The ‘walking’ megalithic statues (moai) of Easter Island

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ABSTRACT

Explaining how the monumental statues (moai) of Easter Island were transported has remained open to debate and speculation, including their resource expenditures and role in deforestation. Archaeological evidence including analysis of moai variability, particularly those abandoned along ancient roads, indicates transport was achieved in a vertical position. To test this proposition we constructed a precise three-dimensional 4.35 metric ton replica of an actual statue and demonstrate how positioning the center of mass allowed it to fall forward and rock from side to side causing it to ‘walk.’ Our experiments reveal how the statue form was engineered for efficient transport by a small number of individuals.

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1. Introduction

The ancient Polynesians of Easter Island carved nearly 1000 massive statues (moai) from volcanic hyalotuff bedrock and transported about 500 along roads traversing a rugged landscape to monumental sites around the island, some as far as 16–18 km distance (Fig. 1). The largest of these statues is over ca. 10 m tall, weighs approximately 74 metric tons and was moved over 5 km. Early European visitors and later researchers have assumed moai carving and transport required a large labor force, a correspondingly large population, and a substantial expenditure of natural resources such as agricultural surplus and trees for rollers or other transport devices. The notion of an irrational statue cult fueled by overpopulation and overexploitation of resources has formed foundations of arguments for “ecocide” and seemed to provide a coherent model for Easter’s prehistory (Diamond, 2005, 2007). However, recent research and new evidence calls into question the longstanding notions of “ecocide” and population collapse before European contact (Hunt and Lipo, 2011).

Understanding the role of carving and transporting hundreds of multi-ton moai remains central to the island’s prehistory. In this paper, we draw on detailed analysis of ancient statues ($n = 961$ total; see Torres Hochstetter et al., 2011), with a focus on those abandoned along roadways (Lipo and Hunt, 2005; $n = 62$ statues; see Table S1) during their transport. Based on our research, we show that movement in a vertical ‘walking’ motion explains systematic variations in moai found in the quarry, on ancient roadways, and those found on platforms (ahu). To test a proposition for vertical transport, we used a precisely scaled five-ton road-statue replica and show experimentally how relatively few people achieve movement in a ‘walking’ motion. Our new explanation of statue transport accounts for systematic variability in the statues and highlights the remarkable engineering skills of the prehistoric Easter Islanders.

2. Previous investigations

The question of how the multi-ton moai of Easter were transported has puzzled visitors and researchers for centuries. No visitors to the island ever witnessed the process, leaving much to an array of speculations. The islanders’ oral traditions have long recounted that the statues ‘walked’. Thomson (1889), for example, was told the statues were “endowed with power to walk about in the darkness.” Metraux (1940: 240) recounts, “the huge blocks
walked for a distance and then stopped.” However, oral tradition offers no detailed explanation of how this ‘walking’ was achieved or to what degree it was meant metaphorically.

Modern experiments began with Heyerdahl’s efforts in the 1950s, including simply dragging them (Heyerdahl, 1989). To resolve problems of friction and damage to statues, later efforts employed wooden sledges, pods, rollers, and sliders in various configurations. Among those proposing use of wooden devices, the debate focused on whether statues were moved in a horizontal or vertical position (Love, 1990, 2000; Van Tilburg and Ralston, 2005). In contrast, Pavel (1995); Heyerdahl et al. (1989) attempted to move a statue in a vertical position using only ropes and padding in a fashion in which the statue was “wiggled” from side to side. While more realistic than horizontal arrangements, his attempt met with limited success given the statue’s unsuitable form, vertical instability, and great friction quickly causing damage to its base. The most recent attempts have employed a wooden sledge with moai in horizontal (prone or supine) positions pulled over logs in a sliding motion (Van Tilburg and Ralston, 2005). A conclusion favoring horizontal movement of moai in prone or supine positions on wooden sledges slid over logs has seen some favor, appearing to fit the assumed impact the statue cult played in the island’s deforestation (Diamond, 2005, 2007). While experimental attempts highlight the plausibility of methods that could have been used to move statues, they have overlooked systematic variation in the statues and their broader context in the archaeological record.

