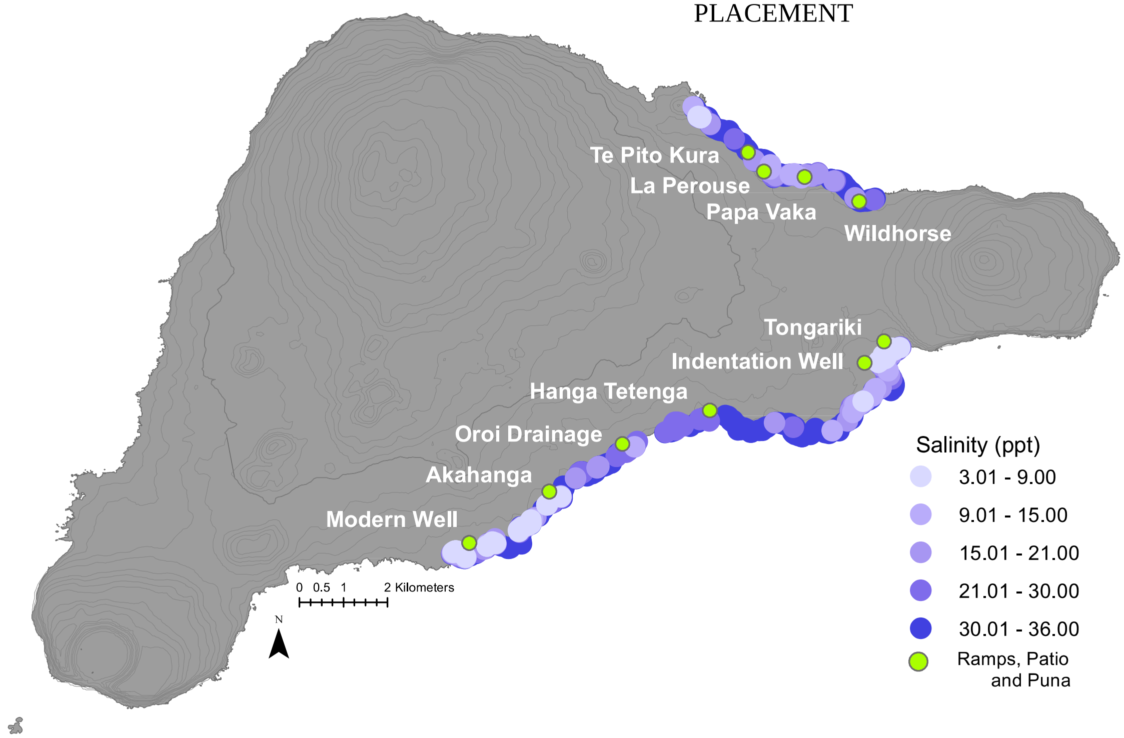
Changes in salinity of water at the marine interface of Easter Island in January 2015 are given, above, in **MAP 2**. Data ranged from 3.01 to 36.00 ppt. The lighter purple represents areas of relatively low salinity and progresses to higher salinity with the deeper purple. Salinity readings had less uncontrolled variability than temperature. Due to the homogenous nature of the ocean, anything below 35-36 ppt indicated influence of other water.

MAP 2: SALINITY SURVEY (ppt) of EASTER ISLAND



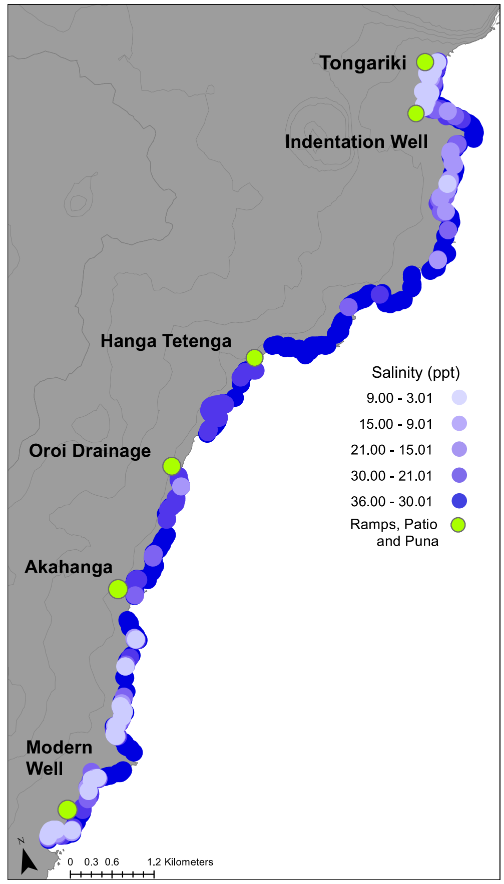
MAP 2 This map depicts the change in salinity of water at the marine interface of Easter Island in January 2015. Data ranged from 3.01 to 36.00 ppt. The lighter purple represents areas of relatively low salinity and progresses to higher salinity with the deeper purple.

