Aerial Survey of Seabirds and Marine Mammals at Kaula Island, Hawaii, August 2018

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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 August 6, 2018. 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 98% of the final image mosaic formed from imagery collected on the high resolution survey.

In total, 23,187 birds were recorded during the survey with brown noddy being the most abundant species (n=7,612) followed by sooty tern (n= 6,535). Other species recorded included red-tailed tropicbird, great frigatebird, red-footed booby, masked booby, brown booby, and grey-backed tern.

The actual count of red-tailed tropicbirds (n=245) is over 50% fewer than the previous survey in July 2017. Assuming all single birds are one of a pair unless visibly doubled up, then there could conceivably be 485 pairs at the time of the current survey.

At the time of the surveys, seven Hawaiian monk seals were recorded resting on ledges on the west side of the island, four in the mid-west of the island and three together towards the southern end (Figure 6-3).

1 Introduction

Normandeau Associates and APEM Ltd. 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).

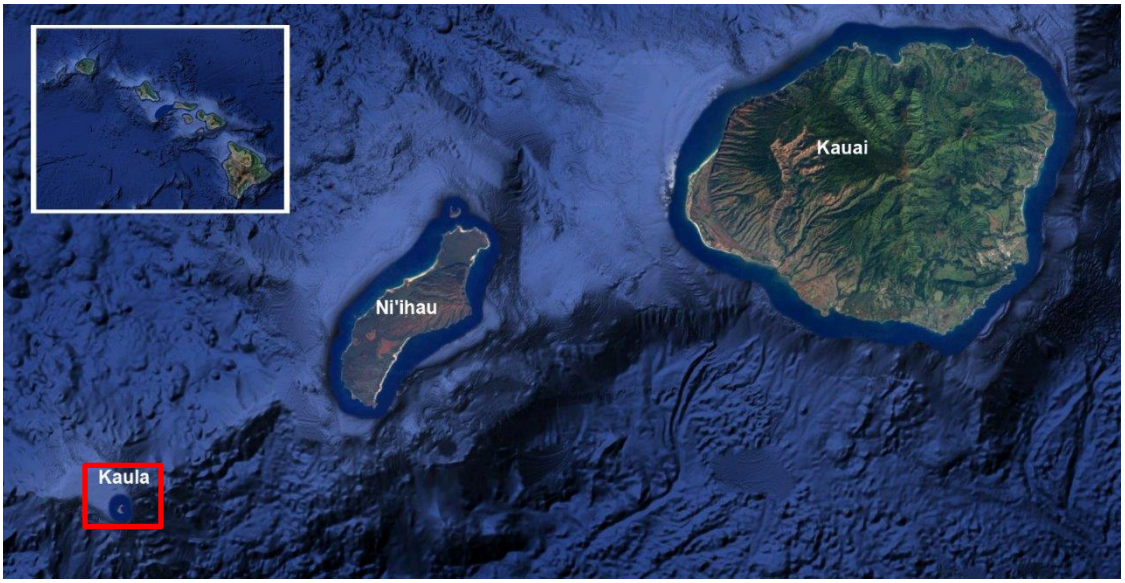

Figure 1-1. Location of Kaula Island relative to the main Hawaiian Islands (inset) and Kauai and Ni'ihau (imagery from ESRI).

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 August 6, 2018 and included oblique imagery capture.

Ultra-high resolution digital still images were collected using a manned light twin-engine survey aircraft (Piper Navajo PA 31 – N91PW) 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 transect was 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 August 6, 2018. 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 immediately after the second vertical survey on the same day, August 06, 2018.

The vertical high altitude survey was conducted between 09:50 and 10:48 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 10:58 and 12:03 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 oblique survey was also carried out on the same day between 12:10 and 13.25 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 identification 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 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 August 4, 2018, a short test flight was conducted in the afternoon of August 5, 2018. This was delayed to an afternoon flight due to Presidential Restricted Airspace. We then waited for a suitable weather window.

On the morning of August 6, 2018, weather forecasts and radar imagery predicted some cloud over the survey area but well above survey height. After a discussion with the pilot, a decision was made to carry out the survey in the morning. This was due to rising humidity and low cloud was predicted to form later that day.

Survey conditions were good with some high cloud cover and a mean wind speed of 25 knots from the south east. 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.

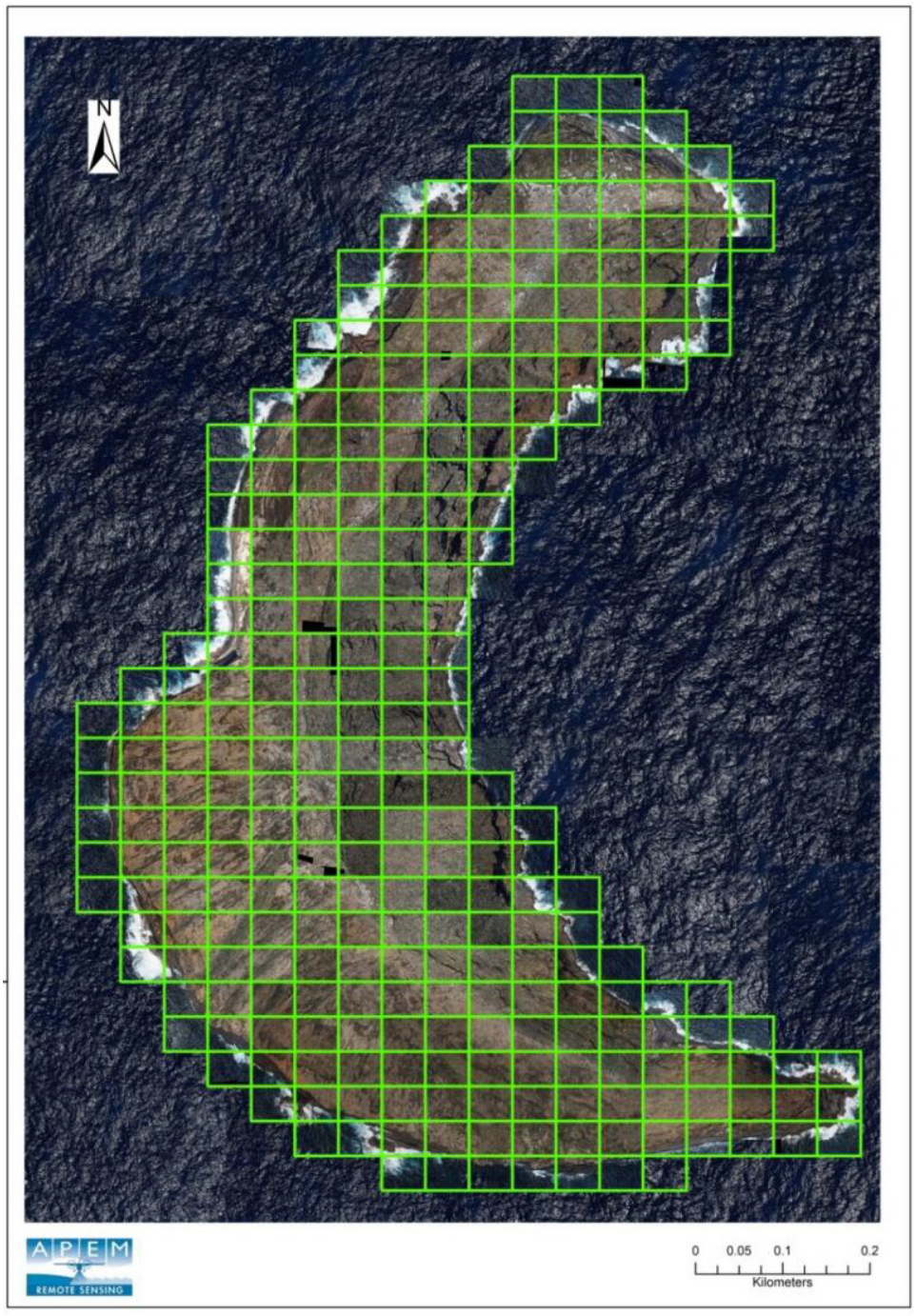

Figure 2-1. Kaula Island image analysis grid. Compiled images from the two vertical surveys were joined to cover Kaula Island. The compiled image was analyzed in 296 grid cell sections (marked in green).

3 Results

3.1 Species Abundance

Seven marine mammals (1 species) and 23,187 birds (8 species) were recorded on Kaula Island during August 2018 (Table 3–1). Brown noddy (n=7,612) was the most abundant bird species, and grey-backed tern (n=5) 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 August 2018

Species/Group	Number Recorded			
	Vertical Survey	Oblique Survey	Visual Observation	Total
Birds				
Red-tailed tropicbird	231	14	-	245
Great frigatebird	719	-	-	719
Masked booby	1,305	7	-	1,312
Brown booby	1,008	223	-	1,231
Red-footed booby	4,755	9	-	4,764
Masked booby /Brown booby	51	-	-	51
Booby species	713	-	-	713
Brown noddy	7,418	194	-	7,612
Sooty tern	6,535	-	-	6,535
Grey-backed tern	-	5	-	5
Total Birds	*22,735*	*452*	-	*23,187*
Marine Mammals				
Hawaiian monk seal	7	-	-	7
Total Birds and Marine Mammals	**22,742**	**452**	-	**23,194**

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 August 2018 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 dense 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 245 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, 233 were in flight (Table 3–2).