3. Roads and statues

Despite longstanding questions of how statues were moved, surprisingly little attention has been paid to the archaeological record directly related to transport or variability in the statues. In 2004, we undertook a study of prehistoric roads constructed as paths for the transport of moai (Lipo and Hunt, 2005, Fig. 1). First noted in 1917 by Routledge (1919), these paths form linear features approximately 4.5 m wide extending out from the quarry at Rano Raraku. Over 25 km of these roads remain visible on the landscape and in satellite images (Lipo and Hunt, 2005). These roads provide direct information about some of the physical parameters necessarily involved in statue movement. For example, a long stretch of moai road along the south coast has uphill gradients as steep as 13° with an average of 2.9°, and downhill slopes of 16° with an average of 2.8° (Fig. S1). Excavations of segments of the moai roads by Love (2001) also show that the roads are concave in cross section, a configuration that largely rules out use of transverse rollers.

Inline Supplementary Fig. S1 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

During field research on moai roads, we documented 62 statues located on and parallel to road features (Table S1). These moai can be explained as those in the process of being moved, but transport failed and they were abandoned. The explanation relies on several lines of evidence. First, the statues lay in a direction parallel to the road direction that runs away from the main quarry at Rano Raraku,
an orientation consistent with transport. Second, these *moai* are not associated with platforms (*ahu*) where they would be erected at their destinations. Third, like the statues remaining at the quarry, none had eye sockets carved in them, in contrast to those erected on platforms. Prehistoric islanders inserted into these eye sockets coral “eyes” with obsidian or red scoria pupils. As with the crowning of red scoria hats (*pukao*) for many statues, adding the eyes was a final step in completing *moai* with emplacement on platforms. None of the road statues in our analyzed set has these eye features, defining their incompleteness and status as in transit when abandoned.

The statues found along the roads have shapes that also distinguish them from those statues erected on *ahu*. The road *moai* have statistically wider bases when measured relative to shoulder width than *ahu moai* (Fig. S2). Once statues arrived on platforms, prehistoric carvers modified the statues to decrease the width of the base relative to shoulder. In addition, while *ahu moai* stand in an upright fashion with their mass located well over their base, road *moai* show a distinctive angled base that would cause the statue to lean significantly forward, often more than 10°. Indeed such forward lean means that most could not stand upright on their own. The reduction of the base width is thus related to changing the vertical orientation of the statue from a forward lean to a more stable upright position (Fig. 2).

Inline Supplementary Fig. S2 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

Finally, three additional observations of the road *moai* inform on their transport. Thirty-seven percent of road *moai* are broken into two or more fragments consistent with breakage that resulted from falling from a vertical position (e.g., Fig. S3). In addition, on the south coast road are two examples of *moai* that did not break and were partially buried at their base and can be explained by ancient workers who attempted to re-erect them by excavating a pit to restore them to an upright position to be ‘walked’ out on a ramp (e.g., Figs. S4 and S5). Second, 70% of road *moai* exhibit evidence of fracture caused by force being applied in inverse vertical fashion along the lateral edges of the base. These fractures form broad shallow concave scars from which a wide pressure flake was removed. Third, the positions of fallen statues are statistically non-random (*p* < 0.05) with respect to the slope on which they lay (Table S2). The majority of statues are found facedown when the road slopes downhill, and often on their backs when going uphill.

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**Fig. 2.** Differences between road *moai* (in transit) and those modified *moai* found at *ahu*. Road statues have a distinctive forward lean that places the center of mass close to or slightly over the front edge. In addition, shoulder width relative to the width of the base is close to 1.0 giving the statue a lower center of mass. *Ahu moai*, in contrast, have a center of mass closer to the center of base. Shoulder widths for *ahu moai* tend to be wider than the base width, making the statue more top-heavy.
Inline Supplementary Figs. S3–S5 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

These road and statue observations are explained by the hypothesis that moai were transported in a standing position and some fell en route. Significantly, hypotheses for horizontal transport using wooden devices cannot account for these archaeological observations. Moreover, the field evidence clearly shows that statues were lowered down into trenches from their quarry bedrock sources above to the base of Rano Raraku where their backs were completed and other details carved, and then moved upright out of these trenches remaining in a vertical position, including their final placement on ahu (Fig. 3). Otherwise, the logistics of lowering and later raising tall multi-ton moai make little sense and imply they remained vertical. Statues found along the

