An exploratory survey method for archaeoastronomy, applied to standing stones at the hauviri and taputapūatea maraes, Ra’iātea

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There is a surprising lack of archaeoastronomical research in Polynesia (Kirch, 2004: 102; Esteban, 2002: 31), and given its vast area, a need for exploratory surveys that can be done quickly and inexpensively to identify sites that warrant closer attention. Where equipment cost and bulk are not constraints, a wide range of options is available for carrying out archaeoastronomical surveys (Prendergast, 2015; Uren and Price, 2010). However, at the low cost, low bulk and personnel end of the spectrum, options are more limited, especially where relative positions of objects and the azimuths between them are important. The objectives of this article are twofold. First, to report on a field trial of a survey method aimed at situations that require good relative positions of objects and good azimuths but only approximate absolute positions of sites. Second, to use the data generated in an exercise to test for possible significance in the placement of standing stones. The case studies chosen were the Taputapuātea and Hauviri maraes in the Opoa district of Ra’iātea, in the Society Islands. An inexpensive, time-efficient, single-handed survey was carried out in November 2014, which has yielded a data set that benchmarks stone positions at that time, is capable of fairly accurate azimuth comparisons, and is sufficiently rich to be mined in different ways in subsequent research. At present, only qualified conclusions are possible, principally because the study has not yet been well-enough situated within a cultural context, such as oral histories, but the survey method nonetheless underwent a fair trial at two sites.

The resulting data set was used to test three hypotheses, namely:

i) Stones line up with voyage destinations, or commemorate significant voyages.

ii) Stones form an analogue “star compass” of directions where significant navigational stars rise and set. In other words, stones form an analogue layout of stars when they are close to the horizon, which could occur at different times of day or night and spread throughout the year.1

iii) Stones line up with important stars at a significant epoch of the year, for example, at a particular time on the day of an important festival. In this kind of “freeze-frame” or “snapshot” scenario, stars could be at differing altitudes (i.e. angles above the horizon), not necessarily rising or setting.

1. Grounds for the hypotheses

Six reasons provided a rationale for testing the above hypotheses. First, in Polynesia there is some consensus about stones being positioned in the direction of significant stars and asterisms (i.e. star groups), or at times in the direction of important islands. For example, Lewis tells us of Te Atibu ni Borau, “The Stones for Voyaging” on Arorae, in the Gilbert Islands, which were probably used to align canoes about to set off on voyages (Lewis, 1994: 363–8). Similarly, stones on Butaritari (pp. 368–9), and the Hangai ‘Uvea stone (which means “facing ‘Uvea”) on Niuatōfiga in Tonga, (p. 370), Kirch et al. suggest that the placing of the Pu’u Pimoe cinder cone2 may have had a significant linkage with the Pleiades (Kirch et al., 2013: 60), and Ruggles points to instances where alignments are plausible as well as to others for which greater caution needs to be exercised (Ruggles, 2015: ch215). Similarly, Chauvin writes of a number of tantalizing yet inconclusive astronomical alignments surrounding ahu ‘altars’, petroglyphs, boulders and heiau ‘temple platforms’ in Hawaii (Chauvin, 2000: 117–123), and Esteban reviews results that have often been marginal but where at times it has been possible to conclude that alignments could have been deliberate (Esteban, 2008). Malo gives two configurations of heiau in terms of the cardinal directions, which carried implications for the direction in which audiences faced (Malo, 1903: 213). These experiences, although tentative, are sufficiently compelling to justify further surveying and testing of standing stones in Polynesia, where studies have been “few and unsystematic” (Esteban, 2002: 31). Taputapuātea is especially worthy of attention since Emory singles it out as being the only recorded instance of a marae’s ahu ‘being at right angles to the sea and, moreover, “lying exactly (according to hand compass) north and south” (i.e. magnetic), so that it “may have been purposely oriented” (Emory, 1933: 34). Liller argues that “the most important marae, heiau and ahu will be the ones that were more divinely oriented”, and also singles out the Taputapuātea marae as deserving special study (Liller, 2000: 137). He wonders if the perpendicular to the ahu wall could have been “purposely directed towards the rising point of a certain star at about azimuth 96.3°” and speculates about stars in Orion (Liller, 2000: 147).

