FINAL

Aerial Survey of Seabirds and Marine Mammals at Ka`ula Island, Hawai`i—August 2013

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U.S. Navy
Commander, U.S. Pacific Fleet Environmental Readiness
250 Makalapa Drive
Pearl Harbor, HI 96860

Via
NAVFAC Pacific, EV22
258 Makalapa Drive, Suite 100
Pearl Harbor, HI 96860-3134

Prepared By

Normandeau Associates, Inc. and APEM, Ltd. Joint Venture
102 NE 10th Avenue
Gainesville, FL 32601
(352) 372-4747

Riverview, A17 Embankment Business Park
Heaton Mersey, Stockport Sk4 3GN
0161 442 8938

www.normandeau.com | www.apemltd.co.uk

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Executive Summary

Aerial surveys of Ka`ula Island, Hawai`i, using a manned light twin-engine survey aircraft and very high resolution digital photography were conducted on 21 August 2013. A vertical (nadir) aerial survey was complemented by an oblique survey to allow counts to be made both of birds on the top of the island and those present on the cliff faces.

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

In total, 5,733 birds of nine species were recorded during the survey with brown noddies being the most abundant species (n=3,673) followed by great frigatebirds (n=1,294). A number of other species were recorded including Laysan albatrosses, red-tailed tropicbirds, masked boobies, brown boobies, red-footed boobies, black Noddies, and sooty terns.

At the time of the survey, 7 Hawai`ian monk seals were resting on ledges in the northeast and south 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 digital high resolution aerial imagery.

Ka`ula Island is a small (0.640 $km^2$), uninhabited crescent shaped islet in the west of the chain of islands making up the Hawai`ian Archipelago (Figures 1–1 and 1–2). The islands closest to Ka`ula are Niihau Island, which is located 37 km to the northeast, and Kauai Island, approximately 111 km to the northeast. A mountain ridge runs along the length of Ka`ula Island (approximately 1,676 m), which at its highest point is 164.6 m above sea level. The terrain drops steeply from the ridge crest at a mean slope of 36° (Palmer 1936, cited in Pepi et al. 2009), 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, cited in Fujimoto and Juola 2012). 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, cited in Pepi et al. 2009).

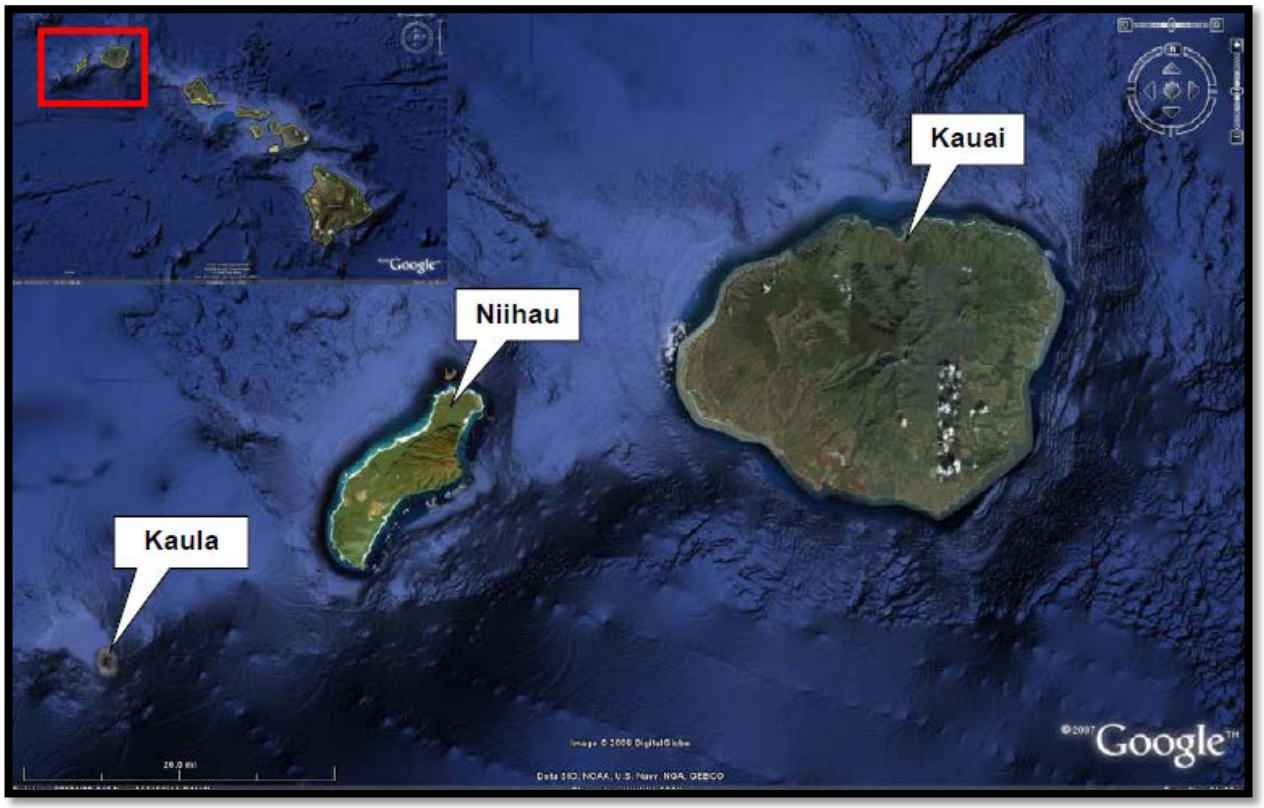

Figure 1–1. Location of Ka`ula Island relative to the main Hawai`ian Islands (inset) and Kauai and Niihau (imagery from Google Earth).

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

Since 1952, the U.S. Navy has used the southeastern tip of the island (approximately 0.06 km^2) as a range to train aviators in air-to-surface and surface-to-surface weapons delivery. Both live and inert ordnance were used during training missions through 1980, but from 1981 through 2009, munitions training by the Navy at Ka`ula has been restricted to inert ordnance delivery and aircraft gunnery (Walker 1983, 1984; cited in Pepi et al. 2009).

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

The U.S. Navy attempted aerial imagery prior to the finalization of the Seabird Monitoring Plan (DoN 2009) but results were unacceptable. Now with improved technology available, the Navy looked to improve and build upon the seabird data gathering 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 is expected to result 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

The digital aerial survey of Ka`ula was undertaken on 21 August 2013. High resolution digital still images were collected using a manned light twin-engine survey aircraft, Aero Commander 500 s N500SJ, and a GPS-linked custom flight management camera system, the APEM SeeBird01, specifically designed by APEM to target high resolution surveys for birds and marine mammals.

To prepare for the survey of Ka`ula, flight planning software was used to define the required flying altitude and speed according to the camera, lens, and required pixel resolution. During the survey, each of the survey transects 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 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. All of the required surveys were carried out on the same day (21 August 2013) and involved vertical surveys of Ka`ula Island including one at high altitude (vertical high altitude survey) and one at lower altitude (vertical low altitude survey) in which the downwards facing camera was at a 90º angle to the aircraft. The third survey involved collecting oblique images (oblique survey) of birds on steep, overhanging cliff faces that would not have been visible from the vertical surveys.

The first survey (between 1258 and 1422 hours) was the vertical high altitude survey conducted at 2,500 feet, which was flown in an east-west direction. This survey captured 2 cm resolution imagery at the higher elevation sections of the island.

Immediately after the first survey (between 1425 and 1607 hours), the vertical low altitude survey was flown in an east-west direction at 2,050 feet. This captured imagery at 2 cm resolution at sea level. The combination of the two surveys allowed the whole island to be captured at a minimum of 2.5 cm resolution.

The oblique survey (between 1616 and 1623 hours) was conducted on the same day (see Section 2.4) by flying clockwise around the island between 900 and 1,800 feet, and images were taken to capture the sides of the steep cliff faces.

2.2 Data Processing

2.2.1 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 ArcView (version 9.2) and spatially joined to create one large image mosaic covering the whole island. Images with the highest resolution for each location on the island were used to compile the mosaic, and any overlapping image sections were removed. This method was considered to

be the most appropriate to minimize the risk of double counting that might have otherwise occurred by treating each individual image in isolation (due to overlapping areas). It is acknowledged that there is a small chance that movement of birds between transects could result in a bird being double counted. There is of course an equally small chance that a bird could be missed in both transects. On this basis, it is reasonable to assume that the risk of double counting is equal to the risk of undercounting, and the effect on the population count is negligible.

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

The mosaic was split into 295 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 which 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. As the software function has not yet been developed for species likely to be encountered in the Pacific, each analyst themselves identified the species detected in each grid cell. This identification is based upon the size, shape and visible characteristics present in the images. The resolution of the images is extremely high, such that the individuals can be identified with a high degree of certainty. In addition a manual check of each grid cell was carried out to ensure that all birds and mammals were captured.

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 comprised of individual points geo-referenced to actual spatial location at the time of sighting.

2.2.2 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 staff 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 and overhanging rock ledges. The results of these counts were then subjected to the same internal process used in the vertical survey.

