Aerial Survey of Seabirds and Marine Mammals at Ka`ula Island, Hawai`i July 2015

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Executive Summary

An aerial vertical survey of Ka`ula Island, Hawai`i, using a manned light twin-engine survey aircraft and ultra-high resolution digital photography was conducted on July 29 and July 30, 2015. A vertical (nadir) aerial survey was complemented by an oblique survey, which was conducted on July 29 and July 30, 2015 to allow counts to be made both of birds on the top of the island and those present on the cliff faces.

This survey was carried out to meet the aims and objectives of the work required by the U.S. Navy to monitor the status of the seabird populations on the island (DoN 2009). The images collected have been analyzed and quality assured, and the raw counts of animals recorded are presented in this report.

The survey was carried out over two days, with 95% of the final image mosaic collected on July 30 using a low altitude survey. The 5% data gap was filled by data collected on July 29 using a high altitude survey. To avoid double counting, only birds sitting on apparently occupied territories were counted in the small portion of data collected on the 29th.

In total, 13,576 birds of eight species were recorded during the survey with brown noddy being the most abundant species (n=7,137) followed by red-footed booby (n= 3,693). A number of other species were recorded including, red-tailed tropicbird, great frigatebird, masked booby, brown booby, sooty tern and a single flying white tern.

Red-tailed tropicbirds were recorded sitting at the entrances to small caverns and underneath overhanging ledges. Groups of noddies and boobies also recorded in the oblique imagery were not visible in the vertical imagery. Due to the nature and size of these caverns and crevasses it is difficult to obtain full detailed coverage of the whole eastern side of the island. As a result, the count of tropicbirds is likely to be an undercount of the actual birds present.

At the time of the surveys, a total of nine Hawai`ian monk seals were resting on ledges, with eight in the northwest section and one in the southeast section of the island.

1 Introduction

APEM and Normandeau were contracted by the U.S. Navy to provide ornithological data for the Pacific island of Ka`ula, Hawai`i, through the capture and analysis of ultra-high resolution digital aerial imagery.

Ka`ula Island is a small (0.64 $km^2$), uninhabited crescent shaped islet in the west of the chain of islands making up the Hawai`ian Archipelago (Figures 1–1 and 1–2). The islands closest to Ka`ula are Niihau Island, which is located 37 km to the northeast, and Kauai Island, approximately 111 km to the northeast. A mountain ridge runs along the length of Ka`ula Island (approximately 1,676 m), which at its highest point is 164.6 m above sea level (Palmer 1936). The terrain drops steeply from the ridge crest at a mean slope of 36° and steep V-shaped ravines have been cut by ephemeral streams on the windward slopes such that the island has little level terrain (Elmer and Swedberg 1971). The northern horn of the island extends 762 m from the summit and ends at an elevation of approximately 85 m, while the southern horn extends 914 m from the summit and ends at an elevation of approximately 30 m (Palmer 1936).

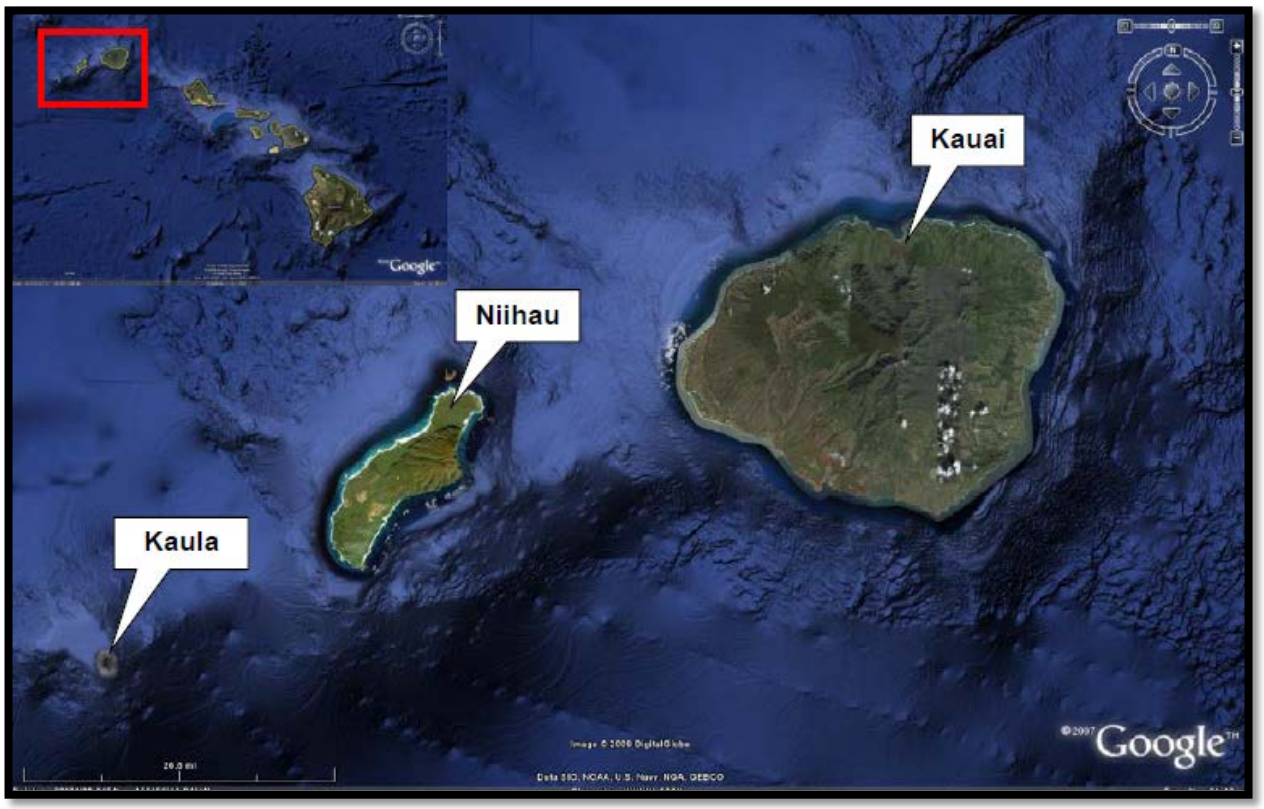

Figure 1-1. Location of Ka`ula Island relative to the main Hawai`ian Islands (inset) and Kauai and Niihau (imagery from Google Earth).

Figure 1-2. Topography of Ka`ula Island.

Since 1952, the U.S. Navy has used the southeastern tip of the island (approximately 0.06 km^2) as a range to train aviators in air-to-surface and surface-to-surface weapons delivery. Both live and inert ordnance were used during training missions through 1980. From 1981 through present, munitions training by the Navy at Ka`ula has been restricted to inert ordnance delivery and aircraft gunnery (DoN 2008; DoN 2013).

Historically, eleven land based avian surveys have been undertaken on the island (Pepi *et al*. 2009), but, due to safety reasons, these were replaced with boat based observations through 2011 (Pepi *et al*. 2009; DoN 2011) and observer based, low altitude aerial surveys (DoN 2011) from 2013 to present.

The U.S. Navy initially attempted aerial imagery prior to the finalization of the Seabird Monitoring Plan (DoN 2009) but results were unacceptable. Now with improved technology available, the Navy looked to improve and build upon the seabird data gathering and marine mammal observation efforts by exploring the use of higher altitude, very high resolution aerial imaging surveys. The first survey using this technique was conducted in April 2013. This improved technology has resulted in the following improvements:

- Increased count accuracy through post-hoc, quantitative analysis of imagery rather than near-instantaneous live counts by observers in the field

- Increased count accuracy through elimination of bird disturbance effects from low-flying helicopters
- Increased count accuracy and bird identification ability on Ka`ula, previously surveyed by boat, because of increased visibility of the top, bottom, and sides of cliffs

2 Methods

2.1 Survey Design

This digital aerial survey of Ka`ula was undertaken on July 29 and July 30 2015. The survey was conducted over two days due to cloud cover at the aircraft height resulting in the survey being aborted on July 29.

Ultra-high resolution digital still images were collected using a manned light twin-engine survey aircraft, Aero Commander 500 s N500SJ, and a GPS-linked custom flight management camera system, the APEM SeeBird01, specifically designed by APEM to target high resolution surveys for birds and marine mammals.

To prepare for the survey of Ka`ula, flight planning software was used to define the required flying altitude and speed according to the camera, lens, and required pixel resolution. During the survey, each of the survey transects were flown using a GPS guided management system and the image acquisitions were automatically triggered at predefined positions.

Due to the wide range of topographical features on Ka`ula (see Figure 1–2), three surveys were carried out to ensure that high quality imagery was achieved over the whole island (100% coverage), including capturing animals on horizontal as well as vertical ledges. The first complete aerial vertical survey was carried out on July 29 2015. This involved vertical surveys of Ka`ula Island at high altitude (vertical high altitude survey). The second lower altitude (vertical low altitude survey) was completed on July 30 2015. An attempt to carry out the survey on 27 July 2015 was aborted due to cloud cover around the island.

The collection of oblique images (oblique survey) of birds on steep, overhanging cliff faces that would not have been visible from the vertical surveys was undertaken on July 29 2015. As weather remained suitable for image collection on July 30, a second dataset was collected as back-up in the event of problems with the imagery collected on July 29. Only imagery captured on July 29 was used in the analysis.

The first complete survey carried out on July 29 2015 (between 08:54 and 09:56 hours) was the vertical high altitude survey conducted at 2,500 feet, which was flown in a north-south direction. This survey captured imagery at 2.5 cm resolution at sea level and 1.9 cm resolution imagery at the higher elevation sections of the island.

The second complete survey carried out on July 30 2015 (between 08:12 and 09:33 hours), the vertical low altitude survey was flown in a north-south direction at 2,050 feet. This captured imagery at 2 cm resolution at sea level and 1.4 cm resolution imagery at the higher elevation sections of the island.

The first oblique survey (between 09:54 and 11:10 hours) was conducted on July 29 2015 (see Section 2.4) by flying clockwise around the island between 800 and 1,800 feet. Due to the weather necessitating a re-run of the second vertical survey, additional oblique survey imagery was captured (between 08:14 and 10:03 hours) on July 30 2015.

2.1.1 Vertical Surveys

As it is not technically possible to capture the entire island at 2 cm resolution in one single image, several survey transects were undertaken to gain full coverage of the island. This generated approximately 1,500 vertical digital photographs collected over an approximate two hour period. These images were imported as geo-referenced images (WGS 84 projection) into ArcView (version 9.2) and spatially joined to create one large image mosaic covering the whole island. Images with the highest resolution for each location on the island were used to compile the mosaic, and any overlapping image sections were removed. This method was considered to be the most appropriate to minimize the risk of double counting that might have otherwise occurred by treating each individual image in isolation (due to overlapping areas). It is acknowledged that there is a small chance that movement of birds between transects could result in a bird being double counted. There is of course an equally small chance that a bird could be missed in both transects. On this basis, it is reasonable to assume that the risk of double counting is equal to the risk of undercounting, and the effect on the population count is negligible.

This small chance of error should be viewed in the context of other visual census techniques that carry a greater risk of error as a result of their longer duration.

The mosaic was split into 296 grid cells (Figure 2-1) to aid the identification stage of the analysis.

