Aerial Survey of Seabirds and Marine Mammals at Kaula Island, Hawaii, July 2017

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Executive Summary

An aerial vertical (nadir) survey of Kaula Island, Hawaii, using a manned light twin-engine survey aircraft and ultra-high resolution digital photography was conducted on July 17, 2017. The vertical 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 conducted 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 completed in one day with 100% of the final image mosaic formed from imagery collected on the high resolution survey.

In total, 14,075 birds of seven species were recorded during the survey with brown noddy being the most abundant species (n=7,871) followed by red-footed booby (n= 2,650). Other species recorded included red-tailed tropicbird, great frigatebird, masked booby, brown booby, and sooty tern.

The actual count of red-tailed tropicbirds (n=502) is the largest since 1971, when 950 were recorded during a land-based survey. However, assuming all single birds are one of a pair unless visibly doubled up, then there could conceivably be 996 pairs at the time of the survey.

At the time of the surveys, eight Hawaiian monk seals were recorded resting on ledges on the west side of the island, four towards the north end of the island, one in the middle, and three together towards the southern end.

1 Introduction

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

Kaula Island is a small (0.64 km^2), uninhabited crescent-shaped islet in the western chain of islands making up the Hawaiian Archipelago (Figures 1–1 and 1–2). The islands closest to Kaula are Ni'ihau, which is located 37 km to the northeast, and Kauai, approximately 111 km to the northeast. A mountain ridge runs along the length of Kaula 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).

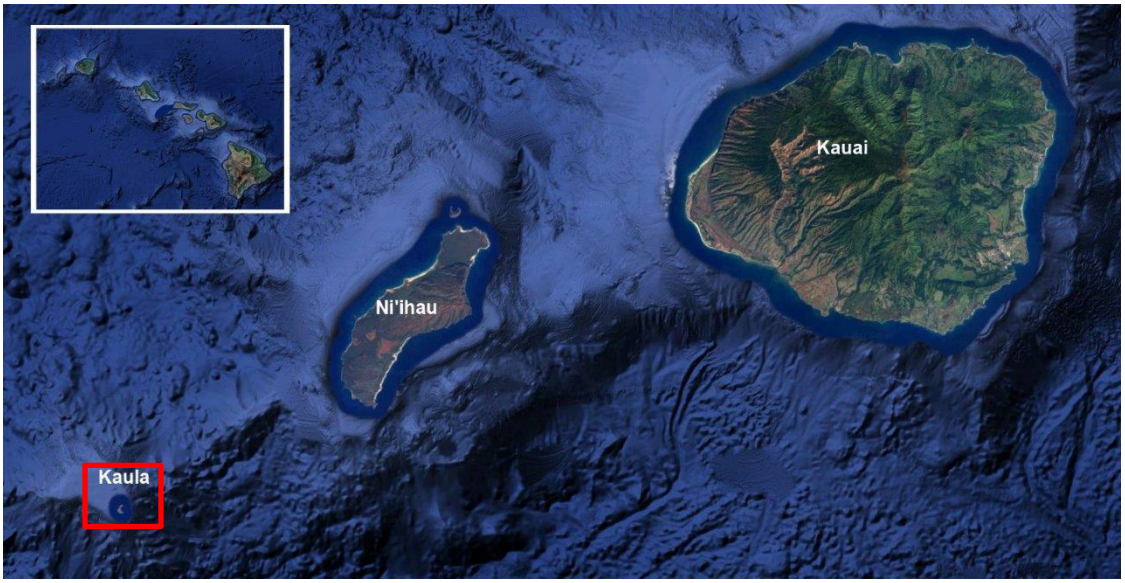

Figure 1-1. Location of Kaula Island relative to the main Hawaiian Islands (inset) and Kauai and Ni'ihau (imagery from ESRI).

Figure 1-2. Topography of Kaula Island (photo taken 17 July 2017).

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. Since 1981, munitions training by the Navy at Kaula 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 seven surveys have been conducted 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 Kaula (previously surveyed by boat) because of increased visibility of the higher sections and slopes of the island

2 Methods

2.1 Survey Design

This digital aerial survey of Kaula was undertaken on July 17, 2017, and included oblique imagery.

Ultra-high resolution digital still images were collected using a manned light twin-engine survey aircraft (Piper PA 31 - 310 N3949W) 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 Kaula, 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 Kaula (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 performed on the morning of July 17, 2017. This involved a vertical survey of Kaula Island at higher altitude (vertical high altitude survey). The second, low altitude (vertical low altitude) survey was completed later that same morning.

The collection of oblique images (oblique survey) of birds on steep overhanging cliff faces that may not have been visible from the vertical surveys was undertaken on the afternoon of July 17, 2017, following the vertical surveys.

The vertical high altitude survey was conducted between 11:38 and 12:25 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 vertical low altitude survey was flown between 12:33 and 13:54 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 oblique survey was also carried out between 15:07 and 17:35 and included transit [see Section 2.3]) by flying counter-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 ensuring consistency with previous surveys (Figure 2–1) and to aid the identification stage of the analysis.

Specially trained APEM staff were responsible for recording the following information from each grid cell of the compiled image covering Kaula 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 seabirds based on size, shape, and coloration. Two full scans of each grid cell are manually completed to find targets for identification, which are analyzed 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 Identification and Quality Assurance

All bird and marine mammal species present in the images from Kaula 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 analysis staff.

Known nesting habits of the booby species were used to aid identifications of juvenile birds in nests where the physical characters that aid identification were not visible. Masked and brown boobies are known to nest on the ground often near a breezy cliff edge or other take-off features. Red-footed boobies usually nest on small trees or shrubs and have a larger nest platform. The nesting substrate / location of nests, that contained only juveniles, was used to assist identifications.

2.3 Weather Conditions and Survey Limitations

This section explains some of the survey limitations and weather conditions. Due to the time of year, 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 July 14, 2017, and a short test flight was conducted, we waited for a suitable weather window.

On the morning of July 17, 2017, weather issues delayed an early flight with radar imagery showing scattered cloud and rain moving into the survey area. After a discussion with the pilot, a decision was made to carry out the survey later that morning as the forecast showed improvements with the showers dissipating in the survey area.

Survey conditions were good with scattered high altitude cloud cover and winds ranging between 15 and 25 knots from the north. 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 and after the flights.