2.3 Quality Assurance

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

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

2.4 Weather Conditions and Survey Limitations

This section explains some of the survey limitations and weather conditions. The survey was scheduled to start at 1015 hours on 21 August 2013 from Kalaeloa Airport on Oahu Island, but due to an indication of rain on the radar it was decided to wait until the weather conditions improved. Conditions were reviewed every 45 minutes until the aircraft was able to depart the airport for the survey area at 1200 hours.

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 flight.

Survey conditions were very good with scattered clouds at 5,000 ft, light winds from the northwest at 5–10 knots, and visibility >10 km.

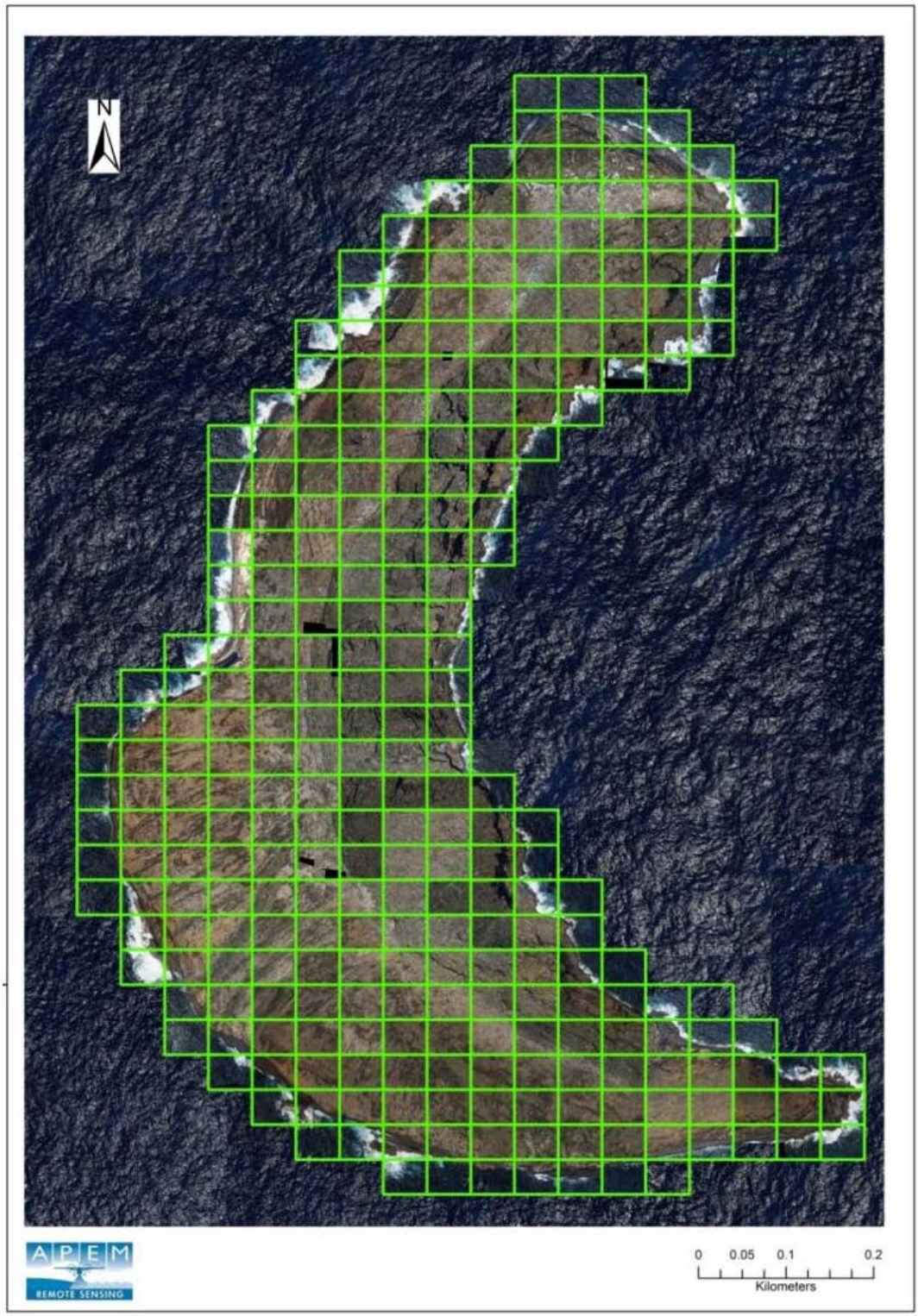

Figure 2–1. Ka`ula Island image analysis grid. Compiled images from the two vertical surveys were joined to cover Ka`ula Island. The compiled image was analyzed in 295 grid cell sections (marked in green).

3 Results

3.1 Species Abundance

A total of 5,726 birds (9 species) and seven marine mammals (1 species) were recorded on Ka`ula Island during August 2013 (Tables 3–1 and 3–2). Brown noddies (n = 3,713) were the most abundant bird species, and sooty terns (n=7) were the least abundant. Scientific names of relevant bird and mammal species is found in Appendix I. Abundance comparison with prior years is provided in Appendix II.

Table 3–1. Total Number of Birds and Marine Mammals Recorded on Ka`ula Island during the August 2013 Survey

Species/Group	Total Number Recorded
Birds	
Laysan albatross	11
Red-tailed tropicbird	85
Great frigatebird	1,369
Masked booby	219
Brown booby	109
Red-footed booby	191
Brown noddy	3,713
Black noddy	22
Sooty tern	7
Total Birds	5726
Marine Mammals	
Hawai`ian monk seal	7
Total Birds and Marine Mammals	**5,733**

Table 3–2. Total Number of Birds and Marine Mammals Recorded in the Vertical and Oblique Surveys on Ka`ula Island during August 2013

Species/Group	Number Recorded in Vertical Survey	Number Recorded in Oblique Survey
Birds		
Laysan albatross	11	-
Red-tailed tropicbird	75	10
Great frigatebird	1,294	75
Masked booby	219	-
Brown booby	109	-
Red-footed booby	185	6
Brown noddy	3,673	40
Black noddy	22	-
Sooty tern	7	-
Total Birds	*5595*	*131*
Marine Mammals		
Hawai`ian monk seal	7	-
Total Birds and Marine Mammals	**5,602**	**131**

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 August 2013 aerial survey. Generally, birds were distributed across the whole island with higher concentrations along the eastern and western coastlines and in the north of the island. Laysan albatross were observed mainly along the central ridge of the island. Great frigatebirds were widely distributed with higher concentrations on the east side of the island. Boobies were also widely scattered—masked boobies were recorded along the central higher areas, brown and red-footed boobies were recorded slightly lower down and in most sections of the island. Brown noddies were mainly located in the southwestern section of the island and a small group of black noddies was also observed in the south of the island. Sooty terns were recorded in the center and southwestern section of the island. Red-tailed tropicbirds were grouped together on the east side of the island. Hawai`ian monk seals were recorded in the south of the island and on ledges in the northeastern section.

3.2.2 Laysan Albatross

A total of 11 Laysan albatross were recorded on Ka`ula Island during the August 2013 survey (Table 3–1). The majority were present along the highest ridge running through the center of the island, with individual birds located in the southeastern and southwestern sections of the island

(Figure 3–2). All but one bird appeared to be adults sitting mostly on bare areas of ground; however, one bird, possibly an immature, was in flight over the western side of the island.

3.2.3 Red-tailed Tropicbird

A total of 85 red-tailed tropicbirds was recorded (Table 3–1). They were mostly found on the east side of the island mainly in the concave section, with relatively few present in the southern and northern parts of the island (Figure 3–3). A small number of birds were recorded flying close to the eastern cliffs and several birds were seen sitting on ledges or nests from the oblique survey in this area.

3.2.4 Great Frigatebird

A total of 1,369 great frigatebirds was recorded during the survey (Table 3–1). High concentrations were observed in the northern section and along the east side in the concave section of the island. Few birds were present in the southwest section (Figure 3–4). There were scattered nesting colonies especially on the slopes and ravines on the eastern side, with many birds still on occupied nests. Several juveniles could also be seen in nests from the oblique survey.

3.2.5 Masked Booby

A total of 219 masked boobies was recorded during the survey (Table 3–1). The highest concentrations were recorded in the northern section of the island mainly along the higher ground and along the ridge crest in the center of the island (Figure 3–5). At least 30 were juveniles some of which were resting fairly close to adult birds mainly along the central ridge.

3.2.6 Brown Booby

A total of 109 brown boobies was recorded on Ka`ula Island during the August 2013 survey (Table 3–1). They were widely distributed across the whole island with no significant concentrations (Figure 3–6). Fewer birds were observed in the southeastern section of the island.

3.2.7 Red-footed Booby

A total of 191 red-footed boobies was recorded during the survey (Table 3–1). They were widely distributed across most of the island with the highest concentrations in the north and northwestern sections along with a cluster in the east concave section (Figure 3–7). Ten were seen under crevices from our oblique survey.

3.2.8 Brown Noddy

A total of 3,713 brown noddies was mainly recorded along the cliffs on the western side of the island (Table 3–1). High numbers were recorded in the southwestern section and to the west of the center of the island. Small numbers were also observed in flight over the island and scattered across the northwestern section with around 30 birds on cliffs at the northern end (Figure 3–8).

3.2.9 Black Noddy

A total of 22 black noddies was recorded during the survey (Table 3–1). All were located in the south of the island mixed in with brown noddies towards the ledges on the western side of Ka`ula Island (Figure 3–9).