MAP 3: SALINITY and SEA RAMP & PUNA PLACEMENT



Locations of sea ramps, ramps with patio areas, and *puna* wells are shown with the neon green circle and seem to correspond with lower salinity measurements. Tongariki was the largest sea ramp and also where we saw the most concentrated freshwater output. Akahanga was also a rather well constructed ramp that at one time might have been large before disturbance by ranchers and farmers. The presence of potable water seeps at the Modern Well location is obviously being utilized by present day people.

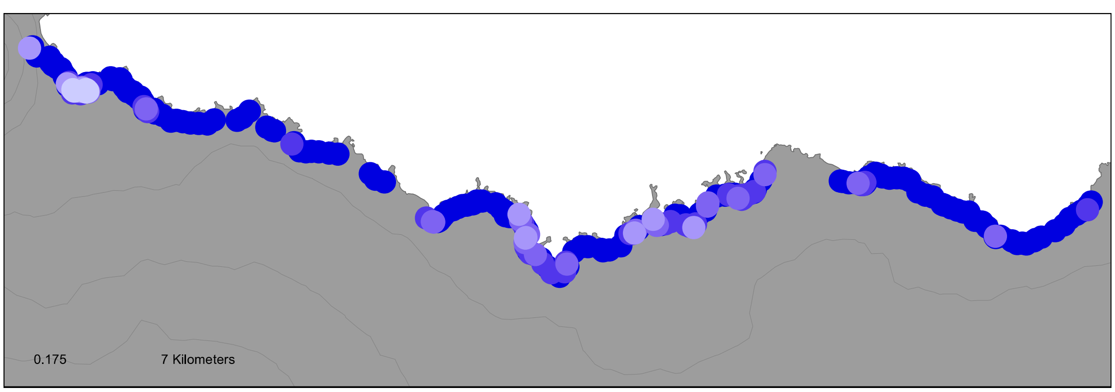
MAP 4: South Shore



This zoom-in map of the south shore of Easter Island shows individual points with better resolution to observe where sea ramps, patios areas, and puna wells are located. From this map, we can see that the number of freshwater data points greatly outnumbered by areas with salinity higher than 9.0 ppt (potable).

Freshwater seeps on the North Shore were not as plentiful, but two of the three puna with sea wall we observed were located on this shore. La Perouse still appears to be in use by native people, and at least horses are utilizing the freshwater resources at Wildhorse Puna.

MAP 5: North Shore



DISCUSSION

of

SEA RAMP, PATIO, and PUNA WELL FEATURES

Now that we have established the basic visible characteristics of these features, we can examine their function and association with monuments and statues.

The material composition of the Island has barely changed on a geological timescale from the burgeoning of indigenous Rapanui culture to modern day. Easter Island is the resultant “build-up of three overlapping shield volcanoes” that erupted over nearly the same time span beginning with the main calderas seen today: Poike, Rano Kau – and, saving the largest for last – Terevaka (Vezzoli and Acocella, 2009). Shield volcanoes are characterized by their basaltic composition of fluid magma that creates a low profile but huge eruption, spreading outwards rather than building upwards, and creating “widespread fissural activity along the slopes of the shields” as it cools (Vezzolie and Acocella, 2009). The faulting and fracturing that occurs as the mantle shifts “enhance[s] permeability” of the existing and forming crust (Stober, 2000). With each consecutive eruption, rock deforms and produces fault breccias that increase the fracture permeability of the bedrock (Stober, 2000). On Easter Island, this process has manifested in a lava field of fissures in a “scattered rift zone” between the three shield volcanoes that form the Island (Vezzoli & Acocella, 2009). Understanding the geologic formation of the Island is interesting, but with a little knowledge of how the water table behaves in relation to geologic characteristics of volcanic islands, it becomes positively intriguing.