![Diagram of quarrying and positioning of moai](image)

Fig. 3. Quarrying and positioning of moai. (A) On the upper slopes of Rano Raraku, an extinct volcanic vent, bedrock hyalotuff is carved into a moai. The figure is usually shaped from the top down leaving a narrow ‘keel’ connecting it to the bedrock. (B) To move the statue from its quarried location, carvers broke the keel and slid the moai downhill. Moai were then placed into standing positions in pits excavated near or at the base of the slope. Here, carvers finished removing material from the back of the moai and prepared statues for movement. (C) Statues were ‘walked’ out of the pit through excavated openings to moai roads. (D) Not all statues were removed from pits; many were left and following sedimentation only the heads and shoulders of these are now visible on the quarry slopes. Statues were moved along road features (E) that were prepared in advance. These roads often have a concave shape that matched the arc of the front edge of the moai base. The concavity of the roads provides constraints to keep the statue moving in the intended direction. Occasionally, the roads have stretches of “curbstones” (F) that line their edges. These stones may serve to keep sediment from filling in the concave roadbed. Along the roads are found examples of statues that failed in transport (G). These are often on the sides of roads demonstrating that the roads are realigned for statue transport as needed. Roads are kept relatively flat through the infilling of low areas and (H) and carving through hills and ridges. Once at their destination statues are walked up temporary ramps made of stone (I). The remains of these stone ramps were often used to form “wings” on the lateral edges of the platform. Upon reaching the top of the platform, the moai then are turned 180° (J) to face the ceremonial area that lay in front of the ahu. The moai are complete once they are reshaped to make them stand upright and their eye sockets are carved for coral insets.
roads that fell during transport were often not re-erected given breakage or the difficulty of raising them. However, the question arising from Pavel’s (1995) attempt at vertical transport remained unanswered: how would damage to the statue base from friction be minimized? If a short distance of vertical transport (in ‘wiggling’ or ‘shuffling’ as Pavel did) significantly damages the base, it seems improbable that the statues could have been moved several kilometers without causing catastrophic damage.

4. Evaluating the ‘walking’ moai

To address detailed problems of statue transport, we constructed a three-dimensional model of an actual road moai (Fig. 4). The original moai (12–220-01) is located along the ancient roadway on the south coast of the island and is 7.35 m in height and 2.83 m in width. It had been transported ca. 3.54 km southwest from the Rano Raraku quarry before it fell on its back intact on an uphill slope of a south coast moai road.

The 3D models of moai allowed us to measure the center of mass along each of three spatial dimensions. The center of mass was located in the middle of the statue in terms of its width as the statues are generally left/right symmetric. The height of the center of mass is also approximately in the center of the statue, midway between the base and the top of the head. But the center of mass in the depth dimension is remarkably forward relative to the base of the statue. This peculiar configuration cannot be explained by a hypothesis of horizontal transport. In horizontal transport, one would expect to find the center of mass toward the base to facilitate raising the statue back up to its vertical orientation when placed on the ahu.

The 3D model provides a means of evaluating how forces acting on it would result in motion. Like other road moai, this statue has a distinctive forward lean and exhibits flaking on the lateral portions of the base. The plan view shape of the statue’s base is also like other road moai with a dorsal edge is relatively straight and a ventral edge is broadly rounded. This rounded front edge is shaped in such a way that it provides a continuous surface across which the statue can roll as it is tilted from side to side.

Inspection of the 3D digital model revealed that the moai would not stand upright on its own. For the moai replicated, like others that were in transit, the center of mass is positioned just over the point of the front edge and standing the statue on its base would cause it to tip forward. Modification of the base for standing on an ahu, therefore, would have been necessary had the statue reached its destination, explaining the difference in the base to shoulder ratios we document.

The basal flaking and forward lean point to how the statue was ‘walked’ in an upright position without significant wear to the base caused by twisting on its basal surface as in Pavel’s earlier attempts. Rather than twisting in place, moai were tilted to the side and allowed to roll forward in the direction of their lean. With a slight tilt to the side, the statue then falls forward toward its inherent front lean. As it falls, the moai rolls across its front edge and rotates slightly to the opposite side. In this way, friction between the base and the ground is minimized allowing for the conservation of energy, increasing overall efficiency and removing the potential for damage as the statue ‘walks.’