3.2.10 Sooty Tern

Seven sooty terns were recorded on Ka`ula Island during the August 2013 survey (Table 3–1). Three were located in the center of the island and two were observed in the southwestern section with the remaining individual recorded to the west of the center of the island (Figure 3–10).

3.2.11 Marine Mammals

During the course of the survey, seven Hawai`ian monk seals were recorded resting on ledges on the island (Table 3–1). A group of four was recorded in the northwestern section and two were resting on a ledge in the southwestern section. A single seal was also observed in the southeastern section of the island (Figure 3–11).

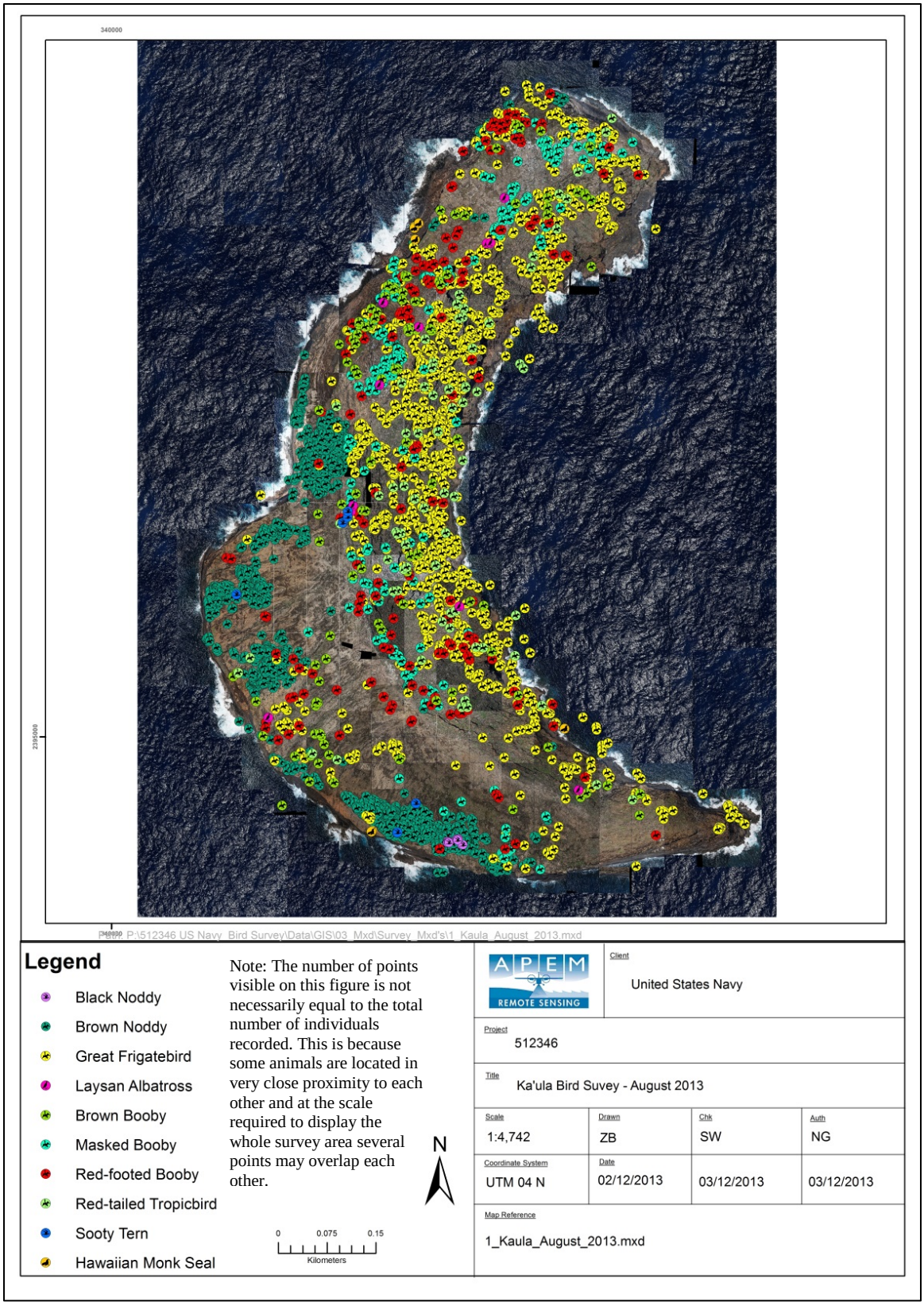

Figure 3–1. Distribution of the total bird species and marine mammals recorded on Ka`ula Island during the August 2013 survey.

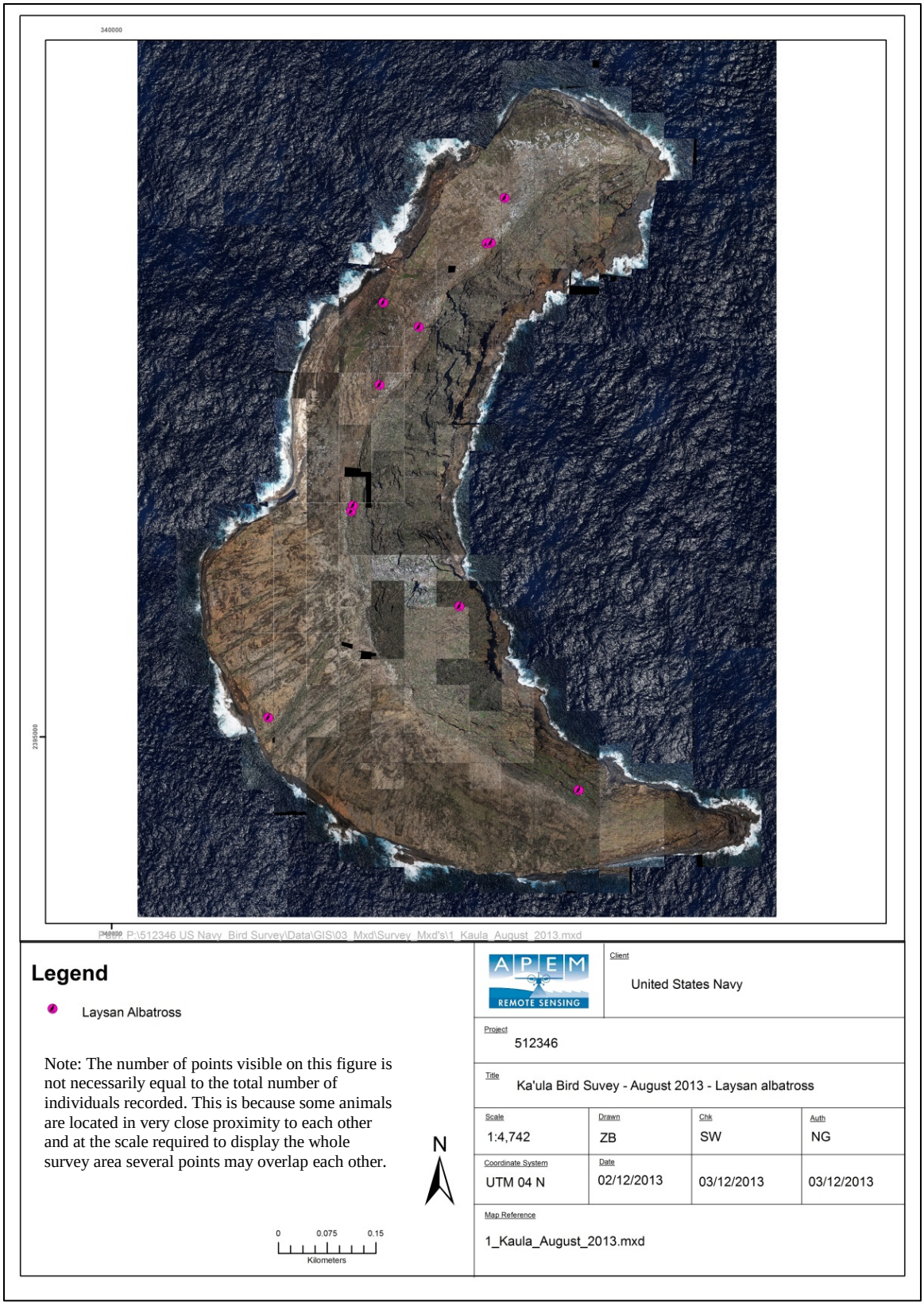

Figure 3–2. Distribution of Laysan albatrosses recorded on Ka`ula Island during the August 2013 survey.