Specially trained APEM staff was responsible for recording the following information from each grid cell of the compiled image covering Ka`ula Island:

- Bird / mammal species by common name (see Appendix III for scientific names)
- Behavior (e.g. sitting, flying, diving or on occupied nest)
- Count (number of individuals)
- Position (easting, northing) of individuals
- Date and time stamp of image collection

Each grid cell was analyzed using APEM's Graphical User Interface (GUI) and GIS software. As part of the identification process, the software contains an automated species separation tool used for identifying regularly encountered seabirds in the Pacific based on size, shape and coloration. Two full scans of each grid cell are manually completed to find targets for identification, and identification is then completed by the analyst and confirmed by the software. The resolution of the images is extremely high, such that the individuals can be identified to species with a high degree of certainty.

Survey data were analyzed to produce maps showing bird and marine mammal distribution in a GIS format. For each map, bird and mammal observations were composed of individual points geo-referenced to actual spatial locations at the time of sighting.

The vertical imagery and GPS information was also loaded into photogrammetry software. This software identified points on the island in several overlapping images from which it could triangulate their elevation. Using the GPS information taken from the camera system during the survey it was able to scale and geo-reference the points and combine their elevations with the imagery product to create a three dimensional model of the island. Although this is not part of the report, APEM/Normandeau would be happy to supply this three dimensional model to the US Navy.

2.1.2 Oblique Surveys

The oblique images were spatially correlated against features in the vertical dataset to ensure correct spatial placement of each image. These images were then passed on to trained ornithologists to identify and enumerate the number of birds and marine mammals in each image that could not have been seen from the vertical imagery due to the presence of steep cliffs, small caves and overhanging rock ledges. The results of these counts were then subjected to the same internal process used in the vertical survey.

2.2 Quality Assurance

All bird and marine mammal species present in the images from Ka`ula Island were identified and quality assured using a standard internal APEM process.

All images containing birds and marine mammals were processed in each grid cell (see Section 2.2) and then checked by APEM's quality assurance manager. The quality assurance manager, an experienced ornithologist, is responsible for maintaining and updating the image library and also provides advice and guidance to the image processing staff.

2.3 Weather Conditions and Survey Limitations

This section explains some of the survey limitations and weather conditions. Due to the time of the year and expected low solar illumination of the survey area, the survey began before solar noon to maximize solar illumination of the eastern side of the island. This limited as much as possible any shadow from the challenging island terrain. Once the equipment had been installed into the aircraft on July 25, 2015 and a short test flight was conducted, we waited for a suitable weather window.

After consideration of weather forecasts and satellite imaging, the weather appeared good enough to survey on the morning of July 27, 2015. Survey conditions were good at first with little high altitude cloud cover, light winds ranging between 15 – 25 knots from the west, and visibility greater than 10 km. However, after attempting a number of survey lines, light cloud appeared at flying altitude and the decision was made to abort the survey.

On July 29, 2015 weather forecasts predicted favorable conditions and the higher vertical survey was successfully completed. During the attempt of the second lower vertical survey, low

scattered cloud caused this to be aborted. Despite landing nearby and waiting to see if conditions improved, the decision was made not to attempt the survey again that day.

On July 30, 2015 with predicted favorable weather conditions and by transiting to the survey area earlier in the day than previous attempts, the lower vertical survey was successfully completed. During an attempt to re-do the higher vertical survey so that all data could be collected on the same day, low scattered cloud caused this to be aborted.

Oblique surveys were carried out on July 29 and July 30, 2015. On July 29, 2015 clouds were scattered at 2,000 feet, light winds blew and visibility remained greater than 10 km. On July 30, 2015 cloud cover remained over 2,000 feet, light winds blew and visibility was greater than 10 km.

Contact with 'Hula Dancer' traffic control was maintained during surveys and the watch supervisor was kept informed of survey plans both leading up to the survey and during the flights.

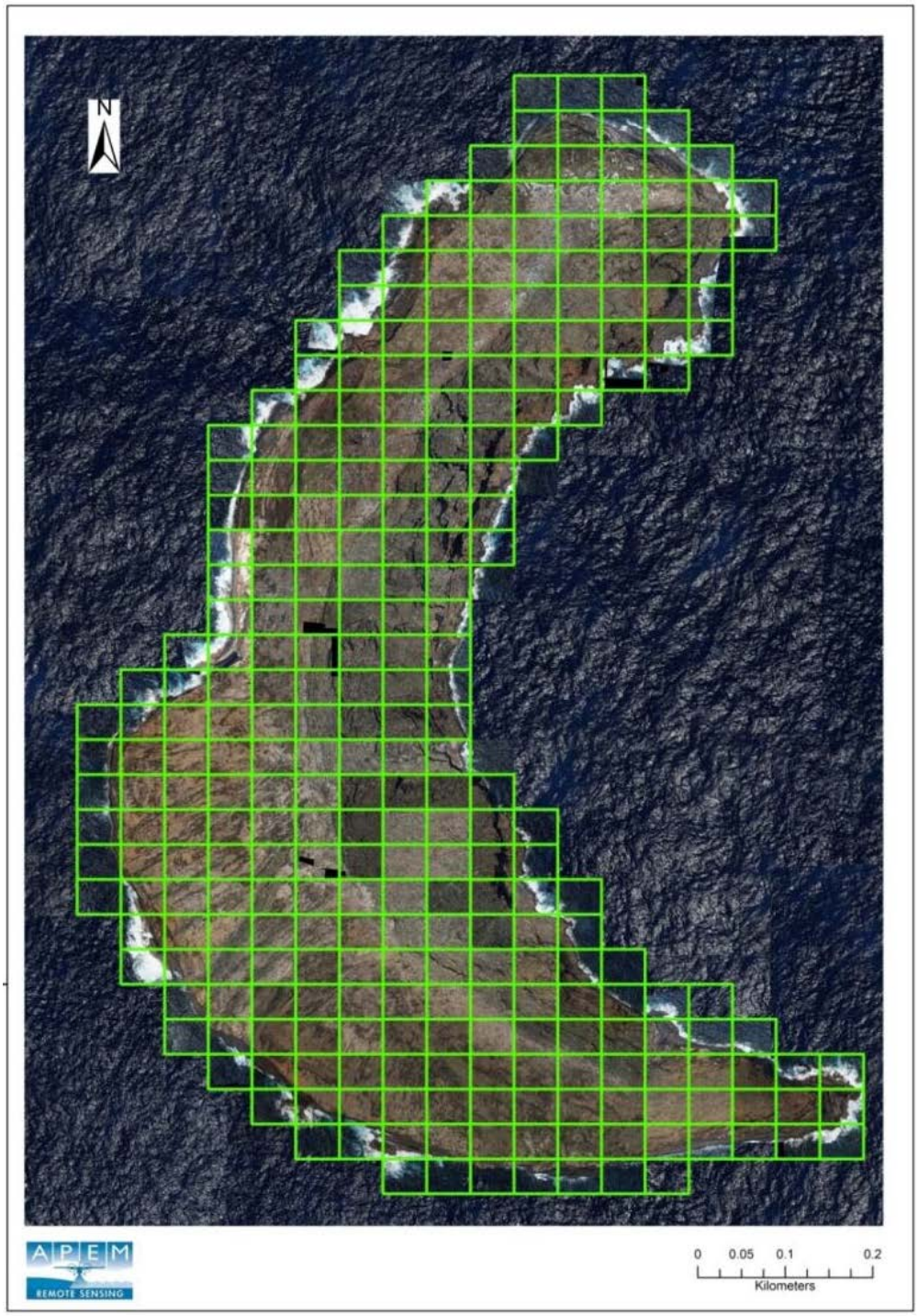

Figure 2-1. Ka`ula Island image analysis grid. Compiled images from the two vertical surveys were joined to cover Ka`ula Island. The compiled image was analyzed in 296 grid cell sections (marked in green).

3 Results

3.1 Species Abundance

A total of 13,576 birds (8 species) and 9 marine mammals (1 species) were recorded on Ka`ula Island during July 2015 (Table 3-1). Brown noddy (n=7,137) was the most abundant bird species, and white tern (n=1) was the least abundant species. Comparison with prior years is provided in Appendix IV.

Table 3-1. Total Number of Birds and Marine Mammals Recorded on Ka`ula Island by Vertical and Oblique Surveys during July 2015.

		Numbers Recorded		
Species/Group	**Vertical Survey**	**Oblique Survey**	**Visual Observation**	**Total**
Birds				
Red-tailed tropicbird	48	52	-	100
Great frigatebird	1,077	1	-	1,078
Masked booby	526	-	-	526
Brown booby	860	7	-	867
Red-footed booby	3,636	57	-	3,693
Red-footed booby / Masked booby	27	-	-	27
Brown noddy	7,053	84	-	7,137
White tern	1	-	-	1
Sooty tern	147	-	-	147
Total Birds	*13,375*	*201*	-	*13,576*
Hawai`ian monk seal	9	-	-	9
Total Birds and Marine Mammals	**13,384**	**201**	**-**	**13,585**

3.2 Species Distribution

3.2.1 Total birds and marine mammals

Figure 3–1 shows the location of all birds and marine mammals recorded on Ka`ula Island during the January 2015 aerial survey. Slightly higher concentrations of birds were located in the north and east than in the south and west of the island but overall birds were widely distributed. Red-tailed tropicbirds were recorded mainly along the eastern concave section with a few singles recorded on the west side. Great frigatebirds were concentrated on the east side of the island with a number also present at the northern end. Boobies were widely scattered, with the majority located along the northern central ridge. Masked boobies were recorded mainly along the higher areas of the island, while brown and red-footed boobies were more widely distributed around the whole island. Brown noddies were recorded along the whole stretch of the west side of the island and small clusters of sooty terns were also in the west section. A single white tern was flying out from the eastern side of the island. Hawai`ian monk seals were recorded mainly in the northwest part of the island.

3.2.2 Red-tailed tropicbird

A total of 100 red-tailed tropicbirds were recorded during the survey (Table 3–1). The majority were present in the eastern concave section of the island with a small number of individuals recorded in flight on the west side of the island (Figures 3–2, 6–5 and 6–7). Of the 60 birds sitting at least 28 were juveniles.

3.2.3 Great frigatebird

A total of 1,078 great frigatebirds were recorded during the survey (Table 3–1), of which 52 were flying. The majority were present in the center and northern half of the island along the east side in the concave section (Figures 3–3 and 6–2). There were scattered nesting colonies especially on the slopes and ravines on the eastern side, with adult and young birds on nests. A total of 306 juveniles were in nests.

3.2.4 Masked booby

A total of 526 masked boobies were recorded during the survey (Table 3–1). The majority were present along the highest ridge running through the center of the island and the northern tip of the island. Smaller numbers were present on the lower slopes of the west side and small clusters were found towards the southern end. (Figure 3–4). A total of 79 juvenile birds could be seen in nests accompanied by adults.

3.2.5 Brown booby

A total of 867 brown boobies were recorded during the survey (Table 3–1), of which 11 were flying. They were widely distributed throughout the whole island with fewer birds in the southwest section of the island. (Figures 3–6, 6–1 and 6–8). They were found all along the central ridge of the island. A total of 114 juveniles could be seen, mostly accompanied by adults.

3.2.6 Red-footed booby

A total of 3,693 red-footed boobies were recorded during the survey (Table 3–1), of which 67 were flying. They were widely distributed across of the whole island, with fewer present around the southern tip. Particular densities were recorded in the northwest and some parts of the eastern slopes (Figures 3–6, 6–1 and 6–8). A total of 732 immatures were recorded which were either downy young in nests or more advanced juveniles.