Groundwater follows the contours of the earth, favoring certain geologic layers more conducive to storing and transporting water (U.S. Geological Survey, 2016). On Easter Island, groundwater accumulates from precipitation over the entire island and collects in the calderas. Driven by gravity, this water then percolates through the soil and into the bedrock. As discussed in the OBSERVATIONS, scoria and fractured basalt both have a high porosity and permeability, making them in form and function ‘rock sponges’ (Jones, 2011). Layers of these highly porous rocks form underground aquifer channels transporting freshwater from the elevated inland area to low-lying coastline. Fissures formed by consecutive eruptions also function as channels, rapidly transferring water from higher elevations to the coast (Stober, 2000). The combination of Easter Island’s rock type and extensive fissures “defines the present-day network of water-conducting features” (Stober, 2000). As freshwater flows through this network and makes its way to the coast, it naturally continues to follow the curvature of the land till it encounters sea level. Because freshwater has a lower density than salt water it cannot percolate further down into the rock already saturated by the sea (Humphrey, 2016: personal communication). Instead, a temporary freshwater lens forms on top of the seawater (Panday et al., 1993: 321). The magnitude of this groundwater discharge has been shown on Hawaii using aerial infrared surveying (Johnson et al., 2008: 5). Though Hawaii has about 10,000km^2 more surface area than Easter Island, the subsurface hydrogeologic mechanics function similarly.

To access this lens before homogenization, prehistoric peoples needed some way to capture freshwater before it rapidly mixed with seawater. Due to compression of geologic layers from increased pressure causing structural stone vesicles to collapse, freshwater would be most readily available in the geologic layers closest to the surface (Humphrey, 2016: personal communication). With minimal effort, therefore, freshwater could be accessed by intersecting the shallow water table before it continued below the tideline, flowing into the ocean.

In order to be potable for humans, water cannot exceed 9 parts per thousand (ppt) salt concentration to water (Porterfield, 2013). Red blood cells in the human body contain roughly 9 ppt salt concentration (Porterfield, 2013). If fluid is added that has a higher salt concentration, water is drawn out of the cells and they creanate (Jensen et al., 2002). The kidneys also work in overdrive to flush out excess salt, and will eventually shut down if the concentration does not decrease (Porterfield, 2013). A cup of water, scooped from the water off Easter Island's coast, has a temperature of roughly 22-25 °C and salinity of 35.85 ppt salt to freshwater [≈36 g salt for every 964 g water] (Morage, 1999:715-731). Clearly, humans cannot consume this on a regular basis. However, as shown in MAP 2, seeps of freshwater with salinity lower than 9 ppt are coming from the Island at low tide. Tanya Zeferjahn's published results of our research show "the majority of freshwater resources are located along the coast and are dominated by coastal seeps" (Zeferjahn, 2015: poster). During our survey, we also noted *ahu* and *moai* were often present at the places we detected these seeps. In fact, "[s]ignificantly larger and fresher coastal seeps are associated with larger ahu or areas with multiple ahu" (Zeferjahn, 2015: poster). These coastal seeps also correspond to locations of sea ramps, ramps with patios, and *puna* wells that I was investigating individually. This connection between freshwater catchment features and the correlation of ceremonial statues with freshwater brings us to the discussion of what role each of these features and freshwater played in the Rapanui society.