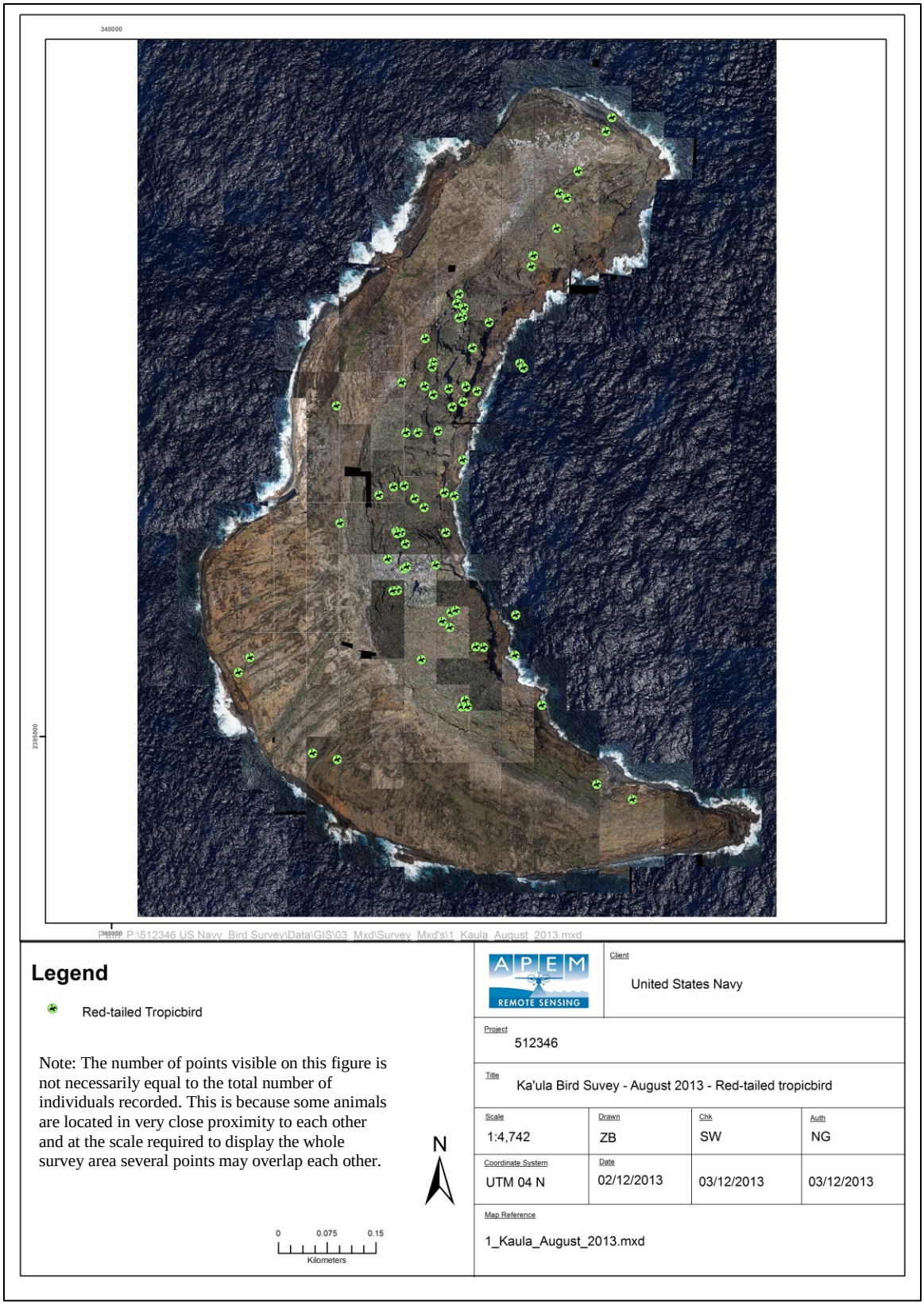

Figure 3–3. Distribution of red-tailed tropicbirds recorded on Ka`ula Island during the August 2013 survey.

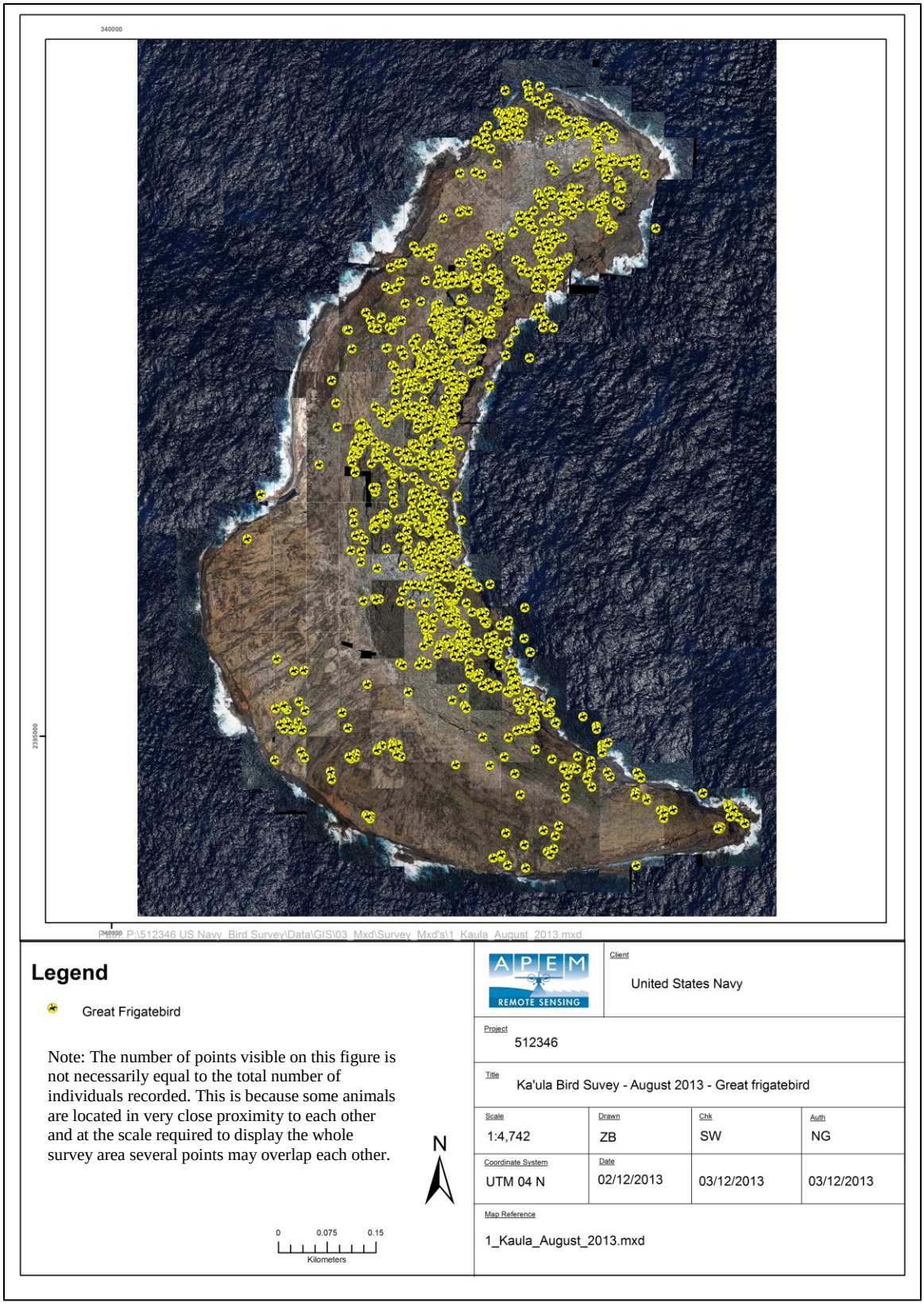

Figure 3–4. Distribution of great frigatebirds recorded on Ka`ula Island during the August 2013 survey.