3.2.7 Red-footed booby/masked booby

A total of 27 unidentified red-footed or masked boobies were recorded during the survey (Table 3-1). The vast majority of these unidentified boobies were juveniles on nests with no adults in attendance (Figure 3–7).

3.2.8 Brown noddy

A total of 7,137 brown noddies (6,483 sitting and 654 flying) were recorded during the survey, of which virtually all were along the western slopes near the cliff edges with birds in the middle of the island stretching up to almost the central ridge (Figures 3–8, 6–3, 6–6 and 6–8). Eighty four birds were located in the oblique imagery along the lower cliffs of the west side.

3.2.9 White tern

A single white tern was recorded flying towards the sea from the southeastern slope of the island (Figure 3–9).

3.2.10 Sooty tern

A total of 147 sooty terns were recorded during the survey, most of which were sitting in groups nearby or amongst brown noddies (Figure 3–10).

3.2.11 Marine mammals

During the course of the surveys, nine Hawai`ian monk seals were recorded resting on ledges on the island (Table 3–1). Eight seals were recorded in the northwest convex section of the island, five together and three just to the south (Figures 3–11and 6–4). The remaining individual was in the southeast side of the island again resting on flat areas of rock.

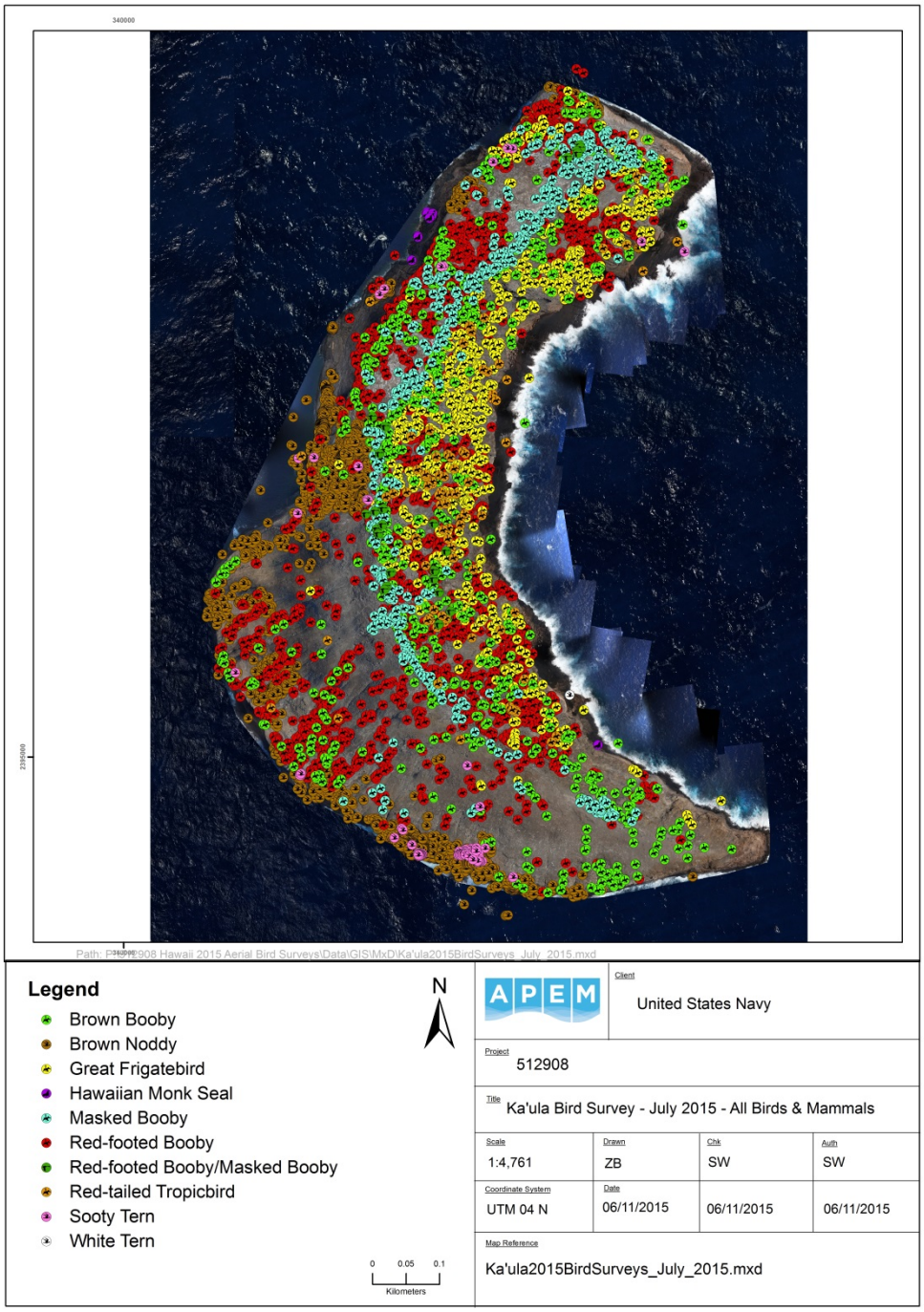

Figure 3-1. Distribution of all birds and marine mammals recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

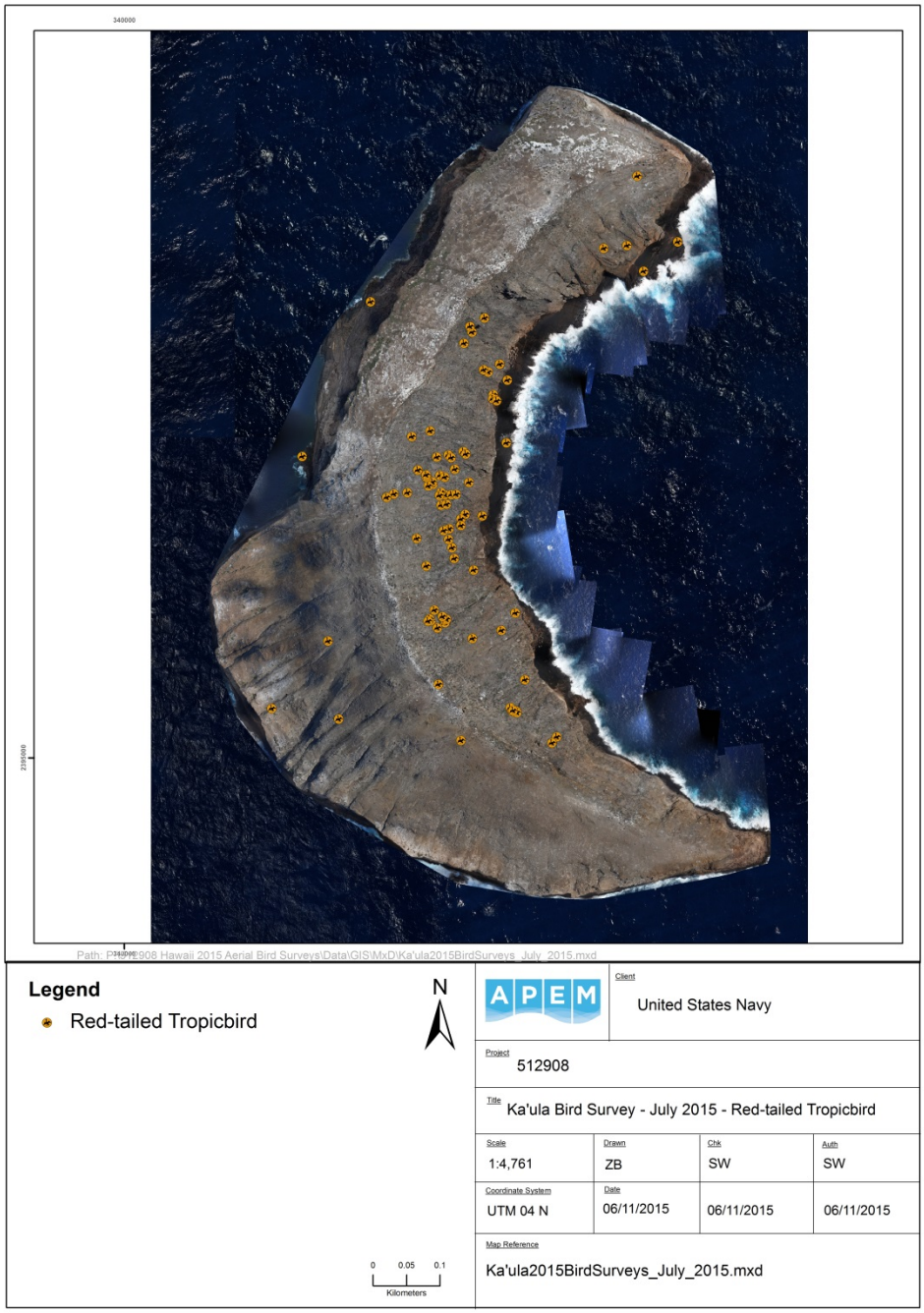

Figure 3-2. Distribution of red-tailed tropicbirds recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

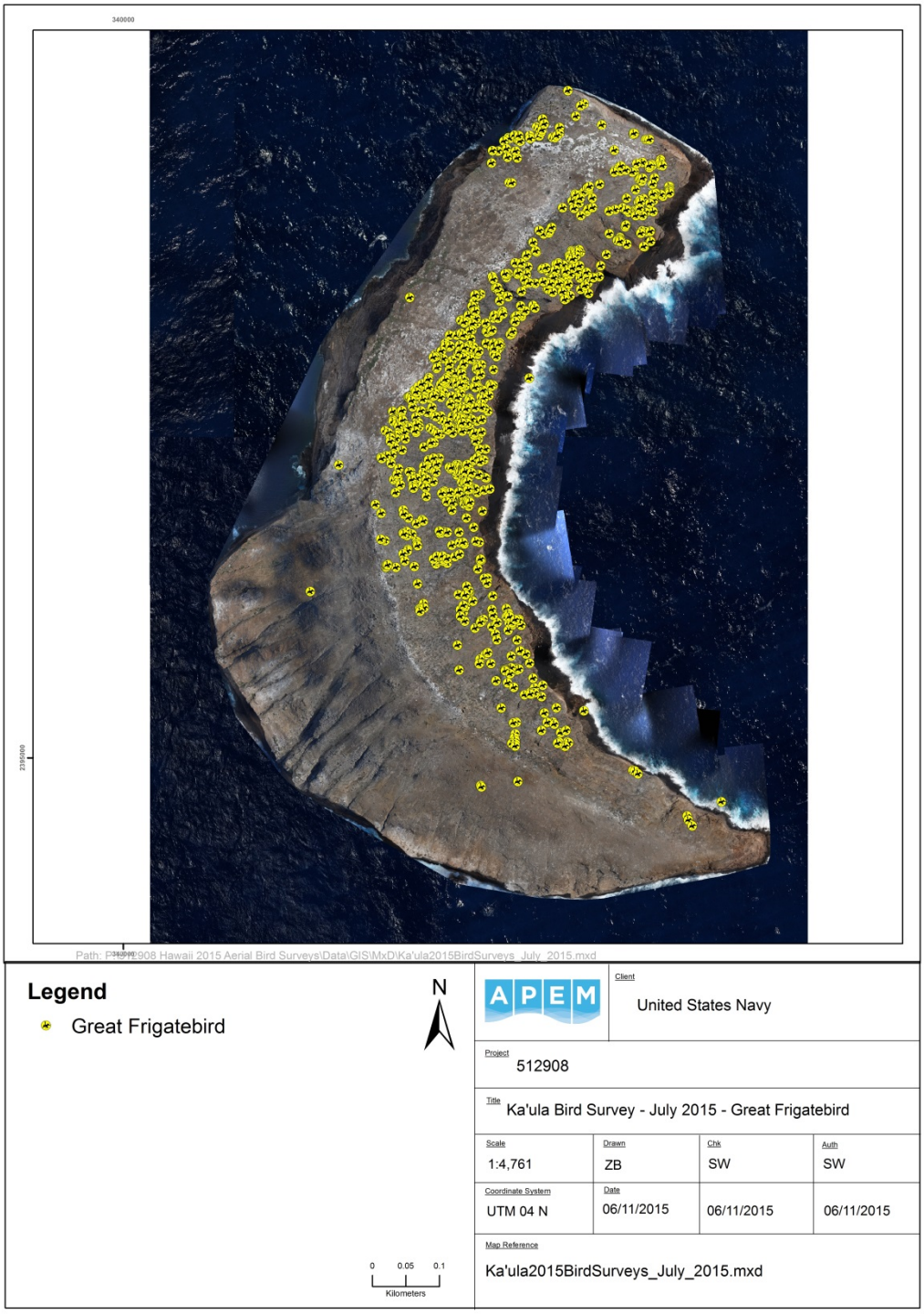

Figure 3-3. Distribution of great frigatebirds recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

