

**Aerial Survey of Seabirds and Marine Mammals at Ka'ula Island, Hawai'i,  
March 2016**

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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 March 10, 2016. A vertical (nadir) aerial survey was complemented by an oblique survey, which was conducted on the same day. Carrying out both surveys allows counts to be made 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 on one day with 98% of the final image mosaic formed from imagery collected on the high resolution survey. The 2% data gap was filled by imagery collected from the high altitude, or lower resolution survey.

In total, 47,664 birds of ten species were recorded during the survey with sooty tern being the most abundant species (n=40,814) followed by brown noddy (n= 4,115). Other species were recorded including black-footed albatross, Laysan albatross, red-tailed tropicbird, great frigatebird, masked booby, brown booby, red-footed booby, and grey-backed tern.

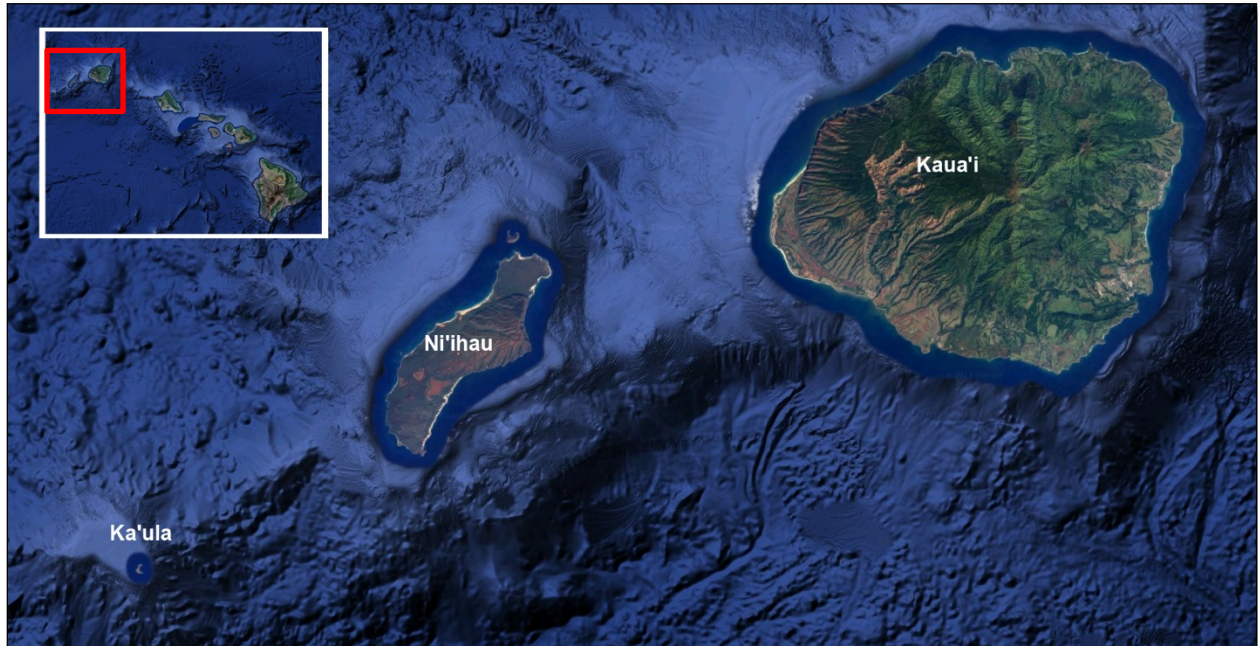
The actual count of sooty terns is the largest since the 1984 land based survey when 83,680 were recorded. However, assuming all single birds are one of a pair unless visibly doubled up, then there could be approximately 80,000 birds.

At the time of the surveys, ten Hawai'ian monk seals were recorded resting on ledges on the east side 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<sup>2</sup>), uninhabited crescent-shaped islet in the western chain of islands making up the Hawai'ian Archipelago (Figures 1–1 and 1–2). The islands closest to Ka'ula are Ni'ihau, which is located 37 km to the northeast, and Kaua'i, 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 Kaua'i and Ni'ihau (imagery from ESRI).**



**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<sup>2</sup>) 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. Since 1981, 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 and aerial observations (2009–2011; Pepi et al. 2009; DoN 2011). Aerial digital surveys commenced in April 2013 and six surveys have been carried out to date.

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 U.S. Navy wanted 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 March 10, 2016, and included the oblique images.

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 (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 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 the morning of March 10, 2016. This involved a vertical survey of Ka'ula Island at low altitude (vertical low altitude survey). The second, higher altitude (vertical high altitude) survey was completed in the afternoon of March 10, 2016.

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 March 10, 2016, after the vertical surveys.

The first complete survey carried out on March 10, 2016 (between 10:01 and 11:25 hours), was the vertical low altitude survey 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.

After refueling at Līhu'e, the second completed survey carried out on March 10, 2016 (between 1350 and 1446 hours), was the vertical high altitude survey conducted at 2,500 feet and 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 oblique survey was also carried out on March 10, 2016 (between 1450 and 1520 hours [see Section 2.3]) by flying clockwise around the island, on several occasions, between 500 and 1,800 feet. Although resolution of the oblique imagery varies, the majority of it is less than 2 cm.

### **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 2-hour period. These images were imported as geo-referenced images (WGS 84 projection) into ArcGIS (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 and the disturbance caused, which results in many birds moving around in response to the observers.

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 I 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. The software contains a detection algorithm that picks out all the objects, which are presented to the image processing staff. As part of the identification process, the software contains an automated species separation tool used for identifying regularly encountered European seabirds 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 U.S. Navy. Examples of the vertical imagery can be found in Appendix II.

### **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. Examples of the oblique imagery can be found in Appendix III.

## **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 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 provides advice and guidance to the image processing staff.

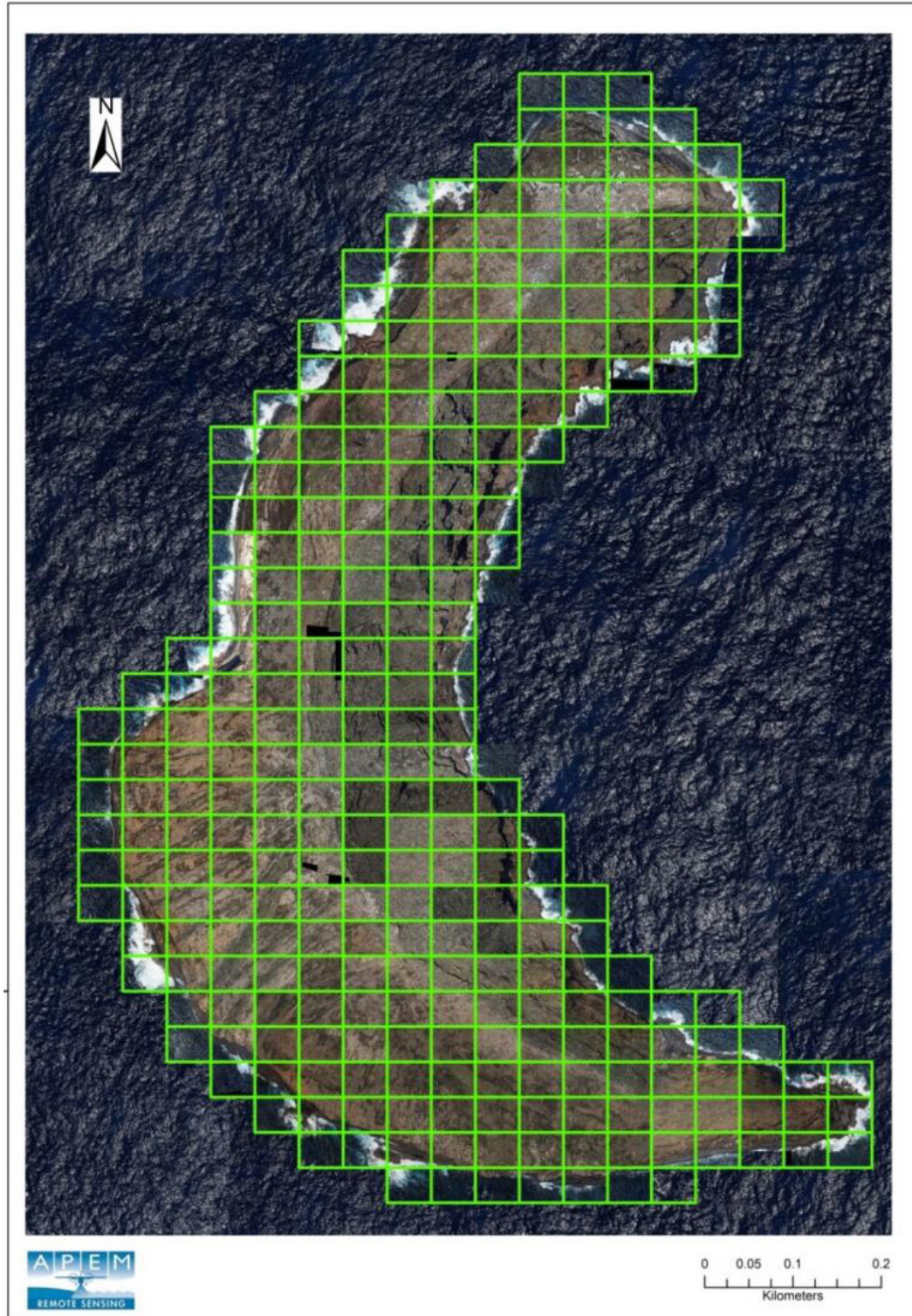
## **2.3 Weather Conditions and Survey Limitations**

This section explains some of the survey limitations and weather conditions. Due to the time of 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 island terrain. Once the equipment had been installed into the aircraft on March 4, 2016, and a short test flight was conducted, we waited for a suitable weather window.