The difference between road moai and those that reach their ahu destinations is significant, though previous experiments overlooked the systematic variations. Van Tilburg and Ralston (2005), for example, created a “statistically average moai” thereby masking statue variability and modeling transport by confounding forms designed to ‘walk’ versus those modified to stand erect on ahu platforms. Significantly, a “statistically average moai” replica would not be capable of transport by ‘walking’ since the vast majority of statues were prehistorically modified to stand stably on platforms.

5. Demonstration of moai ‘walking’

To test the dynamics of motion and the practical constraints involved with walking a moai, we constructed a scaled replica of a size sufficient to represent real-world challenges in moving these monumental figures. Despite previous experiments, ours is the first use of a precise proportionally scaled replica of an actual road moai shaped appropriately for transport, rather than standing erect on an ahu.

Fig. 4. 3D model of a road moai reconstructed using structure from motion algorithms in Microsoft Photosynth. The first step involves taking uncontrolled overlapping photographs of the moai from as many points of view as possible. Second, the photos are synthesized to form a single representation of the moai surface using Microsoft Photosynth. The 3D models are constructed using point cloud data extracted from the completed photosynth.
In four days of field trials in June and November of 2011 at Kualoa Ranch, Hawai‘i, a team of volunteers experimented with placement of ropes (100 hemp), cooperative tactics, and other logistical details (Fig. 5; Video S1; Figs. S6–S10). Initial vertical placement of the replica using a crane confirmed that the moai could not stand on its own without inserts under the front edge sufficient to tilt the center of mass back over its base. ‘Walking’ the replica statue demonstrated that road moai can be moved efficiently and with minimal friction and resulting wear (Fig. 6). The statue’s shaped features are integrated into the range of motion enabling ‘walking.’ Using the fewest inputs possible, we found that three ropes attached around the statue’s head were sufficient to initiate forward motion. We attached one rope near the top of the head at the eyes of the moai and stretched it behind the direction of travel. This rope kept the statue position leaning slightly forward on its front edge, preventing it from falling too far forward. Tied to the same location at the eyes, we stretched two additional ropes perpendicular to the statue’s direction of travel. These lines were pulled in alternating fashion to ‘rock’ the statue from side to side. As the statue began to rock, it rolled forward along its front edge. Each roll caused the statue to take a ‘step.’

Supplementary video related to this article can be found at http://dx.doi.org/10.1016/j.jas.2012.09.029.

Inline Supplementary Figs. S6–S10 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

When the center of mass is positioned in the center of the statue in the vertical direction, rocking the statue back and forth is relatively easy: the taller the moai, the greater the leverage enabling handlers to initiate its rocking. The width of the statue and the elongated head provides the statue the lateral stability and shape similar to a bowling pin. With such a shape, the statue we modeled can be tilted laterally as much as 26° from vertical. The tilting to each side provides clearance on the opposite base edge for steps to be taken in an uphill fashion. By tilting the statue to one side, we could lift a lateral edge over 60 cm in height before the statue would fall sideways. The degree to which the statue can be tilted to the side provides the clearance necessary for the moai to climb uphill as well as provides the dynamic energy involved in each step. Downhill motion was also demonstrated, though we did not explore the potential for moving the statue backwards while descending steep slopes (although no direct archaeological evidence suggests this was attempted).

Describing the moai movement as ‘walking’ is conceptually consistent with our own pedal locomotion. Statue ‘walking’ and our own steps represent mechanics that can be modeled an inverse pendulum: a simple pendulum that is turned upside down so the mass swings back and forth from a fixed base. Pendulums conserve energy and can remain in motion for some duration as long as there is minimal friction during each swing. When moving to walk forward, one pivots on their foot placed on the ground. From that pivot point, our center of mass—located along the vertical centerline of one’s belly—follows the path of an arc as we lift our opposite hip and swing a leg forward. One’s forward foot eventually hits the ground and the arc slows to a stop in that direction. At that point kinetic energy is at a minimum, but potential energy on that side is at a maximum. As one falls forward into the next step, potential

Fig. 5. Scaled 3 m tall, 4.35 metric ton moai-replica ‘walking’ with teams handling three ropes at Kualoa Ranch, Hawai‘i. Using a mold created from the 3D model, the replica is formed of a density-corrected concrete and retains the same mass configuration as the road moai on which it is based.