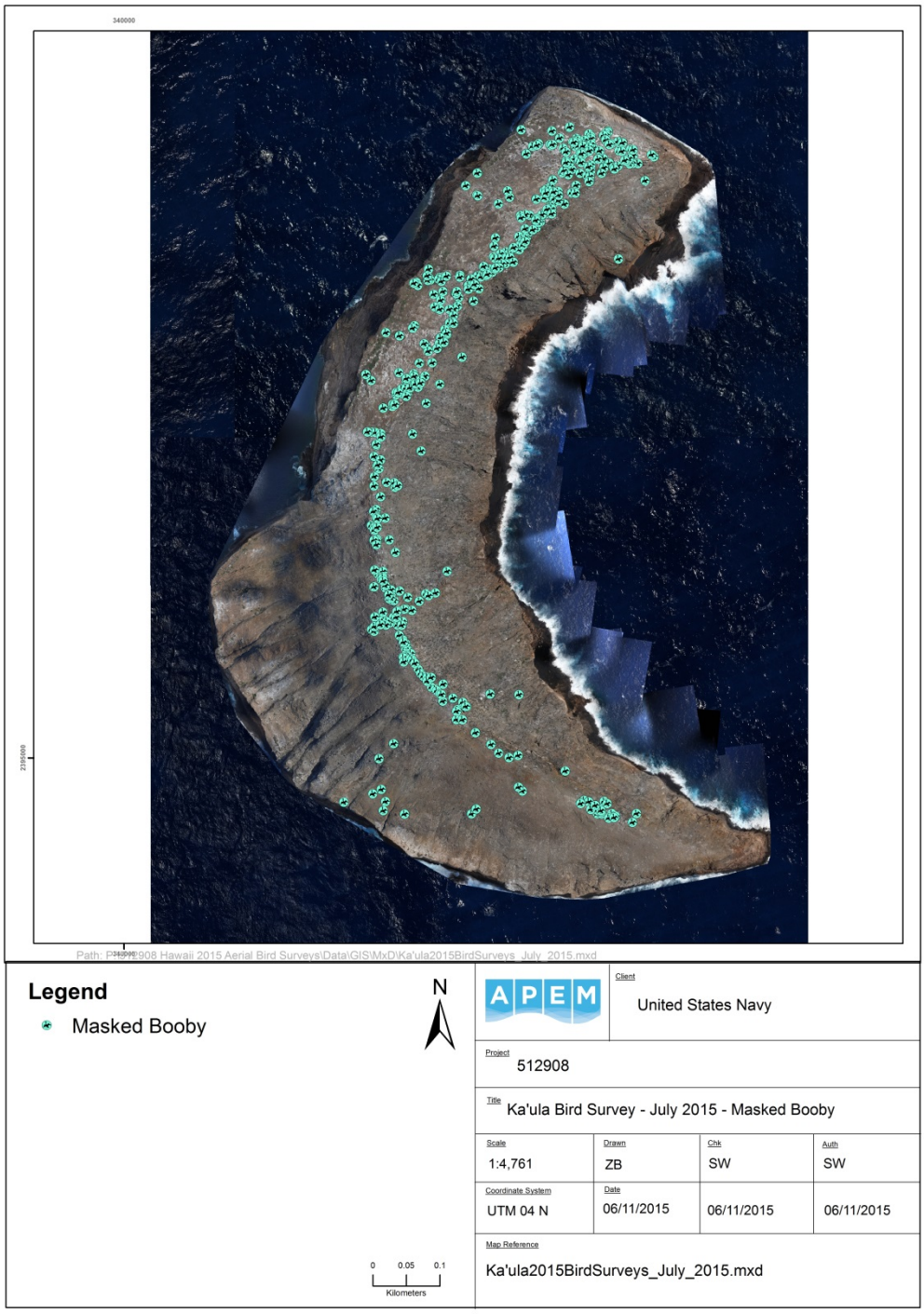

Figure 3-4. Distribution of masked boobies recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

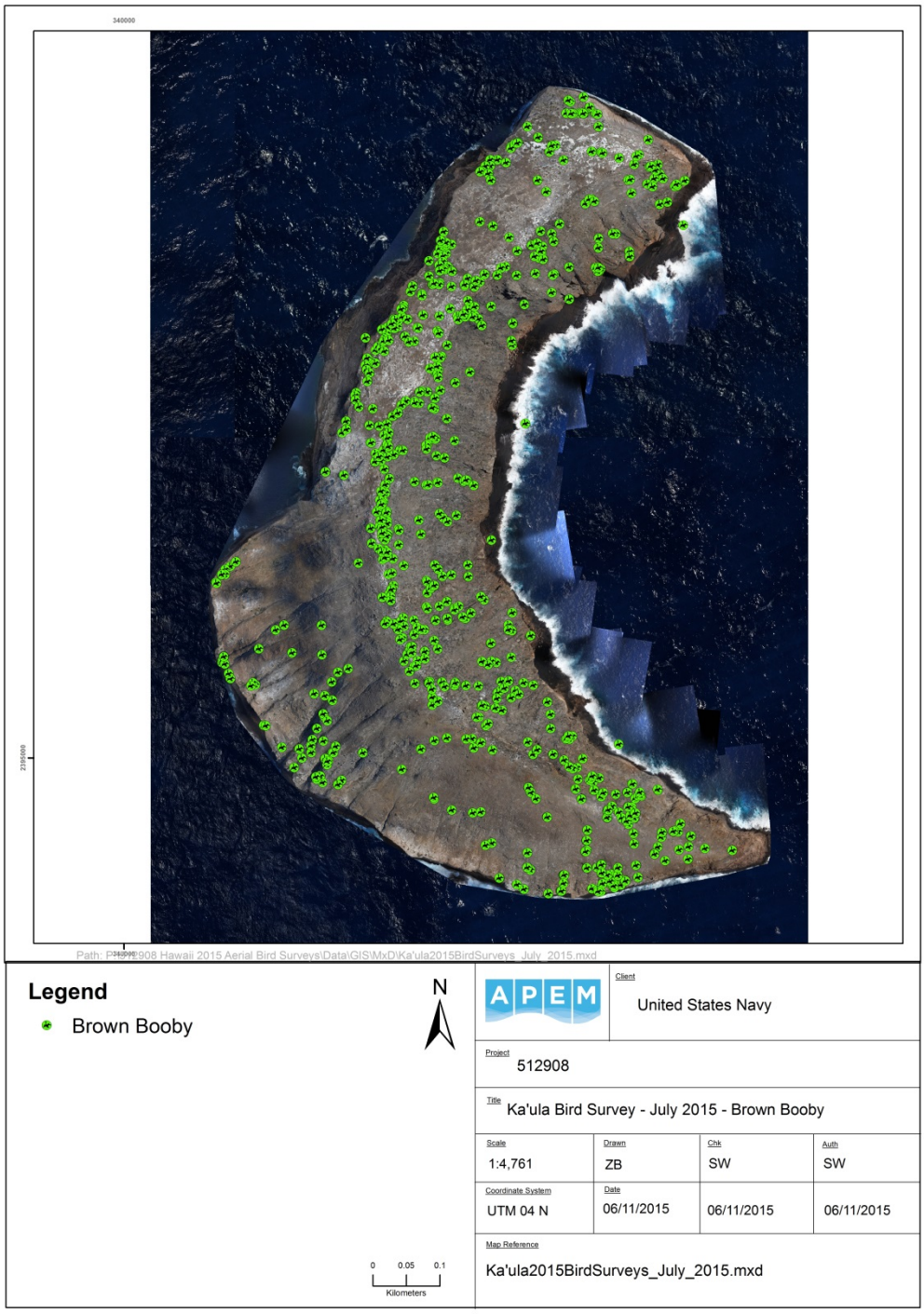

Figure 3-5. Distribution of brown boobies recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

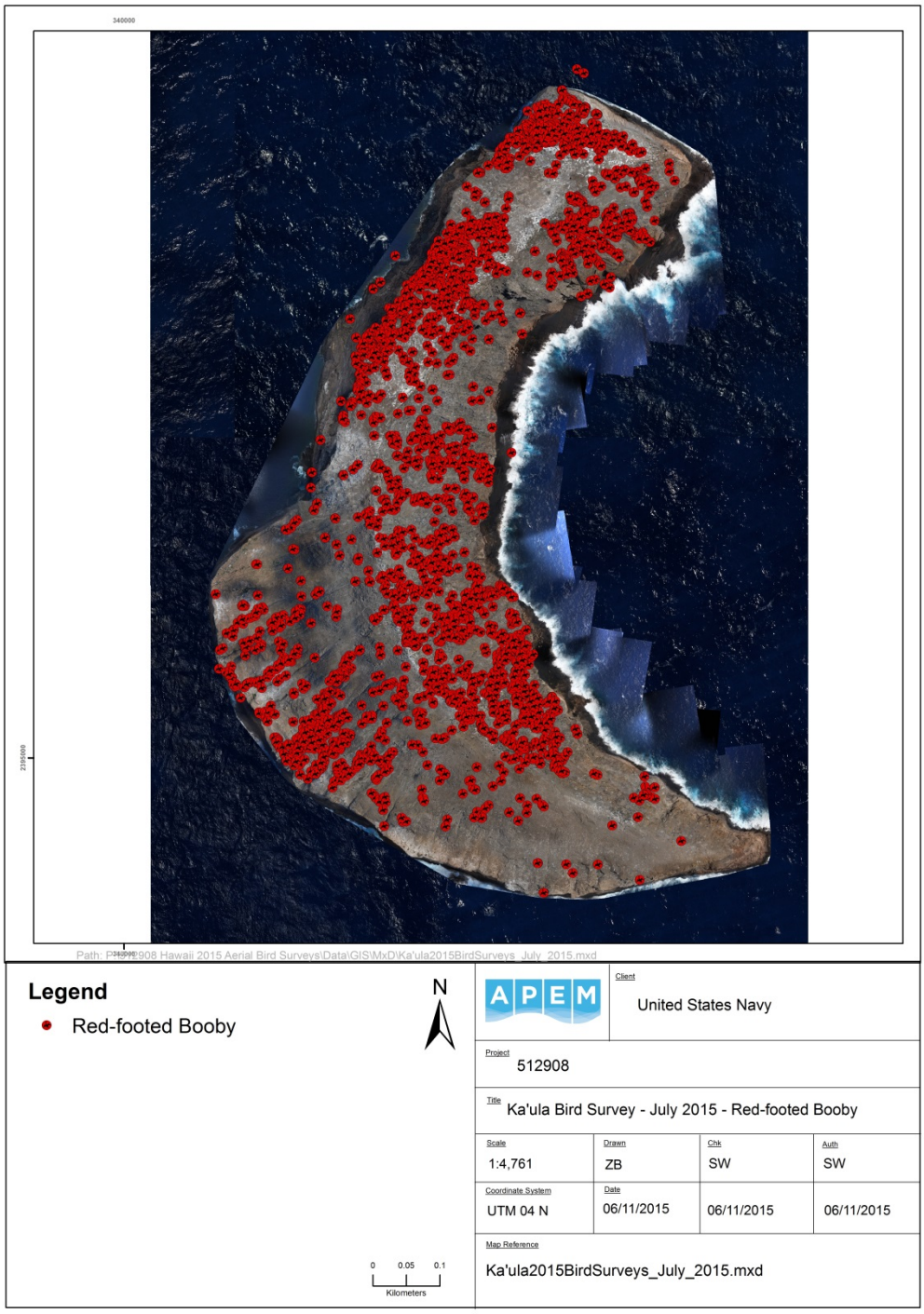

Figure 3-6. Distribution of red-footed boobies recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