Second, there is widespread agreement about stones/pebbles being
used to teach navigation lore, even today. For example, Lewis writes:

“The navigator attains his knowledge of the bearings of etak islands through studying the little diagrams of islands and stars that are shown by pebbles on the canoe house floor during his years of instruction” (Lewis, 1994: 179). Finney describes how Stephen Thomas in the 1980s was instructed by a navigator placing small lumps of coral on a woven mat (Finney, 2006: 159, 171). On the Woleai Atoll, Caroline Islands, Alkire writes that “The navigator instructs his student by placing small stones on the ground or on a mat before them” (Alkire, 1970: 41). Perhaps significantly, on Woleai “the stones are laid out in a rectangle rather than a circle”, and the way that the teaching takes place is that first, only stones denoting the rising stars are laid out on the ground, and then the process is repeated with setting star directions (Alkire, 1970: 47, 49). Gladwin also observed and photographed navigational training with carefully placed pebbles on the mat covering the canoe house floor on the Puluwat Atoll in the Caroline Islands (Gladwin, 1970: 129). It is of interest that pebbles “usually represent stars, but they are also used to illustrate islands” (p. 129). Alkire gives us an island chart for Woleai (Alkire, 1970: 45). It is not a huge stretch of the imagination to wonder whether people familiar with pebbles representing significant stars and islands on a mat, might position stones on a marae according to a similar logic. While in no way being conclusive, this helped to justify surveying and testing the Taputapuātea and Hauviri stones.

Third, there are grounds for supposing that some ceremonies could have been made to coincide with astronomical circumstances. Ruggles suggests that “certain sacred ceremonies, performed at particular heiau, were scheduled in relation to observable astronomical events” (Ruggles and Urton, 2010: 295). This lends weight to the idea of investigating a freeze-frame/snapshot at a significant epoch or epochs in the year when sacred ceremonies might have taken place.

Fourth, both stars and standing stones were associated with ancestors. With regard to stars, Best writes, “... ever in the native mind ... was the idea of associating the star or planet with the past, with remote ancestors ...” (Best, 2002: 4). Ruggles writes that in Polynesia, asterisms were “frequently associated with gods, culture heroes, ancient home- lands, or local chiefs” (Ruggles, 2015: 2236). With regard to standing stones, Emory (1933: 17) quotes Andia Y. Varela as writing: “... although some of these stones remain vacant they pertain to the deceased fathers and ancestors of these [personages] and nobody may seat himself against them.” Again, since both stars and standing stones were linked with ancestors, it does not beggar belief to imagine that ancestral stones could have been positioned according to familiar star layouts from navigation training exercises. In other words, that standing at a particular spot on a particular day of the year, both the standing stone and the star associated with an ancestor would be approximately in line. As always, conclusive proof is problematic, especially where there is a paucity of oral traditions describing astronomical observations (Ruggles, 2015: 2239). Such a cultural strand is increasingly important in archaeoastronomy which, following its emergence as a sub-discipline in the 1960s and 1970s, has since matured in respect of embedding purely astronomical explanations in a wider cultural context (Ruggles, 2015: 353). Certainly, in Pacific cultures, navigation stars may also be tied to a variety of different uses, such as weather forecasting and seasonal time keeping (Alkire, 1970: 38). As Ruggles puts it, “the sky was not only important for navigation; it also played a key role in cosmology, ideology, the ritual cycle, and the ways in which all of these were manipulated for political ends” (Ruggles, 2015: 2241).

Fifth, single stars often denoted whole voyages during which a much greater number of stars were used for direction (Lewis, 1994: 98). In other words, single stars could be a kind of shorthand for voyages for which those stars were key navigational indicators. Such stars would not necessarily be the brightest in the sky, because Goodenough tells us that “stars and constellations appear to be named only in so far as practical considerations require” (Goodenough, 1953: 3). In other words, fainter stars occupying opposite positions in the sky might be named and linked with voyages, while brighter stars could sometimes go unremarked.