Sea ramps were the most common freshwater catchment features we observed (**Models 1 & 2**). It is important to note that for all the features they have undergone centuries of natural and human disturbance so their appearance may differ from their initial construction. These sea ramp features, as seen today, led from the elevated shore into the ocean at high tide. At low tide they were entirely exposed, presumably to capture freshwater from the stones at the base (Hunt, 2016: persona communication). While these features may be continually seeping freshwater, they are most useful during low tide when the ocean isn't obscuring the groundwater output. Even though the productivity of these sea ramps is tidal-dependent, they would still be considered reliable sources because they are fed by groundwater. Groundwater is a product of the entire island and not dependent on singular rain events to contain freshwater like *taheta* or even calderas to an extent. On a daily basis, therefore, these sea ramps could be reliably counted on to provide freshwater. Their location would also make them ideal for people fishing, catching seabirds, or foraging for sea urchins and other creatures to quench their thirst without having to leave the hunting area. The sea ramps increased accessibility and reliability of freshwater sources during everyday life.

Puna wells with sea walls provide an even more reliable source of freshwater. These features are excavated into the ground allowing them to capture groundwater before it even reaches the ocean. The sea wall adds structure to the excavated ground and performs as a dam blocking water from continuing downhill to the coast, and instead forcing it to pool at the base of the *puna* ramp. Sea walls may also have protected the seeping freshwater from the salty spray of the ocean at high tide. On Hawaii, stone walls used to shield plants from the wind "may have resulted in a 20 – 30 percent reduction" in evaporation (Hunt & Lipo, 2012: 35). Hunt and Lipo extrapolate this may be the similar role of Easter Island *manavai* (structures used inland for growing small crops like banana, taro, and sugarcane) (Hunt & Lipo, 2012: 35). On the wind-buffeted shore of Easter Island, the sea wall of a *puna* may have served the same purpose to protect the preciously accumulated potable water from evaporating back into the Island's atmosphere. Salinities of freshwater tested at the base of one of these *puna* features was as low as 3.01 ppt. While this may still seem high compared to the salt concentration of pure freshwater (< 0.5 ppt), as Johnson et al. (2008) note on Hawaii, "coastal well waters are spatially located between the marine…and pristine high-elevation freshwater" so some level of salinity is expected (Johnson et al., 2008: 4). The collection and protection of freshwater provided by wells makes them viable sources at any time, as long as they are not overexploited. The additional energy to excavate a *puna* and build a sea wall, might led us to expect they would be located at the largest *moai* and *ahu* sites. However, there did not appear to be a strong correlation between *puna* wells and size of *ahu* and *moai*. Tongariki, as mentioned above, had a sea ramp instead of *puna* with a sea wall paralleling, and the *puna* well found at Wildhorse was closer to petroglyphs than *ahu* or *moai*.

Today, though, the only town settlement besides Hanga Roa, La Perouse, centers around the *puna* on its shore, indicating the *puna* is still important to modern native people. While I was documenting this *puna* feature, a dead horse being pulled from the water by a half dozen men and a backhoe. Dead horses are found all over the island, left to rot. The air of urgency to remove this one horse signified the water quality by this *puna* was more important than water elsewhere.

The third freshwater catchment feature observed was ramps with patio areas. These seemed to function the same as sea ramps, providing freshwater at low tide, but likely had a different role in society. In a few cases, namely Papa Vaka and the Modern Well location, a patio area wasn't observed, but may have been present in prehistoric times. Stones used to construct the modern well looked like those also used in the sea ramp and could have once composed the patio. The most preserved patio area was around the *puna* well at Akahanga (see **Figure 3**). Due to the implication that the *puna* may have provided for larger gatherings, patio stones may have been placed to decrease soil erosion immediately on top of the water source. Perhaps, patios were created for sea ramps and *punas* based on which were frequented most.

Each freshwater catchment type observed would provide for people during different activities, making each type essential to have for different purposes and occupying particular places in their use to Rapanui society. A sea ramp would serve for immediate reliable access for family groups or individuals. During a community gathering, a *puna* well would provide for larger groups of people to quench their thirst. Patios at either location would protect the ground immediately above the sea ramp or *puna* from erosion. The dispersed placement of these features over the Island would collectively affect cultural practices, settlement patterns, and the daily lives of Rapanui people.