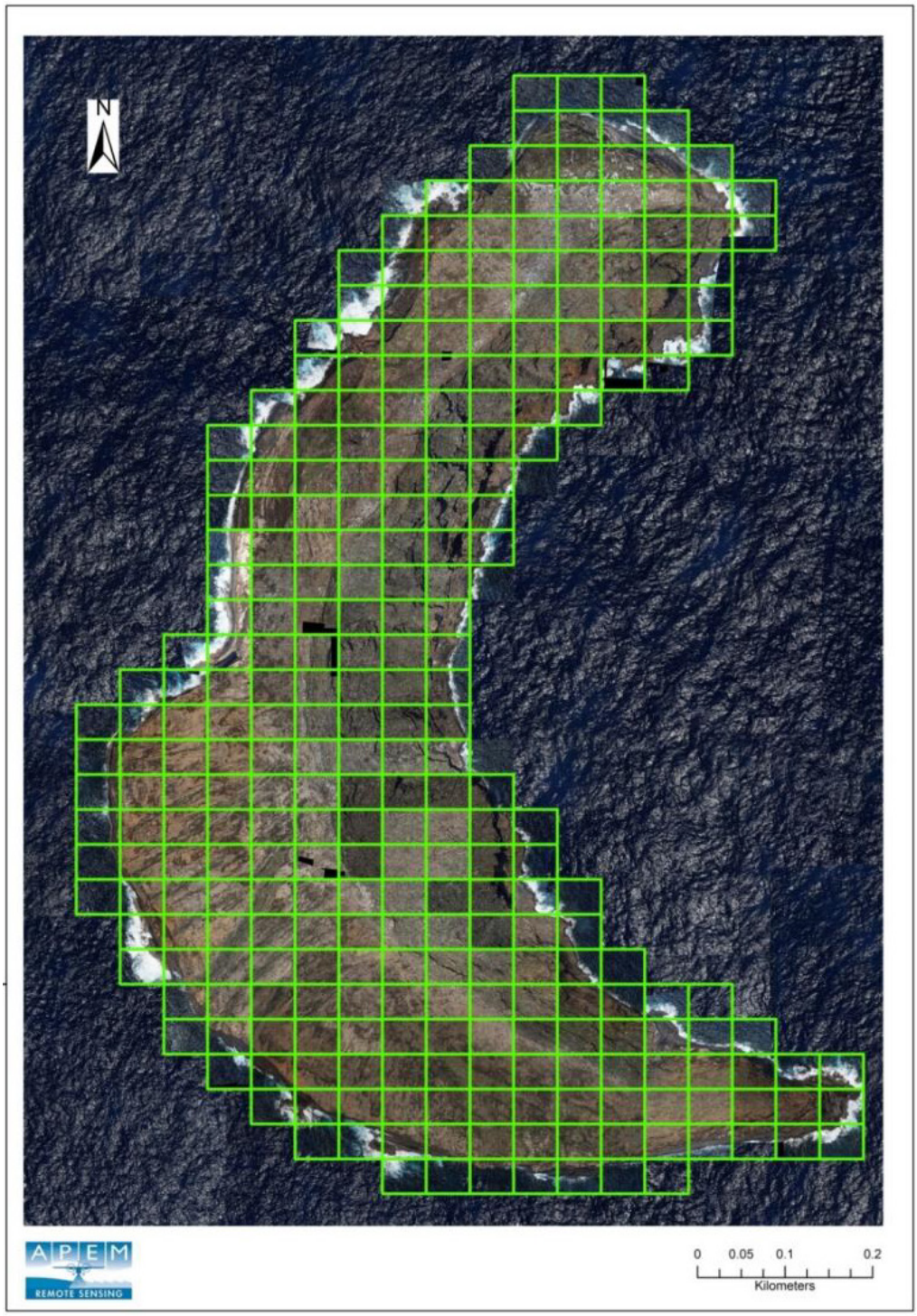

Figure 2-1. Kaula Island image analysis grid. Compiled images from the two vertical surveys were joined to cover Kaula Island. The compiled image was analyzed in 296 grid cell sections (marked in green).

3 Results

3.1 Species Abundance

Eight marine mammals (1 species) and 14,075 birds (7 species) were recorded on Kaula Island during July 2017 (Table 3–1). Brown noddy (n=7,871) was the most abundant bird species, and red-tailed tropicbird (n=502) 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 Kaula Island by Vertical and Oblique Surveys during July 2017

Species/Group	Number Recorded			
	Vertical Survey	Oblique Survey	Visual Observation	Total
Birds				
Red-tailed tropicbird	502	-	-	502
Great frigatebird	777	-	-	777
Masked booby	514	-	-	514
Brown booby	969	-	-	969
Red-footed booby	2,650	-	-	2,650
Masked booby/Red-footed booby	24	-	-	24
Brown noddy	7,794	77	-	7,871
Sooty tern	768	-	-	768
Total Birds	*13,998*	*77*	-	*14,075*
Marine Mammals				
Hawaiian monk seal	8	-	-	8
Total Birds and Marine Mammals	**14,006**	**77**	-	**14,083**

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 Kaula Island during the July 2017 aerial survey. Birds were widely distributed throughout the whole island. The red-tailed tropicbirds and great frigatebirds were recorded mainly along the eastern concave section. 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 mostly along the western side of the island close to the cliff edges. Sooty terns were also found to be along the western side of the island in small groups amongst the noddies. Hawaiian monk seals were found on the ledges along the west side of the island.

3.2.2 Red-tailed Tropicbirds

A total of 502 red-tailed tropicbirds were recorded during the survey (Table 3–1), found mostly in the eastern concave section of the island (Figure 3–2), with fewer birds at the southern and northern ends. Of the total recorded, 444 were in flight (Table 3–2).

3.2.3 Great Frigatebirds

A total of 777 great frigatebirds were recorded during the survey (Table 3–1), of which 54 were flying (Table 3–2). Virtually all were present along the eastern side of the island in the concave section (Figure 3–3) with just a handful of birds present on the west side. A total of 215 juveniles were counted in occupied nests (Table 3–2).

3.2.4 Masked Boobies

A total of 514 masked boobies were recorded during the survey (Table 3–1), of which five were flying (Table 3–2). The majority were present along the highest ridge running through the center of the island and towards the northern end of the island. A total of 79 immature birds were counted of which 41were juveniles in nests with adults in attendance (Table 3–2).

3.2.5 Brown Boobies

A total of 969 brown boobies were recorded during the survey (Table 3–1), of which 18 were flying (Table 3–2). Of the total recorded, 177 were either immature or juvenile birds in nests (Table 3–2). They were widely distributed throughout the whole island, with a large cluster in the southwest section of the island (Figure 3–5).

3.2.6 Red-footed Boobies

A total of 2,650 red-footed boobies were recorded during the survey (Table 3–1), of which 59 were captured in flight (Table 3–2). Out of the total number of birds, 1,990 were adults, 439 were immatures, and 221 were juveniles in nests (Table 3–2). They were present across the whole island (Figure 3–6).

3.2.7 Red-footed Boobies / Masked Boobies

A total of 24 unidentified red-footed or masked boobies were recorded during the survey (Table 3–1), two of which were observed flying (Table 3–2). The vast majority of unidentified boobies

were immature and juvenile birds sitting on nests with no adults in attendance (n=20), although nesting substrate might suggest that these were red-footed boobies (Table 3–2, Figure 3–7).

3.2.8 Brown Noddies

A total of 7,871 brown noddies (7,392 sitting and 479 flying) were recorded during the survey (Table 3–1, Table 3–2), of which virtually all were along the western slopes near the cliff edges (Figure 3–8). Of the total recorded, 77 were found in the oblique imagery, not visible in the vertical imagery (Table 3–1).

3.2.9 Sooty Terns

A total of 768 sooty terns were recorded during the survey (Table 3–1), of which 10 were flying (Table 3–2). Most were found in small groups amongst the brown noddies on the west and south sides of the island (Figure 3–9).

3.2.10 Marine Mammals

During the course of the surveys, eight Hawaiian monk seals were recorded resting on ledges on the west side of the island (Table 3–1, Figure 3–10).

Table 3–2. The species, age and numbers of sitting and flying birds recorded in July aerial surveys

Species	July 2015					July 2017					
	Adult		Immature			Adult		Immature		Juvenile	
	Flying	Sitting	Flying	Sitting	Total	Flying	Sitting	Flying	Sitting	Sitting	Total
Brown Booby	11	742	1	113	867	18	774		85	92	969
Brown Noddy	654	6,483			7,137	479	7,346		6	40	7,871
Great Frigatebird	52	720		306	1,078	54	508		14	201	777
Masked Booby	3	444	1	78	526	5	430		38	41	514
Red-footed Booby	67	2,894	17	715	3,693	53	1,937	6	433	221	2,650
Red-footed Booby/Masked Booby		4		23	27		2	2	7	13	24
Red-tailed Tropicbird	40	32		28	100	444	57	1			502
Sooty Tern	7	140			147	10	758				768
White Tern	1				1						
Total	**835**	**11,459**	**19**	**1,263**	**13,576**	**1,063**	**11,812**	**9**	**583**	**608**	**14,075**