3.2.3 Great Frigatebirds

A total of 719 great frigatebirds were recorded during the survey (Table 3–1), of which 33 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 79 immature birds were counted of which 71 were juveniles in nests (Table 3–2).

3.2.4 Masked Boobies

A total of 1,312 masked boobies were recorded during the survey (Table 3–1), of which 10 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 (Figure 3–4). A total of 205 immature birds were counted of which 145 were juveniles in nests (Table 3–2).

3.2.5 Brown Boobies

A total of 1,231 brown boobies were recorded during the survey (Table 3–1), of which 29 were flying (Table 3–2). Of the total recorded, 147 were either immature or juvenile birds in nests (Table 3–2). They were widely distributed throughout the whole island (Figure 3–5). Of the total recorded, 223 were found in the oblique imagery, not visible in the vertical imagery (Table 3–1).

3.2.6 Red-footed Boobies

A total of 4,764 red-footed boobies were recorded during the survey (Table 3–1), of which 67 were captured in flight (Table 3–2). Out of the total number of birds 457 were immatures and 453 were juveniles in nests (Table 3–2). They were present across the whole island (Figure 3–6).

3.2.7 Masked Boobies / Brown Boobies

A total of 51 unidentified masked or brown boobies were recorded during the survey (Table 3–1), one of which was flying (Table 3–2). Of the 51 unidentified boobies, 29 were immatures and 22 were juveniles on nests with no adults in attendance (Table 3–2).

3.2.8 Booby species

A total of 713 unidentified boobies were recorded during the survey (Table 3–1), seven of which were flying (Table 3–2). Of the 713 unidentified boobies counted 663 were immature birds and 50 were juveniles on nests with no adults in attendance (Table 3–2).

3.2.9 Brown Noddies

A total of 7,612 brown noddies (6,777 sitting and 835 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 3–9). Of the total recorded, 194 were found in the oblique imagery, not visible in the vertical imagery (Table 3–1).

3.2.10 Sooty Terns

A total of 6,535 sooty terns were recorded during the survey (Table 3–1), of which 807 were flying (Table 3–2). Most were found in dense groups amongst the brown noddies on the west and south sides of the island (Figure 3–10).

3.2.11 Grey-backed Terns

A total of five grey-backed terns were recorded during the survey (Table 3–1), of which all were recorded in the oblique imagery and were located on the south west side of the island sitting under the cliff edge (Figure 3–11).

3.2.12 Marine Mammals

During the course of the surveys, seven Hawaiian monk seals were recorded resting on ledges on the west side of the island (Table 3–1, Figure 3–12).

Table 3–2. The species, age and numbers of sitting and flying birds recorded in July 2017 and August 2018 aerial surveys

Species	July 2017						August 2018					
	Adult		Immature		Juvenile		Adult		Immature		Juvenile	
	Flying	Sitting	Flying	Sitting	Sitting	Total	Flying	Sitting	Flying	Sitting	Sitting	Total
Booby species	-	-	-	-	-	-	-	-	7	656	50	713
Brown booby	18	774	-	85	92	969	29	1,055	-	23	124	1,231
Brown noddy	479	7,346	-	6	40	7,871	835	6,720	-	-	57	7,612
Great frigatebird	54	508	-	14	201	777	32	601	1	14	71	719
Great-backed tern	-	-	-	-	-	-	5	-	-	-	-	5
Masked booby	5	430	-	38	41	514	10	1,097		60	145	1,312
Masked/Brown booby	-	-	-	-	-	-	-	-	1	28	22	51
Red-footed booby	53	1,937	6	433	221	2,650	58	3,796	9	448	453	4,764
Red-footed/Masked booby	-	2	2	7	13	24	-	-	-	-	-	-
Red-tailed tropicbird	444	57	1	-	-	502	233	12		-	-	245
Sooty tern	10	758	-	-	-	768	807	5,718		-	10	6,535
Total	**1,063**	**11,812**	**19**	**583**	**608**	**14,075**	**2,009**	**18,999**	**18**	**1,229**	**932**	**23,187**

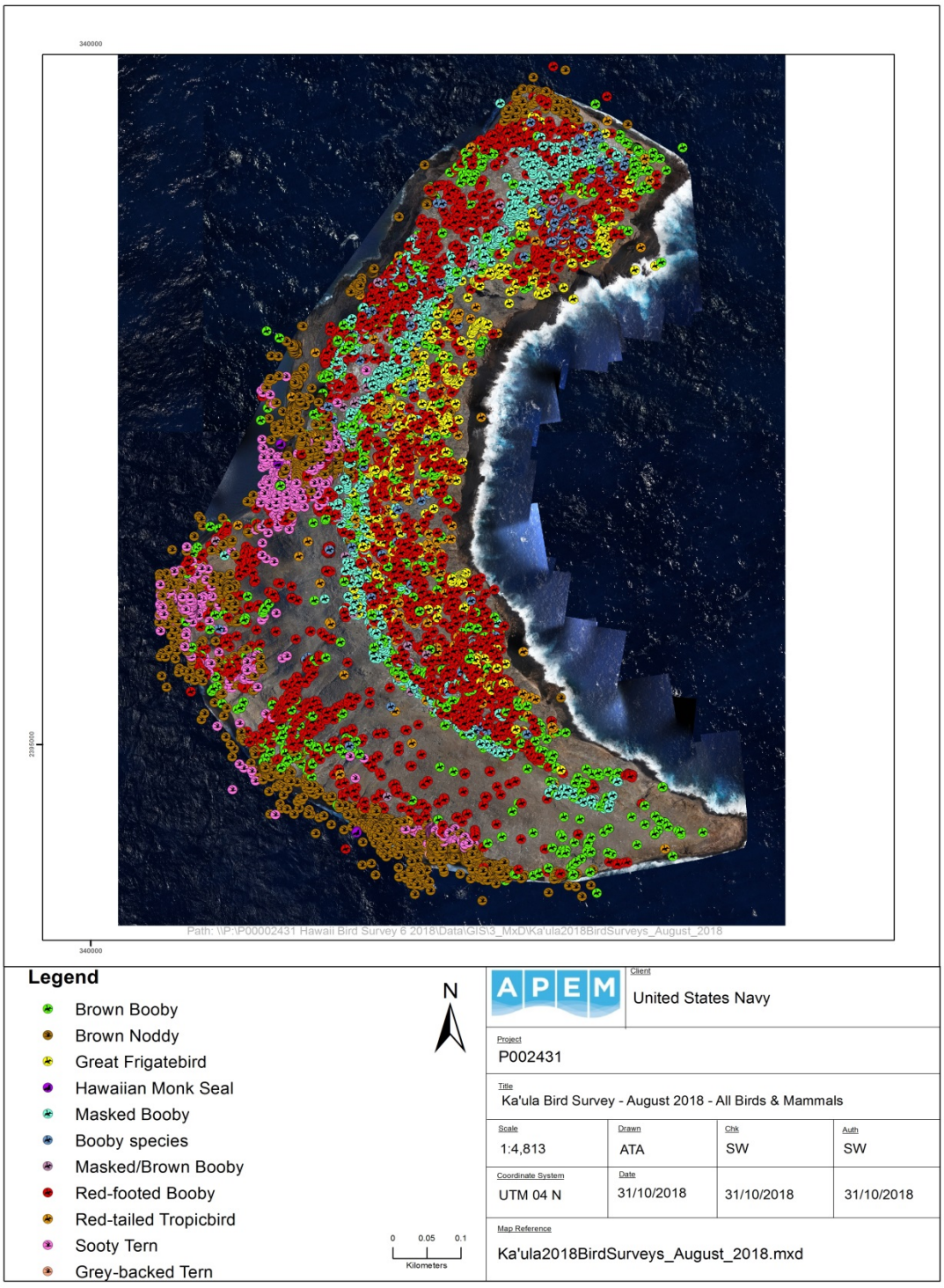

Figure 3-1. Distribution of all birds and marine mammals recorded on Kaula Island during the August 2018 survey.

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.