DISCUSSION

of

CULTURAL IMPLICATIONS

Approximately 97.5% of all Earth's water is seawater, leaving merely 2.5% freshwater and only 1% of that available for human consumption (Bitton, 2014). This ratio makes freshwater a highly limited and highly valuable resource, particularly on an anhydrous island. Therefore, societal practices, culture, and the daily lives of indigenous people naturaly formed around this essential resource. Strangely, the sea ramps, patio ramps, and *puna* wells whose native name means "spring" have not been considered before more fully as the primary source of freshwater on Easter Island. Perhaps this reflects a case of preconceived European notions overshadowing indigenous knowledge.

Previously, the assumption that calderas, a spring at Rano Aroi, and taheta stones provided all the freshwater on Easter Island was widely accepted. At certain times of year (June – August) the spring at Rano Aroi seems like a sufficient water source. However, Rano Aroi is in fact a "minetrophic fen" that means the water coming from it has travelled through other rocks and minerals from a larger water source, in this case "the main island aquifer" (Aber, 2012; Margalef, 2015). Therefore, when the main aquifer that is a collection of groundwater drops below a certain level, Rano Aroi is no longer a functional spring. Taheta are

Figure 9 *Taheta*

another ephemeral water source (Figure 9). Hunt compares taheta to today's "drinking fountains" (Hunt, 2016: personal communication). They are perfect for on-the-go access, but not a significant source of dependable hydration.

This leaves the large calderas as the most obvious reliable source of freshwater. Scientists John Loret and John Tanacredi describe Rano Kao as the "primary source of drinking water on Easter Island" (Loret & Tanacredi, 2003: 115). However, problems exist with this assertion. The sides of the caldera are steep; loose rock held by frail roots makes the descent a scramble and ascent a climb. Once a person had reached the bottom to drink then climbed back up, they would be thirsty again! Gourds, which were "utilized as water-bottles or food-containers," were the only means of transporting water (Safford, 1921: 184). For long distances, prehistoric islanders had no way to carry significant amounts of water (Hunt, 2016: personal communication). All activities it was needed for would have to be done at the caldera or in close proximity. This includes both washing and drinking. Needless to say, not a good mix. If not extremely careful, this combination would almost inevitably lead to faecal coliforms and E. coli contaminating the majority of their drinking water (Moe, 1991: 308). The subtropical climate of Rapa Nui, similar to Hawaii, also provides an ideal climate for waterborne diseases to manifest in warm standing water (which would have accumulated in the calderas) (Mintz, 1994). It is difficult to say from archaeological and human remains whether waterborne diseases ever afflicted the Rapanui population, but it is possible not all the water gathered in the calderas was potable. Perhaps, the Rapanui people were able to access enough freshwater through the combined use of parts of Rano Raraku, Rano Kao, Rano Aroi when it was running, and *taheta* stones. If regular use of *taheta* for drinking water provided a main source, life would be continually fraught with uncertainty between rains, and certainly problematic during long dry spells. For the society to exist as it did, with time and resources to carve enormous statues, it seems there would have to be a larger more reliable source of potable water somewhere on the Island.

One of the earliest clues that points to sea ramps, ramps with patios, and *puna* wells as this missing source comes from Katherine Routledge's 1914 (p. 132) field journal. She recounts hearing the "curious statement of early voyagers that the natives were able to drink salt water" (Routledge, 1998; 132). While no descriptions of the landscape are given, "early voyagers" may have observed native people quenching their thirst at the base of a sea ramp descending into the ocean. Though this spectacle must have seemed nonsensical to foreigners of the parched volcanic island, this behavior might not be unique to indigenous Rapanui people. In the Bishop of Wellington's *Notes on the Maoris of New Zealand and some Melanesians of the South-west Pacific*, collected in 1868 during the exploration of New Zealand and what is now New Caledonia, he describes "the curious way in which they [the natives] get fresh water:"

> "Two go out together to sea, and dive down at some spot where they know there is a fresh-water spring, and they alternately stand on one another's back to keep down the one that is drinking at the bottom before the pure water mixes with the surrounding salt water." (Wellington, 1868)