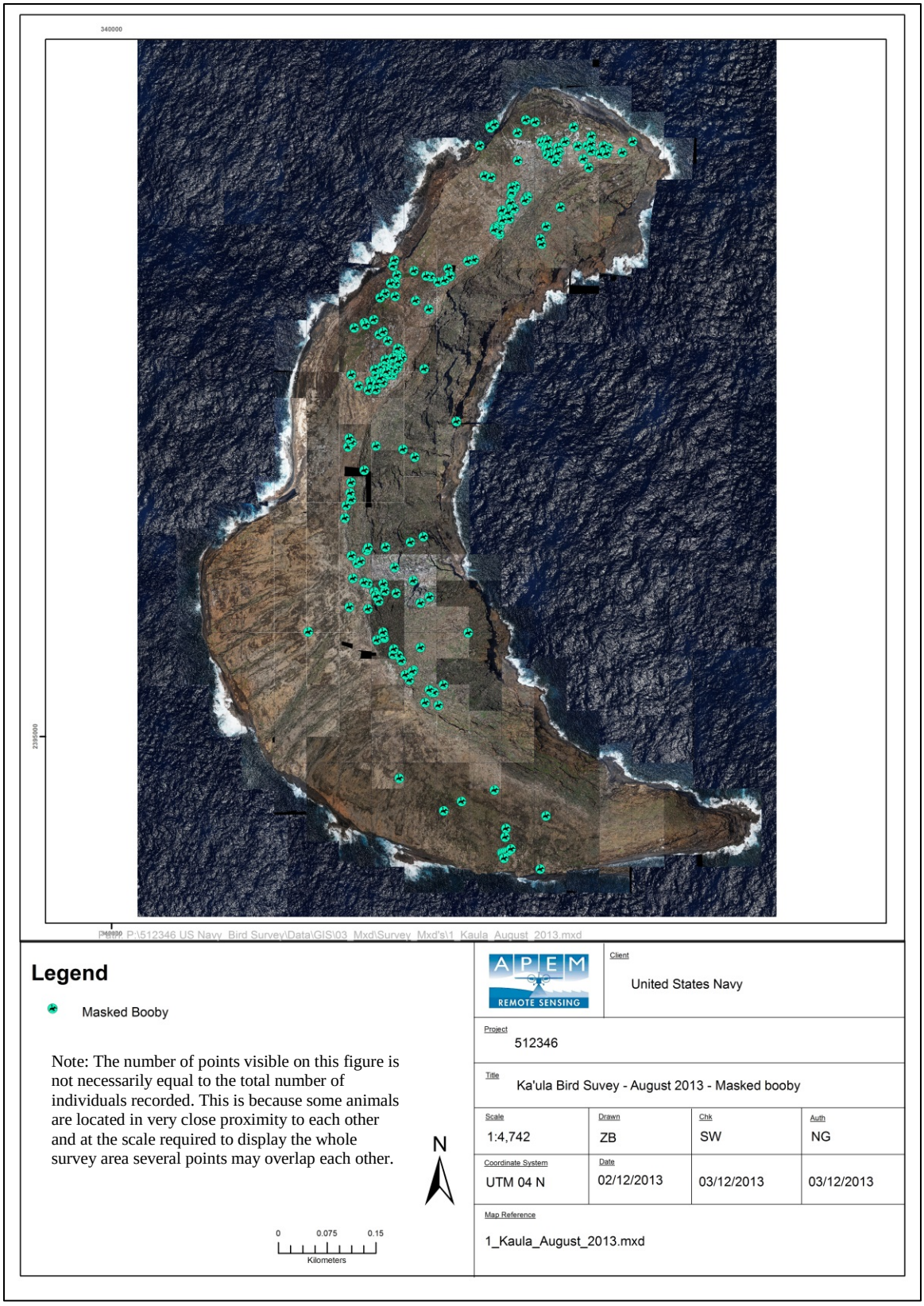

Figure 3–5. Distribution of masked boobies recorded on Ka`ula Island during the August 2013 survey.

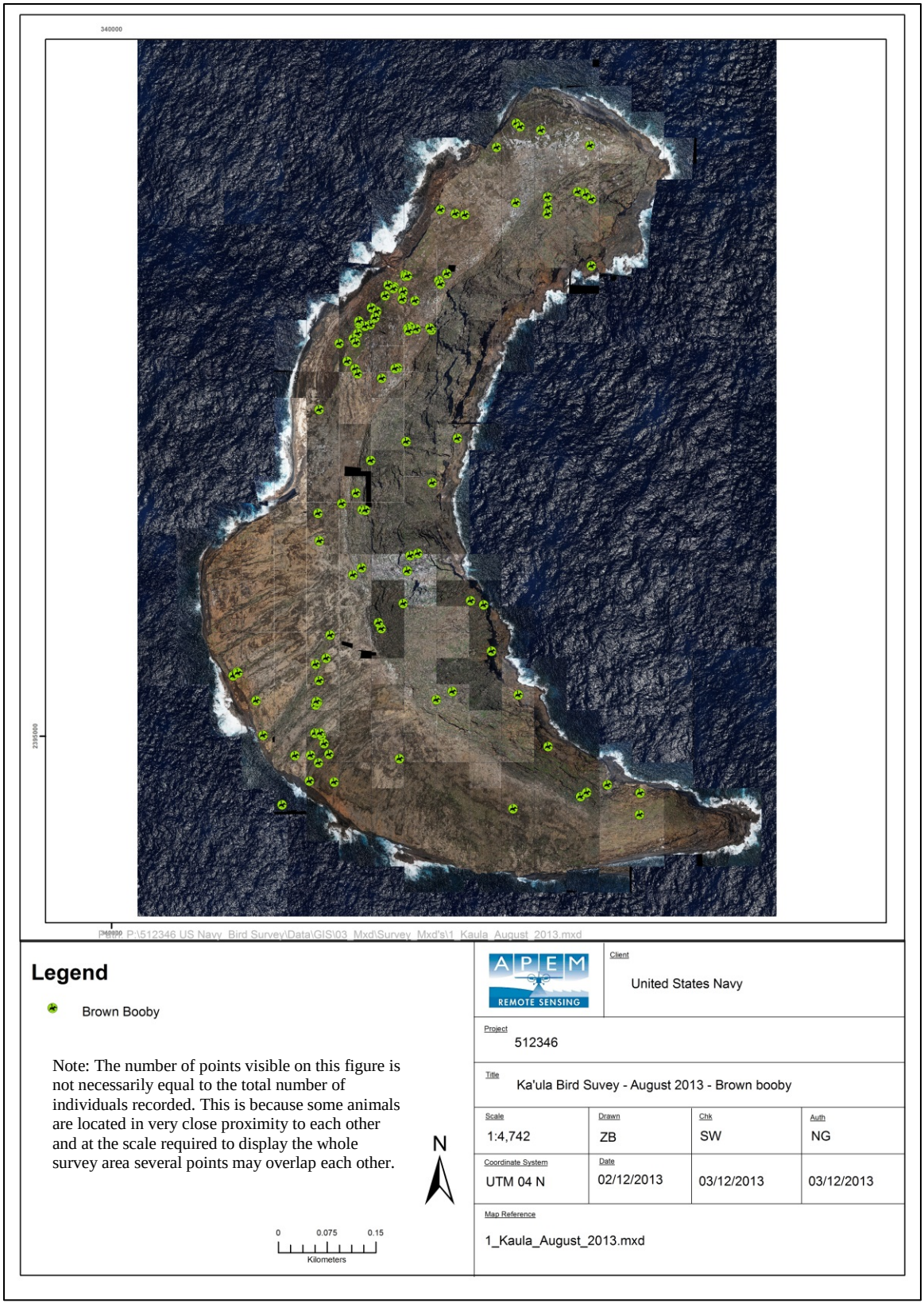

Figure 3–6. Distribution of brown boobies recorded on Ka`ula Island during the August 2013 survey.

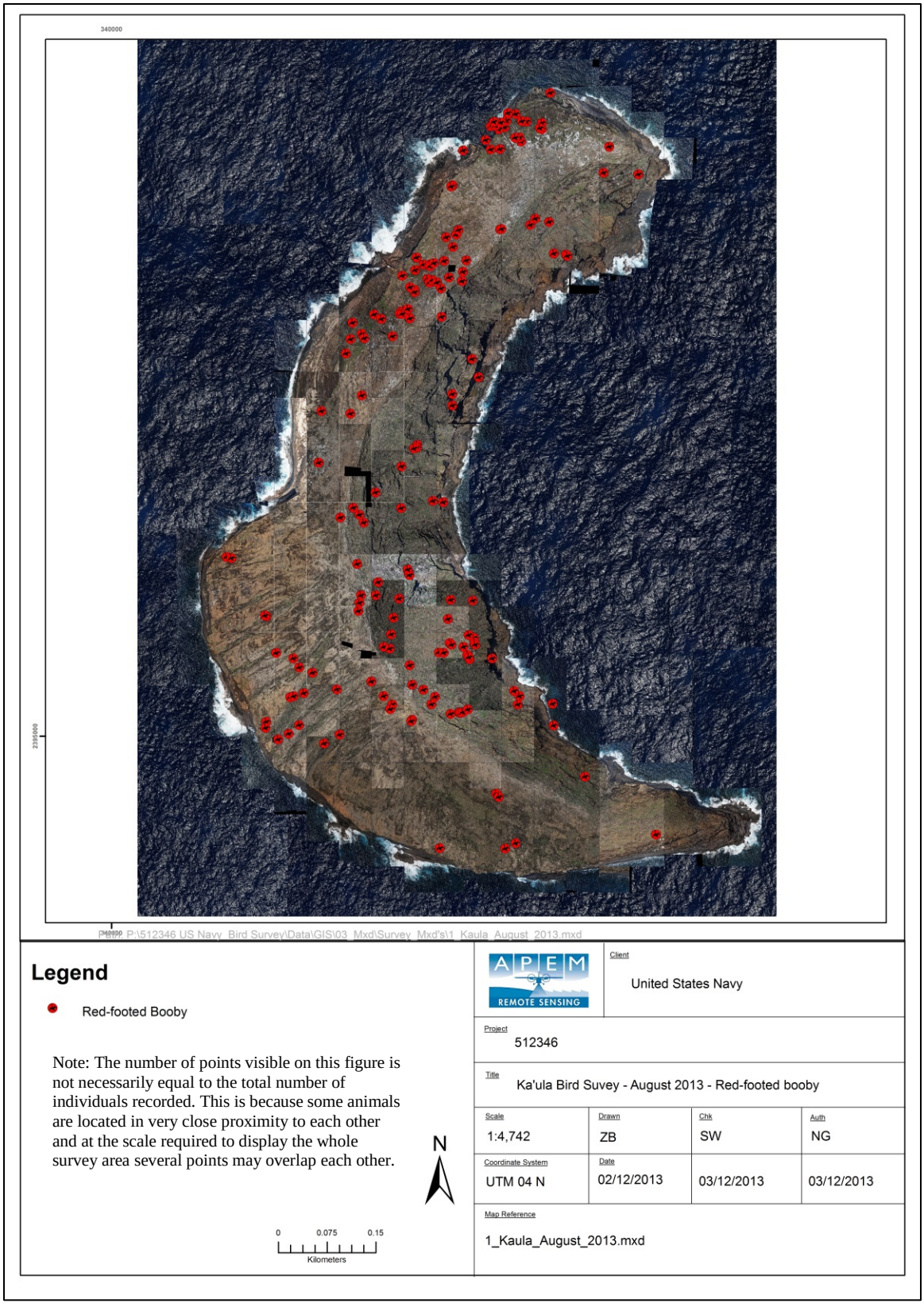

Figure 3–7. Distribution of red-footed boobies recorded on Ka`ula Island during the August 2013 survey.