Sixth, particular stars could also be associated with islands (as opposed to voyages). Zenith stars with the same declinations as an island’s latitude, pass overhead those islands and are known as “the star on top” or fana kenga “the star that points down to an island” (Lewis, 1994: 278, 281; Chauvin, 2000: 105). Finding the islands associated with bright stars (i.e. islands having zenith stars that passed directly over those islands) may have served as a rationale for voyages, as Kyselka’s evo-

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Photograph of the Hauviri marae to accompany Figure 1. Standing stone 9 (or PT9), which is 0.54m in height, has a handheld GPS receiver resting on it. Stone 13 (which is 0.25m high) and stone 15 are circled, and the 2.7m high Coronation stone is labelled.

Fig. 1. The four baselines observed on Hauviri and Taputapuātea marae, Opoa district, Ra‘atea (Source, Google Earth). See the accompanying photograph to obtain an idea of the appearance of the standing stones.
New Zealand’s history, since the island’s old name is Havai‘i or Hawai‘i (or Hawai‘i), the name of the legendary ancestral home of Māori (Hiroa, 1964: 68, 76). The Taputapuātea marae was described as an international marae (Henry, 1928: 119), and is one of the oldest maraeas in the Society Islands (De Bovis, 1980: 43) although not the oldest (Wallin, 1993: 108). It is widely acknowledged by historical sources as the spiritual and cultural centre of Polynesia, and has been termed “the Vatican of the ancient Polynesian religion” (Liller, 2011: 137, 144), with pilgrimages taking place across Polynesia to Taputapuātea (Finney, 2006: 145; Henry, 1928: 123). The Hauviri marae, also called Tautā-a-tapu (landing place for the sacrifices), “formed the outer border of Taputapuātea” (Henry, 1928: 120) and was integral to it, for here the sacrifices were brought ashore. On its paved court stands Tepapa-tea-o-ruea, the white rock of investment, or Coronation stone. “On this pillar a prince or princess … seated on a great stool, was raised when proclaimed sovereign, in the presence of a multitude, on the day of the regal inauguration ceremony” (p. 120). The stone stands nearly three metres high, more than twice the height of any others in the Society Islands (see the photograph accompanying Fig. 1).⁵

Some results have been published of possible marae orientations in the nearby Faaroa Valley, Rāiātea (Edwards, 2011: 277–278), and mention of orientation is made in Emory’s work (Emory, 1933: 26, 34). Emory also gives a site plan of the Hauviri and Taputapuātea maraeas (Emory, 1933: 146), and Wallin, a plan of the latter (Wallin, 1993: 164 No. 350, 351). However, both Emory and Wallin’s plans are at a small scale, and neither shows all the standing stones. Sinoto (2015b) noted the existence of Emory’s original maps at the Bishop Bernice Museum, which may be at a larger scale and show more stones, but I have so far been unable to access these and I am aware of no other published results of standing stone alignments on these marae.

For the above reasons, the Hauviri and Taputapuātea maraeas were thought suitable for testing an exploratory survey method, and a brief research visit of four nights was made to Rāiātea in late 2014 to make a preliminary survey with a view to seeing whether a return visit was warranted with better instrumentation. The surveys needed to be performed single-handed, and a decision was taken to use a hand-held GPS receiver and a plastic tape. No permission was sought because nothing was done that was any more invasive than taking a photograph, which was permitted. Two principal strategies were adopted. First, to enhance azimuth by extending baselines by eye, aided by binoculars, and by observing multiple GPS readings with a hand-held, code-ranging GPS receiver at the ends of the line and near its centre, and checking this by walking the length of the baseline using tracking mode. Second, good relative positions were achieved by a highly redundant taped network, which was computed using a least squares SNAP adjustment that held one end of a baseline and its azimuth fixed (SNAP, n.d.).

An obvious concern, was that the standing stones on the Hauviri and Taputapuātea maraeas might have been moved over the years, in spite of stones being invested with “a great quantity of mana”, and moving them carrying all kinds of consequences (Wallin, 1993: 98). Alternately, stones could have been displaced by trees or repositioned incorrectly in restorative work. This is especially a concern in the light of multiple GPS observations made at the ends and in most cases also somewhere in the middle. For example, Fig. 1 shows that the baseline which extends the northern edge of the Hauviri marae has 4 GPS observations on its SW end, 5 observations somewhere near the middle, and 5 observations at the NE end, totalling 14 observations in all. The photograph accompanying Fig. 1 gives an idea of the appearance of the standing stones.