Clearly, this behavior had been observed on islands before, but discovery of what it could signify had not reached explorers of Easter Island. Routledge may have been on the verge of placing these features rightfully in their place of Easter Island's cultural significance as she identified “fresh-water springs below high water” that sheep were utilizing for freshwater (Routledge, 1998;174). However, walls were quickly erected by ranchers to prevent the sheep from “injuring themselves” from the ingestion of supposed-saltwater, and the more-popular notion that *puna* served as boat ramps pervaded. Flenely may have been one of the greatest promostoes of the idea that these features were boat ramps as he recounts running over the Island’s terrain with a canoe on his back, looking for different “rock ramps” to launch from into the ocean (Bahn & Flenley, 1992). Not only did he personally use the *puna* as boat ramps for his small canoe, but he describes that the “paved ramps, which run into the sea…are generally seen as canoe-ramps, [or] places for large vessels to land or unload” (Bahn & Flenley, 1992). There is little evidence historically, though, of these “large vessels” or even smaller boats and canoes. In fact, for an island community, Rapa Nui curiously lacks a strong aspect of boating in their culture. Even today, people can still be seen fishing in the traditional way; standing on the cliff edge with string wrapped around their hand, using their entire arm as a casting road to send bits of pierced urchin out into the waves. Development of fishing methods such as this and the lack of boating culture on Easter Island may be due simply to the limited materials available to prehistoric peoples.

Easter Island was once forested with the largest species of palm tree in the world, *Paschalococos disperta* (endemic-to and extinct-from Easter Island), but palm “wood” is not ideal for building ocean-going vessels (Gurley and Liller, 1997; 82). It may be a lighter material, but the exterior is brittle and the interior soft and fibrous causing it to crack easily and disintegrate in water after minimal use (Hunt, 2015: personal communication). Even Thor Heyerdahl’s Kon Tiki expedition, intended to exemplify it was possible to drift from Peru to Polynesia, did not attempt to use palm wood and opted for balsa and bamboo (Alfred, 2008; 1). Without more evidence of boating in Rapanui prehistoric culture and lack of appropriate materials to build boats, it is unlikely the few boats islanders arrived with on Rapa Nui warranted the labor-intensive sea ramps and *punas* located in at least a dozen different areas around the Island. The correlation observed between these features and freshwater seeps suggests they served a much greater purpose in Rapanui prehistory, such as innovative structures for securing a reliable supply of potable water.

As previously discussed, fresh potable water is a limiting resource on any island, particularly Easter Island without any permanent running streams. To prevent people from constant problems of dehydration, some form of population control would need to be in place to insure there was enough freshwater to sustain a healthy number of individuals. Hunt and Lipo suggest the evolutionary mechanism of bet-hedging "limited the size of the population" to maintain a sustainable subsistence level on the Island (Hunt and Lipo, 2011: 134). Bet-hedging occurs when a society decides (most often subconsciously) to put their energy into something other than reproduction, like making and moving multi-ton statues, in order to maintain equilibrium with the environment and provide a more prosperous future for the next generations. Often times, the use of energy for monuments or art, referred to as "cultural elaboration," is perceived as wasteful. The opposite of this is true as seen on Rapa Nui where a large population would have required more water than the Island could provide and quickly driven all the inhabitants to extinction. The bet-hedging mechanism of expending energy in non-reproductive ways and relying on fewer offspring to be successful in environments with more plentiful resources is engrained in Rapanui culture by the tradition of *maoi*-making in order not to exceed the Island's resource potential. Freshwater is not the only limiting resource on the Island, but its utmost importance to human survival makes it a limiting factor of population growth and establishes a base line for population control mechanisms like bet-hedging to operate on. A cultural connection to the environment that this suggests goes against previous views on the Rapanui people as reckless ravagers of the land. Sea ramps, patio ramps, and *puna* can be seen as the portal of this connection as they were the link between the people and the most important resource on the Island, freshwater.

