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

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Executive Summary

An aerial vertical survey of Ka`ula Island, Hawai`i, using a manned light twin-engine survey aircraft and ultra-high resolution digital photography was conducted on January 27, 2015. A vertical (nadir) aerial survey was complemented by an oblique survey, which was conducted on January 29, 2015 to allow counts to be made both of birds on the top of the island and those present on the cliff faces.

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

In total, 1,147 birds of seven species were recorded during the survey with great frigatebirds being the most abundant species (n=748) followed by red-footed boobies (n=209). A number of other species were recorded including, black-footed albatrosses, Laysan albatrosses, masked boobies, brown boobies and a single flying red-tailed tropicbird.

Of the 100 Laysan albatrosses recorded, 33 were sitting underneath overhanging ledges or inside small caverns which were not visible in the vertical imagery. This confirms the importance of the extensive oblique survey that allows imagery of the entire eastern side of the island to be collected.

At the time of the surveys, a total of seven Hawai`ian monk seals were resting on ledges in the eastern section of the island. Ten humpback whales were sighted by the survey technician on January 29, approximately 200-300 m southeast of the island, heading in a northerly direction, though these were not captured in the aerial imagery.

1 Introduction

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

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

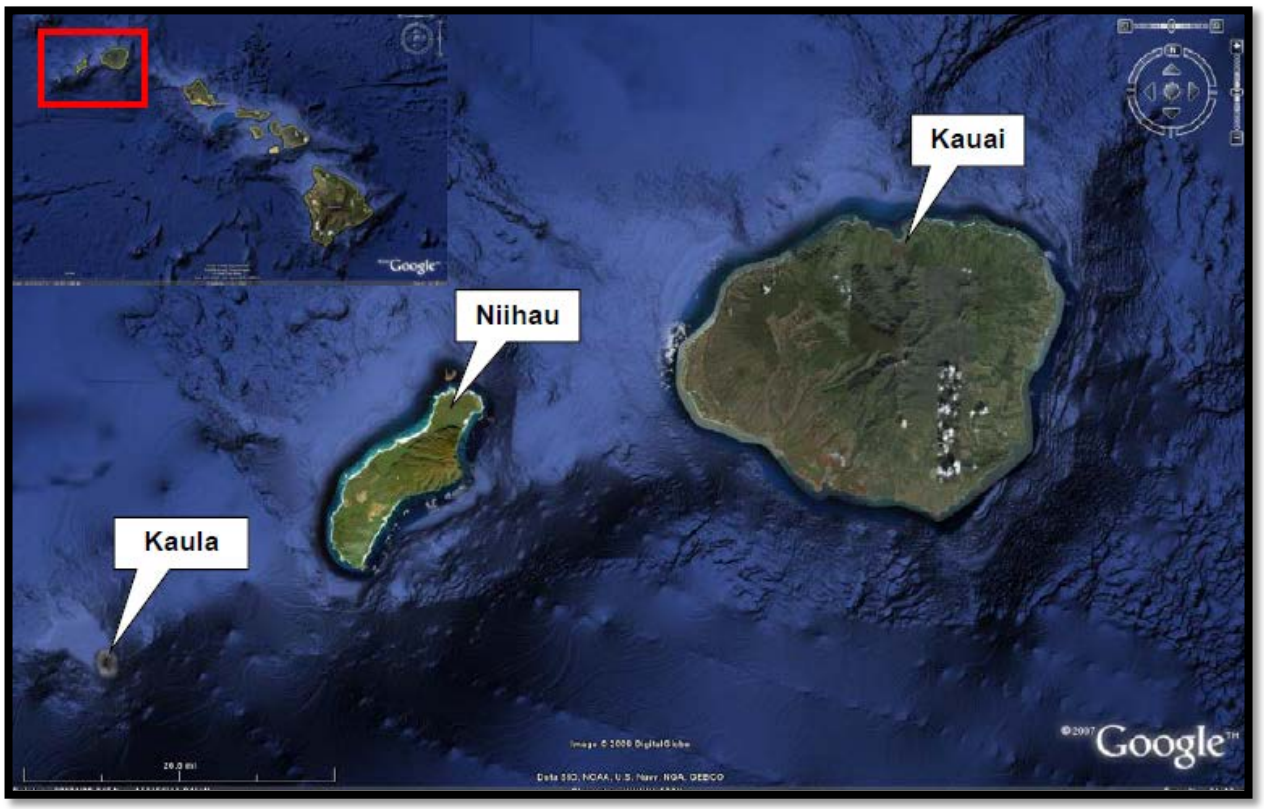

Figure 1-1. Location of Ka`ula Island relative to the main Hawai`ian Islands (inset) and Kauai and Niihau (imagery from Google Earth).

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

Since 1952, the U.S. Navy has used the southeastern tip of the island (approximately 0.06 km^2) as a range to train aviators in air-to-surface and surface-to-surface weapons delivery. Both live and inert ordnance were used during training missions through 1980. From 1981 through present, munitions training by the Navy at Ka`ula has been restricted to inert ordnance delivery and aircraft gunnery (DoN 2008; DoN 2013) with the exception of the inadvertent release by U. S. Army of live ordnance on the southern tip of the island in 2014.

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

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

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

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

2 Methods

2.1 Survey Design

This digital aerial survey of Ka`ula was undertaken on January 27, 2015. Ultra high resolution digital still images were collected using a manned light twin-engine survey aircraft, Aero Commander 500 s N500SJ, and a GPS-linked custom flight management camera system, the APEM SeeBird01, specifically designed by APEM to target high resolution surveys for birds and marine mammals.

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

Due to the wide range of topographical features on Ka`ula (see Figure 1–2), three surveys were carried out to ensure that high quality imagery was achieved over the whole island (100% coverage), including capturing animals on horizontal as well as vertical ledges. The aerial vertical survey was carried out on the morning of January 27, 2015. This 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). Following on from these, 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 oblique survey was carried out immediately after the vertical surveys and an additional oblique survey was carried out on the morning of January 29, 2015.