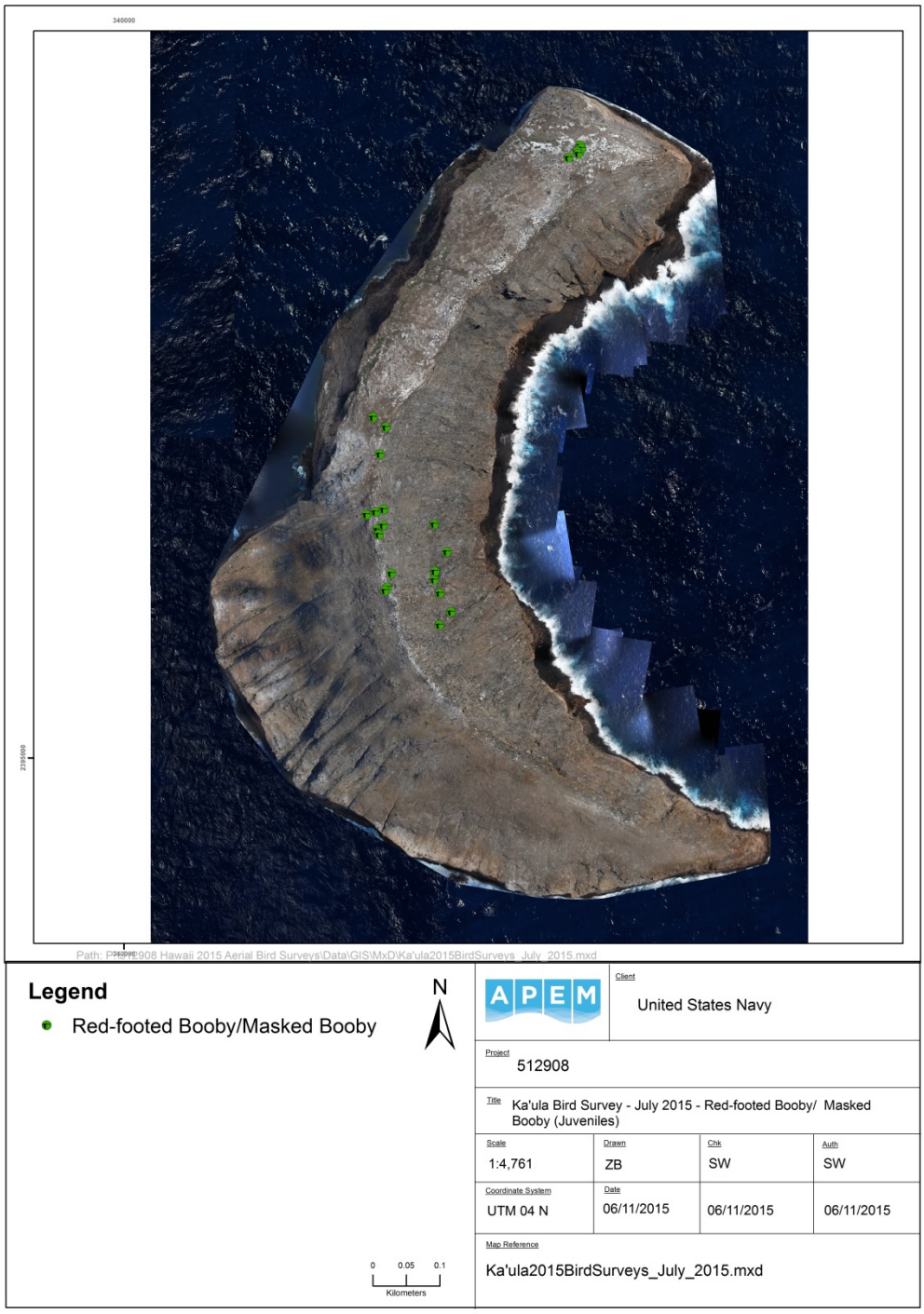

Figure 3-7. Distribution of juvenile masked/red-footed boobies recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

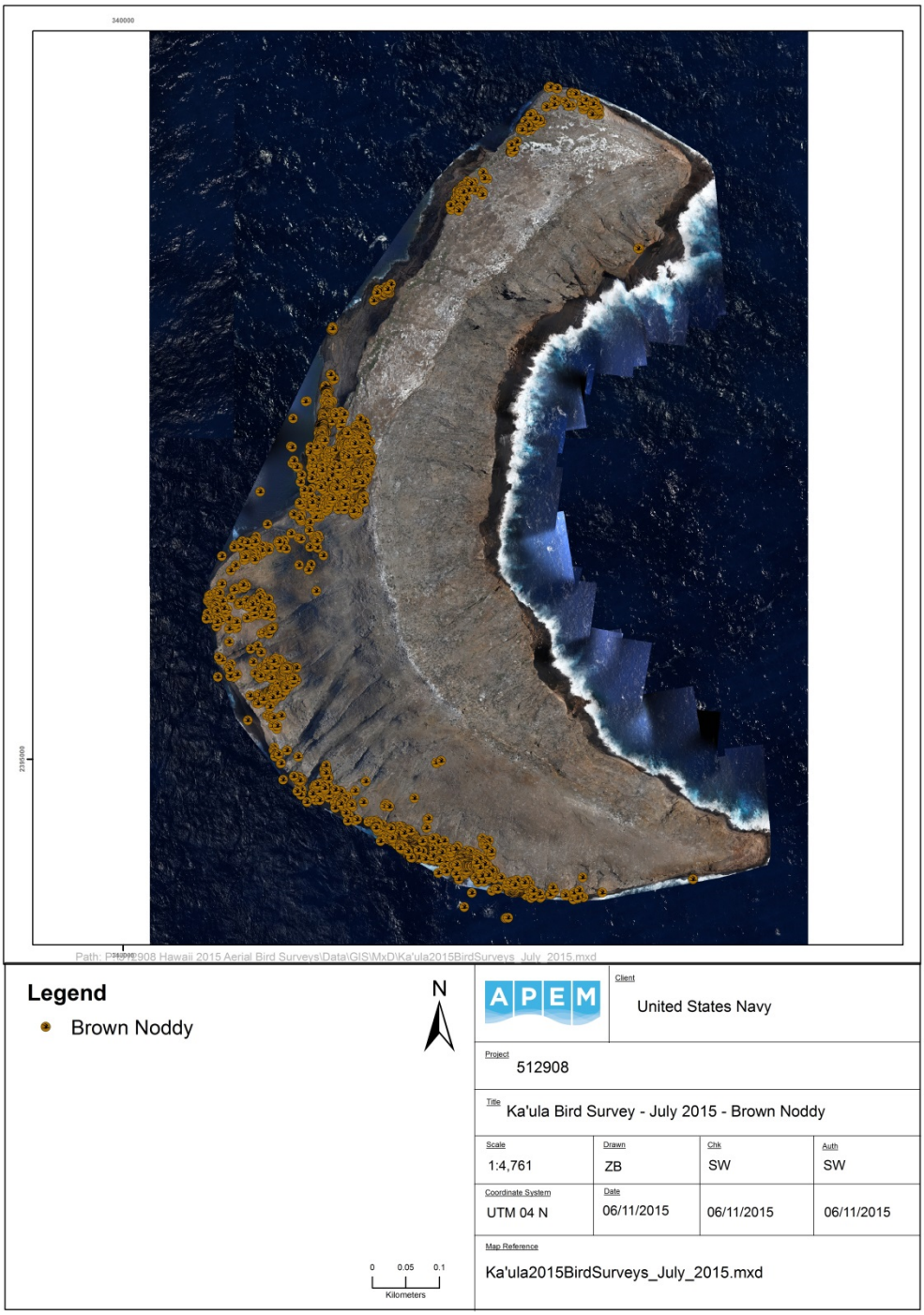

Figure 3-8. Distribution of brown noddies recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