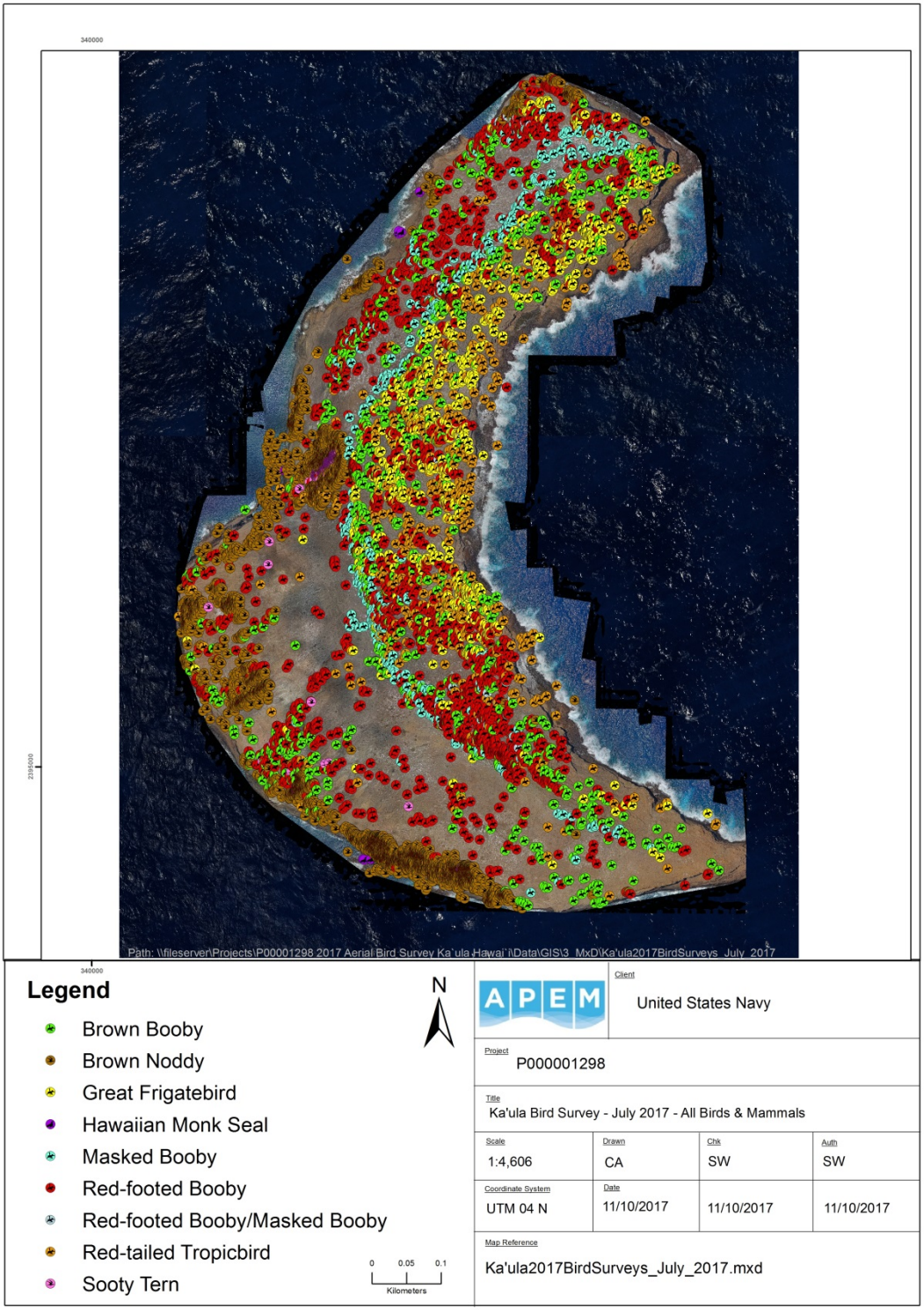

Figure 3-1. Distribution of all birds and marine mammals recorded on Kaula Island during the July 2017 survey.

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 Kaula Island during the July 2017 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.

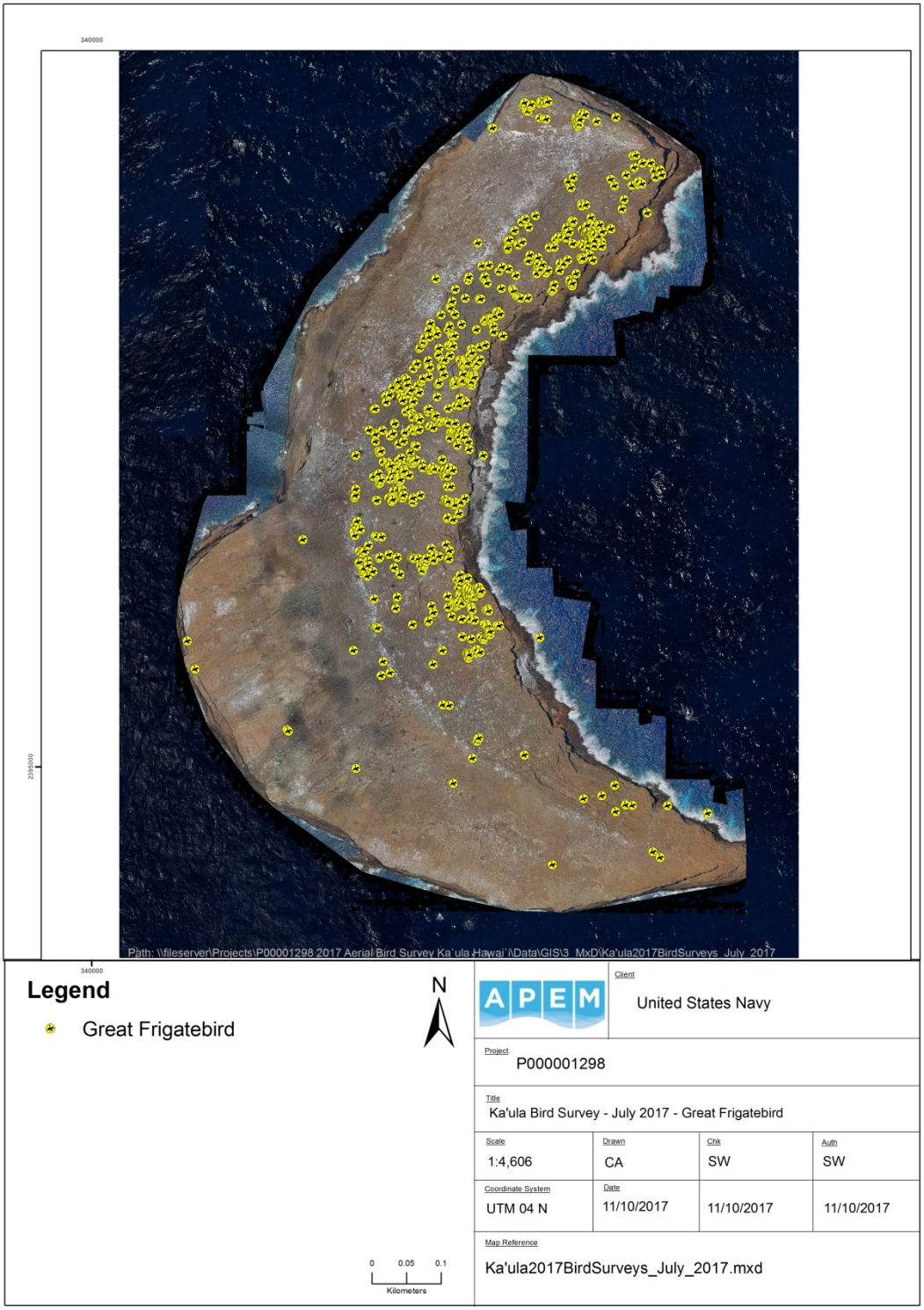

Figure 3-3. Distribution of great frigatebirds recorded on Kaula Island during the July 2017 survey.

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.