The first survey carried out (between 09:00 and 10:00 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 10:05 and 11:17 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 first oblique survey (between 11:20 and 11:35 hours) was conducted on the same day (see Section 2.4) as the vertical surveys by flying clockwise around the island between 800 and 1,800 feet, and images were taken to capture the sides of the steep cliff faces. On review of the imagery by the survey technician it was decided an additional survey would be required to obtain a more complete coverage of the upper slopes of the eastern side of the island. The second oblique survey was therefore carried out (between 09:10 and 09:55 hours) two days later on 29 January, 2015 and it was this imagery that was used for the analysis.

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 a ~two hour period. These images were imported as geo-referenced images (WGS 84 projection) into ArcView (version 9.2) and spatially joined to create one large image mosaic covering the whole island. Images with the highest resolution for each location on the island were used to compile the mosaic, and any overlapping image sections were removed. This method was considered to be the most appropriate to minimize the risk of double counting that might have otherwise occurred by treating each individual image in isolation (due to overlapping areas). It is acknowledged that there is a small chance that movement of birds between transects could result in a bird being double counted. There is of course an equally small chance that a bird could be missed in both transects. On this basis, it is reasonable to assume that the risk of double counting is equal to the risk of undercounting, and the effect on the population count is negligible.

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

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

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

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

Each grid cell was analyzed using APEM's Graphical User Interface (GUI) and GIS software. 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 to species. 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.

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 scope of the project, APEM/Normandeau would be happy to supply this three dimensional model to the US Navy.

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 ornithologists to identify and enumerate the number of birds and marine mammals in each image that could not have been seen from the vertical imagery due to the presence of steep cliffs, small caves and overhanging rock ledges. The results of these counts were then subjected to the same internal process used in the vertical survey.

2.3 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. Due to the time of the year and expected low solar illumination of the survey area, the survey began before solar noon to maximize solar illumination of the eastern side of the island. This limited as much as possible any shadow from the challenging island terrain. Once the equipment had been installed into the aircraft on January 25, we waited for a suitable weather window.

The weather was settled enough to carry out the surveys on the morning of January 27. Survey conditions were very good with no cloud cover, light winds ranging between 15 – 25 knots from the west and good visibility greater than 10 km.

The oblique survey re-flight was carried out on January 29, with scattered clearing clouds at 1,000 feet, lighter winds than on January 27 and visibility greater than 10 km.

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

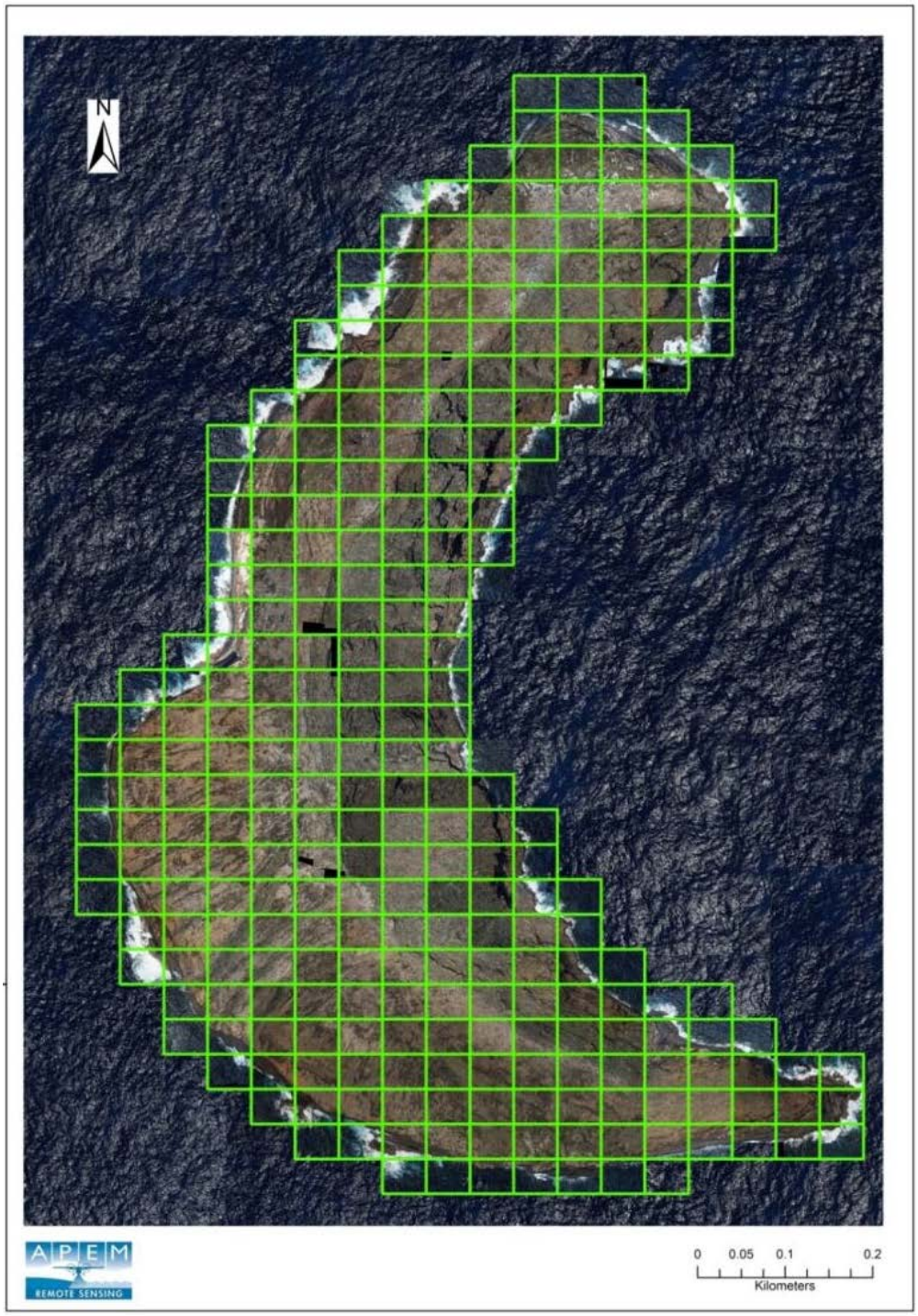

Figure 2-1. Ka`ula Island image analysis grid. Compiled images from the two vertical surveys were joined to cover Ka`ula Island. The compiled image was analyzed in 296 grid cell sections (marked in green).