Photograph of the Hauviri marae to accompany Fig. 1. Standing stone 9 (or PT9), which is 0.54 m in height, has a handheld GPS receiver resting on it. Stone 13 (which is 0.25 m high) and stone 15 are circled, and the 2.7 m high Coronation stone is labelled. Linear regressions were then done in Excel to arrive at least squares best azimuths for the lines. The baseline extending the northern edge of the Hauviri marae is again used as an example (see Fig. 2).

The resulting azimuths were then checked by walking the baselines with the “track” function switched on, lining the Garmin receiver in by eye. Using the same baseline as an example, the track comprised 9 observations, and again Excel was used to arrive at a best fit line (see Fig. 3).

For this baseline, the resulting azimuth differed by 10° of arc (i.e. about 0.27 m linear displacement over the 92 m baseline, and 0.06 m over 20 m, which is a typical separation of the standing stones on both maraeas). The first result was accepted as being more accurate since it was the mean of more observations, and these were stationary, without the added uncertainty of deviations from the track line. This yielded a baseline orientation of 45° 51′ 17″, which represents a grid bearing on the UTM Zone 5S projection, converted from a true azimuth by applying a meridian convergence correction (see Fig. 4 and the numerical example following it).

Meridian convergence uses the formula: Meridian convergence (MC) = Difference in longitude from the central meridian of the projection (CM) × Sin (latitude). For a latitude of 16° 50′ 07″ south, a longitude of 151° 21′ 30″ west and a central meridian (CM) of 153°, the MC = 28′ 32″. With reference to Fig. 4, a true azimuth of 45° 22′ 45″ will thus give a grid bearing of 45° 51′ 17″. This grid bearing was then used in the SNAP adjustment to compute grid coordinates for all stones.

For the Taputapuātea baseline, the comparison between ten static positions and walking the baseline as a “track” was comparable with Hauviri, and it yielded a grid bearing of 5° 43′ 32″. The Coronation stone baseline gave a grid bearing of 321° 36′ 59″, again the product of a linear regression. Although bearings are given to single seconds, accuracies will be less precise, though probably better than to half a degree. If this research was progressed any further, and more accurate

⁵ Emory (1933: 37), writes that the average height of uprights is 1.5 ft (46 cm) and that the largest seen are not more than 4 ft (1.22 m) with the exception of the Coronation stone at 9 ft (2.74 m). The two largest stones on the Taputapuātea marae are also uncommonly tall, being about 1.6 m in height.
azimuths on the WGS84 datum can also be verified approximately on Google Earth. An accuracy test carried out in 2013 gave a difference of 0.02° between the azimuths. For the Ra’iātea marae, ahu edges were checked by Google Earth in this way and a good comparison resulted, but the majority of standing stones did not show up on Google Earth and consequently needed to be surveyed. Baseline orientations were then held fixed, as was the mean position of GPS fixes for an origin point on each marae. For Hauviri, Point 10 (PT10) was used as the origin point, this being the corner of the ahu and enclosing wall on NE end of the baseline (depicted as a solid triangle icon in Fig. 5).

For Taputapuātea, Stone E was held fixed, this being the SW corner of the larger of the two standing stones, the one further from the marae. This point is depicted by a solid triangle icon in Fig. 6. The standing stones on both maraes were trilaterated with a 50 m plastic tape. A SNAP least squares adjustment was performed using single GPS fixes of standing stones as an initial approximation, and thereafter constraining the taped network to the origin point and baseline orientation. Most residuals were of the order of 1 cm, with a maximum residual of about 6 cm, which was considered acceptable given the difficulty of estimating to the centre of large rocks by eye.