On the morning of March 7, 2016, technical issues prevented flight. On March 8, 2016, radar imagery showed cloud and rain moving in to the survey area, preventing any attempt at the survey. This was confirmed with rain reaching Honolulu at approximately 13:45. On March 9, 2016, the radar showed cloud and high winds so no attempt was made to carry out the survey as these conditions had been confirmed by the pilot.

After consideration of weather forecasts and satellite imaging, the weather appeared good enough to survey on the morning of March 10, 2016. Survey conditions were good with high altitude cloud cover, winds ranging between 24 and 30 knots from the northeast; gusts over 40 knots did make the oblique surveying very challenging. Visibility was greater than 10 km during all surveys.

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

Ten marine mammals (1 species) and 47,664 birds (10 species) were recorded on Ka'ula Island during March 2016 (Table 3–1). Sooty tern (n=40,814) was the most abundant bird species, and grey-backed 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 March 2016**

Species/Group	Number Recorded			
	Vertical Survey	Oblique Survey	Visual Observation	Total
<b><i>Birds</i></b>				
Black-footed albatross	4	-	-	4
Laysan albatross	7	14	-	21
Red-tailed tropicbird	7	16	-	23
Great frigatebird	1,005	-	-	1,005
Masked booby	183	-	-	183
Brown booby	177	2	-	179
Red-footed booby	1,319	-	-	1,319
Brown noddy	3,838	277	-	4,115
Sooty tern	40,814	-	-	40,814
Grey-backed tern	1	-	-	1
<i>Total Birds</i>	<i>47,355</i>	<i>309</i>	<i>-</i>	<i>47,664</i>
<b><i>Marine Mammals</i></b>				
Hawaiian monk seal	10	-	-	10
<b>Total Birds and Marine Mammals</b>	<b>47,365</b>	<b>309</b>	<b>-</b>	<b>47,674</b>

## **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 March 2016 aerial survey. Birds were widely distributed throughout the whole island. The albatrosses were mostly found in the higher central or northern parts of the island. Red-tailed tropicbirds were recorded mainly along the eastern concave section. Great frigatebirds were concentrated on the eastern 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 western side of the island and seemed to be in specific clusters with only a few present amongst groups of sooty terns. Sooty terns were also concentrated along the western side of the island and some areas were densely packed. A single grey-backed tern was present amongst the sooty terns on the western side. Hawai'ian monk seals were found on the ledges in the northeastern part of the island.

### **3.2.2 Black-footed Albatross**

Four black-footed albatrosses were recorded during the survey (Table 3–1). All were at the northern end of the island in the grassed areas with three birds sitting close together and one in flight (Figure 3–2).

### **3.2.3 Laysan Albatross**

Twenty-one Laysan albatrosses were recorded during the survey (Table 3–1) of which two were flying. They were thinly distributed along the higher eastern slopes with one of the two flying birds over the western side (Figure 3–3). Of the 21 recorded, 14 of these were found during the analysis of the oblique imagery and were present in small caverns and overhangs.

### **3.2.4 Red-tailed Tropicbirds**

Twenty-three adult red-tailed tropicbirds were recorded during the survey (Table 3–1) of which all were present in the eastern concave section of the island (Figure 3–4). Seven individuals were recorded in flight and all 16 of the sitting birds were found in the oblique imagery sitting in small caverns (Appendix III, Figure 6–5).

### **3.2.5 Great Frigatebirds**

A total of 1,005 great frigatebirds were recorded during the survey (Table 3–1), of which 64 were flying. Virtually all were present in the northern half of the island along the east side in the concave section (Figure 3–5) with just a handful of birds present on the western side and southern section. There were scattered nesting colonies, and small groups of males could be seen displaying their red gular pouches (throat area).

### **3.2.6 Masked Booby**

A total of 183 masked boobies were recorded during the survey (Table 3–1) of which 2 were flying. 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 northwest side close to

the cliff edge and a small cluster was present towards the southern end, also on the ridge (Figure 3–6). Three immature/juvenile birds were noted.

### **3.2.7 Brown Booby**

A total of 179 brown boobies were recorded during the survey (Table 3–1) of which 4 were flying. They were widely distributed throughout the whole island with fewer birds in the southwest section of the island (Figure 3–7). One immature/juvenile bird was noted.

### **3.2.8 Red-footed Booby**

A total of 1,319 red-footed boobies were recorded during the survey (Table 3–1) of which 30 were flying. They were present across the whole island with particular concentrations in some of the ravines on the western and eastern sides (Figure 3–8). Fewer birds were recorded in the southern section. Forty-four immatures were recorded, many of which were perched on rocks with adults (see Appendix III, Figure 6–6).

### **3.2.9 Brown Noddy**

A total of 4,115 brown noddies (3,272 sitting and 843 flying) were recorded during the survey, of which virtually all were along the western slopes near the cliff edges (Table 3–1). They were concentrated in four main areas (Figure 3–9). Of the total birds recorded, 331 were located in the oblique imagery along the lower cliffs of the western side where they were easily visible (Appendix III, Figure 6–7).

### **3.2.10 Sooty Tern**

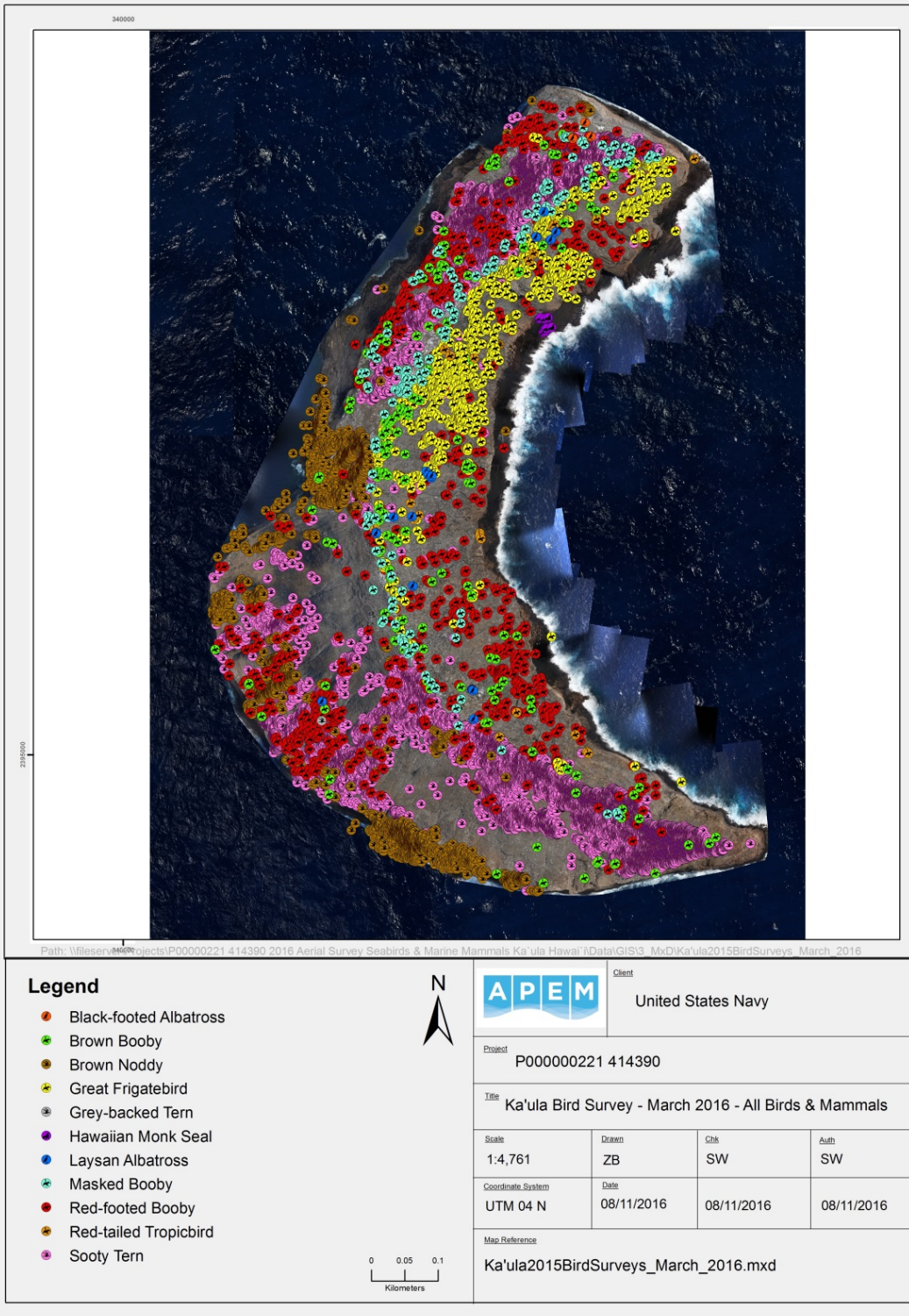
A total of 40,814 sooty terns (40,263 sitting and 551 flying) were recorded during the survey (Table 3–1), most of which were sitting in densely packed groups on the west and south sides of the island (Figure 3–10). In the southern section, birds seemed to be more densely concentrated as over 5,000 were counted in two grid cells alone. The majority of birds recorded on the east side consisted of birds in flight, whereas in the southern section birds seem to spill over onto the sandy eastern slopes.