3 Results

3.1 Species Abundance

A total of 1,147 birds (7 species) and 17 marine mammals (2 species) were recorded on or around Ka`ula Island during January 2015 (Table 3-1). Great frigatebirds (n=748) were the most abundant bird species, and red-tailed tropicbird (n=1) was the least abundant species. Comparison with prior years is provided in Appendix IV.

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

Species/Group	Vertical Survey	Numbers Recorded		
		Oblique Survey	Visual Observation	Total
Birds				
Black-footed albatross	3	-	-	3
Laysan albatross	67	33	-	100
Great frigatebird	737	11	-	748
Masked booby	84	-	-	84
Brown booby	2	-	-	2
Red-footed booby	208	1	-	209
Red-tailed tropicbird	1	-	-	1
Total Birds	*1,102*	*45*	-	*1,147*
Marine Mammals				
Hawai`ian monk seal	5	2	-	7
Humpback whale	-	-	10	10
Total Birds and Marine Mammals	**1,109**	**45**	**10**	**1,164**

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 or around Ka`ula Island during the January 2015 aerial survey. Higher concentrations of birds were located in the north than in the south of the island mostly along the eastern slopes, northern flatter areas and along the central ridge, with low numbers recorded on the west and south sections.

Black-footed albatrosses were present in the far north of the island close to the cliffs. Laysan albatrosses were distributed mostly to the east of the central ridge of the island. Great frigatebirds were concentrated on the northeast side of the island. Boobies were widely scattered, with the majority located along the northern central ridge. Masked boobies were recorded along the higher areas of the island, brown boobies were on the eastern slope and red-footed boobies were more widely distributed throughout the island, though none were recorded in the southern section. Hawai`ian monk seals were recorded in the northeast and southeast sections of the island. Ten humpback whales were recorded by visual observation approximately 200-300 m southeast of the island.

3.2.2 Black-footed albatross

A total of three black-footed albatrosses were recorded on Ka`ula Island during the survey (Table 3–1). They were single birds sitting on higher ground on the northern horn of the island (Figure 3–2).

3.2.3 Laysan albatross

A total of 100 Laysan albatrosses were recorded on Ka`ula Island during the survey (Table 3–1) of which 33 were identified from the oblique imagery. The majority were present along the higher areas of the eastern slopes and along the ridge running through the center of the island, with a few individuals located in the northern grassy sections of the island and a single individual resting in the most south-easterly tip (Figure 3–3). A total of 89 were recorded sitting (67 in singles and 11 in pairs), eight were standing and three were in flight over the island (Figure 6–4). Of the sitting birds, five singles were noted to be present on the same ledges or exact locations as the January 2014 survey. A pair on the northern tip of the island seemed to be attending to a juvenile.

A total of 33 birds were only visible in the oblique imagery, these were noted either sitting under shady overhanging ledges or small caves (see Figure 6–4 and Figures 6–5). One large cave contained five individual birds observed sitting on nests which could be categorized as apparently occupied nests (AON's).

3.2.4 Great frigatebird

A total of 748 great frigatebirds were recorded during the survey (Table 3–1). Apart from a single bird in flight in the southwest section, virtually all were present in the northern half and along the east side in the concave section of the island (Figure 3–4). There were scattered nesting colonies especially on the slopes and ravines on the eastern side, with many birds on apparently occupied nests. Small clusters of male great frigatebirds could also be seen displaying their red gular pouches (throat area).

3.2.5 Masked booby

A total of 84 masked boobies were recorded during the survey (Table 3–1). The majority were present along the highest ridge running through the center of the island and along the west side on the convex section of the island, mainly on the higher ground. Smaller numbers were present along the central ridge in the southern section of the island and on lower ground on the east side. (Figure 3–5).

3.2.6 Brown booby

Two brown boobies were recorded on Ka`ula Island during the survey (Table 3–1). They were sitting on high ground on the eastern slope in the center of the island in close proximity to nesting great frigatebirds and small groups of red-footed boobies. (Figure 3–6).

3.2.7 Red-footed booby

A total of 209 red-footed boobies were recorded during the survey (Table 3–1). They were widely distributed with the majority of birds present on higher ground along the northern central ridge of the island. Smaller numbers were also recorded on lower ground along the western slope. None were present in the far south of the island during both the vertical and oblique surveys (Figure 3–7).

3.2.8 Red-tailed tropicbird

A single red-tailed tropicbird was recorded during the January 2015 survey (Table 3–1). It was flying east over the eastern slopes near to the center of the island (Figure3–8).

3.2.9 Marine mammals

During the course of the surveys, seven Hawai`ian monk seals were recorded resting on ledges on the island (Table 3–1). Five seals were together in one group in the northeast concave section of the island (Figures 3–9 and 6–3). The remaining two seals were together in the southeast section of the island. Although not captured in the survey imagery, ten humpback whales consisting of three individuals, a pod of four and a pod of three were seen from the survey aircraft (Figures 6–4 and 6–5) approximately 200-300 m southeast of the island travelling in a northeasterly direction.