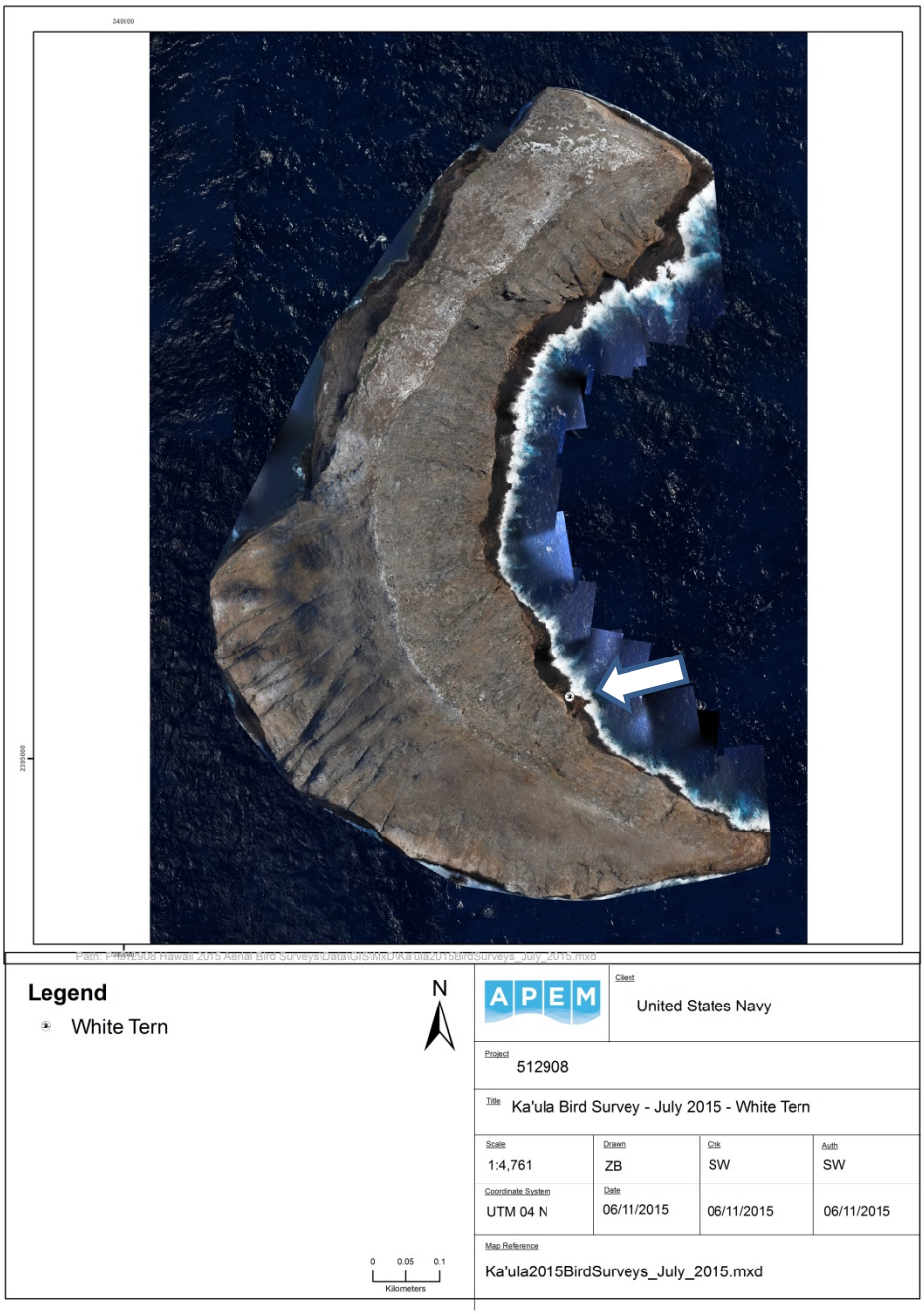

Figure 3-9. Distribution of white terns recorded on Ka`ula Island during the July 2015 survey.

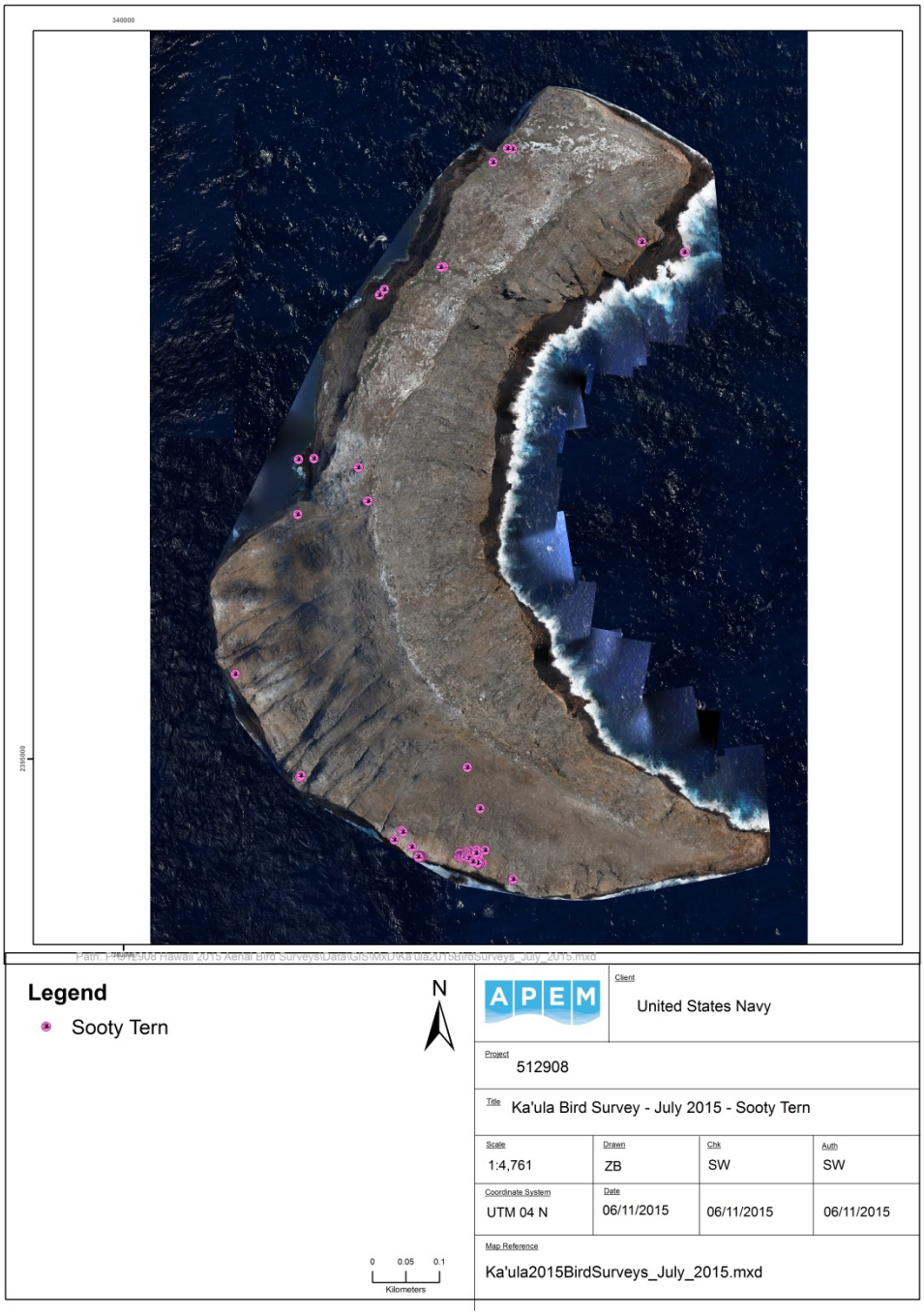

Figure 3-10. Distribution of sooty terns recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

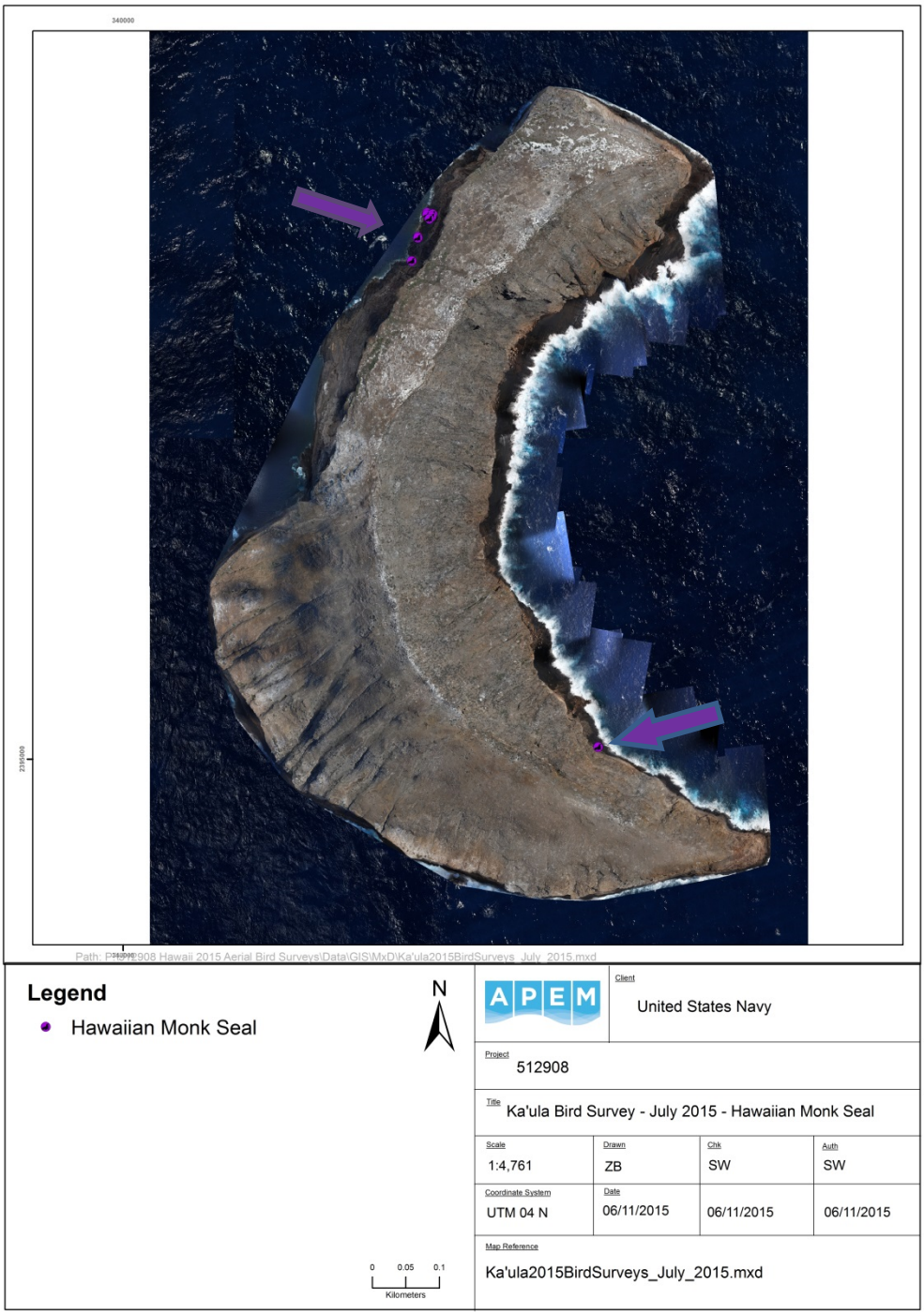

Figure 3-11. Distribution of Hawai`ian monk seals recorded on Ka`ula Island during the July 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

4 Discussion

It should be noted that this year's conditions in Hawai`i are influenced by a strengthening El Niño event, with associated anomalies in sea temperature, wind direction and rainfall.

Overall, during the vertical and oblique surveys, a total of 13,576 birds and nine Hawai`ian monk seals were recorded at Ka`ula Island during the July 2015 survey (Table 3–1). The eight bird species present were red-tailed tropicbirds, great frigatebird, masked booby, brown booby, red-footed booby, brown noddy, sooty tern and white tern. The most abundant species was brown noddy, accounting for 53% (n=7,137) of all the seabirds recorded. The next most abundant species were red-footed booby (n=3,693), great frigatebird (n=1,078) brown booby (n=867) and masked booby (n=526) (see Table 3–1). Sooty tern (n=147), Red-tailed tropicbird (n=100) and white tern (n=1) were the least abundant species recorded.

Red-tailed tropicbirds were mainly found along the eastern side of the island (Figure 3–2). Numbers recorded in this survey (n=100) were broadly similar to previous land based surveys and the recent aerial digital survey in August 2012 (n=85). As red-tailed tropicbirds nest on the ground on Ka`ula Island, inside caverns or crevasses (see Figures 6–5 and 6–7), detecting them by a vertical method alone is not really viable. Both the adults and juveniles are often found sitting inside or at the entrance to these caverns and due to the nature of these crevasses and difficulty in seeing the birds in the oblique imagery, the counts in this report are likely to be less than the actual number of birds present.