### **3.2.11 Grey-backed Tern**

One grey-backed tern was recorded during the survey (Table 3–1), which was present amongst sooty terns on the western side of the island (Figure 3–11).

### **3.2.12 Marine Mammals**

During the course of the surveys, ten Hawai'ian monk seals were recorded resting on ledges on the northeastern side of the island (Table 3–1, Figure 3–12).



**Figure 3–1. Distribution of all birds and marine mammals recorded on Ka'ula Island during the March 2016 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.





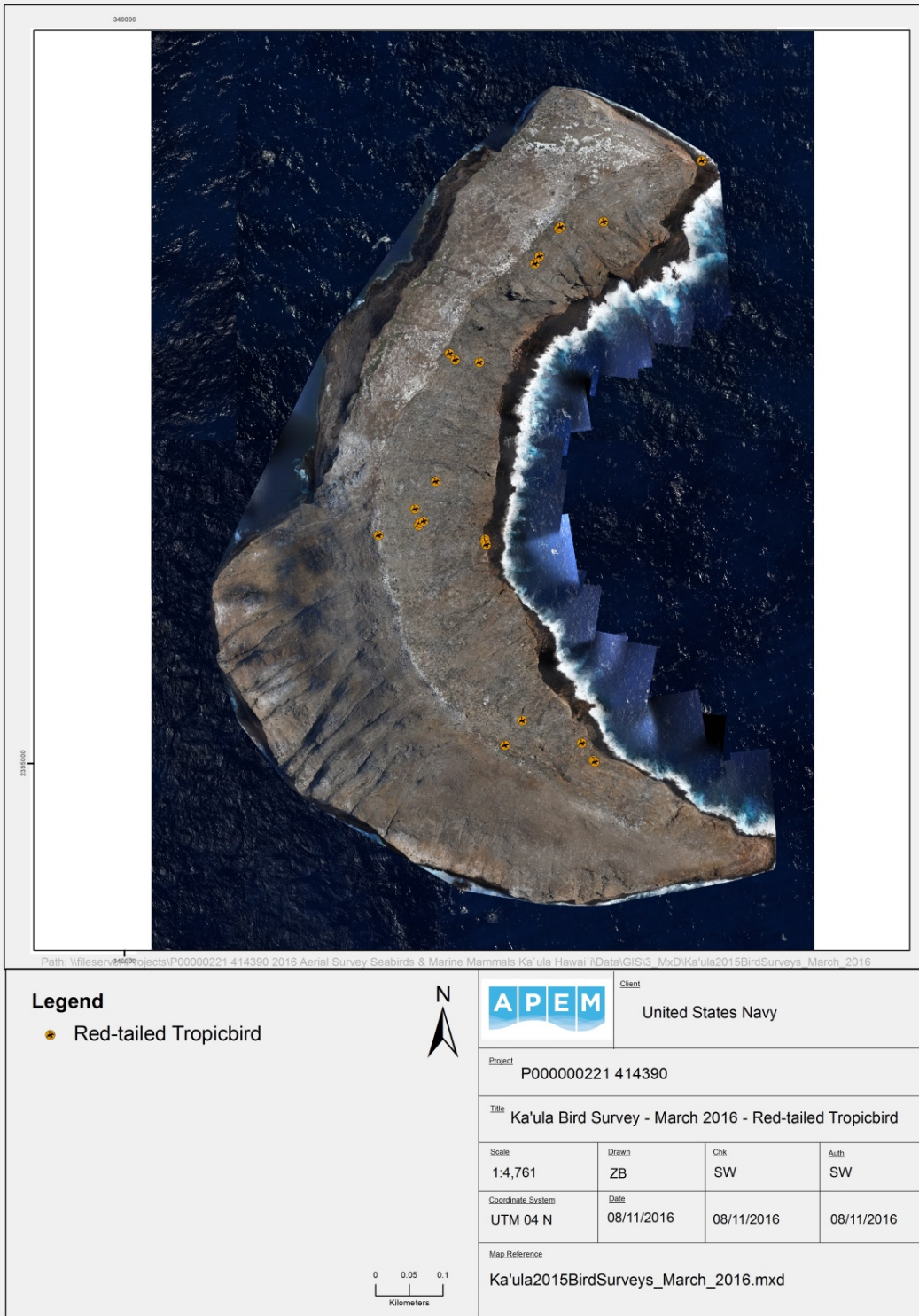
**Figure 3–2. Distribution of black-footed albatrosses recorded on Ka'ula Island during the March 2016 survey.**

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.



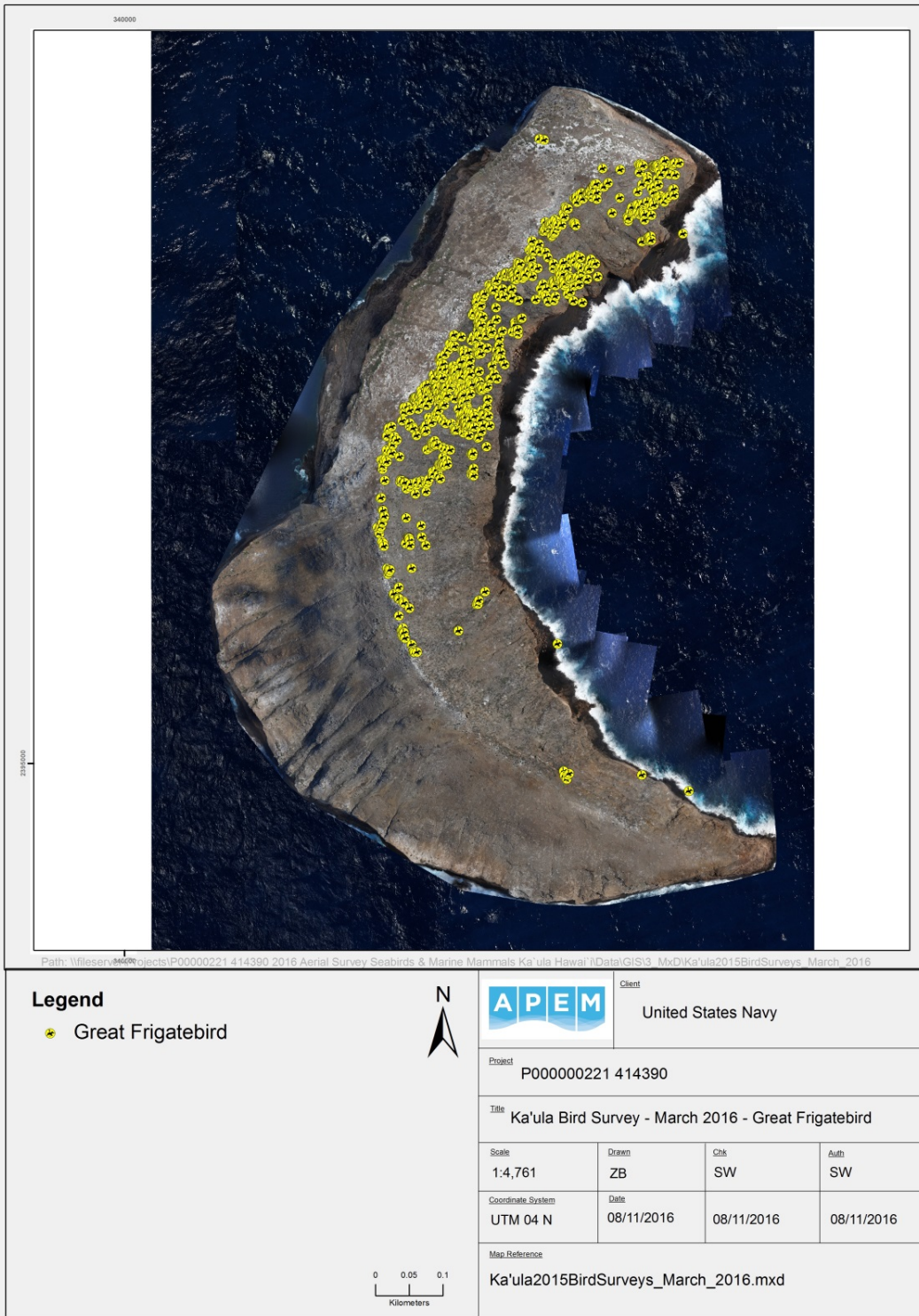
**Figure 3–3. Distribution of Laysan albatrosses recorded on Ka'ula Island during the March 2016 survey.**

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.