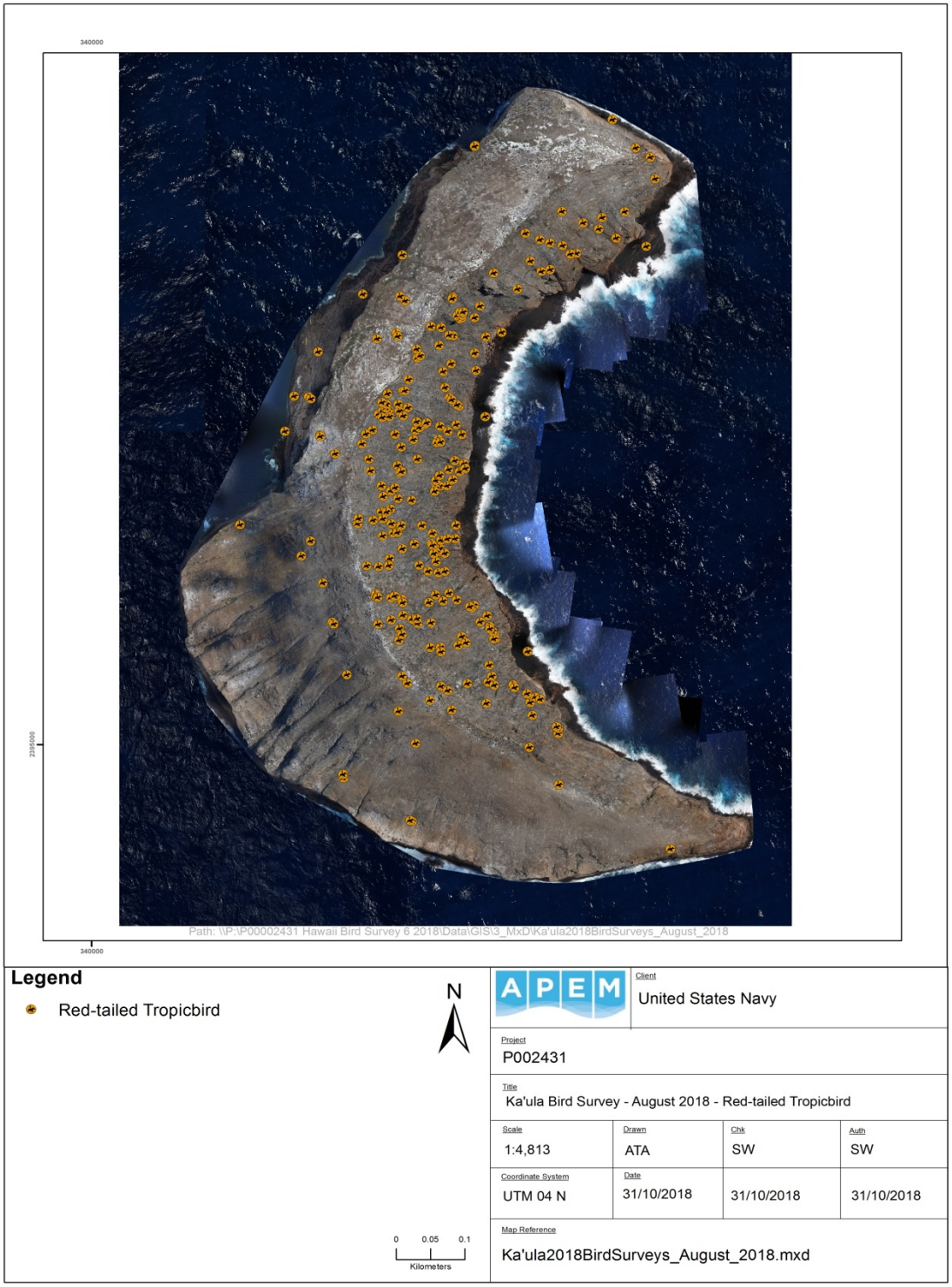

Figure 3-2. Distribution of red-tailed tropicbirds recorded on Kaula Island during the August 2018 survey.

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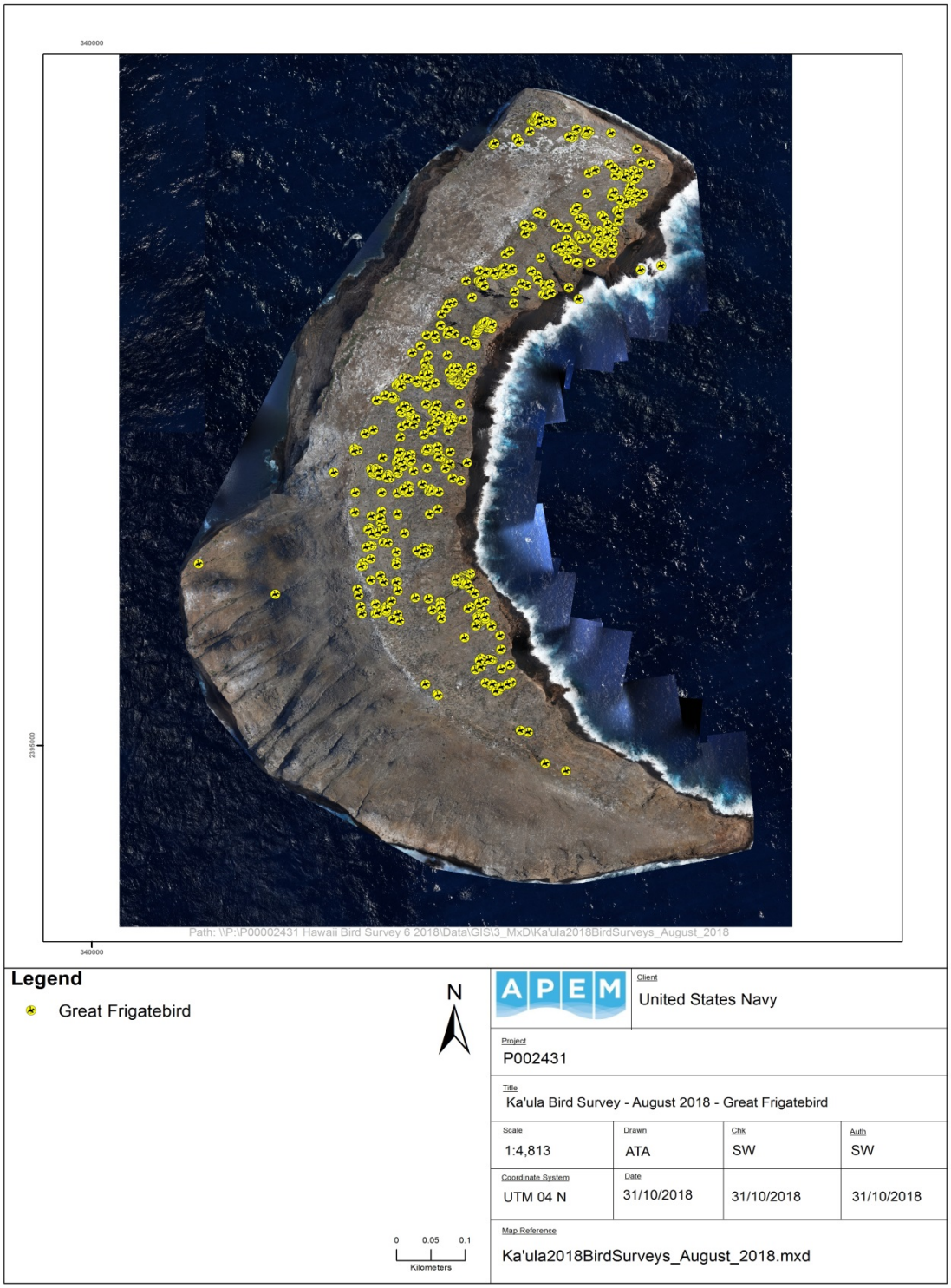

Figure 3-3. Distribution of great frigatebirds recorded on Kaula Island during the August 2018 survey.