Great frigatebirds were distributed mostly in the northeast part of the island as they were during the previous January 2015 survey. Numbers were higher than those in January 2015 (n=748) but less than those recorded in the aerial digital survey in August 2013 (n=1,369). Numbers recorded from recent aerial digital surveys have generally been much higher than those from previous boat based surveys between July 2009 and July 2012 (see Appendix IV), which averaged less than 200 birds per survey. This is likely to be due to the aerial imagery allowing for more accurate counts to be made of relatively tight clustered groups of birds on high ledges and ravines that may not have been visible from a boat at sea level.

Of the booby species recorded, red-footed booby was by far the most abundant during the July 2015 survey followed by brown booby and masked booby (see Table 3–1). The count of 3,696 red-footed boobies during this survey is far higher than any previous count made on the island. The previous highest counts were 1,690 from an aerial digital survey in April 2013 and before this, June 1993 when 1,375 were counted by a land based survey (Appendix IV). The count made in July 2015 was bolstered by a large number of juveniles in nests (n=732). Of all adult birds recorded, there were 166 pairs and a further 2,496 sitting single birds, so conceivably there could have been up to 2,662 breeding pairs present.

Brown boobies, during this survey, were present in the highest numbers (n=867) since the land based survey in September 1976 when 1,000 were estimated (Appendix IV). Numbers have significantly increased since the last summertime aerial digital survey in August 2013 (n=109; Appendix IV). Of the adult birds recorded, there were 122 pairs and a further 486 sitting single birds, though some could be non-breeders, it is possible that up to 600 pairs could be breeding.

Masked boobies were distributed mainly along the central ridge where up to 122 pairs were present with a further 486 single birds. Numbers were similar to those in the survey in April 2013 (n=550; Appendix IV) and higher than August 2013 (n=219; Appendix IV). The species is known to lay eggs from February through to April but this can be earlier or later (Richardson, 1957). The higher numbers recorded during both the August 2013 and July 2015 surveys suggest that breeding on Ka`ula could occur mainly through the summer months. The distribution of birds during July 2015 was broadly similar to that recorded in previous aerial digital surveys.

The most abundant species during this survey was brown noddy (n=7,137) and these were all recorded along the western side of the island (Figure 3-8). Numbers were nearly double what was recorded in the aerial digital survey in August 2013 (n=3,713) and generally similar to previous land based counts in June 1993 (n=5,778) and September 1976 (7,000).

A total of 147 sooty terns were recorded, which were mostly in groups along the cliff edges (Figure 3-10). Birds were seen clustered in tight groups. This number is massively less than previous summertime counts from boat based surveys (n=6,169 in July 2009 and n=9,745 in June 2011). El Niño events are most intense through equatorial Pacific (Wyrtki *et al.* 1976), and throughout its range the sooty tern's breeding success is known to be strongly negatively affected by El Niño events (Duffy 1990, Ratcliffe *et al.* 1999). It is also possible they could have bred earlier in the year as high number were present in April 2013 (n=14,635) (Appendix IV).

Nine Hawai`ian monk seals, which are highly endangered, were recorded on the ledges around the island (Figure 3-11). Numbers have remained fairly consistent throughout the five aerial digital surveys carried out between 2013 and 2015 (Appendix VI).

Seabirds can spend long periods of time out at sea so single birds recorded during this survey may be half of a pair. Appendix V shows the minimum estimated number of birds present based on the actual individuals recorded in the imagery and a maximum estimated number of birds based on relevant single birds being one half of a pair. However, please note that as the breeding season of seabirds in Hawai`i is spread throughout the year not all birds may be paired up in July.

Overall the aerial survey method demonstrates that complete counts of seabirds can be obtained including ability to accurately assess the number of birds on apparently occupied nests (AON's) that would be almost impossible to record from boat surveys. Aerial imagery also creates a permanent record / snapshot of the area at a specific time, allowing users to revisit the imagery / data as often as required. It is also important to note that survey techniques have differed historically on the island and may not all be directly comparable (see Appendix IV for a list of all bird species previously observed and survey type).

5 References

DoN (2008). Hawaii Range Complex FEIS/OEIS. Department of Navy, Commander Fleet Air Hawai`i.

DoN (2009). Ka`ula Island Seabird Monitoring Plan. Department of Navy, Commander Fleet Air Hawai`i.

DoN. (2011). Ka`ula / Kaua`i field report, HRC marine species monitoring, February 15–20, 2011. Prepared for Commander Pacific Fleet by NAVFAC Pacific.

DoN (2013). Hawaii-Southern California Training and Testing EIS/OEIS. Department of Navy, Commander Fleet Air Hawai`i.

Duffy, D. C. 1990. Seabirds and the 1982-84 El Niño-Southern Oscillation. Pages 395-415 *in* Global ecological consequences of the 1982-83 El Niño-Southern Oscillation. (Glynn, P. W., Ed.) Elsevier, Amsterdam.

Elmer, J. S., and G. Swedberg. (1971). Assessment of environmental impact, Ka`ula Island target. DoN, Commander Fleet Air Hawai`i.

Fujimoto, J., and F. Juola. (2012). *Ka`ula Island ship-based seabird survey, 6 July 2012.* Prepared for Commander Pacific Fleet by NAVFAC Pacific.

Mobley, J., Spitz, S. and R. Grotefendt. (2001). *Abundance of humpback whales in Hawaiian waters: Results of 1993-200 aerial surveys.* Prepared for the Hawaiian Islands Humpback Whale National Marine Sanctuary Office of National Marine Sanctuaries National Oceanic and Atmospheric Administration U.S. Department of Commerce and the Department of Land and Natural Resources State of Hawaii.

Palmer, H. S. (1936). Geology of Lehua and Ka`ula islands. Bernice P. *Bishop Museum Occasional Papers* 12(13). (Referenced in Pepi et al 2009)

Pepi, V. E., Kumar, A., Laut, M. E., Hallman, J., Kim, J., and Anders, A. D. (2009). *Ka`ula Island ship-based seabird and marine mammal surveys, 21-22 July 2009.* Prepared for Commander, Pacific Fleet by NAVFAC Pacific.

Ratcliffe, N., J. Hughes, and F. A. Roberts. 1999. The population status of Sooty Terns *Sterna fuscata* on Ascension Island. Atl. Seabirds 1:159-168.

Richardson, F. (1957). The Breeding Cycles of Hawaiian Sea Birds. Bernice P. *Bishop Museum Bulletin* No. 218. Honolulu.

Walker, R. R. (1983). *Report on trip to Ka`ula Island, June 19-20, 1980*. (Referenced in Pepi et al 2009)

Walker, R. R. (1984). *Ka`ula trip report, April 16-18, 1984*. (Referenced in Pepi et al 2009)

Wyrtki, K., E. Stroup, W. Patzert, R. Williams, and W. Quinn. 1976. Predicting and observing El Niño. Science 191:343-346

6 Appendices

Appendix I. Survey Imagery: Vertical Image Examples

Figure 6-1 Adult and juvenile red-footed and brown boobies (pair circled), along the north-west side of Ka`ula Island during the July 2015 survey.

Figure 6-2 Adult and juvenile great frigatebirds (juveniles in nests circled) on the eastern slopes of Ka`ula Island during the July 2015 survey.

Figure 6-3 Brown noddies situated on the western slopes of Ka`ula Island during the July 2015 survey.

Figure 6-4 Two Hawai`ian monk seals (circled) resting on ledges on the north-eastern side of Ka`ula Island, during the July 2015 survey.

Appendix II. Survey Imagery: Oblique Image Examples

Figure 6-5 Adult red-tailed tropicbird, just below the central ridge of Ka`ula Island during the July 2015 survey.

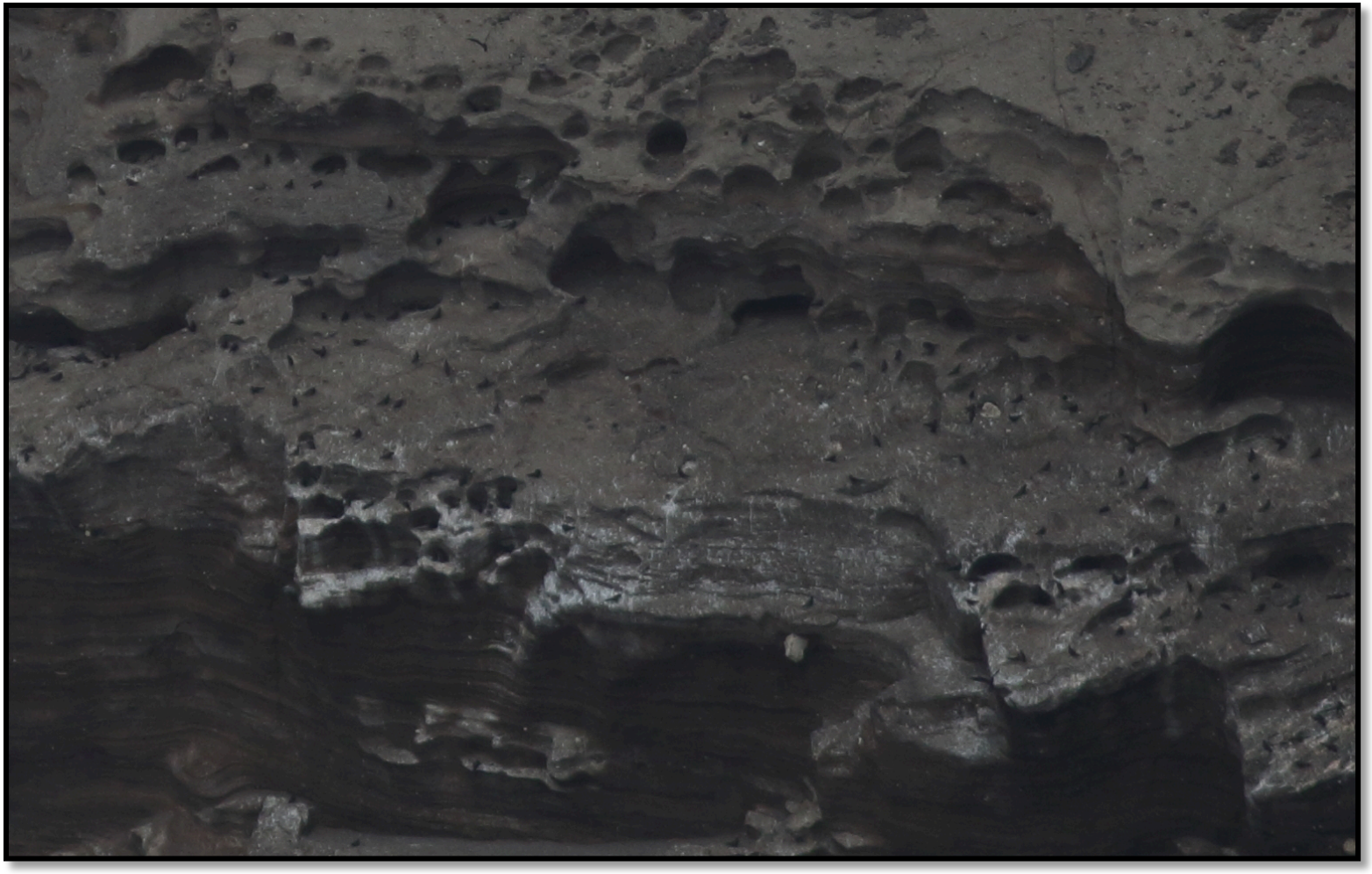

Figure 6-6 Brown noddies present on low ledges and hollows on the west side of Ka`ula Island, during the July 2015 survey.