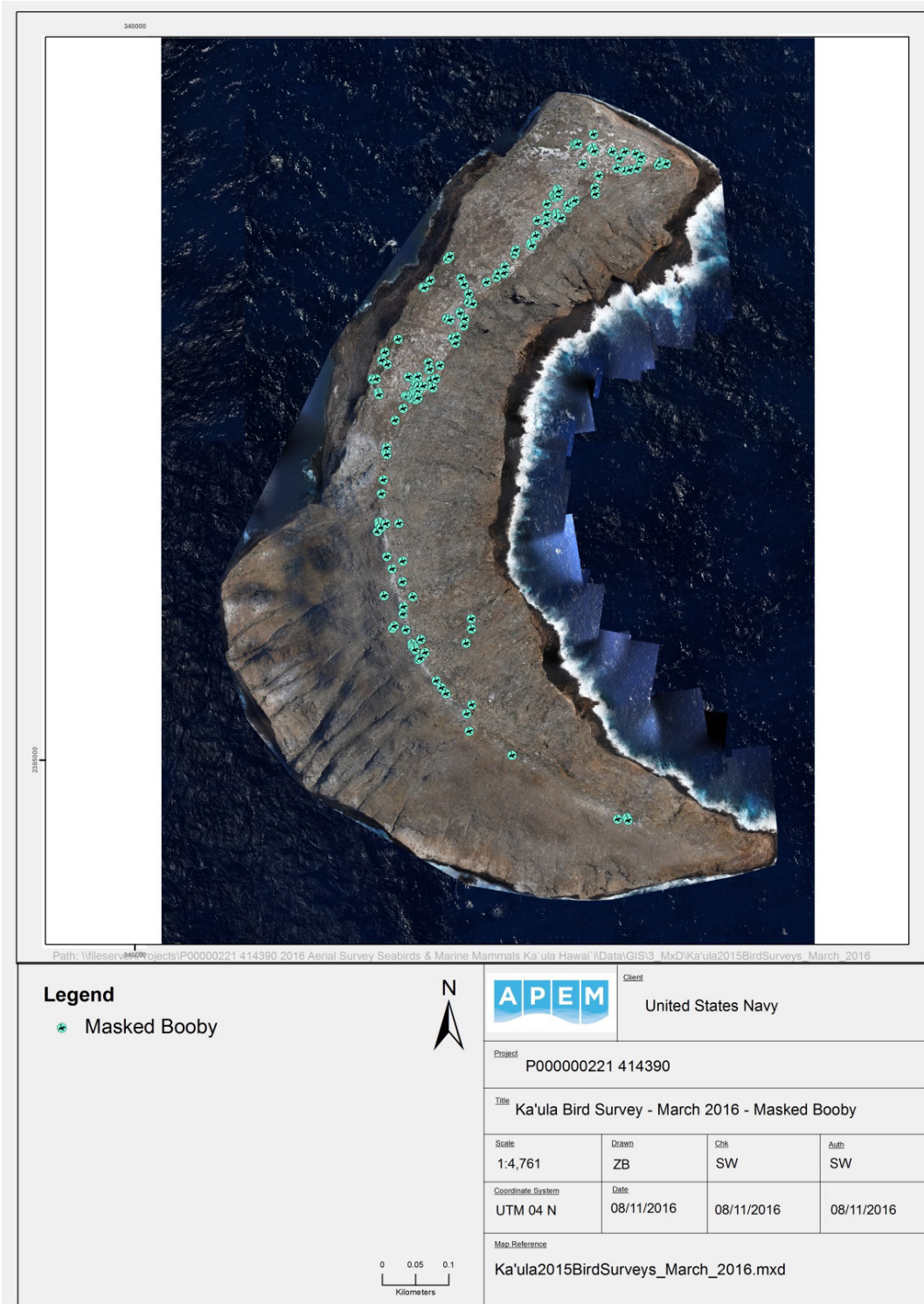
**Figure 3–4. Distribution of red-tailed tropicbirds recorded on Ka'ula Island during the March 2016 survey.**

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.



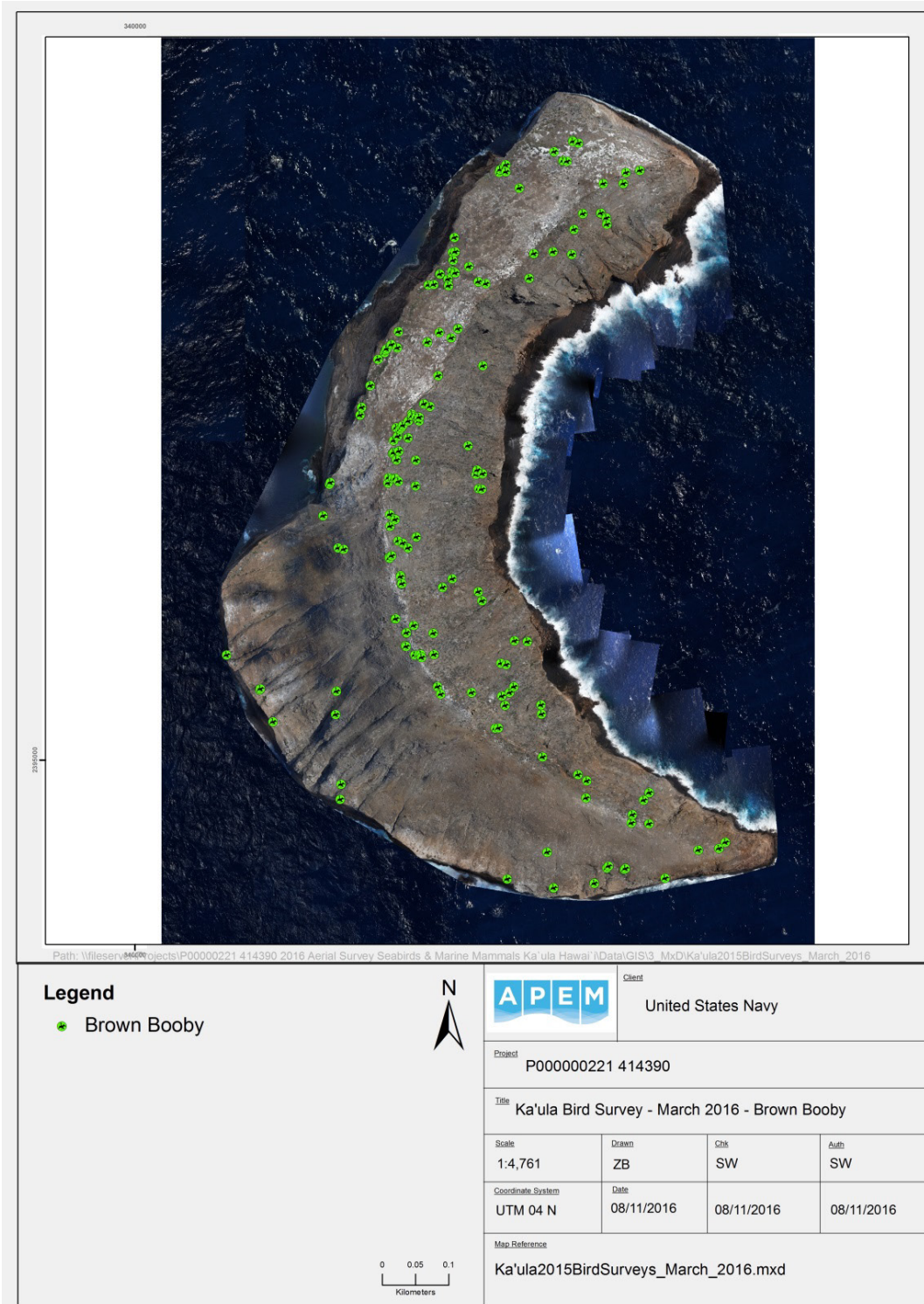
**Figure 3–5. Distribution of great frigatebirds recorded on Ka'ula Island during the March 2016 survey.**

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.