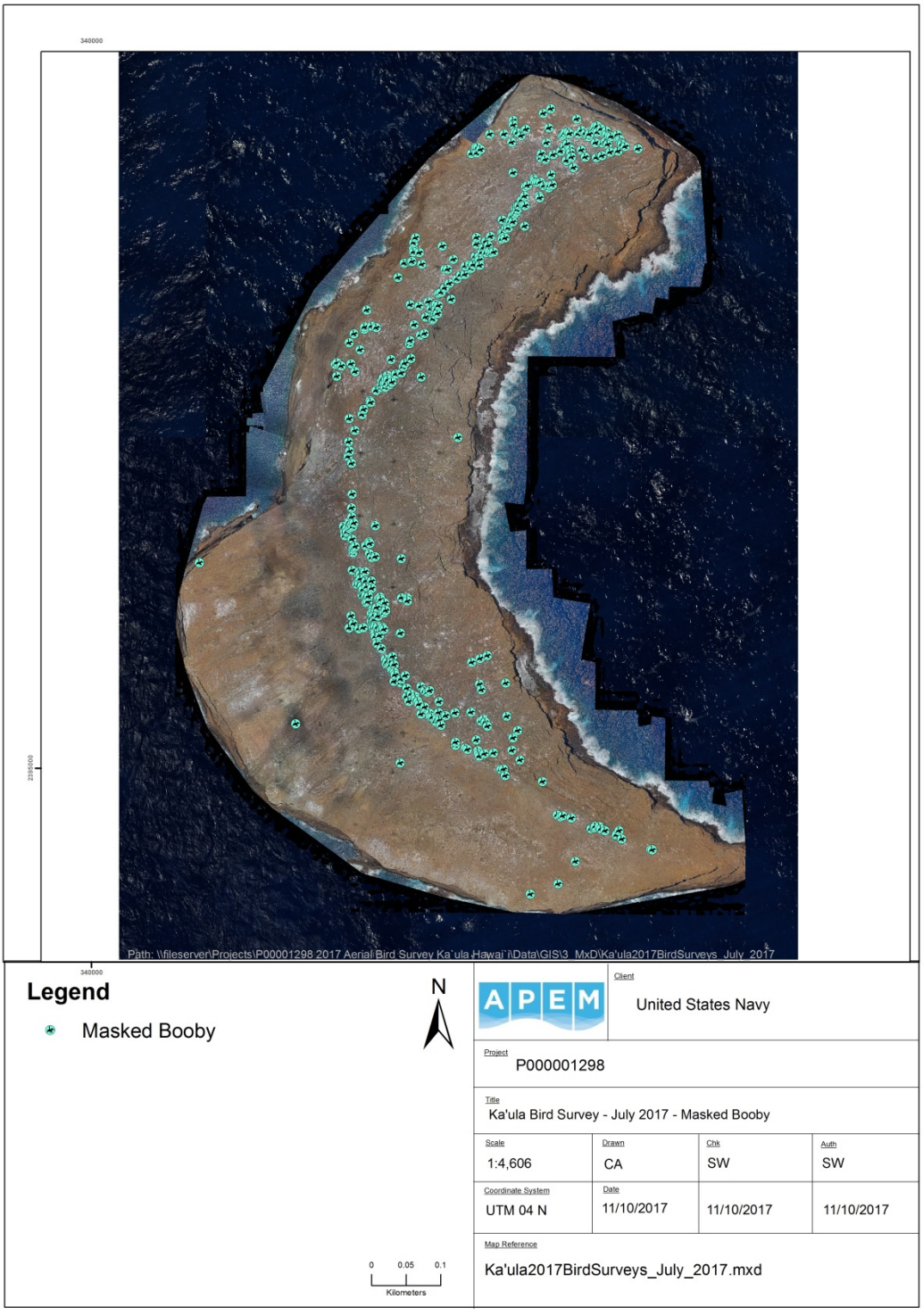

Figure 3-4. Distribution of masked boobies recorded on Kaula Island during the July 2017 survey.

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.

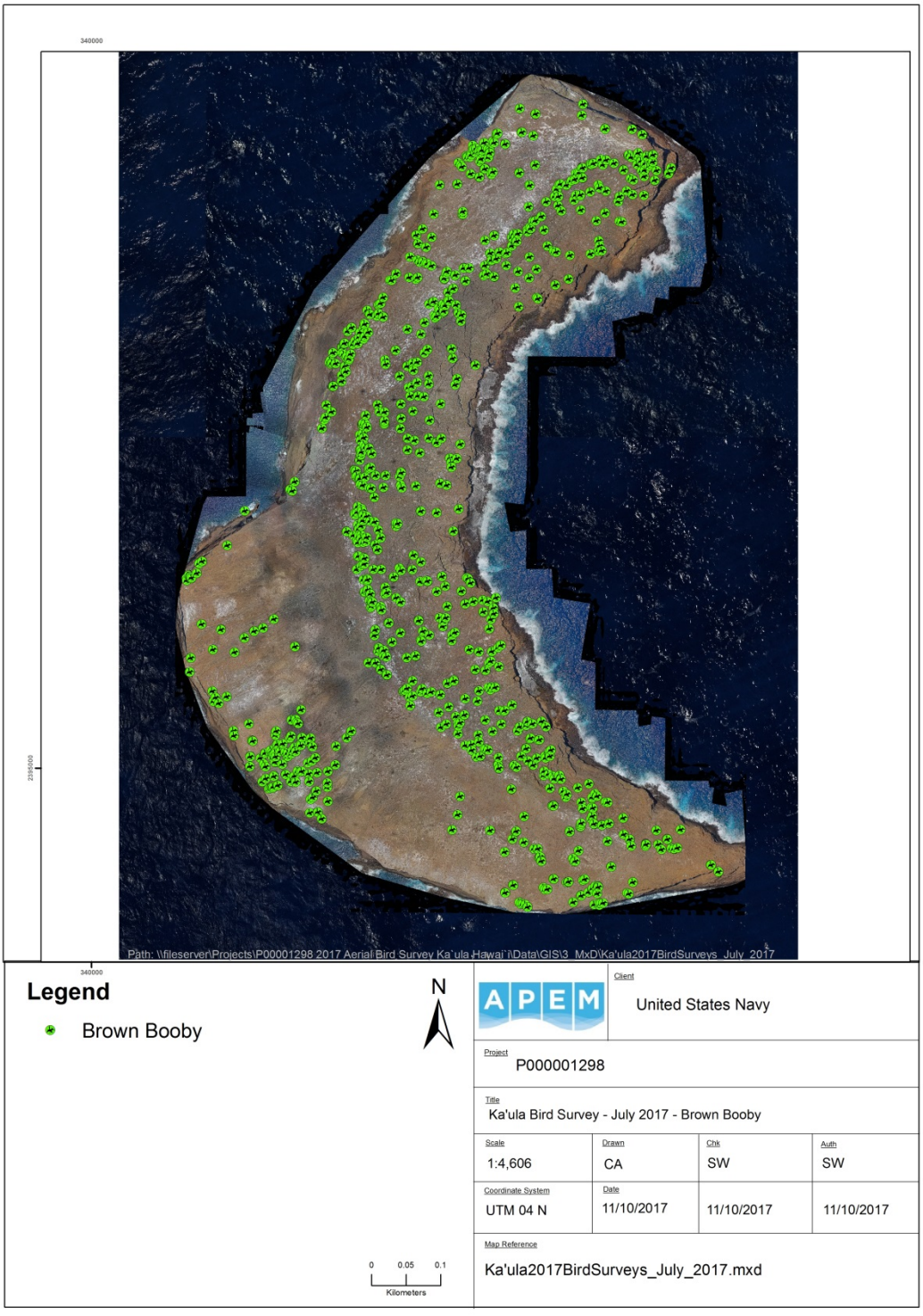

Figure 3-5. Distribution of brown boobies recorded on Kaula Island during the July 2017 survey.

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.