Figure 6-7 Juvenile red-tailed tropicbirds, sat at entrances to burrows on the east side of Ka`ula Island, during the July 2015 survey. Also a juvenile red-footed booby bottom right.

Figure 6-8 Red-footed and brown boobies (top right) and brown noddies (bottom left) on ledges at the very northern tip of Ka`ula Island during the July 2015 survey.

Appendix III. Scientific Names of Relevant Bird and Mammal Species

Common Name	Scientific Name
Red-tailed tropicbird	*Phaethon rubricauda*
Great frigatebird	*Fregata minor*
Masked booby	*Sula dactylatra*
Brown booby	*Sula leucogaster*
Red-footed booby	*Sula sula*
Masked/red-footed booby	*Sula species*
Brown noddy	*Anous stolidus*
White tern	*Gygis alba*
Sooty tern	*Onychoprion fuscatus*
Hawai`ian monk seal	*Neomonachus schauinslandi*

Appendix IV. Results of Bird Surveys Conducted on Ka`ula Island, Hawai`i, 1932–2015*

Common Name	Scientific Name	Aug 1932 Land based survey (A)	Aug 1971 Land based survey (A)	Jan 1976 Land based survey (A)	Sep 1976 Land based survey (A)	Mar 1978 Land based survey(A)	Aug 1978 Land based survey(A)	Mar 1979 Land based survey(A)	Jun 1980 Land based survey(A)	Apr 1984 Land based survey (A)	Jun 1993 Land based survey (A)	Nov 1998 Land based survey (A)	Jul 2009 Boat based survey (B)	Jun 2010 Boat based survey (A)	Jun 2011 Boat based survey (C)	July 2012 Boat based survey (C)	Apr 2013 Aerial digital survey (D)	Aug 2013 Aerial digital survey (D)	Jan 2014 Aerial digital survey (D)	Jan 2015 Aerial digital survey (D)	July 2015 Aerial digital survey (D)
Laysan albatross	*Phoebastria immutabilis*	-	1 old egg	150	-	100	-	100	9	33	44	60	-	-	-	-	20	11	81	100	-
Black-footed albatross	*Phoebastria gripes*	1 old egg	-	100	-	75	-	75	-	2	4	10	-	-	-	-	3	-	11	3	-
Bonin petrel	*Pterodroma poleuca*	1 chick	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
Bulwer's petrel	*Bulweria bulwerii*	several	100	-	100	-	50	-	100	580	100	-	1	1		-	-	-	-	-	-
Wedge-tailed shearwater	*Puffinus pacificus*	many burrows	4,100	-	4,000	-	800	-	1,415	980	400	200	16	-	-	-	-	-	-	-	-
Christmas shearwater	*Puffinus ativitatis*	-	450	-	250	-	100	25	20	60	18	-	-	-	-	-	-	-	-	-	-
White-tailed tropicbird	*Phaethon pturus*	-	3	1	1	-	1	2	-	-	-	1	-	-	-	-	-	-	-	-	-
Red-tailed tropicbird	*Phaethon ubricauda*	common	950	-	450	60	100	40	276	209	146	15	31	3	5	1	314	85	-	1	100
Great frigatebird	*Fregata minor*	common	950	250	800	400	250	250	134	155	701	650	131	430	105	26	1,415	1,369	621	748	1,078
Masked booby	*Sula dactylatra*	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219	65	84	526
Brown booby	*Sula leucogaster*	common	1,700	50	1,000	75	60	200	212	169	397	60	112	1	6	40	101	109	3	2	867
Red-footed booby	*Sula sula*	uncommon	1,300	100	150	85	200	400	344	222	1,375	1,200	-	-	-	-	1,690	191	98	209	3,693
Masked/red-footed booby	*Sula dactylatra / sula*	-	-	-	-	-	-	-	-	-	-	-	820	850	1,859	912	-	-	-	-	27
Pacific golden plover	*Pluvialis fulva*	several	-	10	14	-	1	2	-	21	-	15	-	-	-	-	-	-	-	-	-
Wandering tattler	*Heteroscelus canus*	-	-	5	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Ruddy turnstone	*Arenaria terpres*	-	50	5	20	-	4	24	1	7	1	12	-	-	-	-	-	-	-	-	-
Brown noddy	*Anous stolidus*	most numerous	67,700	-	7,000	7,000	10,000	1,000	10,560	3,950	5,778	-	-	-	-	-	57	3,713	-	-	7,137
Black noddy	*Anous minutus*	-	100	20	100	75	200	-	-	207	6	-	-	-	-	-	-	22	-	-	-
Brown/black noddy	*Anous species*	-	-	-	-	-	-	-	-	-	-	-	711	705	306	597	-	-	-	-	-
Blue-grey noddy	*Procelsterna erulea*	small colony	-	-	200	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-
White tern	*Gygis alba*	uncommon	10	10	200	40	10	-	9	12	9	-	10	9	9	12	6	-	-	-	1
Sooty tern	*Onychoprion scatus*	common	16,800	2,500	1,000	130,000	2,500	50,000	28,850	83,680	27,255	200	6,169	3,382	9,745	4,509	14,635	7	-	-	147
Grey-backed tern	*Onychoprion natus*	uncommon	2,800	-	250	1,250	50	300	4,110	1,467	35	-	1	3	-	-	4	-	-	-	-
Barn owl	*Tyto alba*	-	1	3	3	-	1	6	4	2	7	3	-	-	-	-	-	-	-	-	-
Japanese white-eye	*Zosterops ponicus*	-	-	2	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-

Common Name	Scientific Name	Aug 1932 Land based survey (A)	Aug 1971 Land based survey (A)	Jan 1976 Land based survey (A)	Sep 1976 Land based survey (A)	Mar 1978 Land based survey(A)	Aug 1978 Land based survey(A)	Mar 1979 Land based survey(A)	Jun 1980 Land based survey(A)	Apr 1984 Land based survey (A)	Jun 1993 Land based survey (A)	Nov 1998 Land based survey (A)	Jul 2009 Boat based survey (B)	Jun 2010 Boat based survey (A)	Jun 2011 Boat based survey (C)	July 2012 Boat based survey (C)	Apr 2013 Aerial digital survey (D)	Aug 2013 Aerial digital survey (D)	Jan 2014 Aerial digital survey (D)	Jan 2015 Aerial digital survey (D)	July 2015 Aerial digital survey (D)
Northern mockingbird	*Mimus polyglottos*	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern cardinal	*Cardinalis*	-	2	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
House finch	*Haemorhous mexicanus*	-	6	15	40	-	20	6	-	1	1	8	-	-	-	-	-	-	-	-	-
Nutmeg mannikin	*Lonchura punctulata*	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Estimated Number of Birds		**-**	**98,022**	**3,521**	**16,811**	**139,285**	**14,548**	**52,831**	**46,280**	**91,959**	**36,847**	**2,785**	**8,001**	**5,385**	**12,035**	**6,097**	**18,795**	**5,733**	**879**	**1,145**	**13,576**
Total Number of Species		**16**	**19**	**16**	**24**	**12**	**19**	**17**	**15**	**19**	**19**	**15**	**11**	**11**	**8**	**8**	**11**	**9**	**6**	**7**	**8**

*Data sourced from:

A - DON (2011). Ka`ula / Kaua`i field report, HRC marine species monitoring, February 15-20, 2011. Prepared for Commander Pacific Fleet by NAVFAC Pacific.

B – Pepi, V. E., A. Kumar, M. E. Laut, J. Hallman, J. Kim, and A. D. Anders. (2009). *Ka`ula Island ship-based seabird and marine mammal surveys, 21-22 July 2009*. Prepared for Commander, Pacific Fleet by NAVFAC Pacific.

C – Fujimoto, J & Juola, F. (2012). *Ka`ula Island ship-based seabird survey, 6 July 2012*. Prepared for Commander, Pacific Fleet by NAVFAC Pacific.

D – Normandeau Associates, Inc. and APEM, Ltd. Joint Venture 2013. Aerial Survey of Seabirds and Marine Mammals at Ka`ula Island, Hawai`i. Prepared for Commander, Pacific Fleet through a contract with NAVFAC Pacific.

Appendix V. Estimates of Seabird Numbers during the July 2015 Aerial Digital Survey of Ka`ula Island, Hawai`i.

Species/Group	Minimum estimate of bird numbers	Maximum estimate of bird numbers*
Birds		
Great frigatebird	1,078	1,822
Red-tailed tropicbird	100	172
Masked booby	526	859
Brown booby	867	1,376
Red-footed booby	3,693	6,324
Red-footed booby / Masked booby	27	31
Brown noddy	7,137	13,670
Sooty tern	147	264
White tern	1	2
Total Estimated Number of Birds	**13,576**	**24,520**

*A pair is assumed to be two birds, all singles (including single flying birds) are assumed to be one of a pair and are doubled up to obtain maximum estimate.

Appendix VI. Results of Aerial Digital Surveys conducted by Normandeau/APEM of Ka`ula Island, Hawai`i, 2013-2015*

Common Name	Scientific Name	Global Population	Regional Population[2] (Hawai`i) Breeding Pairs	Apr 2013	Aug 2013	Jan 2014	Jan 2015	July 2015
Black-footed albatross	*Phoebastria nigripes*	64,500 breeding pairs[4]	55,000	3	-	11	3	-
Laysan albatross	*Phoebastria immutabilis*	1,180,000 mature individuals[4]	590,000	20	11	81	100	-
Red-tailed tropicbird	*Phaethon rubricauda*	> c.32,000 individuals[1]	9,000-12,000	314	85	-	1	100
Great frigatebird	*Fregata minor*	500,000-1,000,000[2]	10,000	1,415	1,369	621	748	1,078
Masked booby	*Sula dactylatra*	Unquantified. Described as 'fairly common'[3]	2,500	550	219	65	84	526
Brown booby	*Sula leucogaster*	> c.200,000 individuals[1]	1,400	101	109	3	2	867
Red-footed booby	*Sula sula*	> c.1,000,000 individuals[1]	7,000-10,500	1,690	191	98	209	3,693
Masked/red-footed booby	*Sula species*	-	-	-	-	-	-	27
Brown noddy	*Anous stolidus*	500,000-1,000,000 breeding pairs[2]	112,000	57	3,713	-	-	7,137
Black noddy	*Anous minutus*	1-1.5 million breeding pairs[2]	12,000	-	22	-	-	-
White tern	*Gygis alba*	Likely exceeds 100,000 breeding pairs[2]	15,000	6	-	-	-	1
Sooty tern	*Onychoprion fuscatus*	60-80 million breeding pairs[2]	>1,000,000	14,635	7	-	-	147
Grey-backed tern	*Onychoprion lunatus*	Likely 70,000 breeding pairs[2]	44,000	4	-	-	-	-
Hawai`ian monk seal	*Neomonachus schauinslandi*	1,209 individuals of all age classes[5]	632 sexually mature seals[5]	11	7	5	7	9
Total Estimated Number of Birds				**18,795**	**5,733**	**879**	**1,147**	**13,576**
Total Number of Species				**11**	**9**	**6**	**7**	**8**

[1] del Hoyo et al. 1992
[2] Hawaii Department of Land and Natural Resources (http://dlnr.hawaii.gov/wildlife/cwcs/hawaii/species/fact-sheets/)
[3] Stotz et al. 1996
[4] Birdlife International http://www.birdlife.org/datazone/
[5] IUCN Red List http://www.iucnredlist.org/details/13654/0