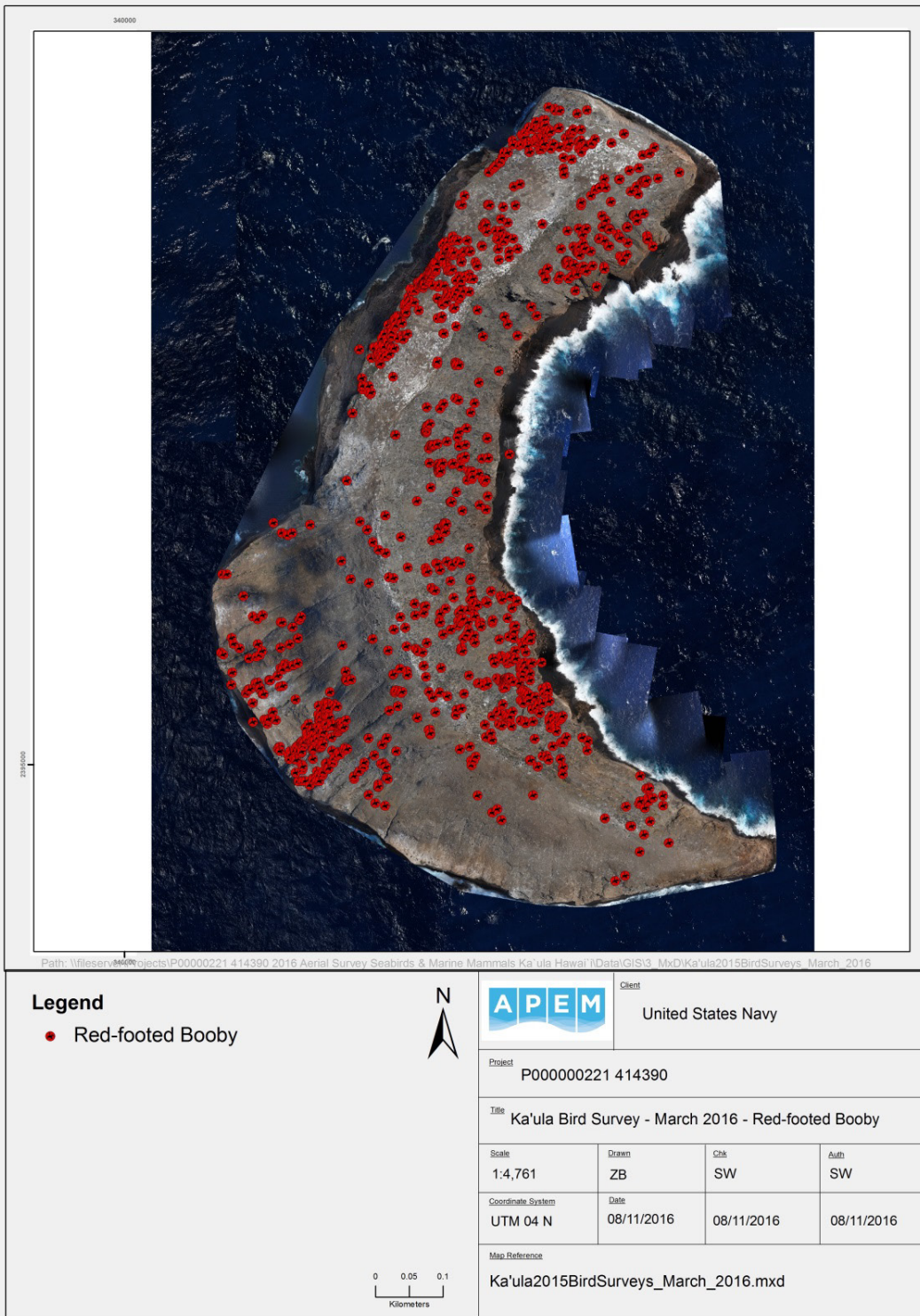
**Figure 3–6. Distribution of masked boobies recorded on Ka'ula Island during the March 2016 survey.**

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.



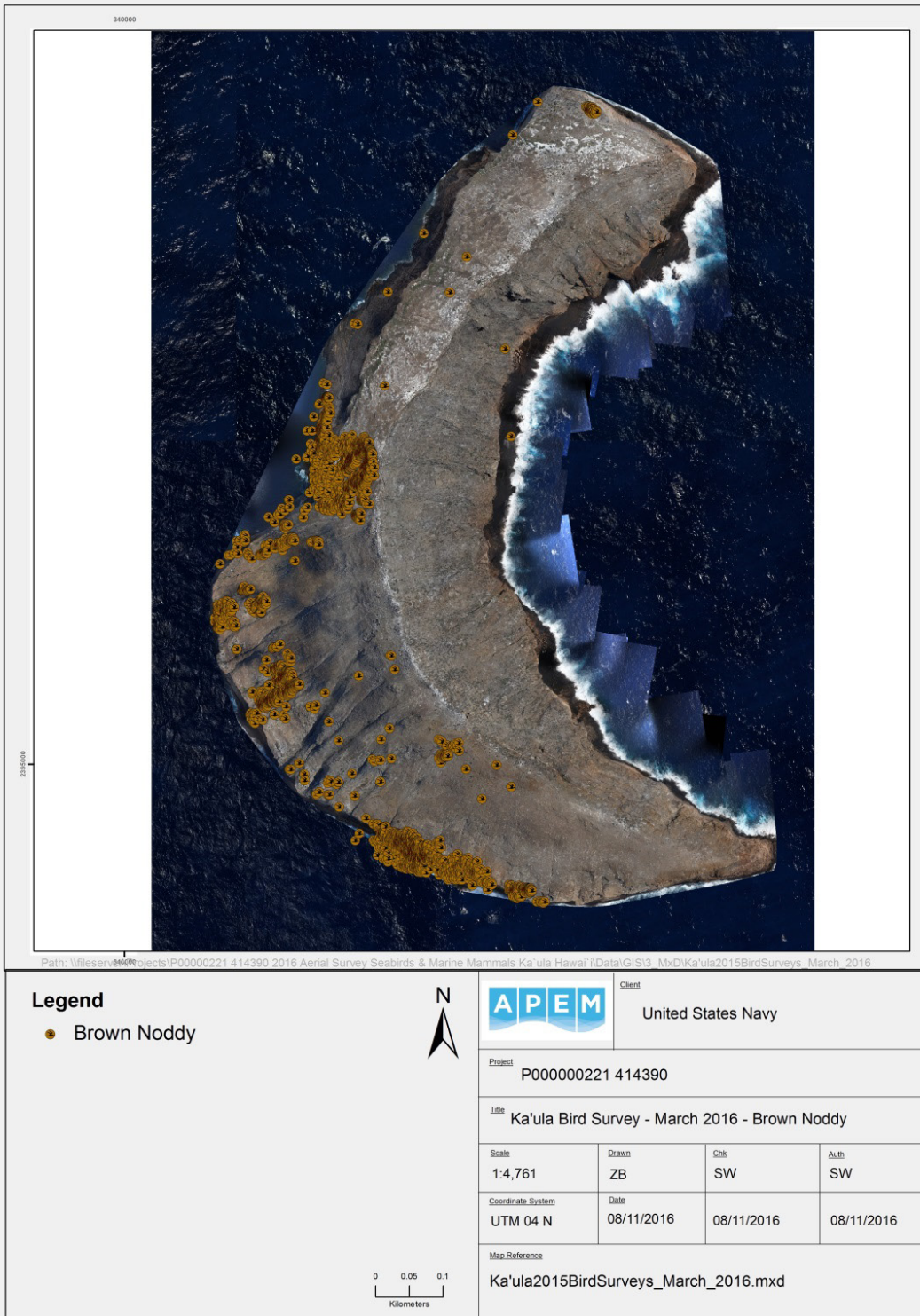
**Figure 3–7. Distribution of brown boobies recorded on Ka'ula Island during the March 2016 survey.**

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 red-footed boobies recorded on Ka'ula Island during the March 2016 survey.**

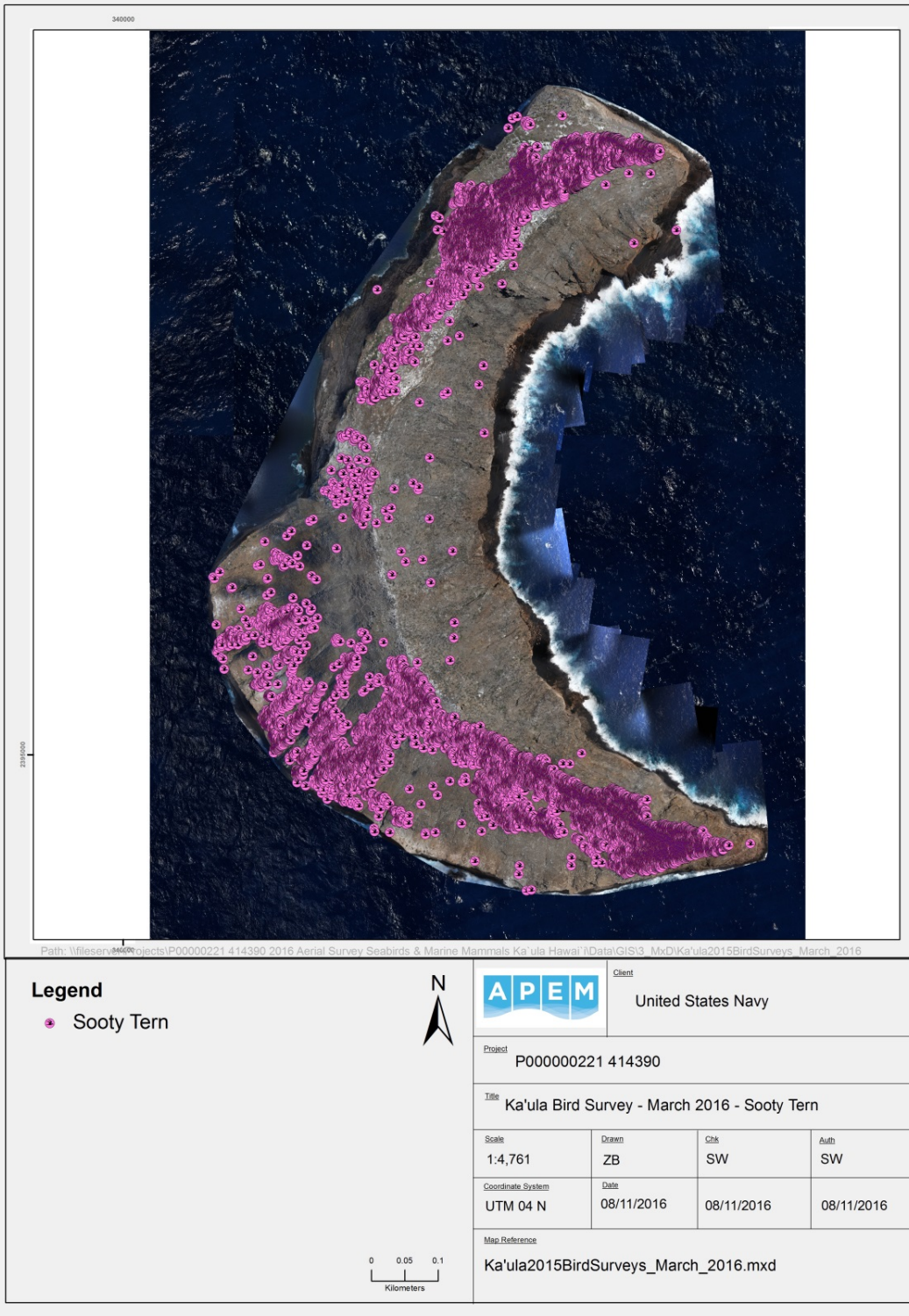
Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.