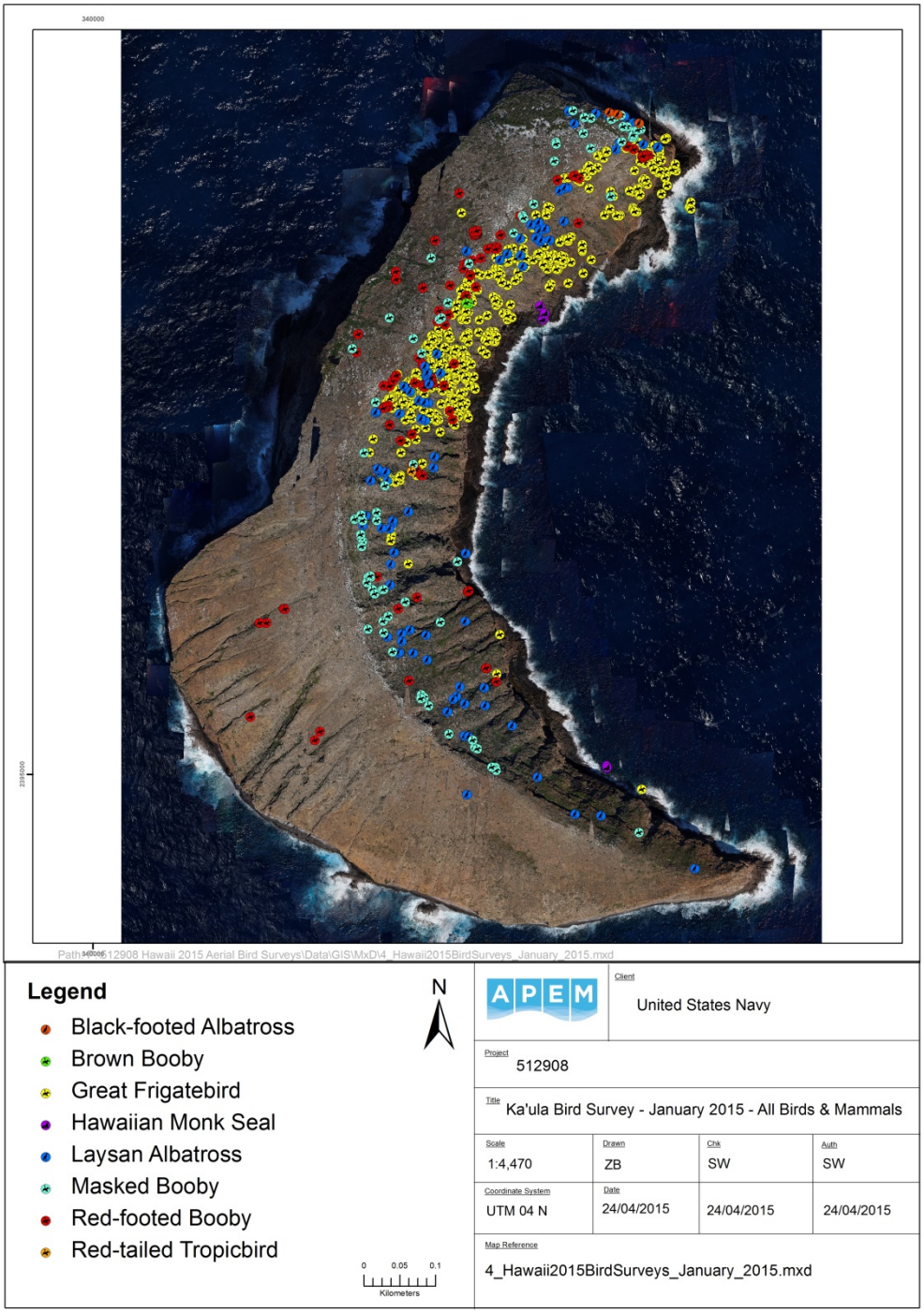

Figure 3-1. Distribution of all birds and marine mammals recorded on Ka`ula Island during the January 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to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