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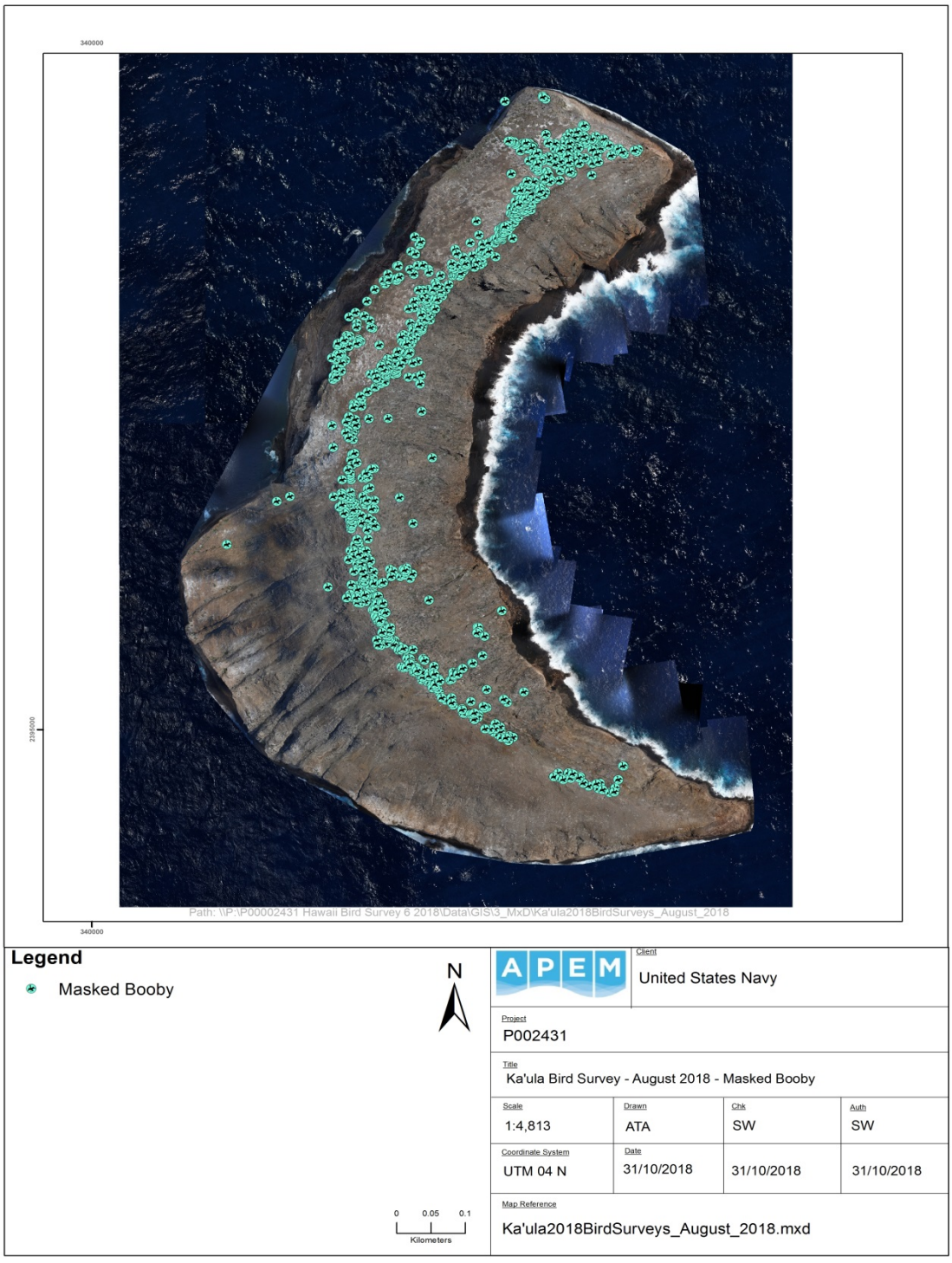

Figure 3-4. Distribution of masked boobies recorded on Kaula Island during the August 2018 survey.

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.

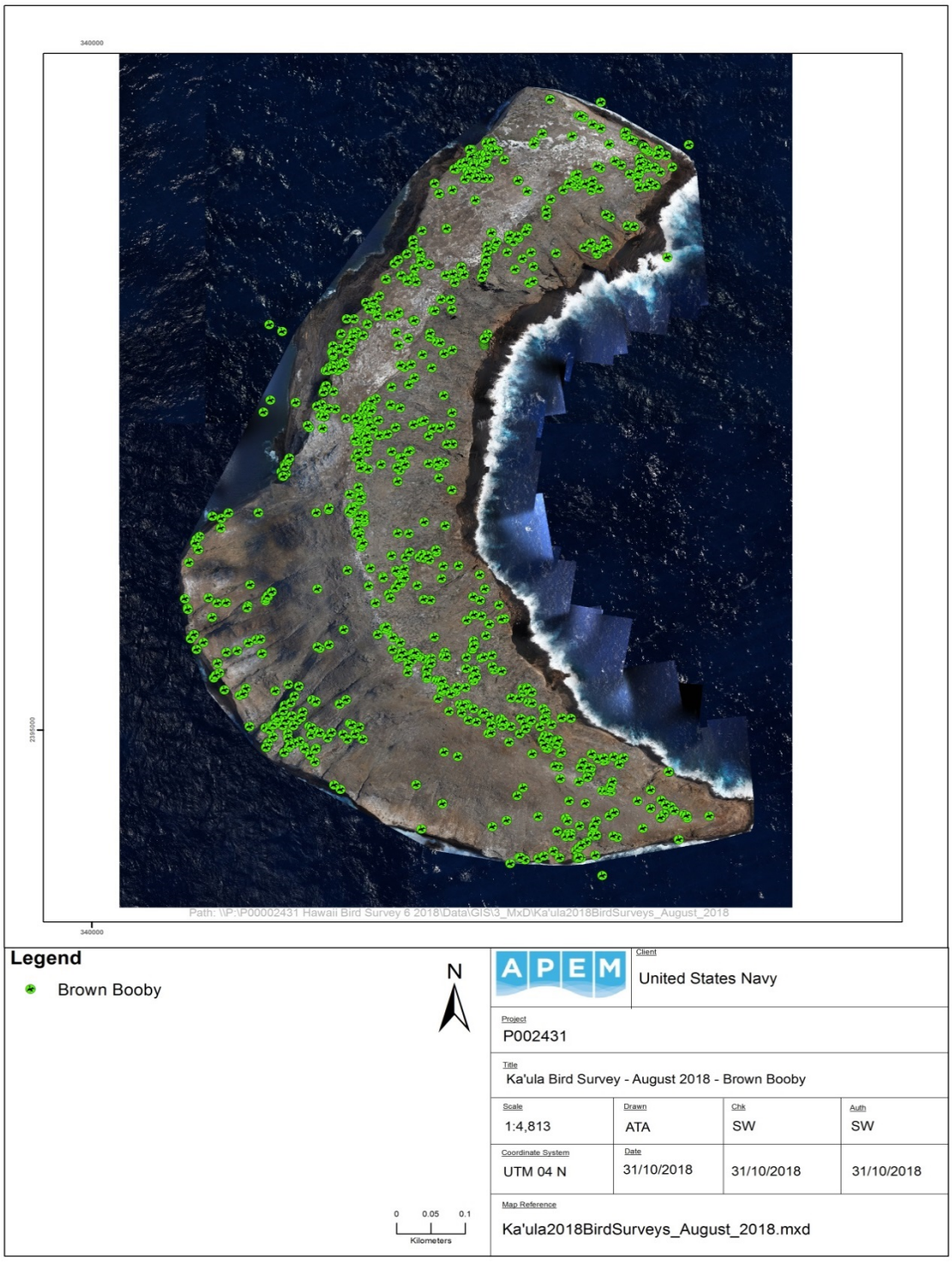

Figure 3-5. Distribution of brown boobies recorded on Kaula Island during the August 2018 survey.

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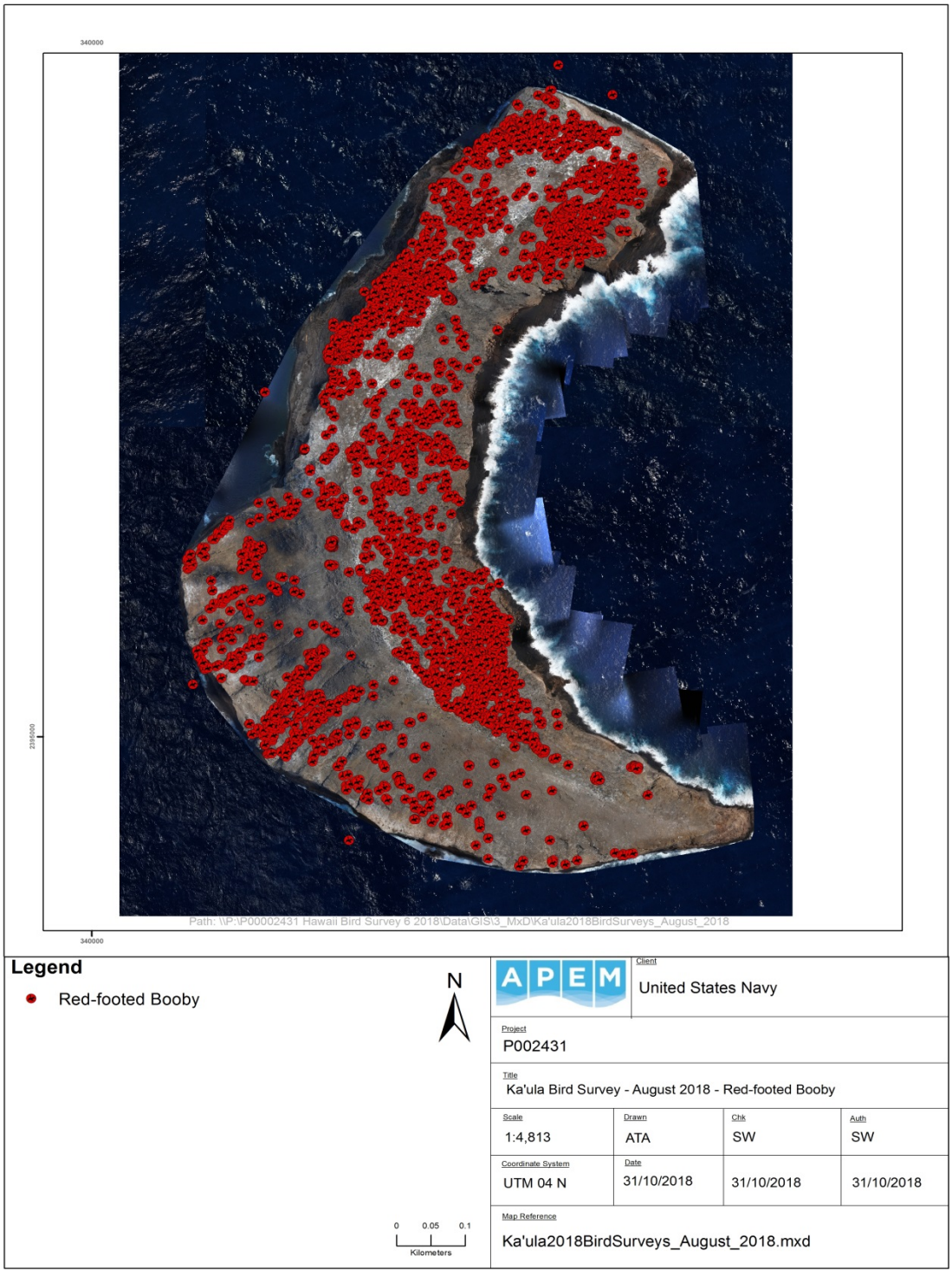

Figure 3-6. Distribution of red-footed boobies recorded on Kaula Island during the August 2018 survey.