**Figure 3–9. Distribution of brown noddies recorded on Ka'ula Island during the March 2016 survey.**

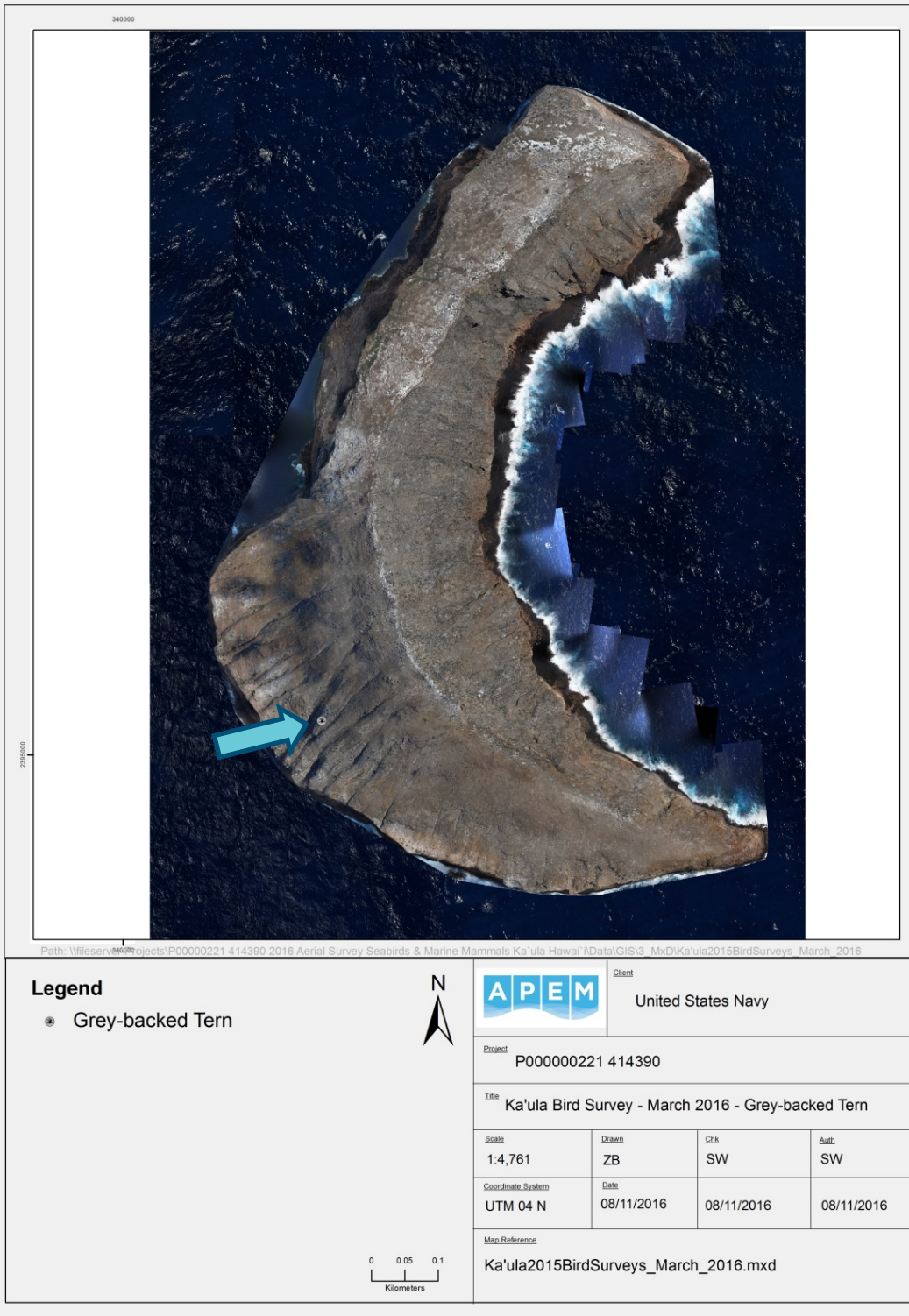
Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.





**Figure 3–10. Distribution of sooty terns recorded on Ka'ula Island during the March 2016 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 grey-backed terns recorded on Ka'ula Island during the March 2016 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 3–12. Distribution of Hawai'ian Hawaiian monk seals recorded on Ka'ula Island during the March 2016 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 were still being influenced by an El Niño event with associated anomalies in sea temperature, wind direction, and rainfall.

During the March 2016 vertical and oblique surveys, a total of 47,664 birds and ten Hawai'ian monk seals were recorded at Ka'ula Island (Table 3–1). The ten bird species present were black-footed albatross, Laysan albatross, red-tailed tropicbird, great frigatebird, masked booby, brown booby, red-footed booby, brown noddy, sooty tern, and grey-backed tern. The most abundant species was sooty tern, accounting for 86% (n=40,814) of all the seabirds recorded. The next most abundant species were brown noddy (n=4,115), red-footed booby (n=1,319), and great frigatebird (n=1,005) (see Table 3–1). Masked booby (n=183), brown booby (n=179), red-tailed tropicbird (n=23), Laysan albatross (n=21), black-footed albatross (n=4), and grey-backed tern (n=1) were the least abundant species recorded.

Four black-footed albatrosses were recorded at the northern end of the island (see Figure 3–2). This area of grassed vegetation has also been a favored location for this species in previous surveys. Higher numbers of black-footed albatross were recorded during land based surveys in January 1976 (n=100; Appendix IV) and in a previous aerial digital survey in January 2014 (n=11; Appendix IV). Although only a small number of birds were recorded, numbers were similar to those in April 2013 (n=3; Appendices IV and VI).

Laysan albatrosses were distributed along the higher eastern slopes with one flying bird over the western side. Numbers (n=21) were similar to those recorded from aerial digital survey in April 2013 (n=20; Appendices IV and VI) but much lower than those recorded by the same survey method in January 2015 (n=100; Appendices IV and VI). Laysan albatrosses are known to breed in this region between November and February. One cavern contained three birds, one of which could potentially have been a juvenile, although plumage differences were not visible.

Red-tailed tropicbirds were mainly found along the eastern side of the island (Figure 3–4). Numbers recorded in this survey (n=23) were much lower than the aerial digital survey in April 2013 (n=314) and August 2013 (n=85). Numbers in the winter are usually less than those present in July or August; however, numbers seem to vary considerably with each survey. Red-tailed tropicbirds nest on the ground on Ka'ula Island inside caverns or crevasses (see Appendix III, Figure 6–5) and detecting them by a combination of vertical and oblique imagery is necessary. Even with this combination, it is likely that some individuals are hidden from view. Counts contained in this report are likely to be less than the actual number of birds present.

Great frigatebirds were distributed mostly in the northeastern part of the island. This behavior is the same as recorded in previous aerial digital surveys carried out by Normandeau/APEM. Numbers were very similar (n=1,005) to those recorded in the latest aerial digital survey carried out in July 2015 (n=1,078; Appendix IV). Numbers recorded from recent aerial digital surveys have generally been much higher than those recorded in previous boat-based surveys. Boat-based surveys conducted between July 2009 and July 2012 averaged less than 200 birds per survey (see Appendix IV). One explanation for this could be that aerial imagery allows more accurate counts to be made of relatively tight clustered groups of birds on high ledges and ravines that are otherwise difficult to see from a boat at sea level.

Of the booby species recorded, red-footed booby was the most abundant during the March 2016 survey followed by masked booby and brown booby (see Table 3–1), as has been the case on all six of the aerial digital surveys conducted to date. The count of 1,319 red-footed boobies during this survey is similar to those recorded in April 2013 (n=1,690). Recent surveys seem to suggest the bulk of breeding occurs during June and July. Although there were a number of sub-adult birds noted during this survey, there were no chicks or juveniles noted in nests.

Brown booby numbers (n=179) were comparable to recent aerial digital surveys and higher than those recorded in April 2013 (n=101) and lower than those recorded in July 2015 (n=867). Numbers from July 2015 represent the highest count since September 1976. All birds observed seemed to be adults.