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

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

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

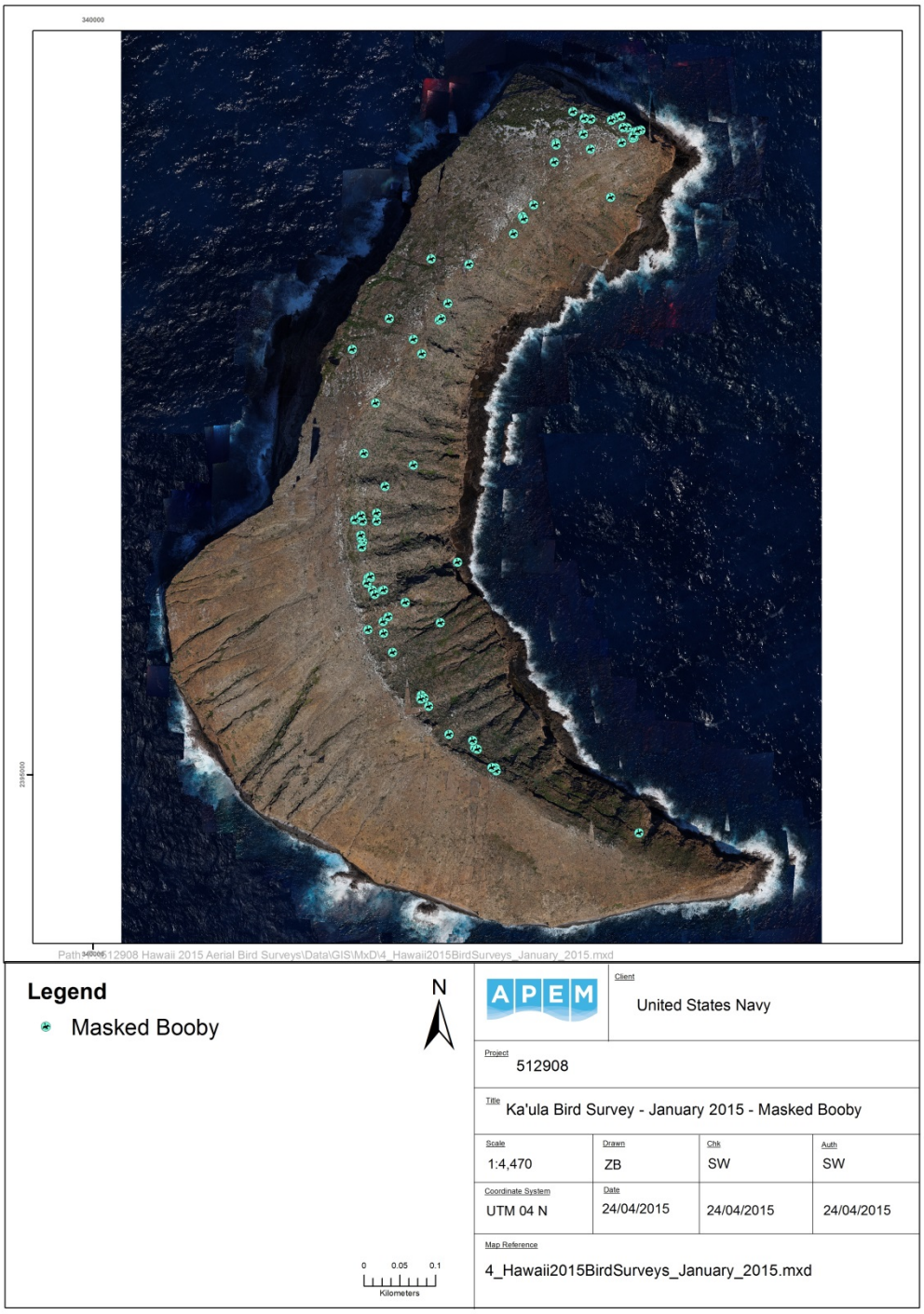

Figure 3-5. Distribution of masked boobies recorded on Ka`ula Island during the January 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and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

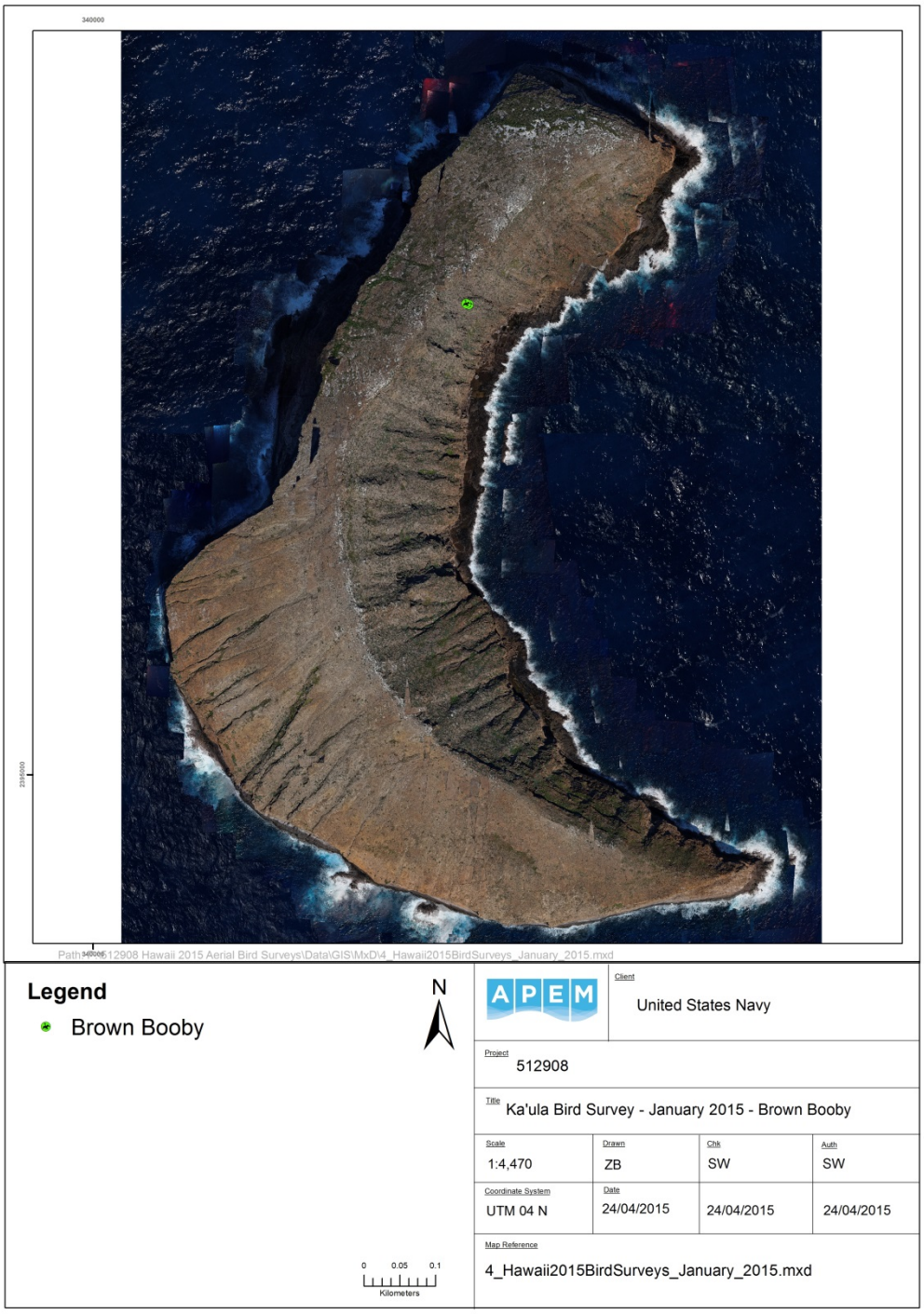

Figure 3-6. Distribution of brown boobies recorded on Ka`ula Island during the January 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and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