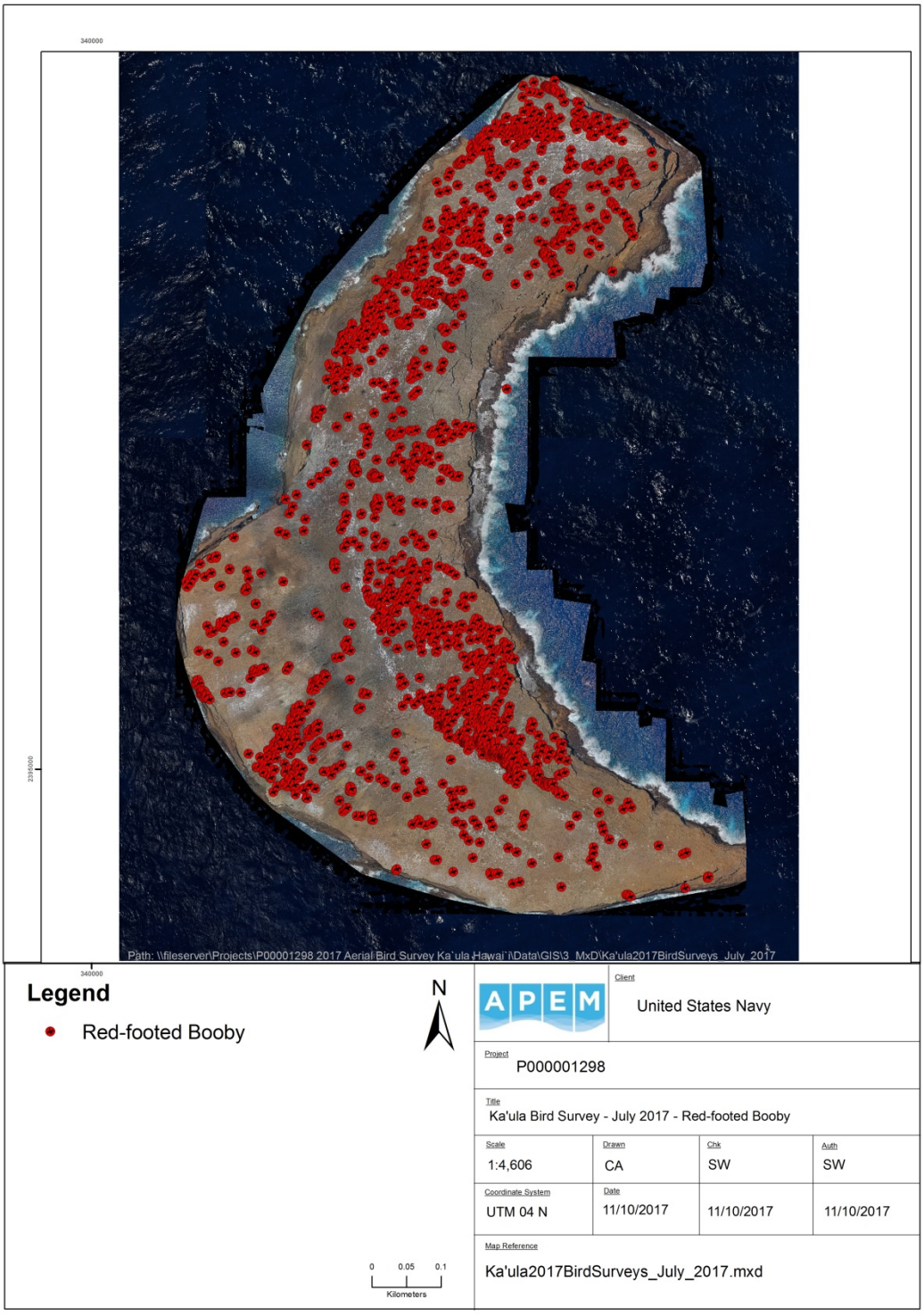

Figure 3-6. Distribution of red-footed boobies recorded on Kaula Island during the July 2017 survey.

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.

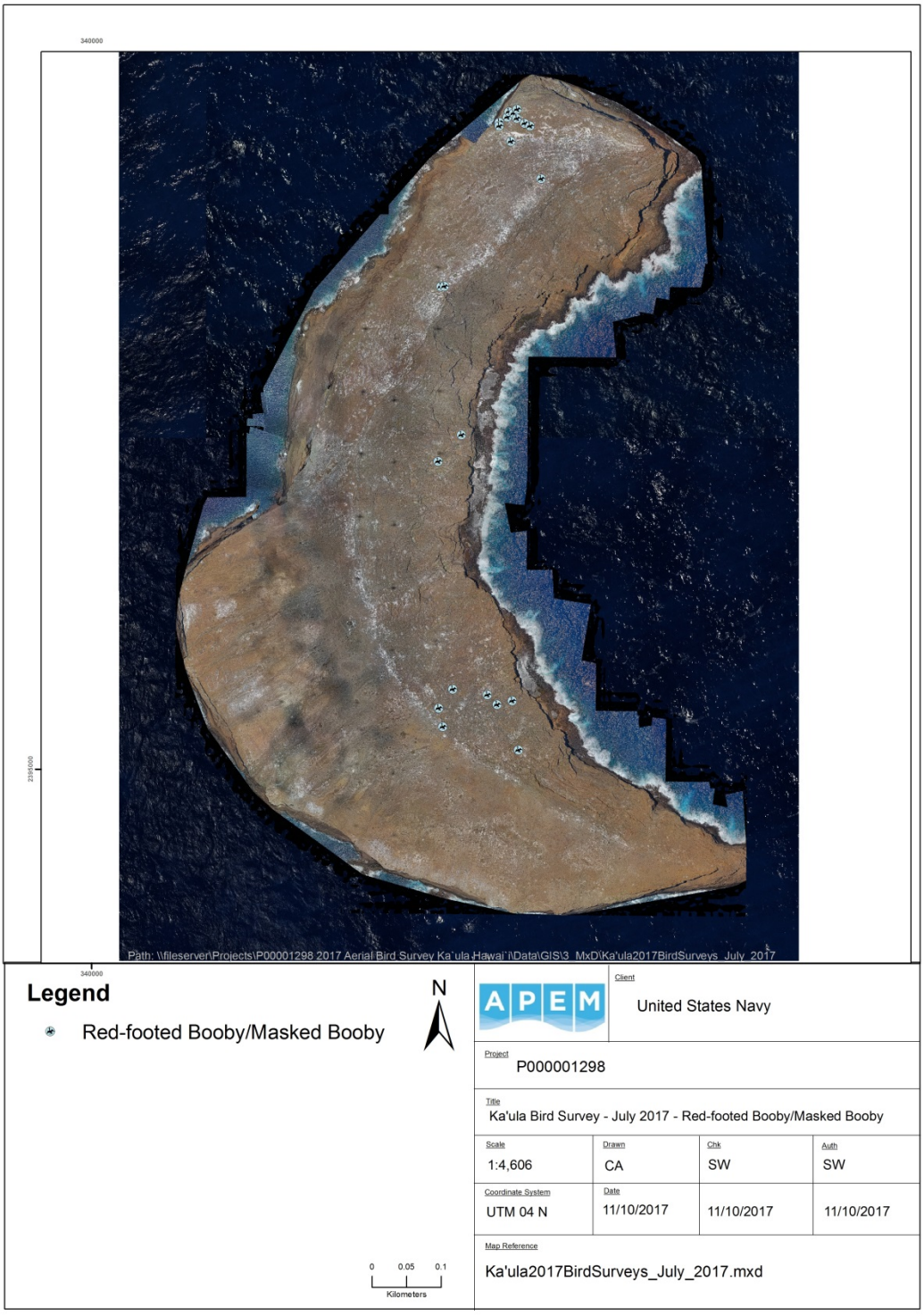

Figure 3-7. Distribution of red-footed booby/masked boobies recorded on Kaula Island during the July 2017 survey.

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.