Masked boobies were distributed mainly along the central ridge, in a similar way to previous aerial digital surveys, with very few in the southwestern section (Figure 3–6). Numbers (n=183) were less than those in the April 2013 survey (n=550; Appendix IV) and higher than those in January 2015 (n=84; Appendix IV). The species is known to lay eggs from February to April but this can be earlier or later (Richardson 1957). The recent aerial surveys suggest numbers on Ka'ula Island tend to peak between April and July.

Brown noddies were distributed along the western slopes and cliffs with groups often interspersed with sooty terns. They were again present on the lower “noddy ledges” half way down the cliff face (see Appendix III, Figure 6–7). Numbers (n=4,115) were broadly similar to those present during the aerial digital survey in August 2013 (n=3,713) but less than those in the most recent July 2015 aerial digital survey (n=7,137).

The most abundant species during this survey was sooty tern (n=40,814), which represents the highest count from any of the previous five aerial digital surveys. The previous highest count by aerial digital survey was in April 2013 (n=14,635) (Appendix IV). Though numbers were less than those recorded in previous land-based surveys at this time of year (n=130,000 in March 1978 and n=83,680 in April 1984), assuming all single birds are part of a pair, then conceivably the actual numbers present could be in the region of 81,000 or 40,500 pairs. It was noticeable in the vertical imagery that sitting birds were very evenly spaced as can be seen in Appendix II (Figures 6–1 and 6–2). This, coupled with the fact that there were only 88 obviously paired up birds (two birds either stood side by side or in very close proximity to each other) visible in imagery, would suggest that overall numbers were much higher than the 40,814 counted at the time the imagery was taken. No definite juvenile birds were noted, which was surprising given the quality of imagery obtained, though this could be explained by the timing of the survey and that most sitting birds could have been incubating.

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 March.

Ten Hawaiian monk seals, which are highly endangered, were recorded on the islands east side (Figure 3–12). Numbers have remained fairly consistent throughout the six aerial digital surveys carried out between 2013 and 2016 (Appendix VI).

Overall, the aerial survey method demonstrates that complete counts of seabirds can be obtained including the ability to accurately assess the number of birds on apparently occupied nests 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

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## 6 Appendices

### Appendix I. Scientific Names of Relevant Bird and Mammal Species

Common Name	Scientific Name
Black-footed albatross	<i>Phoebastria nigripes</i>
Laysan albatross	<i>Phoebastria immutabilis</i>
Red-tailed tropicbird	<i>Phaethon rubricauda</i>
Great frigatebird	<i>Fregata minor</i>
Masked booby	<i>Sula dactylatra</i>
Brown booby	<i>Sula leucogaster</i>
Red-footed booby	<i>Sula sula</i>
Brown noddy	<i>Anous stolidus</i>
Sooty tern	<i>Onychoprion fuscatus</i>
Grey-backed tern	<i>Onychoprion lunatus</i>
<del>Hawaiian</del> <u>Hawaiian</u> monk seal	<i>Neomonachus schauinslandi</i>

## Appendix II. Survey Imagery: Vertical Image Examples



**Figure 6–1. Masked booby (bottom left) and sooty terns along the highest ridge of Ka'ula Island during the March 2016 survey.**



**Figure 6–2. Masked booby, brown booby (both circled in red) and sitting sooty terns (assumed pair bottom left circled in purple) towards the southern end of Ka'ula Island during the March 2016 survey.**



Figure 6–3. Six ~~Hawai'ian~~Hawaiian monk seals resting on ledges on the northeastern side of Ka'ula Island during the March 2016 survey.

### Appendix III. Survey Imagery: Oblique Image Examples



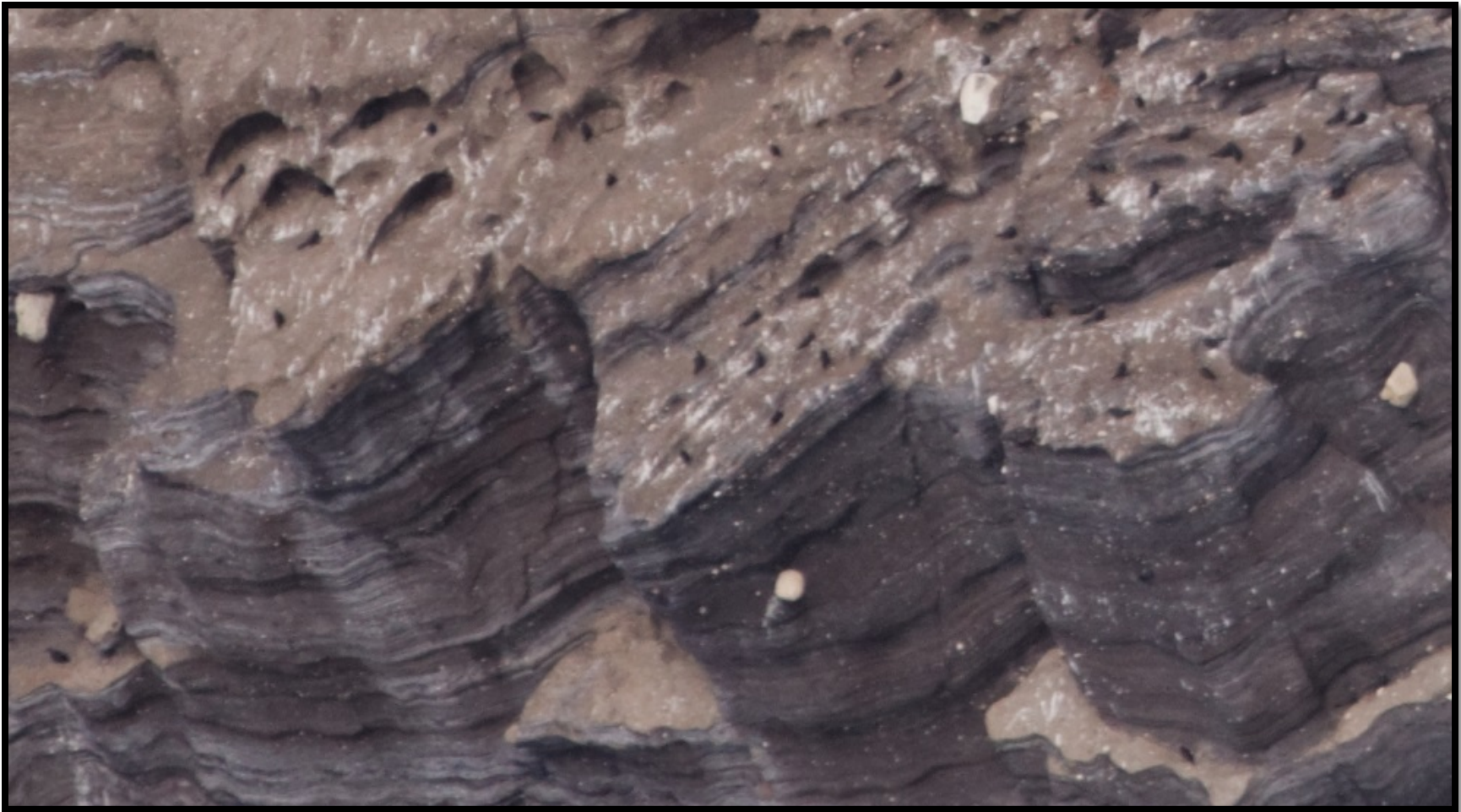
**Figure 6–4. Adult red-footed boobies and sooty terns on the western slopes of Ka'ula Island during the March 2016 survey.**



**Figure 6–5. Three red-tailed tropicbirds, including two sitting (circled) in small caverns on the southeastern side of Ka'ula Island during the March 2016 survey.**



**Figure 6–6. Adult and juvenile red-footed boobies on the eastern side of Ka'ula Island during the March 2016 survey.**



**Figure 6–7. Brown noddies present on low cliff ledges on the western side of Ka'ula Island during the March 2016 survey.**