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.

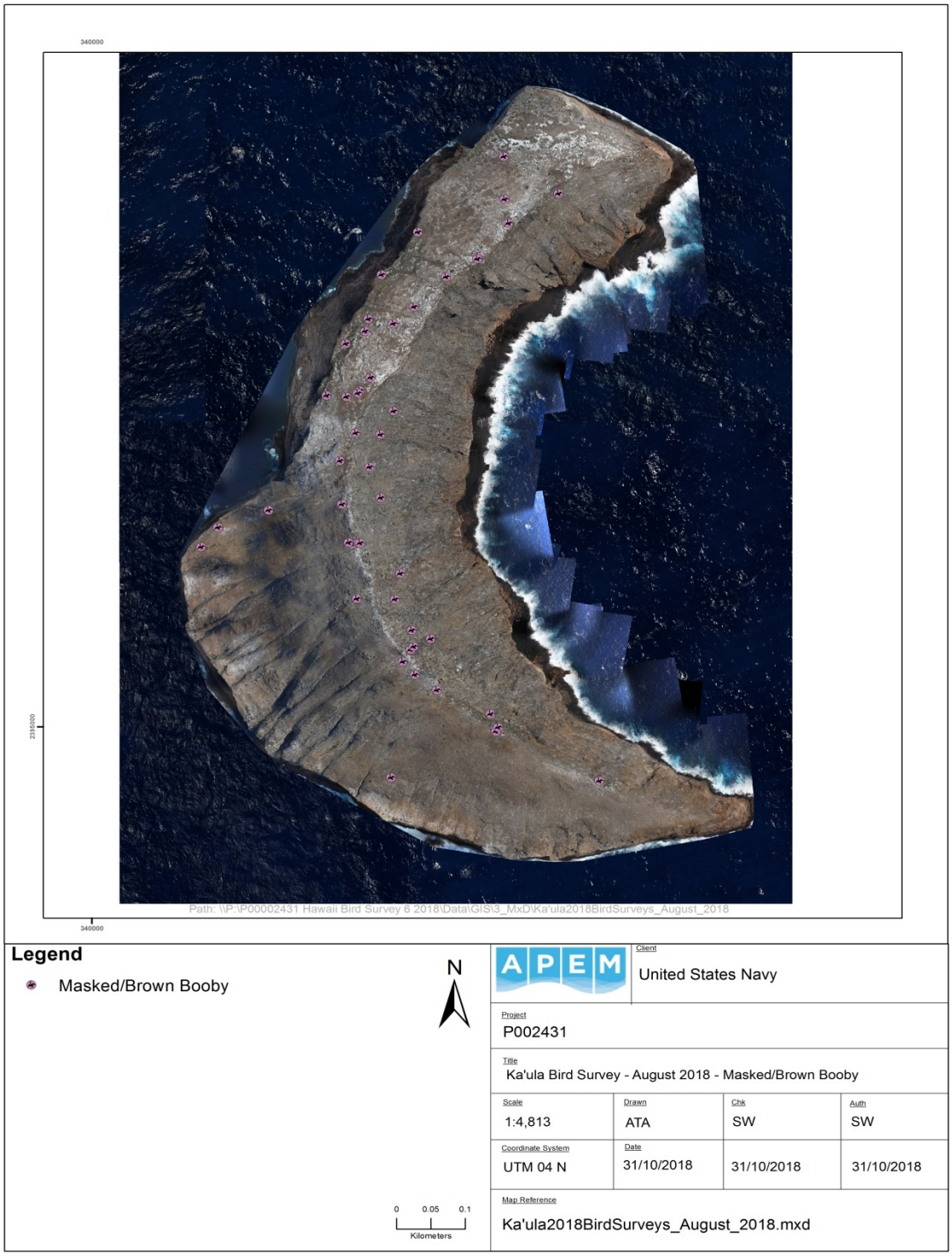

Figure 3-7. Distribution of masked/brown boobies recorded on Kaula Island during the August 2018 survey.

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.

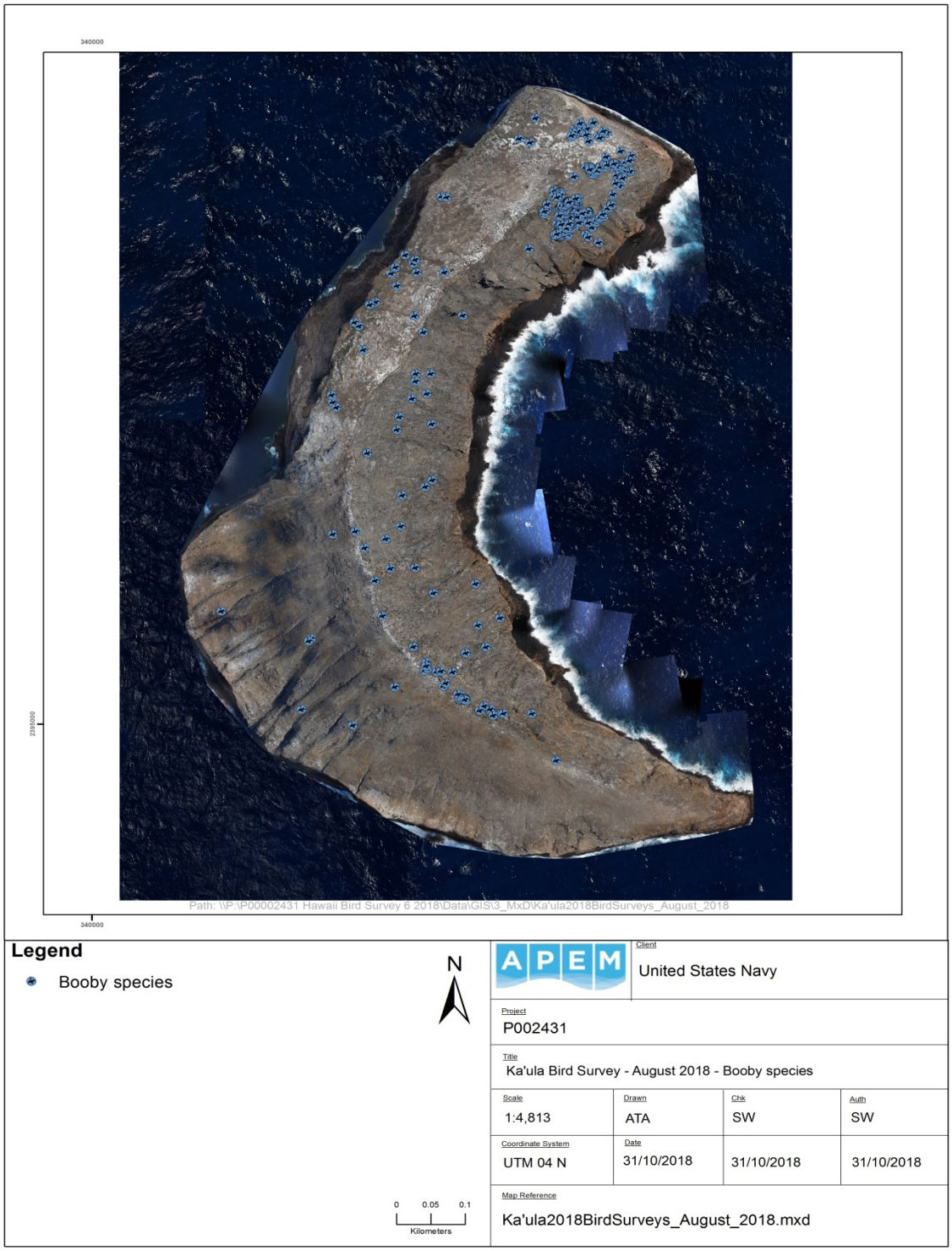

Figure 3-8. Distribution of booby species recorded on Kaula Island during the August 2018 survey.