Fig. 6. (A). Moai movement propelled by forward lean and side rocking using three ropes; solid lines with arrows show force of ropes; dashed lines show directions of movement. (B). Overhead view of moai walking motion.
energy is converted back into kinetic energy, and continues to move forward. This is the basic physics of walking.

Moving large moai takes advantage of the same principle. During forward movement the statue tilts sequentially in opposite directions. The transfer of energy back and forth, however, does not involve the high friction “wiggle” motion as proposed by the Pavel (1995) method. Rather, road moai are designed so that when the statue rocks from one side to the other it also falls slightly forward and rolls across its front edge. In this way, once the moai is set in motion it efficiently maintains the energy invested in the initial tilting. Energy is smoothly converted from potential energy at the point of the statue’s greatest tilt to kinetic energy as it swings back to the other side. Through this rocking and rolling motion, the statue takes incremental steps and moves forward. Once in motion, relatively small amounts of energy must be added to the system through gentle tugs on opposite sides.

This system of transportation is only possible, however, because the statue is shaped to move in this fashion. Two factors are essential. First, the statues must lean forward so that they fall forward and any rocking motion also results in the statue rolling on the front edge. Second, the statue bases must be shaped in a way to provide an edge across which the statue can roll. The outlines of the bases for road moai have a flat back edge and distinct rounded front edge (Fig. S11). Once moai reached their final locations, however, prehistoric reshaping was necessary to allow them to stand upright in a stable fashion on their constructed stone platforms. Consequently, completed statues at the ahu could no longer be ‘walked.’

Inline Supplementary Fig. S11 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

‘Walking’ the moai was achieved by creating inherent instability with its forward lean. In transit, statues would not be able to stand on their own, and without ropes or left stationary, they required stones, for example, wedged under them to balance the center of mass. This observation seems to explain stone arrangements discovered in excavations at the bases of moai on roads (see Heyerdahl et al., 1989; Richards et al., 2011). Thus, moai left standing along roads would have been highly unstable and prone to fall without significant further modification of their form.

This observation rebuts early (Routledge, 1919) and recently elaborated (Richards et al., 2011) speculations that road moai are not fallen attempts at moving a statue, but deliberate placements that mark a ritual path. The notion of a ritual path, however, bears no impact on the issue of how the statues were transported, since it has no direct empirical implications. Nor does such speculation explain why road statues have their characteristic shape and lack eye sockets as found in all ahu moai. Indeed, the presence of stones near the base of some of the road moai locations is easily explained as relating to the process of transport. Since few statues could have been moved from quarry to ahu in a single day, most would have had to have been left standing between moving efforts. With the instability inherent in the shape of statues and the relatively soft ground, this situation would have required stabilization around the base as has been noted in excavations.

In our experiments, remarkably small teams were easily able to initiate ‘walking’ the 4.35 metric ton road statue replica. Even with our limited practical experience moving the statue, a minimum of only 18 people could achieve ‘walking.’ The lower limit for the number of individuals derives from the number needed on the sides to initiate rocking. The greatest initial energy input is the initiation of rocking of the statue from a static upright position. We achieved this with four individuals on each lateral rope. Once the statue began rocking, however, relatively little input was required from each team of lateral rope handlers as the statue motion conserved energy in its repeated transitions from kinetic to potential to kinetic energy. Ten people were needed to maintain the rear rope allowing the statue to lean forward, but not fall to the ground. We were also able to easily ‘walk’ the statue uphill and downhill slopes as great as 6°, turn and change directions, as well as rotate the statue 180°, requiring little, if any, more space than its own base. While several near-falls were averted by quick cooperative action of the rope handlers, we did drop the statue (face-forward) several times and re-positioned it vertically using a large hydraulic crane. It would have been impossible to resurrect the statue by the handlers using ropes alone. The great difficulty of raising a fallen statue may explain why so many were abandoned along the roads even though they were not broken.