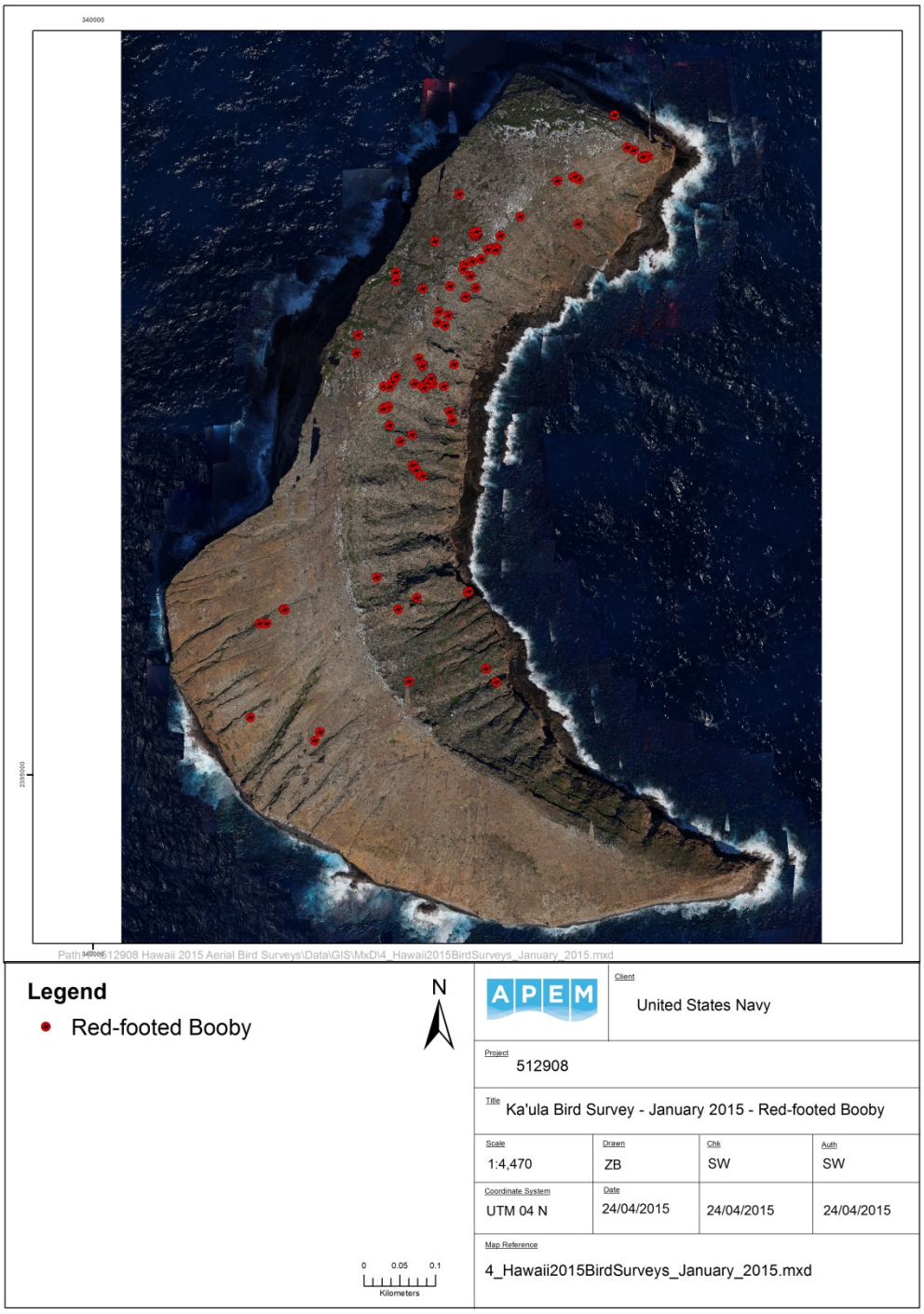

Figure 3-7. Distribution of red-footed boobies recorded on Ka`ula Island during the January 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other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