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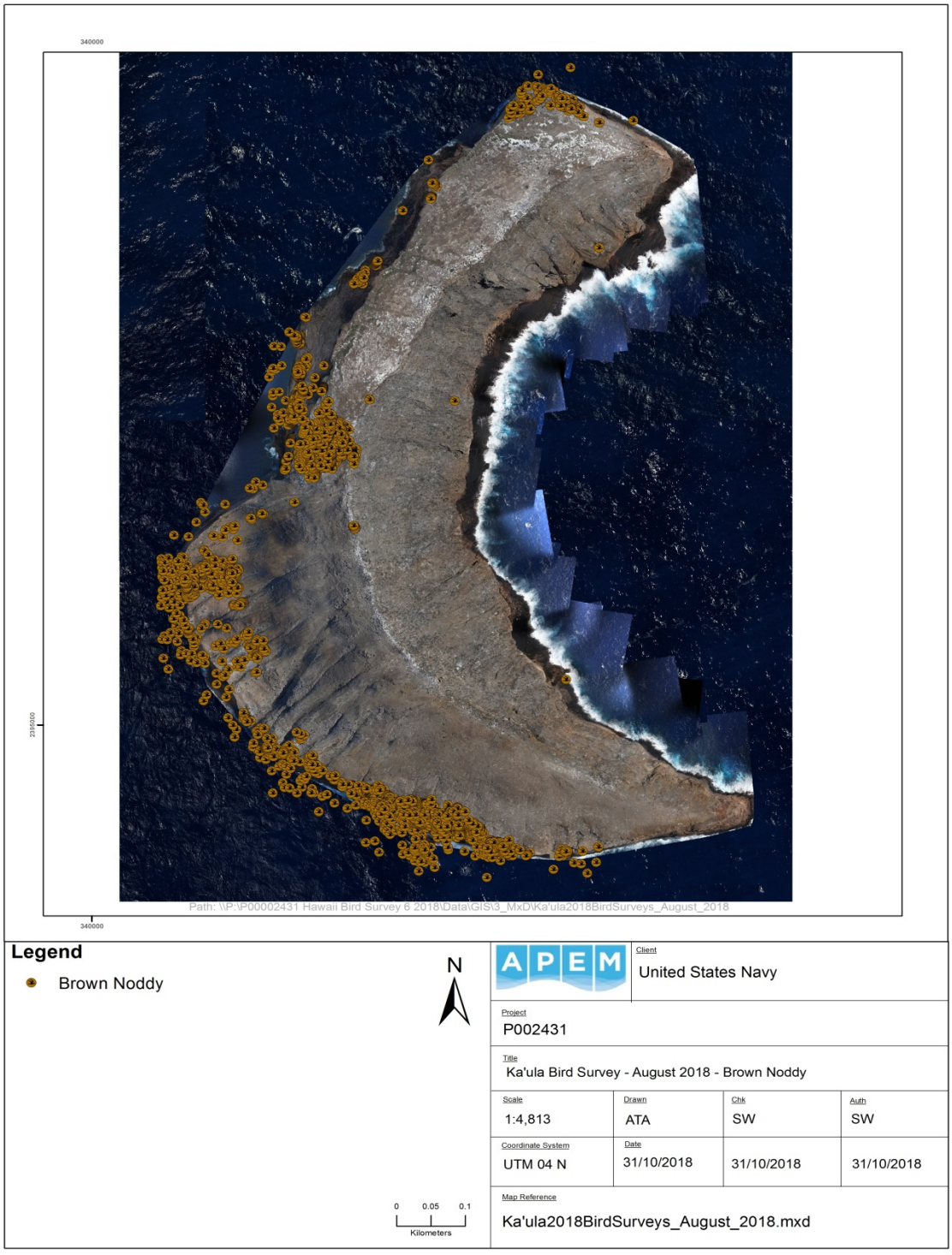

Figure 3-9. Distribution of brown noddies recorded on Kaula Island during the August 2018 survey.

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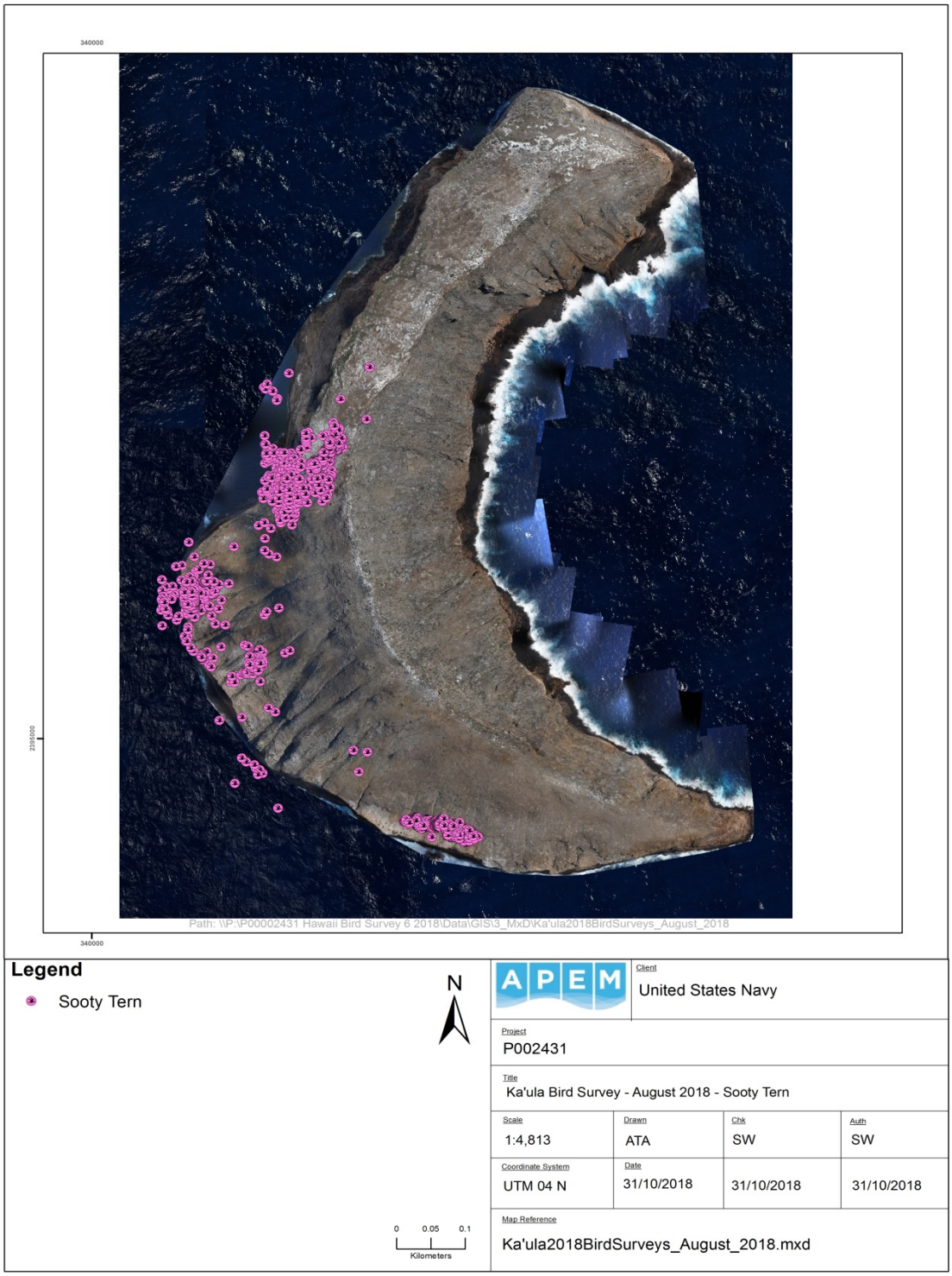

Figure 3-10. Distribution of sooty terns recorded on Kaula Island during the August 2018 survey.