The ‘walking’ covered ground rapidly. In one continuous effort we were able to move the statue about 100 m in just 40 min. In contrast, Heyerdahl et al. (1989) estimated that a highly experienced crew might “wiggle” a moai 100 m in a full day. The relatively rapid rate we achieved in ‘walking’ suggests that statues could have been moved several kilometers across the island in only a matter of weeks or months. It also follows that investment in statues was likely a part-time effort requiring relatively small groups of people.

While large, our experimental moai replica is slightly smaller than the mean size for statues across the island (ca. 4 m). Many examples of moai that were successfully moved are much larger, with the largest moved measuring about 10 m in height. Unlike methods of movement using sleds, however, the ‘walking’ transport method scales well as statues get larger. Larger statues would also be taller, thus providing proportionally greater leverage for the rope handlers on the sides. At the same time, taller statues become narrower overall and have increasingly longer and thinner heads relative to their bodies (Figs. S12 and S13). This “bowling pin” shape not only gives moai their characteristic look, but it also means their volume is decreased more than if they were scaled proportionally in all dimensions and had a lower center of mass. Each of these features reduces the effort that is required to tip the statue enough to initiate its rocking and thus ‘walking’ motion.

Inline Supplementary Figs. S12 and S13 can be found online at http://dx.doi.org/10.1016/j.jas.2012.09.029.

Indeed, the larger the statues, the less likely they could have been moved in any way other than ‘walking.’ The fact that statues get thinner with longer heads means that they become more fragile and prone to breakage at the neck, as evident by frequent neck breaks among the fallen road moai. Transporting large statues in a horizontal fashion would put stress on the weakest point of the statue. The hyalotuff that composes the statues is a relatively low-density material (Gioncada et al., 2011) that has good compressive strength, but low shear strength. Thus, while vertical objects can be successfully made from the hyalotuff, horizontal shapes would be more prone to breakage. Even greater stresses would be placed on moai if they also had to be levered up to a vertical position after transport. In this way, the shapes of the road moai are clearly inappropriate for transport methods other than ‘walking’ upright.

6. Conclusions

The successful transport of hundreds of multi-ton statues on prehistoric Easter Island has puzzled observers for centuries. Modern research has focused on attempts such as hauling statues in horizontal positions on log contraptions with accompanying rollers or sliders. Significantly, such efforts have ignored systematic variations in moai form. Statues were designed for movement and those fallen on roads would have been further modified had they reached their destinations at ahu. Moai patterns of breakage and wear, and positions on roads relative to slope are also explained by a hypothesis of vertical ‘walking’ transport. As our research and experiments illustrate, these observations explain the archaeological record for how the statues were moved.

In contrast to popular notions of sledges, rollers or sliders of trees, the evidence shows that moai were specifically engineered to ‘walk’ in an upright position achieved using only ropes, human labor, and simple cleared pathways. A relatively small number of people are capable of moving a statue: just 18 rope handlers could ‘walk’ a statue weighing more than 4.35 metric tons. The statue evidence does not imply that a large population once existed on Easter, contrary to earlier and now popularized notions (e.g., Brown, 1924; Diamond, 2005, 2007). Apart from labor and engineering expertise, statue transport required only ropes; few if any trees were required in statue transport. In fact, the primary vegetation on the island was the now extinct palm, *Jubaea chilensis* or a close relative, and given palm structure would likely not have been suitable for use in building contraptions or making rollers that could support a great amount of weight. Material for ropes, however, was abundant on the island as they were made from a woody shrub (*Triumfetta semitrioba*) that grows in disturbed habitats, see Metraux, 1940. Consequently, statue making and transport cannot be linked to deforestation, nor can forest clearance for extensive cultivation of agricultural surplus to feed thousands of statue workers, as some have supposed (see Diamond, 2005, 2007; Van Tilburg and Ralston, 2005: 299). The evidence for moai carving and transport points to activities by small-scale social groups rather than the product of laborers unified under a powerful centralized chiefdom. Here monumentality does not imply large-scale social organization as assumed for many cases worldwide. Instead, we see moai carving and ‘walking’ as vivid expressions of costly signaling and evolutionary bet hedging in a competitive environment. Multiple lines of evidence, including the ingenious engineering to ‘walk’ statues, point to Easter Island as a remarkable history of success in a most unlikely place.

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### Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2012.09.029.

### References