UTM coordinates of the stones on both maraes are given in Tables 1 and 2. While these coordinates could be improved upon with better equipment, even in this form they provide baseline data of sufficient precision to be used in different ways by future researchers. Ten coordinate pairs are given for Hauviri and five for Taputapuātea (see Tables 1 and 2). Coordinates of PT06, PT20, PT27, PT28 and PT10, which are the inside corners of the outer wall of the marae, are omitted from the table owing to Sinoto’s comment about the outer wall being anachronistic (Sinoto, 2001: 260). Having said that, PT10 and PT06 are respectively also the left and right ends of the ahu, warranting PT06’s relationship with Rigel being depicted in Fig. 10.

Grid joins (or inverses) were then computed between the adjusted UTM coordinates of the stones, and a reverse meridian convergence applied to yield true azimuths between stones (i.e. angles clockwise from the meridian towards true north). These azimuths, which were considered to have accuracies comparable with that of the baselines, were then used to test the three hypotheses given earlier.

3. Testing the hypotheses

Hypothesis 1. That the stones line up with voyage destinations or commemorate voyages.

Bearing in mind that surveys are only provisional, a result that was judged to be sufficiently accurate for comparing great circle courses to islands was obtained by tracing azimuths between stones from a SNAP plot of the points and overlaying this tracing as a transparency on Google Earth, adjusting the opaqueness until both lines and islands could be seen. This low accuracy solution seemed adequate for trying out scenarios and deciding whether it was worth investing time and resources in a more precise solution. The technique is illustrated by Fig. 7, which shows lines radiating out from the Coronation stone to the other stones when overlaid on Google Earth.

For the Hauviri marae, with the Coronation stone as the origin, the first three stones east of north – PT09, PT13 and PT15 (see Fig. 5) – do not appear to line up with significant islands. For the rest of the standing stones, lines all pass through or near to islands, but it is unclear today, many centuries later, which of the numerous Pacific islands or island groups, nearby and remote, might warrant marking by a standing stone. Again, an in-depth cultural strand is lacking. Doing the same exercise with different stones on Taputapuātea as origin comes up against the same difficulties, principally that we do not know which islands were most important.

One possible measure that we have of which islands were known about and were deemed significant, is the chart Tupaia drew for James Cook in 1769 (Tupaia’s chart, n.d.). By depicting some islands but not others, this chart carries an implicit screening of what was deemed important in the eighteenth century, and possibly reflects a prioritisation perpetuated from earlier centuries through stories, songs and prayers. With this in mind, the bearings of stones were also overlaid on Tupaia’s chart, but again there was insufficient evidence for rejecting some islands and including others. A different possibility involving Tupaia’s chart is that it is “a mosaic of subject-centred sailing directions or bearings to distant islands” (Di Piazza and Pearthree, 2007: 324), and a better fit might result if sailing directions from each origin point are rotated. For Ra’iātea, the re-orientation suggested by Di Piazza and Pearthree is 30° (p331), and a tracing of stone orientations rotated by this value could fit a variety of destinations. However, while there is justification for rotating Tupaia’s chart, if it is indeed a composite of plotting diagrams from a variety of origin marks, rotating stones that...
are supposed to indicate real world sailing directions is far less probable, and this hypothesis is also rejected. So too is the idea of viewing standing stones in terms of the abstract representation of where islands are in relation to one another used for the star-course navigation system (Gell, 1985: 283–284). Without a layer of oral tradition, there is again insufficient data to draw firm conclusions.

Hypothesis 2. That stones form a graphical “star compass” of points where stars rise/set (different times of day and of the year).

On the Caroline Islands, Micronesia, star compasses and star courses between islands are still used and taught by tracing lines in the sand or arranging pebbles and sticks on a mat (Gladwin, 1970: 129–31). Star compasses are given in a variety of sources (e.g. Lewis, 1994: 118; Evans, 2011: 62; Goodenough, 1953: 6; Finney, 2006: 159, 161). Fig. 8 is given as an example:

Choice of century is important, given the action of precession (Goodwin, 2017). Carbon dating gives two differing date ranges for clam shells from Taputapuātea, namely 1243–1348 or 1518–1811.
Fig. 6. SNAP least squares adjustment of the standing stones on the Taputaputēa marae. The red triangle is the origin point for the network, which is held fixed, and the dashed blue line and red arrow indicate the orientation of the network, also held fixed. Solid blue lines are measured distances. Black circles are measured points (for example, Stone B has measurements at the centres of end points of the stone, while Stone D, which is larger, has measurements to each of its four corners). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Azimuths from the Coronation stone to standing stones on the Hauviri marae.