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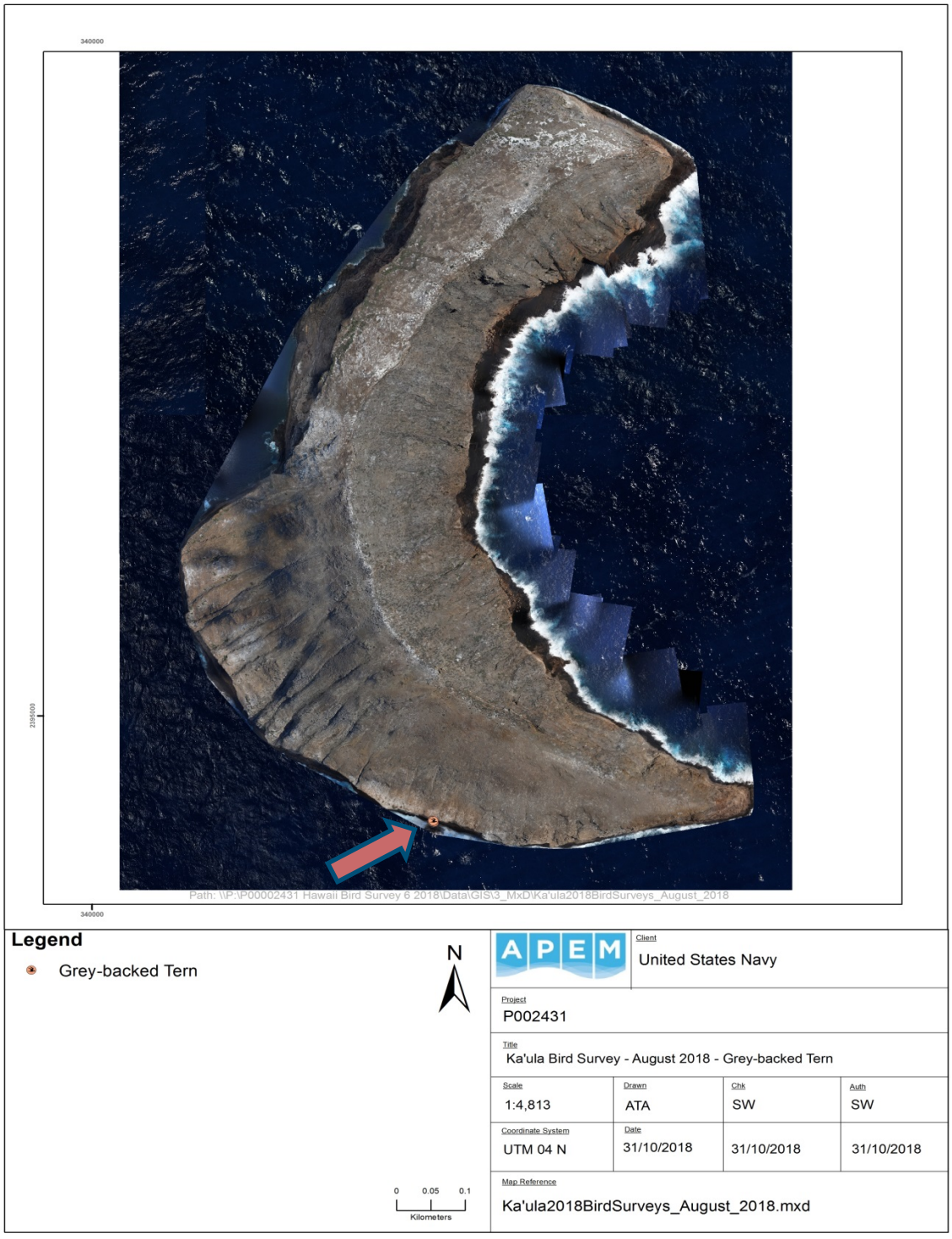

Figure 3-11. Distribution of grey-backed terns recorded on Kaula Island during the August 2018 survey.

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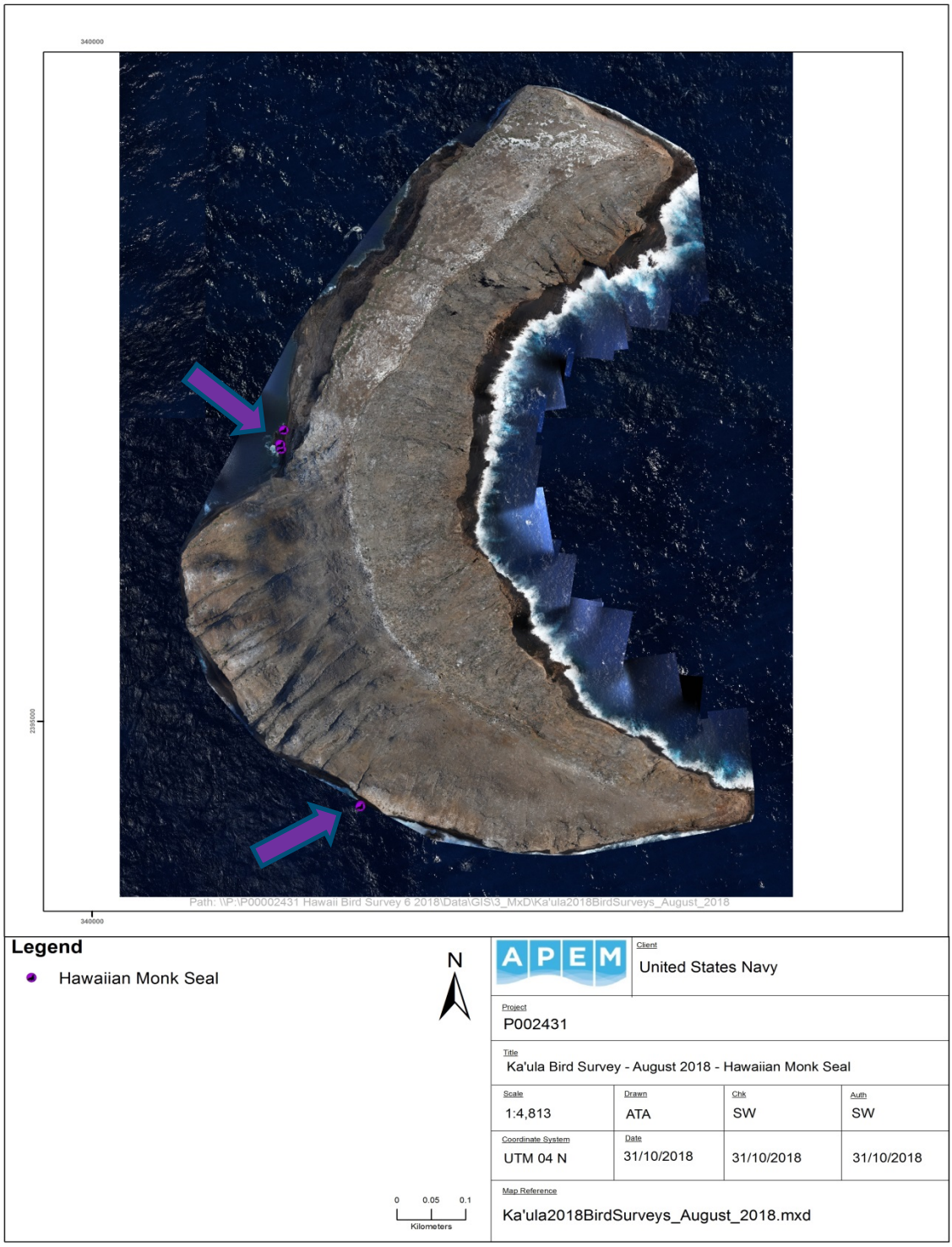

Figure 3–12. Distribution of Hawaiian monk seals recorded on Kaula Island during the August 2018 survey.

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 August 2018 vertical and oblique surveys, a total of 23,187 birds and seven Hawaiian monk seals were recorded at Kaula Island (Table 3–1). The eight bird species present were red-tailed tropicbird, great frigatebird, masked booby, brown booby, red-footed booby, brown noddy, grey-backed tern and sooty tern. The most abundant species was brown noddy, accounting for 33% (n=7,612) of all the seabirds recorded. The next most abundant species were sooty tern (n=6,535), red-footed booby (n=4,764), masked booby (n=1,312) and brown booby (n=1,231) (see Table 3–1). Great frigatebird (n=719), red-tailed tropicbird (n=245) and grey-backed tern (n=5) were the least abundant species recorded. A total of 764 unidentified immature boobies were also recorded (Table 3–2).

Red-tailed tropicbirds were mainly found along the eastern side of the island (Figure 3–2). Numbers recorded in this survey (n=245) were less than those recorded in the aerial digital survey carried out in July 2017 (n=502) but were higher than those recorded in the previous August survey in 2013 (n=85). 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, only a small number (n=14) 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=719) were similar to those recorded in the aerial digital survey carried out in July 2017 (n=777; Appendix IV). However this number is still lower than average when compared to the previous seven aerial digital surveys since August 2013; especially records from summer months (July or August). The number of juveniles in nests during this survey (n=86) were less than those recorded in July 2017 (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.

Known nesting habits of the various booby species was used to aid identification, based on the assumption that juvenile boobies in occupied nests on shrubs or vegetation were likely to be red-footed booby this left 51 young boobies on bare ground that had no adults in attendance which were therefore classified as masked / brown boobies. There were also large groups of roosting boobies, in which 713 immatures could not be identified to species (Figure 6-4).

Of the booby species recorded, red-footed booby was the most abundant during the August 2018 survey followed by masked booby and brown booby (see Table 3–1). The count of 4,764 red-footed boobies during this survey is the highest ever recorded count on the island. Recent surveys seem to suggest the bulk of breeding occurs during June and July. Of the 910 immature (non-breeding and not in adult plumage) birds recorded, 453 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 175 pairs and a further 3,502 single birds, so conceivably there could have been up to 7,179 breeding pairs present (Appendix V).

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). The total of 1,312 birds is the highest recorded count on the island. 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 (n=1107) or well grown immatures (n=60; Table 3–2). Of all the adult birds recorded, there were 201 pairs and a further 705 single birds, so conceivably there could have been up to 1,611 breeding pairs present (Appendix V). The three largest counts have now occurred in either August or September on Kaula (Appendix IV).