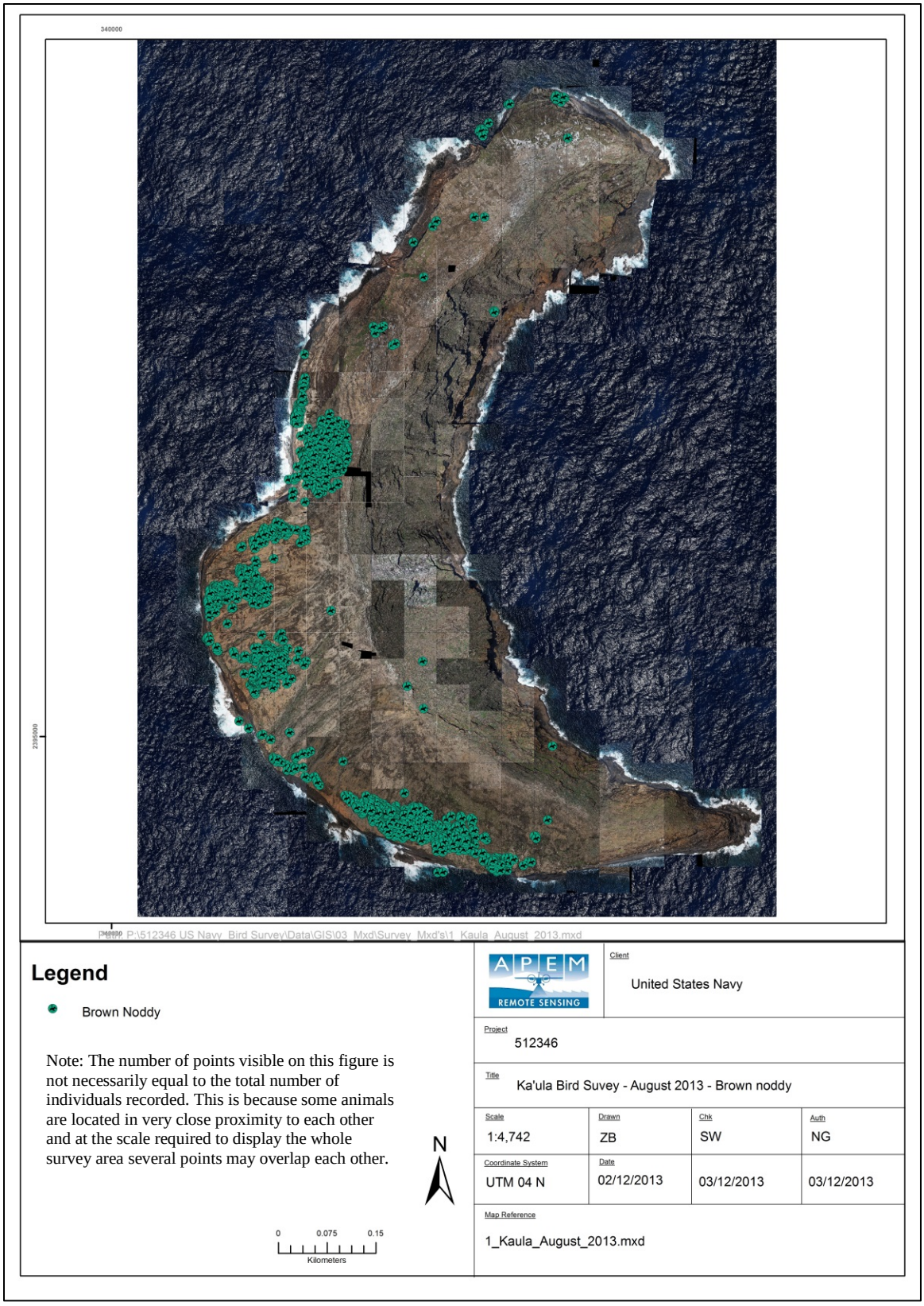

Figure 3–8. Distribution of brown noddies recorded on Ka`ula Island during the August 2013 survey.

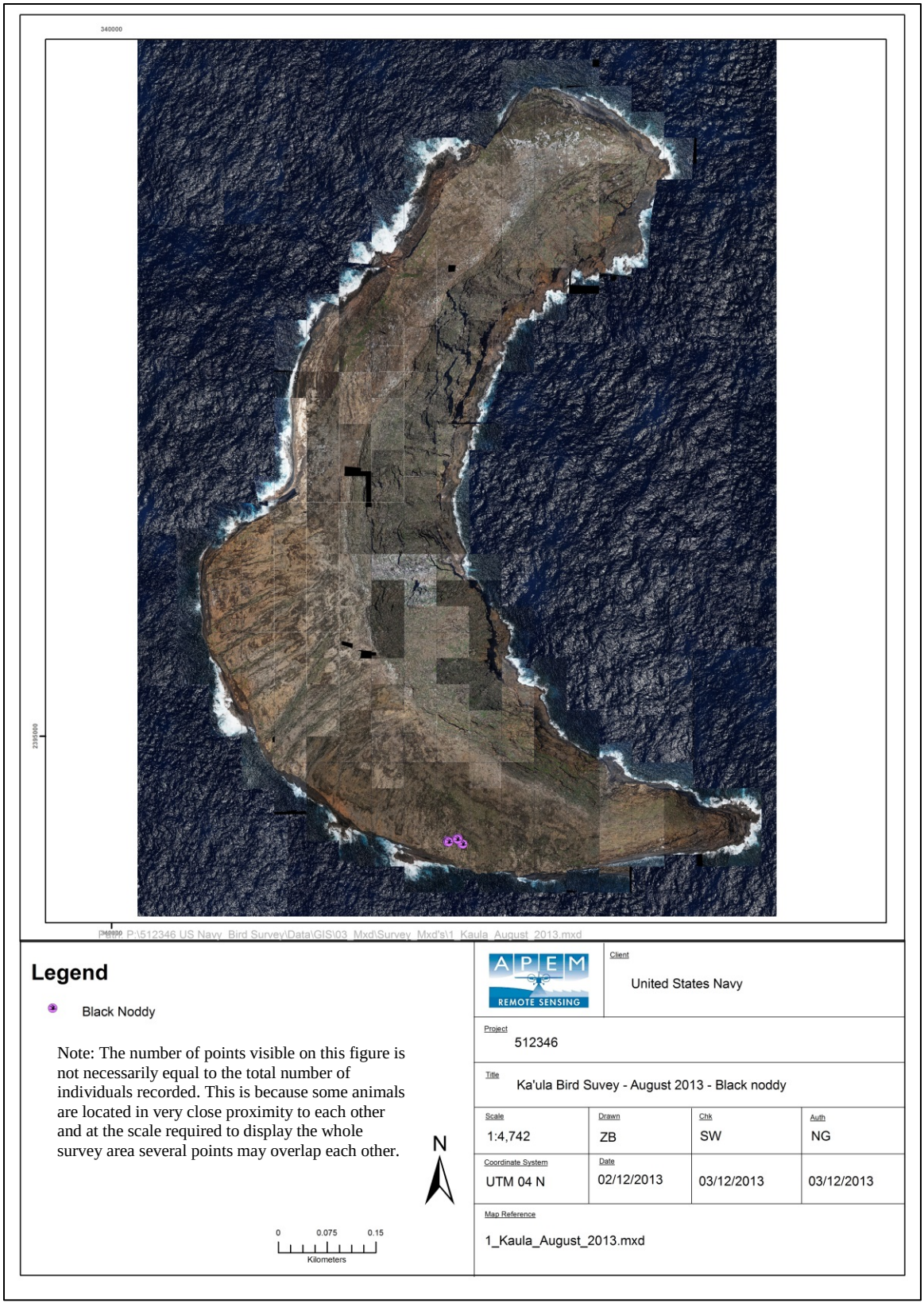

Figure 3–9. Distribution of black noddies recorded on Ka`ula Island during the August 2013 survey.