<table>
<thead>
<tr>
<th>Merid. converg. (degr.min s) =</th>
<th>0.28315</th>
</tr>
</thead>
<tbody>
<tr>
<td>E°</td>
<td>N°</td>
</tr>
<tr>
<td>PT18</td>
<td>674,898.959</td>
</tr>
<tr>
<td>PT07</td>
<td>674,918.666</td>
</tr>
<tr>
<td>PT14</td>
<td>674,909.668</td>
</tr>
<tr>
<td>PT13</td>
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<tr>
<td>PT15</td>
<td>674,903.916</td>
</tr>
<tr>
<td>PT17</td>
<td>674,899.830</td>
</tr>
<tr>
<td>PT09</td>
<td>674,908.674</td>
</tr>
</tbody>
</table>

Azimuths are from the centre of the Coronation stone (denoted as SSmid, i.e. “Standing Stone middle”) when Sirius is just rising. See Fig. 5 for the numbering of stones (Note: PT simply denotes “point”). Columns from left to right are: grid coordinates (Eastings and Northings, in metres); grid bearings (abbreviated to “Grid Bng”) which are coordinate joins from SSmid to the respective points. Join is abbreviated to “JN”, and is synonymous with what some software terms a coordinate “inverse.” For example, the first value, 321.4211, is the coordinate join from SSmid to PT18, with units in degrees minutes and seconds of arc (Note: these are entered to Excel as degr.minsecs or “d.ms”, so that 321.4211 denotes 321° 42′ 11″; astronomic azimuths (with a meridian convergence applied, and again in units of d.ms); distance away of stones (metres); star names; star magnitudes (for details, see Fig. 9); star azimuth in 1250 in d.ms (Cartes du Ciel. Copyright©, 2006; SkyMap Pro 11, n.d.); difference between the azimuths in degrees and minutes of arc (d.m); difference in metres subtended at the distance away of the stone (metres); and the altitude of stars (i.e. angle above the horizon in degrees and minutes). See Fig. 10 for a plan view and Fig. 11 for an elevation impression of the sky at this same instant.

a UTM Zone 5S.
b 1250 CE, Ra'iātea: 16°50′07″S; 151°21′30″W.
Another measure of time is via "genealogies...as chronological devices of historical events" (Wallin, 1993: 105), and Wallin in this way dates the Taputapu\text{ā} tea marae at 1200–1380 CE (p108). Emory comes up with a similar figure, of 29 generations before the time of writing (Emory, 1933:39), which assuming generations to be 20–25 years, gives a range say 1200–1350 CE. Henry (1928: 247) puts the figure at 26 generations prior to 1900, which at 20–25 years per generation gives a range say 1200–1350 CE.

Henry (1928: 247) puts the figure at 26 generations prior to 1900, which at 20–25 years per generation gives a range say 1200–1350 CE. The date certainly has to be before 1350 CE, when a great quarrel is said to have ended the periodic meetings at Opoa (Wallin, 1993: 120; Henry, 1928: 126). In this article I have taken 1250 CE as a plausible date for the erection of stones, being the earlier carbon dating interval and within Henry's and Emory's generational ranges, and I have compared azimuths between stones with star azimuths in this year. Several scenarios were tried, both from Hauviri and Taputapu\text{ā} tea maraes, although, in line with the surveying emphasis of this article, only one resulting star chart is shown, in Fig. 9.

There are several difficulties that stand in the way of accepting the standing stones as an analogue star chart. For instance, why are there stones for some stars—not necessarily the brightest—and not for others? And, whereas navigators on the Carolines and elsewhere are still teaching navigation with pebbles on a mat, why is no mention made in the literature of stones being placed in the same way on maraes? Similar difficulties were found for the various scenarios tried from Taputapu\text{ā} tea, and this hypothesis is rejected. Having said that, given the uncertainly in dating, if stones "fit" better for one epoch than another, this could contribute an additional strand when weighting evidence, and this is something that might repay further work. However, the effect of precession between 1250 CE and today is only of the order of about 10 cm at the typical distance of the stones, and the stones are irregular, which would make this an extremely coarse measure of time.