Brown booby numbers (n=1,231) were higher than in the aerial digital survey in July 2017 (n=969) (Table 3–2, Appendix IV) and were the highest recorded since the land-based survey in September 1971 (n=1,700) (Appendix IV). Of the total recorded during this survey, 1,084 were adults (Table 3–2) of which there was 82 pairs and a further 918 single birds, so conceivably there could have been up to 1,918 breeding pairs present (Appendix V). Higher than expected numbers of brown boobies (n=223) were recorded in the oblique imagery on ledges on the vertical cliffs of the island which hasn't been noted before in previous aerial digital surveys (Figure 6-5). From the imagery it was difficult to determine with any certainty if they were breeding there, or using the ledges for resting.

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 on the western side of the island. Numbers (n=7,612) were slightly lower than those present during the aerial digital survey in July 2017 (n=7,871) (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 380 adult pairs and a further 6,795 single birds, so conceivably there could have been up to 13,970 pairs (Appendix V). Also of note 57 chicks (Table 3–2; Figure 6-1) were counted amongst the colonies, all were very close to adult birds. Any black noddies present could potentially have been overlooked but no definite candidates could be located in the imagery.

Sooty terns (n=6,535; 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 higher than those recorded in the July 2017 survey (n=768). The number from this survey is 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 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 derived from potential for being 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. Seven Hawaiian monk seals were recorded on the west side of the islands

(Figure 3–12). Numbers have remained fairly consistent throughout the seven aerial digital surveys carried out between 2013 and 2018 (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
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*
Grey-backed tern	*Onychoprion lunatus*
Sooty tern	*Onychoprion fuscatus*
Hawaiian monk seal	*Neomonachus schauinslandi*

Appendix II. Survey Imagery: Vertical Image Examples

Figure 6-1. Brown noddies (juvenile and pairs circled) on the west side of Kaula Island during the August 2018 survey.

Figure 6-2. Red-footed boobies (adult and chick circled) on the west side of Kaula Island during the August 2018 survey.

Figure 6-3. Three Hawaiian monk seals (circled) resting on ledges on the north-west side of Kaula Island during the August 2018 survey.

Figure 6-4. Mixed group of roosting boobies of different ages on the east side of the central ridge of Kaula Island during the August 2018 survey.

Appendix III. Survey Imagery: Oblique Image Examples

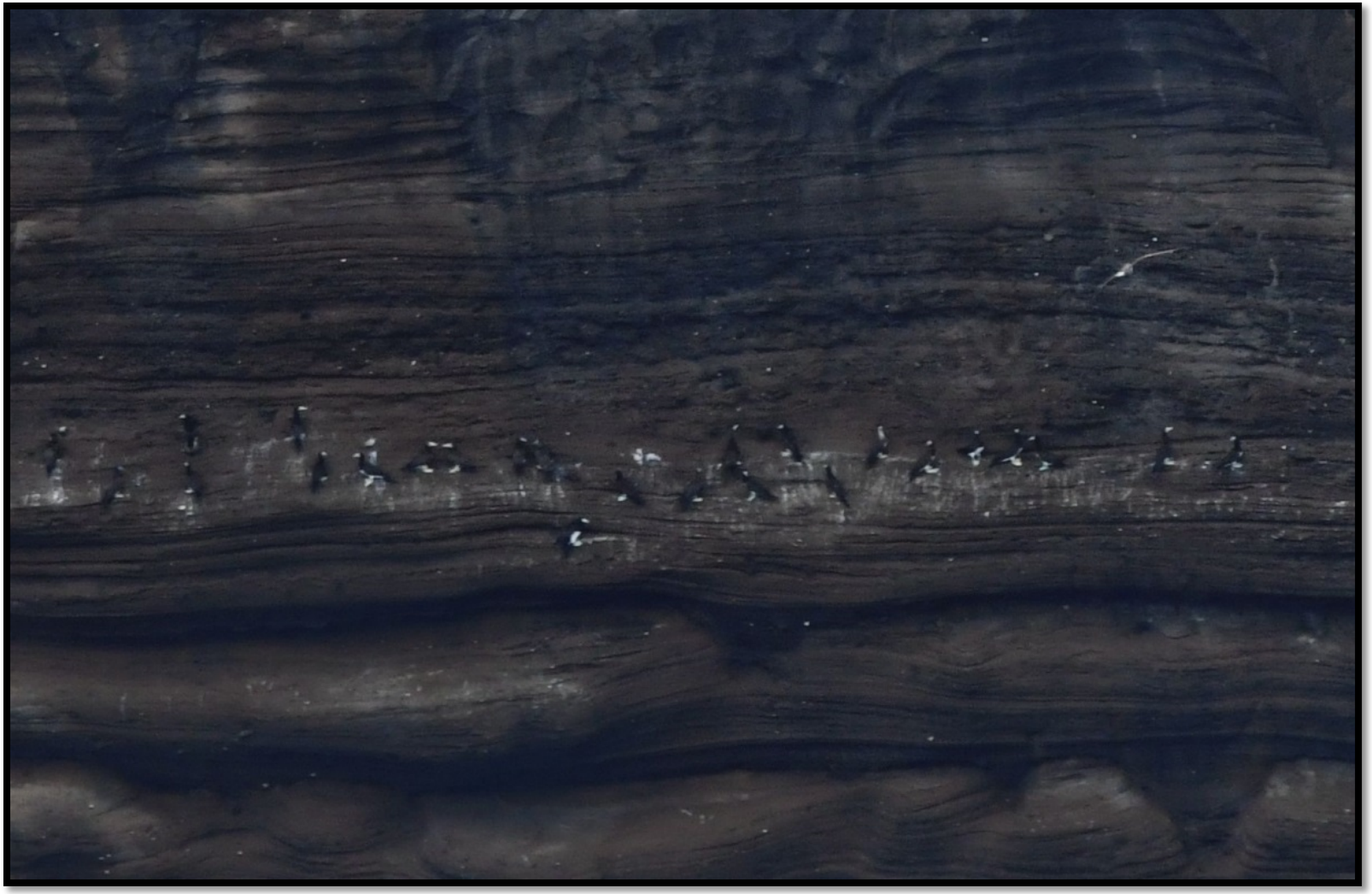

Figure 6-5. **Brown boobies on cliff face on the west side of Kaula Island during the August 2018 survey.**

Figure 6-6. **Brown boobies (right and bottom) and red-footed boobies (top left) on the western side of Kaula Island during the August 2018 survey.**

Appendix IV. Results of Bird Surveys Conducted on Kaula Island, Hawaii (1932–2018)*

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	Aug 2018
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	245
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	719
Booby species *Sula species*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	713
Masked booby *Sula dactylatra*	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219	65	84	526	183	514	1,312
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	1,231
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	4,764
Masked/red-footed booby *Sula dactylatra / S. sula*	-	-	-	-	-	-	-	-	-	-	-	820	850	1,859	912	-	-	-	-	27	-	24	-
Masked/brown booby *Sula dactylatra / S. leucogaster*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	51
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	7,612
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	-	-	-	-	-	-	-	-	-	-

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	Aug 2018
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	6,535
Grey-backed tern *Onychoprion lunatus*	uncommon	2,800	-	250	1,250	50	300	4,110	1,467	35	-	1	3	-	-	4	-	-	-	-	1	-	5
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**	**23,187**
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**	**8**

*Data sourced from:

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

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Appendix V. Estimates of Seabird Numbers during the August 2018 Aerial Digital Survey of Kaula Island, Hawaii

Species/Group	Minimum Estimate	Maximum Estimate*
Birds		
Red-tailed tropicbird	245	485
Great frigatebird	719	1,203
Masked booby	1,312	1,611
Brown booby	1,231	1,918
Red-footed booby	4,764	7,179
Masked booby/ Brown booby	51	-
Booby species	713	-
Brown noddy	7,612	13,970
Sooty tern	6,535	12,886
Grey-backed tern	5	10
Total Estimated Number of Birds	**23,187**	**39,262**

*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 (2013–2018)*

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	Aug 2018
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	245
Great frigatebird	*Fregata minor*	500,000-1,000,000[2]	10,000	1,415	1,369	621	748	1,078	1,005	777	719
Booby species	*Sula speceis*	-	-	-	-	-	-	-	-	-	713
Masked booby	*Sula dactylatra*	Unquantified. Described as 'fairly common'[3]	2,500	550	219	65	84	526	183	514	1,312
Brown booby	*Sula leucogaster*	> c.200,000 individuals[1]	1,400	101	109	3	2	867	179	969	1,231
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	4,764
Masked/red-footed booby	*Sula species*	-	-	-	-	-	-	27	-	24	-
Masked/brown booby	*Sula species*	-	-	-	-	-	-	-	-	-	51
Brown noddy	*Anous stolidus*	500,000-1,000,000 breeding pairs[2]	112,000	57	3,713	-	-	7,137	4,115	7,871	7,612
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	6,535
Grey-backed tern	*Onychoprion lunatus*	Likely 70,000 breeding pairs[2]	44,000	4	-	-	-	-	1	-	5
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	7
Total Estimated Number of Birds				**18,795**	**5,733**	**879**	**1,147**	**13,576**	**47,664**	**14,075**	**23,187**
Total Number of Species				**11**	**9**	**6**	**7**	**8**	**10**	**8**	**9**

[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