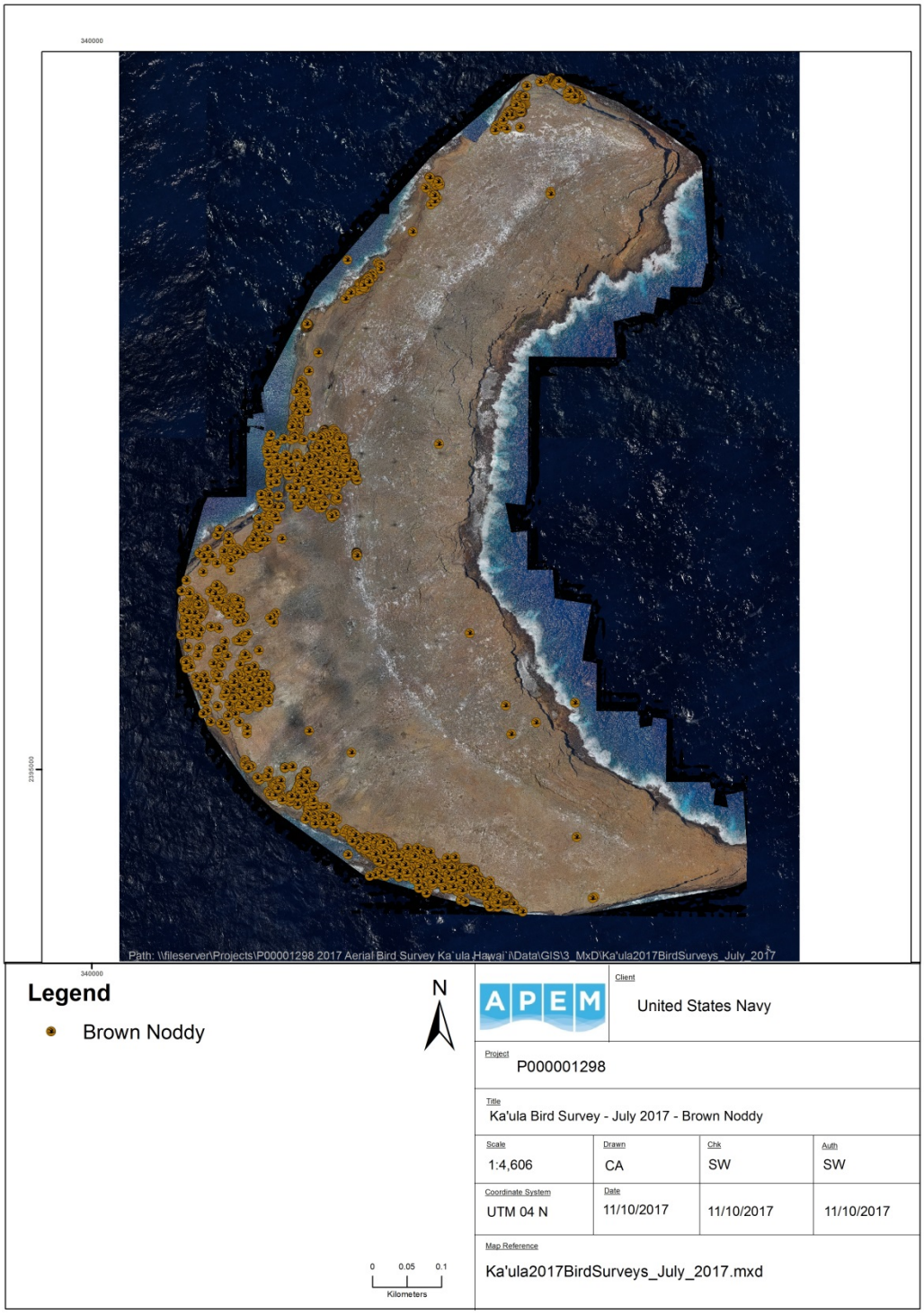

Figure 3-8. Distribution of brown noddies recorded on Kaula Island during the July 2017 survey.

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.

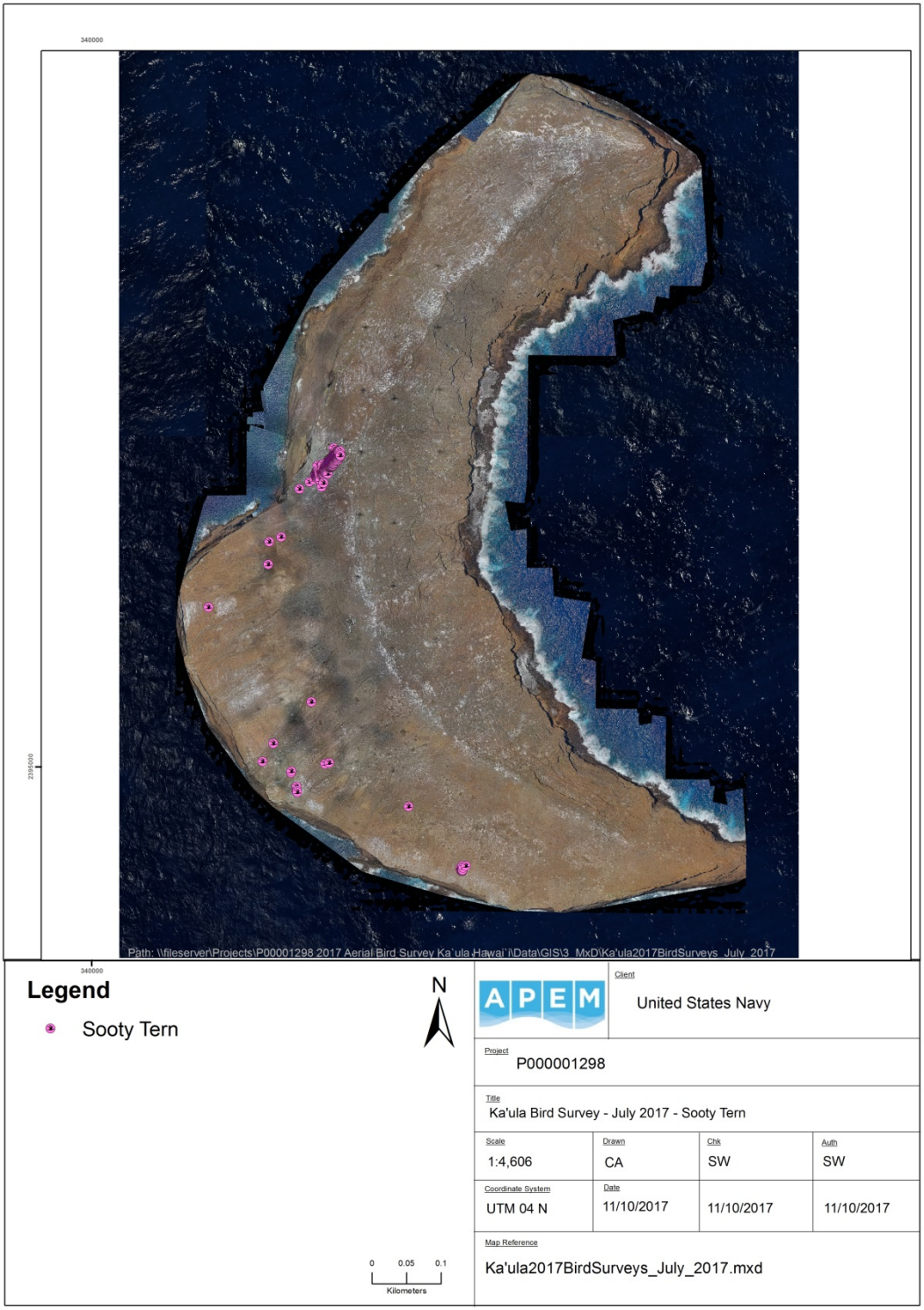

Figure 3-9. Distribution of sooty terns recorded on Kaula Island during the July 2017 survey.

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.