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

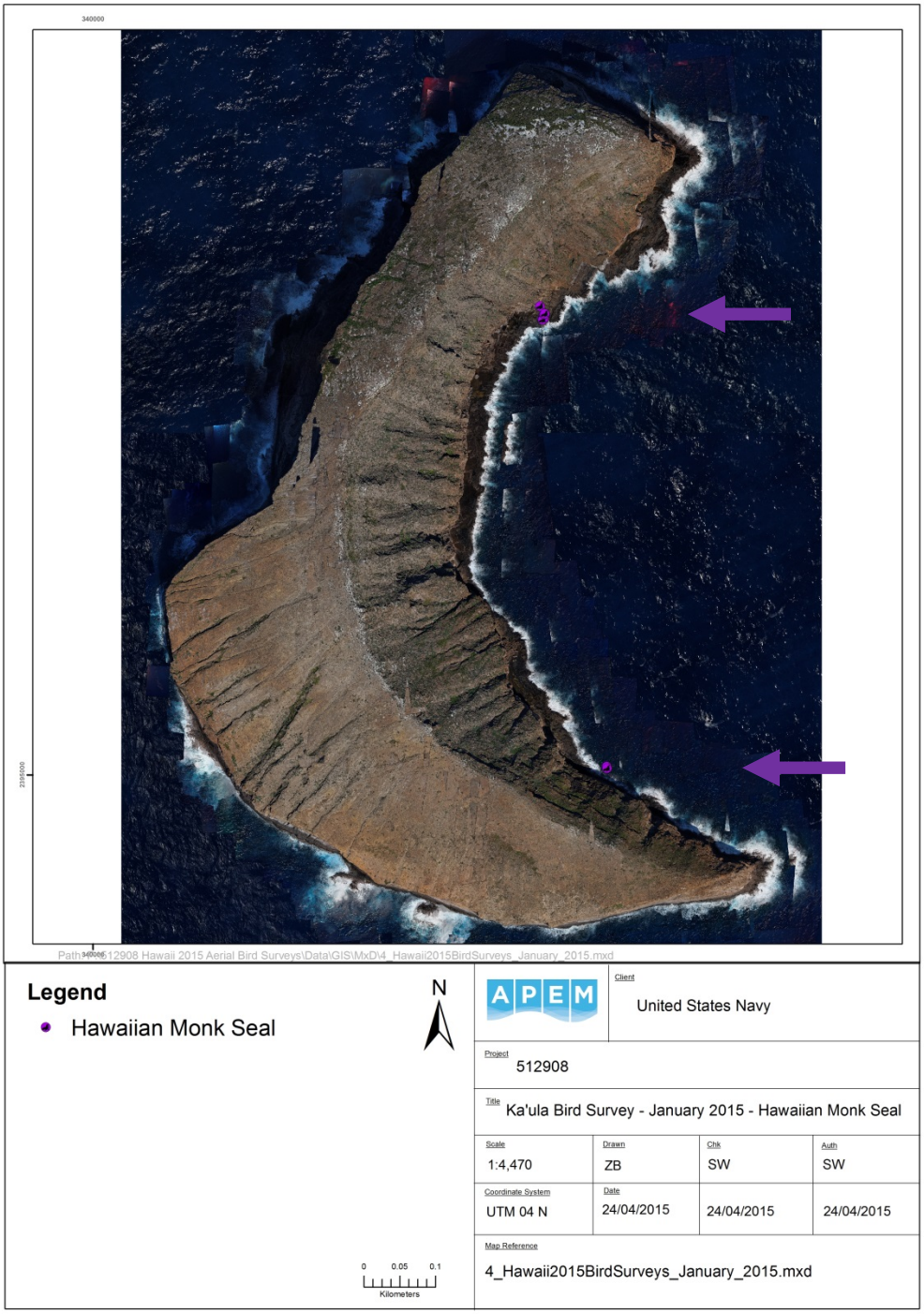

Figure 3-9. Distribution of Hawai`ian monk seals recorded on Ka`ula Island during the January 2015 survey. Note: The number of points visible on this figure is not necessarily equal to the total number of individuals recorded. This is because some animals are located in very close proximity to each other and at the scale required to display the whole survey area several points may overlap each other.

4 Discussion

Overall, during the vertical and oblique surveys, a total of 1,147 birds, seven Hawai`ian monk seals and 10 humpback whales were recorded at Ka`ula Island during the January 2015 survey (Table 3–1). The seven bird species present were black-footed albatross, Laysan albatross, great frigatebird, masked booby, brown booby, red-footed booby and red-tailed tropicbird. The most abundant species was great frigatebird, accounting for 63% (n=748) of all the seabirds recorded. The next most abundant species were red-footed booby (n=209), Laysan albatross (n=100), masked booby (n=84) (see Table 3–1). Black-footed albatross (n=3) and red-tailed tropicbird (n=1) were the least abundant species recorded.

The three black-footed albatrosses were sitting on higher ground on the northern horn of the island (see Figure 3-2). Higher numbers of black-footed albatross were recorded during land based surveys in January 1976 (n=100; Appendix IV) and in November 1998 (n=10; Appendix IV). Higher numbers of black-footed albatrosses were recorded during the previous aerial digital survey in January 2014 (n=11); the highest recorded since June 1980 (Appendix IV).

Laysan albatrosses were mainly present on the higher areas of the eastern slopes and along the central ridge with a cluster on the northern end (see Figure 3–3). Numbers recorded in this survey (n=100) were lower than previous counts made from land based surveys in January 1976 (n=150; Appendix IV), but were higher than counts recorded during the previous aerial digital survey conducted in January 2014 (n=81; Appendix IV). As Laysan albatrosses are known to incubate their eggs between November and February it is possible that many of the sitting birds present at the time of the survey could be classed as on occupied nests. This could be supported by the number of birds noted to be sitting during the analysis (67 singles and 11 pairs) and by assuming all single birds are one of a pair then potentially up to 78 pairs could be present at the time of the survey (compared to a possible 51 pairs in January 2014). This increase could be due to greater coverage of oblique imagery especially across the highest part of the eastern slope which contained a high density of sitting birds (as seen in Figure 6-6 and Figure 6-7), many of which were not visible in the vertical surveys, so potentially a more accurate count could be obtained compared to previous non-land based surveys.

Great frigatebird was the most abundant species recorded in January 2015 (n=748). These were mainly distributed across the northeast section of the island as they were in January 2014, with only singles recorded in the south of the island. Numbers recorded were higher than those from previous land based surveys of January 1976 (n=250; Appendix IV). 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 have increased since the last digital aerial survey in January 2014 (n=621; Appendix IV) but are less than those of the digital aerial surveys conducted in April 2013 (n=1,415; Appendix IV) and August 2013 (n=1,369; Appendix IV).

Of the booby species recorded, red-footed booby was the most abundant during the January 2015 survey followed by masked booby and brown booby (see Table 3–1). The count of red-footed booby during the January 2015 survey (n=209) was higher than land based counts made in January 1976 (n=100; Appendix IV) and during the previous aerial digital survey in January 2014 (n=98; Appendix IV). Numbers had increased compared to the August 2013 aerial digital

survey (n=191; Appendix IV) but decreased compared to the April 2013 aerial digital survey (n=1,690; Appendix IV).

Similar to the previous aerial digital survey conducted in January 2014 (n=3; Appendix IV) low numbers of brown booby were recorded during the January 2015 survey (n=2). Numbers had decreased compared to those recorded from land based January 1976 survey (n=50; Appendix IV)) and the August 2013 aerial digital survey (n=109; Appendix IV).