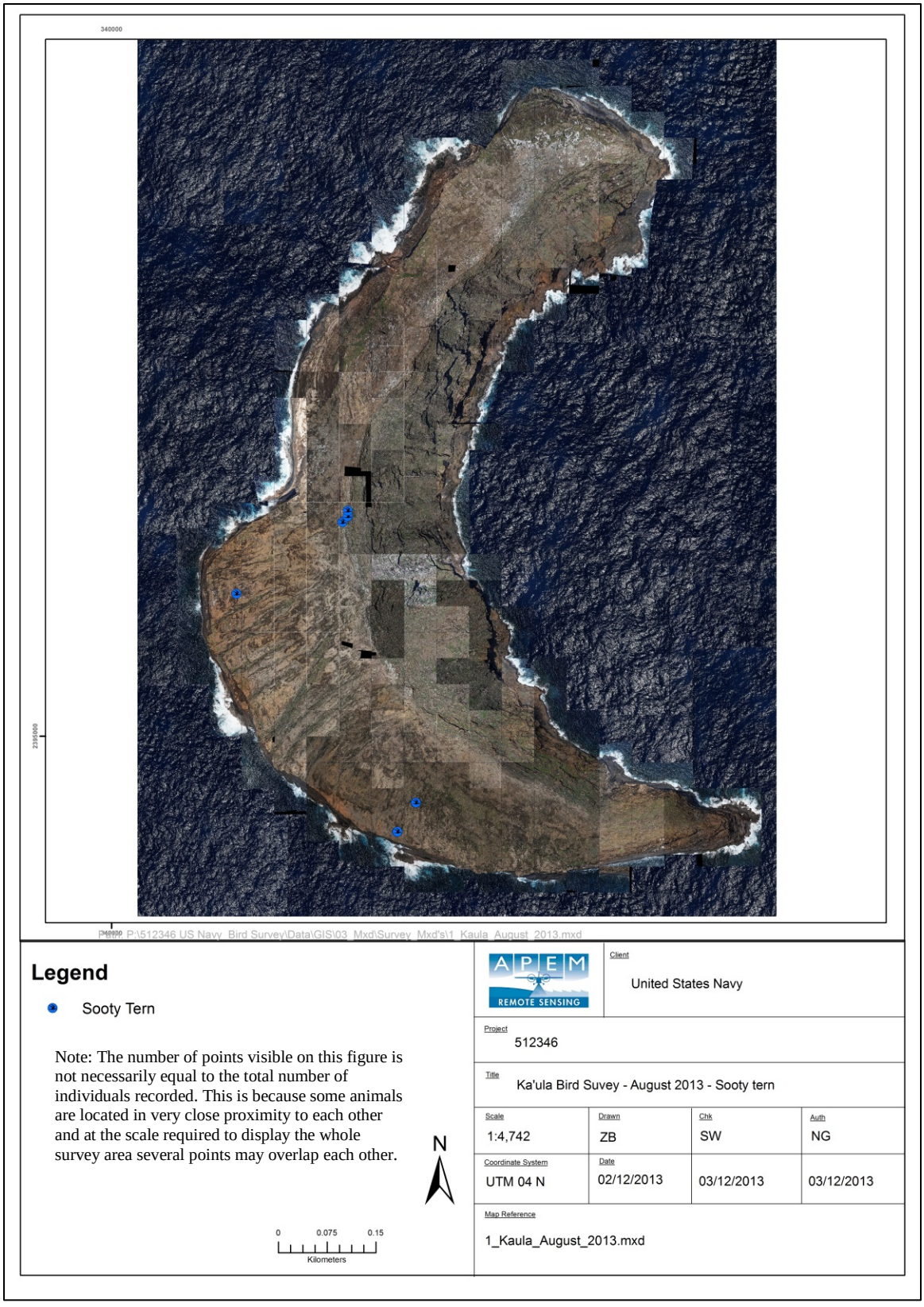

Figure 3–10. Distribution of sooty terns recorded on Ka`ula Island during the August 2013 survey.

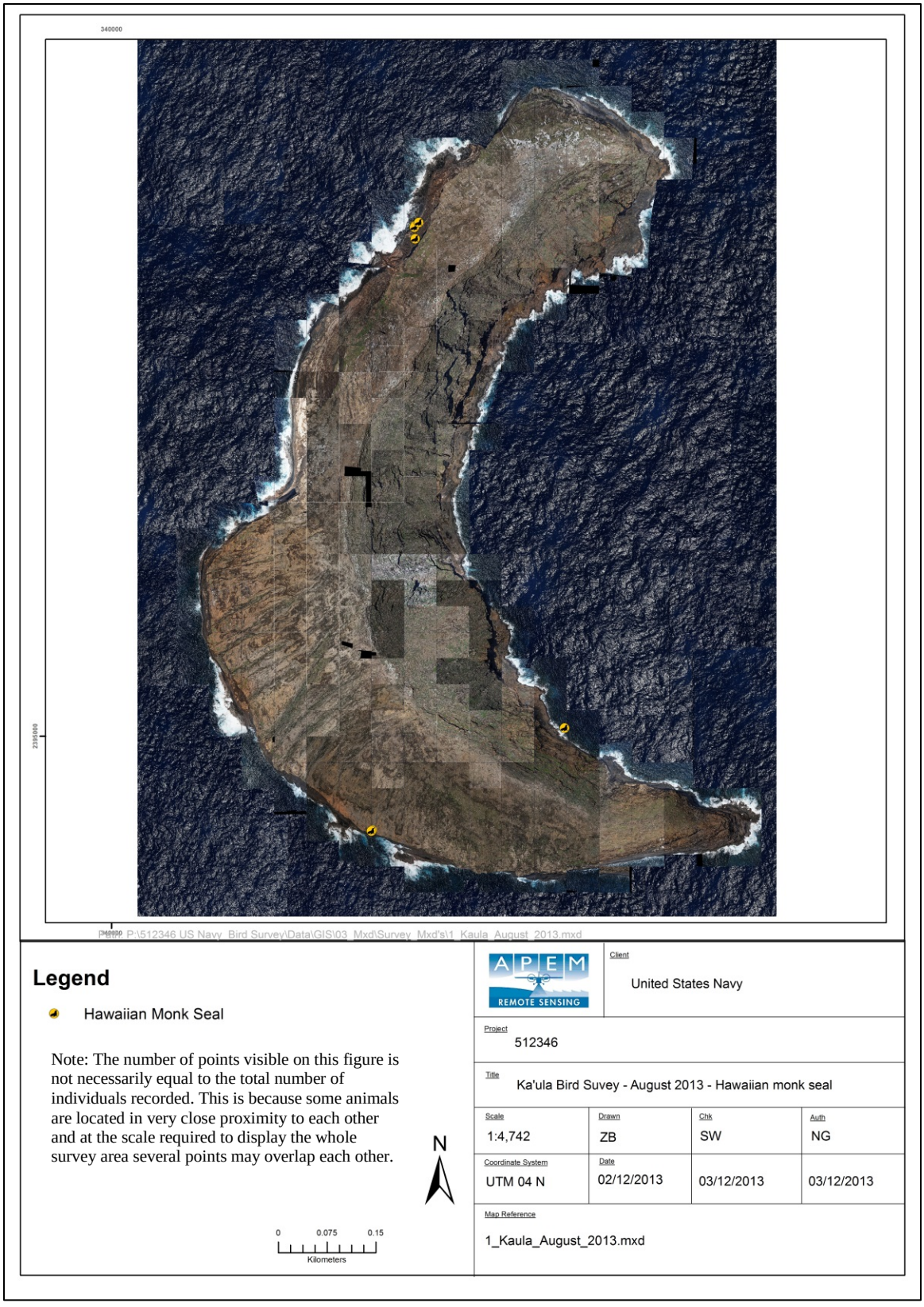

Figure 3–11. Distribution of Hawai`ian monk seals recorded on Ka`ula Island during the August 2013 survey.

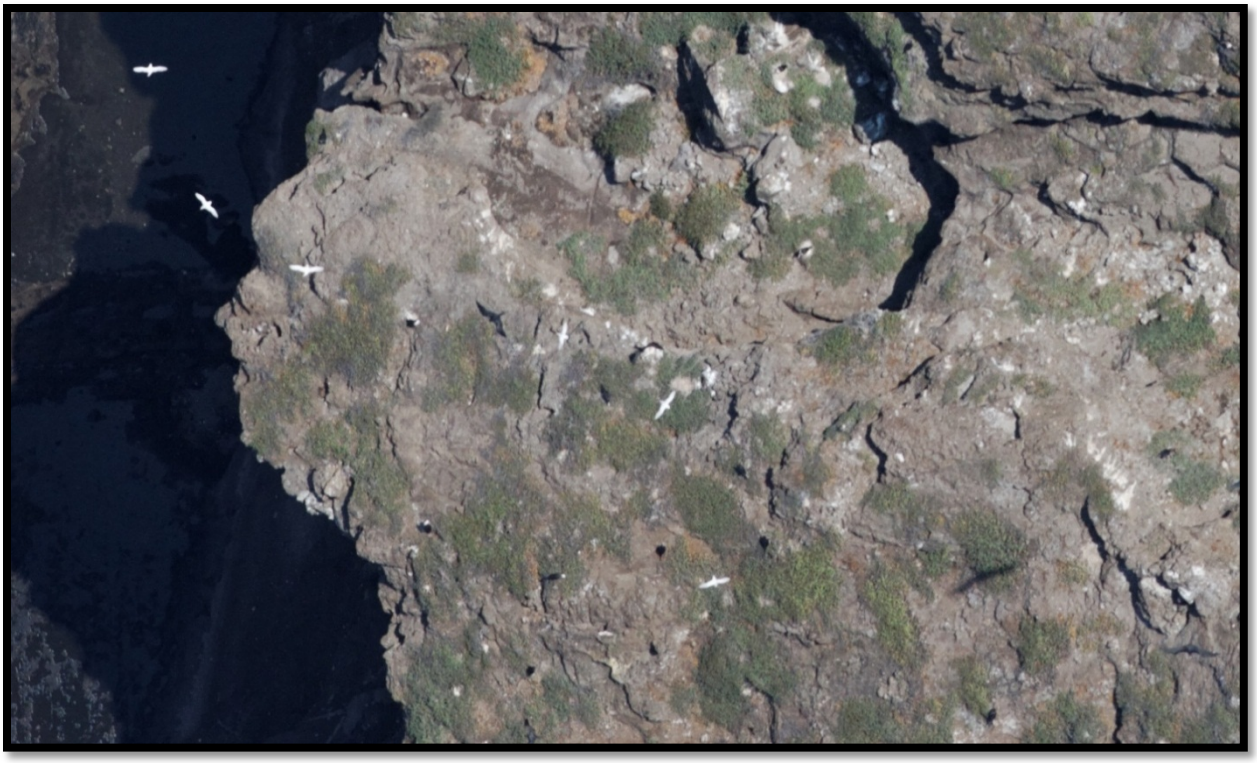

Figure 3–12. Red-tailed tropicbirds and great frigatebirds both flying and sitting on occupied nests along the east side of Ka`ula Island during the August 2013 survey.