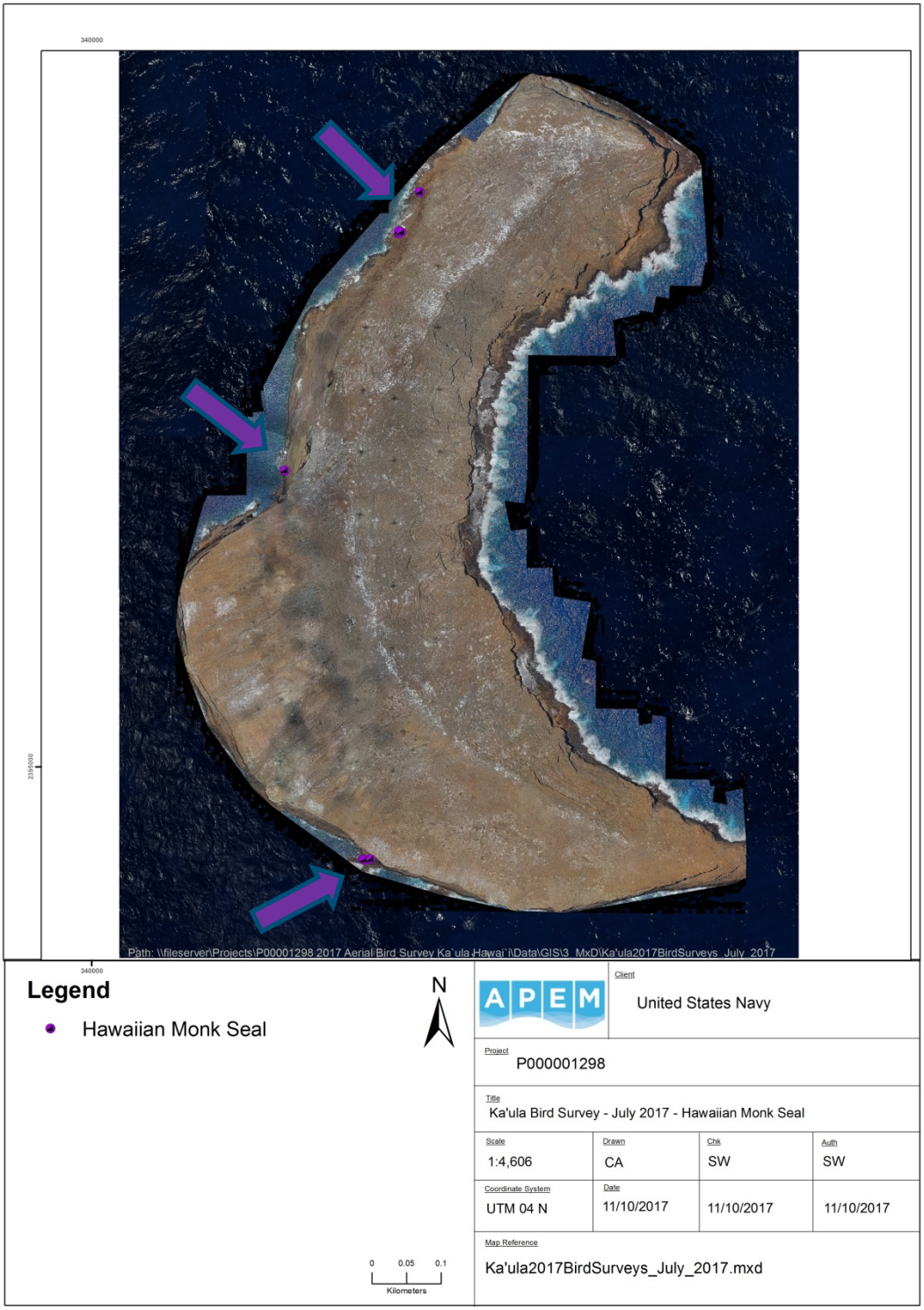

Figure 3–10. Distribution of Hawaiian monk seals recorded on Kaula Island during the July 2017 survey.

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

During the July 2017 vertical and oblique surveys, a total of 14,075 birds and eight Hawaiian monk seals were recorded at Kaula Island (Table 3–1). The seven bird species present were red-tailed tropicbird, great frigatebird, masked booby, brown booby, red-footed booby, brown noddy, and sooty tern. The most abundant species was brown noddy, accounting for 56% (n=7,871) of all the seabirds recorded. The next most abundant species were red-footed booby (n=2,650), brown booby (n=969) and great frigatebird (n=777) (see Table 3–1). Sooty tern (n=768), masked booby (n=514), and red-tailed tropicbird (n=502) were the least abundant species recorded. A total of 20 sitting unidentified immature and juvenile boobies were also recorded (Table 3–2), although nesting substrates suggest that these were most likely red-footed boobies, making a total of 24 boobies categorized as red-footed/masked.

Red-tailed tropicbirds were mainly found along the eastern side of the island (Figure 3–2). Numbers recorded in this survey (n=502) were the highest recorded since the land-based survey in August 1971 when 950 were estimated as being present. The only other previous count near this was 450 in September 1976 (Appendix IV). The number present in this survey is the highest count of any of the seven aerial digital surveys carried out by Normandeau/APEM. 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 Kaula Island inside caverns or crevasses and detecting them by a combination of vertical and oblique imagery is necessary; however, none could be seen inside overhanging ledges in our oblique imagery during this survey.

Great frigatebirds were distributed mostly in the northeastern part of the island (Figure 3–3). This follows the same pattern recorded in previous aerial digital surveys carried out by Normandeau/APEM. Numbers (n=777) were less than those recorded in the aerial digital survey carried out in July 2015 (n=1,078; Appendix IV). The number of juveniles in nests during this survey (n=215) were similar to those recorded in July 2015 (n=306) (Table 3–2). 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 the 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 July 2017 survey followed by brown booby and masked booby (see Table 3–1). The count of 2,650 red-footed boobies during this survey was higher than those recorded in March 2016 (n=1,319) and less than those recorded in the last July survey in 2015 (n=3,693) (Appendix IV), the highest count ever recorded on the island. Recent surveys seem to suggest the bulk of breeding occurs during June and July. Of the 439 immature (non-breeding and not in adult plumage) birds recorded, 221 of these were juveniles in occupied nests with an adult close by in attendance (Table 3–2). Of all the adult birds recorded, there were 71 pairs and a further 1,848 single birds, so conceivably there could have been up to 3,767 breeding pairs present (Appendix V).

Brown booby numbers (n=969) were higher than in the aerial digital survey in July 2015 (n=867) (Table 3–2, Appendix IV) and were the highest recorded since the land-based survey in

September 1976 (n=1,000) (Appendix IV). Of the total recorded during this survey, 792 were adults (Table 3–2) of which there was 69 pairs and a further 654 single birds, so conceivably there could have been up to 1,378 breeding pairs present (Appendix V). As with the other booby species they usually peak in the June to August period.

Masked boobies were distributed mainly along the elevated central ridge, in a similar way to previous aerial digital surveys with very few in the southwestern section (Figure 3–4). Numbers (n=514) were slightly lower than those in the April 2013 survey (n=550; Appendix IV) and very similar to the previous July survey carried out by Normandeau/APEM in July 2015 (n=526). The species is known to lay eggs from February to April but this can be earlier or later (Richardson 1957). This could explain why most of the masked boobies were either adults or well grown immatures (n=38; Table 3–2). Of all the adult birds recorded, there were 62 pairs and a further 311 single birds, so conceivably there could have been up to 684 breeding pairs present (Appendix V). The recent aerial surveys suggest numbers on Kaula Island tend to peak between April and July.

The most abundant species during this survey were brown noddies, which were found concentrated along the western slopes and cliffs. They were again present on the lower "noddy ledges" halfway down the cliff face (see Appendix II, Figure 6–1). Numbers (n=7,871) were slightly higher than those present during the aerial digital survey in July 2015 (n=7,137) (Table 3–2, Appendix IV). As noddies breed in close proximity to each other, determining paired birds can be difficult, but from the imagery analysts were able to count 443 adult pairs and a further 6,939 single birds, so conceivably there could have been up to 14,319 pairs (Appendix V). Also of note 46 chicks (Table 3–2) were counted amongst the colonies, all next to an adult bird.

Sooty terns (n=768; Table 3–2) were found on the west side of the island sitting amongst the colonies of noddies (Figure 3–9). They could be seen around the more vegetated areas of the western slopes compared to the noddies, which are mostly observed breeding on bare terrain (Figures 6–1, 6–2). The numbers present during this survey were expectedly less than the number encountered during March 2016 (n=40,814) (Appendix IV) as the period March to April is the peak time for them in Hawaii.

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 Hawaii is spread throughout the year, not all birds may be paired up in July.

Hawaiian monk seals are highly endangered, protected under the U.S. Endangered Species Act, the U.S. Marine Mammal Protection Act, and Hawaii State Senate Bill 2441, and classed by IUCN as category C1. Eight Hawaiian monk seals were recorded on the west side of the islands (Figure 3–10). Numbers have remained fairly consistent throughout the seven aerial digital surveys carried out between 2013 and 2017 (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).

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6 Appendices

Appendix I. 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*
Brown noddy	*Anous stolidus*
Sooty tern	*Onychoprion fuscatus*
Hawaiian monk seal	*Neomonachus schauinslandi*

Appendix II. Survey Imagery: Vertical Image Examples

Figure 6-1. Brown noddies on the lower "Noddy Ledge" on the west side of Kaula Island during the July 2017 survey.

Figure 6-2. Sooty terns and a single red-footed booby (circled) on the west side of Kaula Island during the July 2017 survey.