**Appendix IV. Results of Bird Surveys Conducted on Ka'ula Island, Hawai'i (1932–2016)\***

Common Name Scientific Name	Land-Based Survey (A)											Boat-Based Survey (A, B, C)				Aerial Digital Survey (D)					
	Aug 1932	Aug 1971	Jan 1976	Sep 1976	Mar 1978	Aug 1978	Mar 1979	Jun 1980	Apr 1984	Jun 1993	Nov 1998	Jul 2009 (B)	Jun 2010 (A)	Jun 2011 (C)	Jul 2012 (C)	Apr 2013	Aug 2013	Jan 2014	Jan 2015	Jul 2015	Mar 2016
<b>Laysan albatross</b> <i>Phoebastria immutabilis</i>	-	1 old egg	150	-	100	-	100	9	33	44	60	-	-	-	-	20	11	81	100	-	21
<b>Black-footed albatross</b> <i>Phoebastria nigripes</i>	1 old egg	-	100	-	75	-	75	-	2	4	10	-	-	-	-	3	-	11	3	-	4
<b>Bonin petrel</b> <i>Pterodroma hypoleuca</i>	1 chick	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Bulwer's petrel</b> <i>Bulweria bulwerii</i>	several	100	-	100	-	50	-	100	580	100	-	1	1	-	-	-	-	-	-	-	-
<b>Wedge-tailed shearwater</b> <i>Puffinus pacificus</i>	many burrows	4,100	-	4,000	-	800	-	1,415	980	400	200	16	-	-	-	-	-	-	-	-	-
<b>Christmas shearwater</b> <i>Puffinus nativitatis</i>	-	450	-	250	-	100	25	20	60	18	-	-	-	-	-	-	-	-	-	-	-
<b>White-tailed tropicbird</b> <i>Phaethon lepturus</i>	-	3	1	1	-	1	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-
<b>Red-tailed tropicbird</b> <i>Phaethon rubricauda</i>	common	950	-	450	60	100	40	276	209	146	15	31	3	5	1	314	85	-	1	100	23
<b>Great frigatebird</b> <i>Fregata minor</i>	common	950	250	800	400	250	250	134	155	701	650	131	430	105	26	1,415	1,369	621	748	1,078	1,005
<b>Masked booby</b> <i>Sula dactylatra</i>	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219	65	84	526	183
<b>Brown booby</b> <i>Sula leucogaster</i>	common	1,700	50	1,000	75	60	200	212	169	397	60	112	1	6	40	101	109	3	2	867	179
<b>Red-footed booby</b> <i>Sula sula</i>	uncommon	1,300	100	150	85	200	400	344	222	1,375	1,200	-	-	-	-	1,690	191	98	209	3,693	1,319
<b>Masked/red-footed booby</b> <i>Sula dactylatra / S. sula</i>	-	-	-	-	-	-	-	-	-	-	-	820	850	1,859	912	-	-	-	-	27	-
<b>Pacific golden plover</b> <i>Pluvialis fulva</i>	several	-	10	14	-	1	2	-	21	-	15	-	-	-	-	-	-	-	-	-	-
<b>Wandering tattler</b> <i>Heteroscelus incanus</i>	-	-	5	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Ruddy turnstone</b> <i>Arenaria interpres</i>	-	50	5	20	-	4	24	1	7	1	12	-	-	-	-	-	-	-	-	-	-
<b>Brown noddy</b> <i>Anous stolidus</i>	most numerous	67,700	-	7,000	7,000	10,000	1,000	10,560	3,950	5,778	-	-	-	-	-	57	3,713	-	-	7,137	4,115
<b>Black noddy</b> <i>Anous minutus</i>	-	100	20	100	75	200	-	-	207	6	-	-	-	-	-	-	22	-	-	-	-
<b>Brown/black noddy</b> <i>Anous species</i>	-	-	-	-	-	-	-	-	-	-	-	711	705	306	597	-	-	-	-	-	-
<b>Blue-grey noddy</b> <i>Procelsterna cerulea</i>	small colony	-	-	200	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-

Common Name <i>Scientific Name</i>	Land-Based Survey (A)											Boat-Based Survey (A, B, C)				Aerial Digital Survey (D)					
	Aug 1932	Aug 1971	Jan 1976	Sep 1976	Mar 1978	Aug 1978	Mar 1979	Jun 1980	Apr 1984	Jun 1993	Nov 1998	Jul 2009 (B)	Jun 2010 (A)	Jun 2011 (C)	Jul 2012 (C)	Apr 2013	Aug 2013	Jan 2014	Jan 2015	Jul 2015	Mar 2016
<b>White tern</b> <i>Gygis alba</i>	uncommon	10	10	200	40	10	-	9	12	9	-	10	9	9	12	6	-	-	-	1	-
<b>Sooty tern</b> <i>Onychoprion fuscatus</i>	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	40,814
<b>Grey-backed tern</b> <i>Onychoprion lunatus</i>	uncommon	2,800	-	250	1,250	50	300	4,110	1,467	35	-	1	3	-	-	4	-	-	-	-	1
<b>Barn owl</b> <i>Tyto alba</i>	-	1	3	3	-	1	6	4	2	7	3	-	-	-	-	-	-	-	-	-	-
<b>Japanese white-eye</b> <i>Zosterops japonicus</i>	-	-	2	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
<b>Northern mockingbird</b> <i>Mimus polyglottos</i>	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Northern cardinal</b> <i>Cardinalis cardinalis</i>	-	2	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>House finch</b> <i>Haemorhous mexicanus</i>	-	6	15	40	-	20	6	-	1	1	8	-	-	-	-	-	-	-	-	-	-
<b>Nutmeg manikin</b> <i>Lonchura punctulata</i>	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total Estimated Number of Birds</b>	-	<b>98,022</b>	<b>3,521</b>	<b>16,811</b>	<b>139,285</b>	<b>14,548</b>	<b>52,831</b>	<b>46,280</b>	<b>91,959</b>	<b>36,847</b>	<b>2,785</b>	<b>8,001</b>	<b>5,385</b>	<b>12,035</b>	<b>6,097</b>	<b>18,795</b>	<b>5,733</b>	<b>879</b>	<b>1,145</b>	<b>13,576</b>	<b>47,664</b>
<b>Total Number of Species</b>	<b>16</b>	<b>19</b>	<b>16</b>	<b>24</b>	<b>12</b>	<b>19</b>	<b>17</b>	<b>15</b>	<b>19</b>	<b>19</b>	<b>15</b>	<b>11</b>	<b>11</b>	<b>8</b>	<b>8</b>	<b>11</b>	<b>9</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>10</b>

\*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 March 2016 Aerial Digital Survey of Ka'ula Island, Hawai'i

Species/Group	Minimum Estimate	Maximum Estimate*
<b><i>Birds</i></b>		
Black-footed albatross	4	6
Laysan albatross	21	36
Red-tailed tropicbird	23	46
Great frigatebird	1,005	1,966
Masked booby	183	328
Brown booby	179	322
Red-footed booby	1,319	2,464
Brown noddy	4,115	8,144
Sooty tern	40,814	81,540
Grey-backed tern	1	2
<b>Total Estimated Number of Birds</b>	<b>47,664</b>	<b>94,854</b>

\*A pair is assumed to be two birds, all singles (including single flying birds and excluding juveniles) 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 (2013–2016)\*

Common Name	Scientific Name	Global Population	Regional Population <sup>2</sup> (Hawai'i) Breeding Pairs	Apr 2013	Aug 2013	Jan 2014	Jan 2015	July 2015	Mar 2016
Black-footed albatross	<i>Phoebastria nigripes</i>	64,500 breeding pairs <sup>4</sup>	55,000	3	-	11	3	-	4
Laysan albatross	<i>Phoebastria immutabilis</i>	1,180,000 mature individuals <sup>4</sup>	590,000	20	11	81	100	-	21
Red-tailed tropicbird	<i>Phaethon rubricauda</i>	> c.32,000 individuals <sup>1</sup>	9,000-12,000	314	85	-	1	100	23
Great frigatebird	<i>Fregata minor</i>	500,000-1,000,000 <sup>2</sup>	10,000	1,415	1,369	621	748	1,078	1,005
Masked booby	<i>Sula dactylatra</i>	Unquantified. Described as 'fairly common' <sup>3</sup>	2,500	550	219	65	84	526	183
Brown booby	<i>Sula leucogaster</i>	> c.200,000 individuals <sup>1</sup>	1,400	101	109	3	2	867	179
Red-footed booby	<i>Sula sula</i>	> c.1,000,000 individuals <sup>1</sup>	7,000-10,500	1,690	191	98	209	3,693	1,319
Masked/red-footed booby	<i>Sula species</i>	-	-	-	-	-	-	27	-
Brown noddy	<i>Anous stolidus</i>	500,000-1,000,000 breeding pairs <sup>2</sup>	112,000	57	3,713	-	-	7,137	4,115
Black noddy	<i>Anous minutus</i>	1-1.5 million breeding pairs <sup>2</sup>	12,000	-	22	-	-	-	-
White tern	<i>Gygis alba</i>	Likely exceeds 100,000 breeding pairs <sup>2</sup>	15,000	6	-	-	-	1	-
Sooty tern	<i>Onychoprion fuscatus</i>	60-80 million breeding pairs <sup>2</sup>	>1,000,000	14,635	7	-	-	147	40,814
Grey-backed tern	<i>Onychoprion lunatus</i>	Likely 70,000 breeding pairs <sup>2</sup>	44,000	4	-	-	-	-	1
<del>Hawaiian</del> Hawaiian monk seal	<i>Neomonachus schauinslandi</i>	1,209 individuals of all age classes <sup>5</sup>	632 sexually mature seals <sup>5</sup>	11	7	5	7	9	10
<b>Total Estimated Number of Birds</b>				<b>18,795</b>	<b>5,733</b>	<b>879</b>	<b>1,147</b>	<b>13,576</b>	<b>47,664</b>
<b>Total Number of Species</b>				<b>11</b>	<b>9</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>10</b>

<sup>1</sup> del Hoyo et al. 1992

<sup>2</sup> Hawaii Department of Land and Natural Resources (<http://dlnr.hawaii.gov/wildlife/cwcs/hawaii/species/fact-sheets/>)

<sup>3</sup> Stotz et al. 1996

<sup>4</sup> Birdlife International <http://www.birdlife.org/datazone/>

<sup>5</sup> IUCN Red List <http://www.iucnredlist.org/details/13654/0>