Table 2
Azimuths from Stone E (see Fig. 6) to other standing stones on Taputapu\text{ā} tea marae. Departures are given in degrees and minutes of arc and as metres. Again, d.m denotes degrees minutes and seconds of arc. For example, the azimuth to Stone D of 108° 9′ 6″ is entered as 108.0906. The "Altit." column is the altitude (angle above the horizon of stars in degrees and minutes of arc. For example, 3.44 is 3° 44′).

<table>
<thead>
<tr>
<th>Meridian convergence</th>
<th>0.28315</th>
<th>(d.m)</th>
</tr>
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<tbody>
<tr>
<td><strong>E°</strong></td>
<td><strong>N°</strong></td>
<td>Grid Bng (Join Simid - Stone)</td>
</tr>
<tr>
<td>Stone A</td>
<td>674,803.147</td>
<td>8,137,863.228</td>
</tr>
<tr>
<td>Stone B</td>
<td>674,800.320</td>
<td>8,137,851.410</td>
</tr>
<tr>
<td>Stone C</td>
<td>674,813.842</td>
<td>8,137,843.511</td>
</tr>
<tr>
<td>Stone D</td>
<td>674,829.599</td>
<td>8,137,861.445</td>
</tr>
<tr>
<td>Stone E</td>
<td>674,819.878</td>
<td>8,137,864.722</td>
</tr>
</tbody>
</table>

Fig. 7. A plot of true azimuths from the Coronation stone to standing stones 7, 9, 13, 14, 15 and 19 on the Hauviri marae, overlaid on Google Earth. Straight lines on the UTM projection become curved when depicted on the Google Earth sphere. Islands are outlined in yellow, and what appear to be white dots are merely sites of photographs on Google Earth.

(Wallin, 1993: 36). Another measure of time is via "genealogies...as chronological devices of historical events" (Wallin, 1993: 105), and Wallin in this way dates the Taputapu\text{ā} tea marae at 1200–1380 CE (p108). Emory comes up with a similar figure, of 29 generations before the time of writing (Emory, 1933:39), which assuming generations to be 20–25 years, gives a range say 1200–1350 CE.
Fig. 8. Nainoa’s star compass [Kyselka, 1987: 39].

Fig. 9. Stars rising and setting. Solid red lines denote rays from the centre of the Coronation stone to standing stones on the Hauviri marae, which are indicated by small circles. Solid black lines mark the approximate perimeter of the marae. Broken purple lines are from the same point to bright stars for a 1250 epoch. Positive and negative numbers indicate approximate star magnitudes (a negative magnitude indicates a very bright star, down to about magnitude of about +5 still being visible to the naked eye). The approximate annual range of the sun is also shown. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Hypothesis 3. Stones line up with important stars at a significant epoch of the year, for example, at a particular time on the day of an important festival.

For testing this hypothesis, the same year is used that is discussed above, namely 1250 CE. For this “freeze-frame” situation, an exact day and instant of time needs to be settled on. One season that stands out is that of Matariki, with an inherent difficulty being that there is no universally agreed time for this ceremony. Matariki in Hawaii is “the first appearance of the Pleiades in the eastern sky at sunset” (Chauvin, 2000: 113), in other words, sometime in November. In contrast, for the peoples of East Polynesia, Matariki is often the heliacal rising of the Pleiades (Williams, 2013: 7), in other words, the first appearance of the Pleiades before sunrise after a period when it has not been visible. This occurs in late May or early June. Alternatively, Matariki may be the first new moon following this (Liller, 2000: 134). There are also other ways of marking the New Year, such as the first rising of Rigel (Puanga/ Puaka), or the first new moon thereafter (Best, 2002: 45).