Figure 3–13. Three Hawai`ian monk seals (circled) in the northwestern part of Ka`ula Island during the August 2013 survey.

Figure 3–14. Great frigatebirds flying above brown noddies on the northwestern side of Ka`ula Island during the August 2013 survey.

Figure 3–15. Juvenile Laysan albatrosses (top left) and brown noddies at the western side of Ka`ula Island during the August 2013 survey.

Figure 3–16. Brown noddies and black noddies (circled) on the southwestern slopes of Ka`ula Island during the August 2013 survey. Image captured during the oblique survey.

4 Discussion

Overall, during the vertical and oblique surveys, a total of 5,733 birds and seven Hawai`ian monk seals was recorded on Ka`ula Island on 21 August 2013 (Table 3–1). The nine bird species present were Laysan albatross, red-tailed tropicbird, great frigatebird, masked booby, brown booby, red-footed booby, brown noddy, black noddy and sooty tern. The most abundant species was brown noddy, accounting for 65% (n=3,713) of all seabirds recorded. Lower numbers (n=57) of brown noddies were recorded during the April 2013 survey. The next most abundant species were great frigatebird, masked booby, and red-footed booby (see Table 3–1). Laysan albatross (n=11) and sooty tern (n=7) were the least abundant species recorded.

Laysan albatross were mainly present on the higher ground scattered along the central ridge (see Figure 3–2). Numbers recorded in this survey were higher to previous counts made from land based surveys in July and August (n=0; Appendix II) and were lower than those estimated in April 2013 (n=20). A single juvenile bird was recorded flying over the island (Figure 3–14).

Red-tailed tropicbirds were primarily present on the eastern side of the island mainly in the concave section (see Figure 3–3). Numbers recorded in this survey (n=85) were similar to previous land based surveys in August 1978 (n=100) and had increased compared to more recent

boat based surveys in July 2009 (n= 31) and July 2012 (n=1). Numbers decreased compared to the last aerial digital survey conducted in April 2013 (n= 314). Several birds appeared to be on occupied nests including a number perched next to small caves captured on the oblique survey.

Great frigatebird was the second most abundant species (n=1,369), and these were widely distributed across the east side and in the north of the island (see Figure 3–4). Numbers recorded were higher than those from previous land based surveys (Appendix II). This could be due to the aerial imagery allowing for accurate counts to be made of relatively tight clustered groups of birds on ledges and small plateaus that may not have been visible or may have been disturbed during previous surveys. However, numbers decreased compared to the last digital aerial survey conducted in April 2013 (n=1,415).

Of the booby species, masked booby was the most abundant during the survey followed by red-footed booby and brown booby (see Table 3–1). The count of masked boobies during the August 2013 survey (n=219) was comparable to most of the previous surveys undertaken (Appendix II). Numbers decreased compared to the April 2013 survey (n=550). This could have been due to the seasonal timing of the survey, as they are known to lay eggs during the winter months (DoN 2011; Richardson 1957). Indeed, at least 30 juvenile masked boobies were identified during the August 2013 survey. Numbers of red-footed booby (n=191) were lower than those recorded in previous surveys between August 1978 to April 2013 (Appendix II). Brown booby numbers were very similar to those recorded from boat based surveys in July 2009 (n=112) and had increased compared to July 2012 (n=40).

A total of seven sooty terns were present in the center and southwest of the island (see Figure 3–10). Numbers decreased from the previous survey in April 2013 (n=14,635) and were the lowest recorded to date. Sooty terns are known to complete their annual breeding cycle in late summer, with fledged juveniles and adults leaving the island during this time (Pepi et al. 2009). This could help explain the low numbers recorded as the survey was conducted in mid-late August.

Brown noddies were the most abundant species recorded during the August 2013 survey. A high number of brown noddy were recorded from the vertical survey during August 2013 compared to previous surveys carried out in July 2009 and July 2012 (n=711 and n=597 black/brown noddy species, respectively). Numbers had decreased compared to August 1971 (n= 67,700) and August 1978 (n=10,000). A total of 22 black noddies was recorded in the south of the island (see Figures 3–9 and 3–16). No black noddies were observed during the April 2013 survey and between July 2009 and July 2012 brown noddies and black noddies could not be separated making comparison to previous survey months difficult.

Overall the aerial survey method demonstrates that complete counts of seabirds can be obtained including ability to accurately assess the number of birds on apparently occupied nests (AON's) that would be almost impossible to record from boat surveys. Aerial imagery also creates a permanent record / snapshot of the area at a specific time, allowing users to revisit the imagery / data as often as required. The oblique survey imagery was important in obtaining accurate counts of frigatebirds, boobies, and tropicbirds that were hidden on small ledges, sometimes in small caves and under cliff faces that were not captured during the vertical survey. It is also important to note that survey techniques have differed historically on the island and may not all be directly comparable (see Appendix II for a list of all bird species previously observed and survey type).

5 References

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Appendix I. Scientific Names of Relevant Bird and Mammal Species

Common Name	Scientific Name
Laysan albatross	*Phoebastria immutabilis*
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*
Black noddy	*Anous minutus*
Sooty tern	*Onychoprion fuscatus*
Hawai`ian monk seal	*Monachus schauinslandi*

Appendix II. Results of Bird Surveys Conducted on Ka`ula Island, Hawai`i, 1932–2013*

		Land Based Surveys											Boat Based Surveys				Aerial Digital Surveys	
Common Name	**Scientific Name**	**Aug 1932 (A)**	**Aug 1971 (A)**	**Jan 1976 (A)**	**Sep 1976 (A)**	**Mar 1978 (A)**	**Aug 1978 (A)**	**Mar 1979 (A)**	**Jun 1980 (A)**	**Apr 1984 (A)**	**Jun 1993 (A)**	**Nov 1998 (A)**	**Jul 2009 (B)**	**Jun 2010 (A)**	**Jun 2011 (C)**	**Jul 2012 (C)**	**Apr 2013 (D)**	**Aug 2013 (D)**
Laysan albatross	*Phoebastria immutabilis*	-	1 old egg	150	-	100	-	100	9	33	44	60	-	-	-	-	20	11
Black-footed albatross	*Phoebastria nigripes*	1 old egg	-	100	-	75	-	75	-	2	4	10	-	-	-	-	3	-
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
Great frigatebird	*Fregata minor*	common	950	250	800	400	250	250	134	155	701	650	131	430	105	26	1,415	1,369
Masked booby	*Sula dactylatra*	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219
Brown booby	*Sula leucogaster*	common	1,700	50	1,000	75	60	200	212	169	397	60	112	1	6	40	101	109
Red-footed booby	*Sula sula*	uncommon	1,300	100	150	85	200	400	344	222	1,375	1,200	-	-	-	-	1,690	191
Masked/red-footed booby	*Sula* species	-	-	-	-	-	-	-	-	-	-	-	820	850	1,859	912	-	-
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
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	-
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
Grey-backed tern	*Onychoprion lunatus*	uncommon	2,800	-	250	1,250	50	300	4,110	1,467	35	-	1	3	-	-	4	-
Barn owl	*Tyto alba*	-	1	3	3	-	1	6	4	2	7	3	-	-	-	-	-	-

Common Name	Scientific Name	Land Based Surveys											Boat Based Surveys				Aerial Digital Surveys	
		Aug 1932 (A)	Aug 1971 (A)	Jan 1976 (A)	Sep 1976 (A)	Mar 1978 (A)	Aug 1978 (A)	Mar 1979 (A)	Jun 1980 (A)	Apr 1984 (A)	Jun 1993 (A)	Nov 1998 (A)	Jul 2009 (B)	Jun 2010 (A)	Jun 2011 (C)	Jul 2012 (C)	Apr 2013 (D)	Aug 2013 (D)
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 mannikin	*Lonchura punctulata*	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Estimated Number of Birds		**-**	**98,022**	**3,521**	**16,811**	**139,285**	**14,548**	**52,831**	**46,280**	**91,959**	**36,847**	**2,785**	**8,001**	**5,385**	**12,035**	**6,097**	**18,795**	**5,733**
Total Number of Species		**16**	**19**	**16**	**24**	**12**	**19**	**17**	**15**	**19**	**19**	**15**	**11**	**11**	**8**	**8**	**11**	**9**

*Data sourced from:

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