Not only does the freshwater accessed by sea ramps, ramps with patios, and *puna* wells suggest a connection between resources, people, and statues, but where these *puna* are placed also refutes the depiction of an ignorant indigenous population. As seen in other prehistoric societies – Egyptians along the Nile, Kalapuya of Willamette Valley – freshwater becomes the lifeline of society. Living areas naturally settle along its main artery and peripheral veins. Interestingly, a pattern of settlement immediately adjacent to water sources is not observed on Easter Island. A lack of *paenga* stones (house foundations) or *manavai* (gardening structures used to shield plants from the elements) around *puna* areas reveals their separation from these activities. By examining case studies of other civilizations that chose to live close to, or even on top of, their water sources the issue with such easy accessibility becomes clear: contamination. For example, on the Philippine Island of Cebu, "pit latrines and communal bath and laundry activities near water supplies create[d] conditions with a high potential for groundwater contamination," which eventually did make the water non-potable (Moe, 1991). The potential for contamination is also increased when the water table is shallow or near to the surface (Vacher & Quinn, 2004). In Cebu, this became apparent as shallower wells were much more likely to carry faecal coliforms, bacterial *Escherichia coli*, *Enterococci*, or *Faecal streptococci* (Moe, 1991: 308). Whereas deeper dug wells provided purer water that the byproducts of human waste had yet to percolate through the soil and pollute (Moe, 1991: 308).

On Easter Island where the groundwater lens is shallow, contamination could have easily occurred if the people were not careful. Archaeologist Sue Hamilton describes how “houses and rock gardens of the interior” parts of the Island often times were in sight of an *ahu* or *moai*, but were an entirely different “interface” of the Island (Hamilton, 2013). The “interfaces” which she uses to describe the Island in different sections, insinuates the living areas were quite separate from the *ahu* gathering areas, and supports the idea people did not want to live too close to their water source in case of contamination (Hamilton, 2013). While precautions to avoid contamination may have controlled settlement patterns, it likely did not limit accessibility. The visible proximity of living areas to the *puna* sites (no more than one to two kilometers) would still allow entire families, fishermen, seabird hunters, or workers thirsty from erecting 60-ton *moai* to use the sea ramps and *puna* easily on a daily basis. During ceremonies when dispersed groups gathered around the *moai* and *ahu*, the *puna* would become an essential element of the ritual by simply providing water for the community so they were not forced to disperse to the calderas for freshwater whenever thirsty.

Puna have been a feature of Rapa Nui as long as native memory extends, back through the folklore of generations. They appear in the forms of stone ramps, sometimes with a patio-like area, sometimes with a wall at the base, and sometimes descending into the sea. While their appearance is dramatic amid the dry grasses of the Island, their function in Rapanui society may be even more drastic. On an island lacking permanent running streams, freshwater becomes the most valuable commodity to survival. Due to its intrinsic importance, prehistoric societies naturally form their settlement patterns, cultural practices, and daily lives around water.

CONCLUSION

Deep understanding of the natural landscape would have been required for the Rapanui to know where to build sea ramps, patio ramps, and *puna* wells to unlock the freshwater supply kept in the Island's geologic layers. As discussed, the geologic complexity of the Island and movement of freshwater through it is not a simple process. Building *puna* and sculpting of societal practice to sustain the resource availability gives additional support to the hypothesis Rapanui people were in tune with their environmental resources. Narratives of demise and deceit fueled by statue worship disrespect the environmental stewardship practiced by prehistoric Rapanui.

In terms of freshwater resource, Easter Island should not be used as "a parable for our current global crisis" as Diamond or Bahn & Flenley suggest, but as an example of how to live in equilibrium with limited resources (Hunt & Lipo, 2009: 601-616). Techniques of prehistoric peoples' population and resource management allowed them to thrive in equilibrium with an environment most people today would deem unlivable. While technology has advanced so freshwater, or a lack of it, no longer has control over population size or living patterns this research could still be employed to aid in repairing the cultural genocide of Rapanui people by European assumptions.

The greatest asset of the Rapanui people that allowed them to establish life on the most isolated island in the world was their connection to nature in the creation, culture, and practices of their society. They understood natural resources are the controlling factors of environmental and human health, not human desire. To be successful in a world of limited resources, we must shape our societal practices around the resources available, not expect them to bow to us. Easter Island is not a lesson about ignorant resource abuse, but a lesson to be taken by the rest of the world of how to live in equilibrium with our environment. Using Rapa Nui to see our own reflection rather than reflect our evils, we have two choices: to adopt an understanding of the importance of natural resources as an intrinsic aspect of our culture and allow our future innovations to be shaped around it not us, or ultimate demise.

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