A decision was taken to work in the first instance with approximately the West Polynesian Matariki, in other words, the first appearance of the Pleiades after sunset. A fairly arbitrary date was selected of 5th November, at a time when the Pleiades has been up for 2 h. This rather arbitrary timing has been used because Sirius, the brightest star in the sky and prominent in Polynesian traditions (e.g. Best, 2002: 31), is just rising. Notwithstanding the arbitrariness of this choice, this epoch seems as good as any as a case to which to apply data from the exploratory survey method, and the data in Table 1 would allow testing at other epochs, such as mid-December (Best, 2002: 51).

This scenario is also not without difficulties, principally that of arbitrary timing. Although roughly the season of Polynesian Matariki, it is perhaps contrived to wait for the rising of Sirius even given its importance and surpassing brightness. Cultural data would be needed to give this choice any substance. Second, the absence of stones for Sirius, Aldebaran and Achernar seems anomalous, notwithstanding the fact that sometimes the most important stars were not necessarily the brightest, as discussed earlier. Third, only magnitude 3 stars are over stone PT16 at this epoch. Fourth, there is no evidence that α Persei, the bright star over PT09, was in any way special to navigators.

A number of other scenarios were tested, both for the Hauviri and Taputapuatea maraes using different dates and different stones as observation points, some of which were tested as part of an honours thesis by Michaela Thomson (Thomson, 2016). However, for the purposes of this article only the above scenario is shown for Hauviri, and only one of the more promising scenarios for Taputapuatea is shown in Table 2 below.

The Taputapuatea scenario has similar difficulties to the Hauviri scenario earlier, with one additional difficulty being that of topography, since the low altitude stars over stones A, B and C would lie behind a hill. The third hypothesis is therefore rejected for Taputapuatea and, erring on the side of caution, for Hauviri also.

4. Conclusions

The primary purpose of this article was to field test an exploratory surveying method that used inexpensive and non-bulky equipment and could be done single-handed, yet was adequate for surveys where relative positions of objects and azimuths between them are important. The case-study surveys described here have successfully produced coordinates of the current positions of standing stones at the Hauviri and Taputapuatea maraes and demonstrated that these are able to be used for testing a variety of scenarios.
The secondary purpose, to test three hypotheses, has produced mostly inconclusive results. Certainly for the navigation chart hypothesis, the method works well enough but for both maraes there are just too many imponderables to support a definite conclusion. Similarly, for the star chart hypothesis, the answer is a negative. For the freeze-frame scenario chosen, rather many assumptions needed to be made concerning the epoch and the length of time after sundown, and topography was also an issue for Taputapua. There appears to be a clear NO for Taputapua, but for Hauviri, the conclusion is less definite. Although nothing definitive emerged, there was also nothing to rule out the view that standing stones on the Hauviri marae may have served some astronomical function, and perhaps sufficient encouragement is offered to warrant further work. This kind of conclusion was, after all, the main object of this research, namely to try out an exploratory survey method capable of eliminating certain possibilities without incurring too much time and expense, thereby narrowing the field. Certainly, visiting the Hauviri marae in about November and standing with your back against the great Coronation stone and watching the sun set directly over the sizeable stone (PT19) in the general direction of Taputapua, it is difficult not to believe that there is something deliberate about the placing of these stones. This feeling is reinforced a couple of hours later, when Sirius rises. Standing now on the seaward side of the Coronation stone, arms stretched wide along its northeast face, Deneb and Canopus are at the tips of your fingers. In front of you, Matariki, Rigel, Betelgeuse, Capella, Orion's belt, α Persei, and the fainter α Pictor and α Reticulum all seem to hover over standing stones. As stated in an earlier section, the effect of precession between 1250 CE and today is of the order of about 10 cm at the typical distance of the stones, which does not stand in the way of imagining what the sky looked like back then, and the sight is quite extraordinary. It does not stretch credulity unduly to begin to wonder if there could in fact be some purpose and order behind the placing of these stones.

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Fig. 11. The sky as an elevation view (SkyMap). The sun set approximately 2 h before, directly over stone PT19 [behind the observer]. Deneb and Canopus are almost exactly on the extension of the axis of the coronation stone to left and right. Note that Sirius, Aldebaran and Achernar are not over standing stones, and PT16 has only stars of magnitude 3 above it.