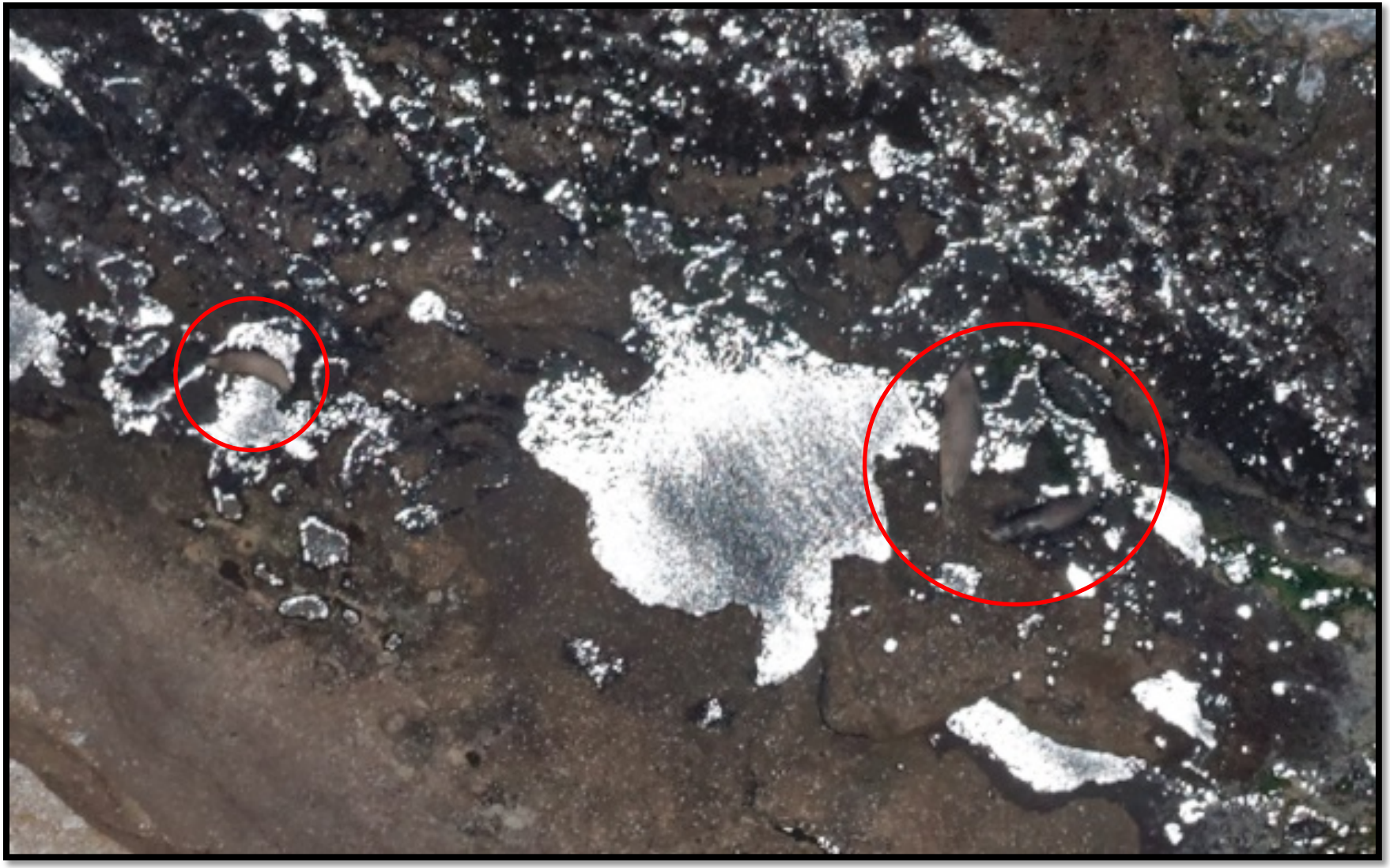

Figure 6-3. Three Hawaiian monk seals (one circled and two to the right) resting on ledges on the southern side of Kaula Island during the July 2017 survey.

Figure 6-4. Great frigatebirds, adult and juvenile (top left), three masked boobies (center), brown booby (circled), and four flying red-tailed tropicbirds along the central ridge of Kaula Island during the July 2017 survey.

Appendix III. Survey Imagery: Oblique Image Examples

Figure 6-5. Brown noddies on very low ledge, just above sea level on the western side of Kaula Island during the July 2017 survey.

Appendix IV. Results of Bird Surveys Conducted on Kaula Island, Hawaii (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	Jul 2017
Laysan albatross *Phoebastria immutabilis*	-	1 old egg	150	-	100	-	100	9	33	44	60	-	-	-	-	20	11	81	100	-	21	-
Black-footed albatross *Phoebastria nigripes*	1 old egg	-	100	-	75	-	75	-	2	4	10	-	-	-	-	3	-	11	3	-	4	-
Bonin petrel *Pterodroma hypoleuca*	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 nativitatis*	-	450	-	250	-	100	25	20	60	18	-	-	-	-	-	-	-	-	-	-	-	-
White-tailed tropicbird *Phaethon lepturus*	-	3	1	1	-	1	2	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Red-tailed tropicbird *Phaethon rubricauda*	common	950	-	450	60	100	40	276	209	146	15	31	3	5	1	314	85	-	1	100	23	502
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	1,005	777
Masked booby *Sula dactylatra*	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219	65	84	526	183	514
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	179	969
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	1,319	2,650
Masked/red-footed booby *Sula dactylatra / S. sula*	-	-	-	-	-	-	-	-	-	-	-	820	850	1,859	912	-	-	-	-	27	-	24
Pacific golden plover *Pluvialis fulva*	several	-	10	14	-	1	2	-	21	-	15	-	-	-	-	-	-	-	-	-	-	-
Wandering tattler *Heteroscelus incanus*	-	-	5	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ruddy turnstone *Arenaria interpres*	-	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	4,115	7,871
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 cerulea*	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 fuscatus*	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	768
Grey-backed tern *Onychoprion lunatus*	uncommon	2,800	-	250	1,250	50	300	4,110	1,467	35	-	1	3	-	-	4	-	-	-	-	1	-

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	Jul 2017
Barn owl *Tyto alba*	-	1	3	3	-	1	6	4	2	7	3	-	-	-	-	-	-	-	-	-	-	-
Japanese white-eye *Zosterops japonicus*	-	-	2	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Northern mockingbird *Mimus polyglottos*	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern cardinal *Cardinalis cardinalis*	-	2	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
House finch *Haemorhous mexicanus*	-	6	15	40	-	20	6	-	1	1	8	-	-	-	-	-	-	-	-	-	-	-
Nutmeg manikin *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**	**47,664**	**14,075**
Total Number of Species	**16**	**19**	**16**	**24**	**12**	**19**	**17**	**15**	**19**	**19**	**15**	**11**	**11**	**8**	**8**	**11**	**9**	**6**	**7**	**8**	**10**	**7**

*Data sourced from:

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Appendix V. Estimates of Seabird Numbers during the July 2017 Aerial Digital Survey of Kaula Island, Hawaii

Species/Group	Minimum Estimate	Maximum Estimate*
Birds		
Red-tailed tropicbird	502	996
Great frigatebird	777	1,106
Masked booby	514	684
Brown booby	969	1,378
Red-footed booby	2,650	3,767
Red-footed / masked booby	24	24
Brown noddy	7,871	14,319
Sooty tern	768	1,536
Total Estimated Number of Birds	**14,075**	**23,810**

*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 Kaula Island, Hawaii (2013–2017)*

Common Name	Scientific Name	Global Population	Regional Population[2] (Hawaii) Breeding Pairs	Apr 2013	Aug 2013	Jan 2014	Jan 2015	July 2015	Mar 2016	July 2017
Black-footed albatross	*Phoebastria nigripes*	64,500 breeding pairs[4]	55,000	3	-	11	3	-	4	-
Laysan albatross	*Phoebastria immutabilis*	1,180,000 mature individuals[4]	590,000	20	11	81	100	-	21	-
Red-tailed tropicbird	*Phaethon rubricauda*	> c.32,000 individuals[1]	9,000-12,000	314	85	-	1	100	23	502
Great frigatebird	*Fregata minor*	500,000-1,000,000[2]	10,000	1,415	1,369	621	748	1,078	1,005	777
Masked booby	*Sula dactylatra*	Unquantified. Described as 'fairly common'[3]	2,500	550	219	65	84	526	183	514
Brown booby	*Sula leucogaster*	> c.200,000 individuals[1]	1,400	101	109	3	2	867	179	969
Red-footed booby	*Sula sula*	> c.1,000,000 individuals[1]	7,000-10,500	1,690	191	98	209	3,693	1,319	2,650
Masked/red-footed booby	*Sula species*	-	-	-	-	-	-	27	-	24
Brown noddy	*Anous stolidus*	500,000-1,000,000 breeding pairs[2]	112,000	57	3,713	-	-	7,137	4,115	7,871
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	40,814	768
Grey-backed tern	*Onychoprion lunatus*	Likely 70,000 breeding pairs[2]	44,000	4	-	-	-	-	1	-
Hawaiian monk seal	*Neomonachus schauinslandi*	1,209 individuals of all age classes[5]	632 sexually mature seals[5]	11	7	5	7	9	10	8
Total Estimated Number of Birds				**18,795**	**5,733**	**879**	**1,147**	**13,576**	**47,664**	**14,075**
Total Number of Species				**11**	**9**	**6**	**7**	**8**	**10**	**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