Numbers of masked booby increased during the 2015 survey (n=84) compared to the previous aerial digital survey conducted in January 2014 (n= 65; Appendix IV), with the highest concentrations recorded on the higher ground and along the ridge crest in the center of the island (see Figure 6-4). Of the 84 present at the time of the surveys, 60 were singles and 12 were in pairs suggesting a possible 42 pairs. Numbers decreased compared to the survey in April 2013 (n=550; Appendix IV) and August 2013 (n=219; Appendix IV). The species is known to lay eggs from February through to April but this can be earlier or later (Richardson, 1957). The higher numbers recorded during August 2013 suggest that breeding on Ka`ula could occur mainly through the summer months. The distribution of birds during January 2015 was broadly similar to that recorded in January 2014.

A single red-tailed tropicbird was recorded in flight during the 2015 survey. No red-tailed tropicbirds were recorded during the previous aerial digital survey conducted in January 2014 and previous land based survey of January 1976 (Appendix VI). Numbers recorded were lower than those from aerial digital surveys of August 2013 (n=85; Appendix VI).

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

The survey technician in the aircraft recorded ten adult humpback whales approximately 200-300 m southeast of the island travelling in a general northeasterly direction. Two pods consisting of four and three individuals, and a further three adults were observed in the same location on different loops over the island. Humpback whales undertake seasonal migrations from high latitude feeding grounds in spring and summer to tropical breeding grounds where they mate and calve during winter (Mobley, 2001).

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

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6 Appendices

Appendix I. Survey Imagery: Vertical Image Examples

Figure 6-1. Laysan albatrosses (3 bottom left), red-footed boobies and great frigatebirds along the central ridge of Ka`ula Island during the January 2015 survey.

Figure 6-2. Sitting Laysan albatrosses (bottom and middle) and black-footed albatross (circled) on the northern end of Ka`ula Island during the January 2015 survey.

Figure 6-3. Five Hawai`ian monk seals resting on a ledge in the northeast of Ka`ula Island during the January 2015 survey.

Appendix II. Survey Imagery: Oblique Image Examples

Figure 6-4. Four adult humpback whales located 200-300 m off the southwest coast of Ka`ula Island during the January 2015 survey.

Figure 6-5. Adult humpback whale off the southwest coast of Ka`ula Island during the January 2015 survey.

Figure 6-6. Sitting Laysan albatrosses (circled) on ledges just below the ridge in the center of Ka`ula Island during the January 2015 survey.

Figure 6-7. Six sitting Laysan albatrosses on eastern slope towards the north end of Ka`ula Island during the January 2015 survey. The circled ones were only visible in the oblique imagery.

Appendix III. Scientific Names of Relevant Bird and Mammal Species

Common Name	Scientific Name
Black-footed albatross	*Phoebastria nigripes*
Laysan albatross	*Phoebastria immutabilis*
Great frigatebird	*Fregata minor*
Masked booby	*Sula dactylatra*
Brown booby	*Sula leucogaster*
Red-footed booby	*Sula sula*
Red-tailed tropicbird	*Phaethon rubricauda*
Hawai`ian monk seal	*Neomonachus schauinslandi*
Humpback whale	*Megaptera novaeangliae*

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

Common Name	Scientific Name	Aug 1932 Land based survey (A)	Aug 1971 Land based survey (A)	Jan 1976 Land based survey (A)	Sep 1976 Land based survey (A)	Mar 1978 Land based survey (A)	Aug 1978 Land based survey (A)	Mar 1979 Land based survey (A)	Jun 1980 Land based survey (A)	Apr 1984 Land based survey (A)	Jun 1993 Land based survey (A)	Nov 1998 Land based survey (A)	Jul 2009 Boat based survey (B)	Jun 2010 Boat based survey (A)	Jun 2011 Boat based survey (C)	July 2012 Boat based survey (C)	Apr 2013 Aerial digital survey (D)	Aug 2013 Aerial digital survey (D)	Jan 2014 Aerial digital survey (D)	Jan 2015 Aerial digital survey (D)
Laysan albatross	*Phoebastria immutabilis*	-	1 old egg	150	-	100	-	100	9	33	44	60	-	-	-	-	20	11	81	100
Black-footed albatross	*Phoebastria nigripes*	1 old egg	-	100	-	75	-	75	-	2	4	10	-	-	-	-	3	-	11	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	-	1
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
Masked booby	*Sula dactylatra*	common	1,000	300	1,200	125	200	400	236	202	567	350	-	-	-	-	550	219	65	84
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
Red-footed booby	*Sula sula*	uncommon	1,300	100	150	85	200	400	344	222	1,375	1,200	-	-	-	-	1,690	191	98	209
Masked/red-footed booby	*Sula dactylatra / S. sula*	-	-	-	-	-	-	-	-	-	-	-	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	-	-	-	-	-	-	-	-
Japanese white-eye	*Zosterops japonicus*	-	-	2	3	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-
Northern mockingbird	*Mimus polyglottos*	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Northern cardinal	*Cardinalis*	-	2	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
House finch	*Haemorhous mexicanus*	-	6	15	40	-	20	6	-	1	1	8	-	-	-	-	-	-	-	-
Nutmeg mannikin	*Lonchura punctulata*	-	-	-	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Estimated Number of Birds		**-**	**98,022**	**3,521**	**16,811**	**139,285**	**14,548**	**52,831**	**46,280**	**91,959**	**36,847**	**2,785**	**8,001**	**5,385**	**12,035**	**6,097**	**18,795**	**5,733**	**879**	**1,145**
Total Number of Species		**16**	**19**	**16**	**24**	**12**	**19**	**17**	**15**	**19**	**19**	**15**	**11**	**11**	**8**	**8**	**11**	**9**	**6**	**7**

*Data sourced from:

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

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

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

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

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

Species/Group	Minimum estimate of birds numbers	Maximum estimate of birds numbers*
Birds		
Black-footed albatross	3	6
Laysan albatross	100	156
Red-tailed Tropicbird	1	1
Great frigatebird	748	1,440
Masked booby	84	144
Brown booby	2	4
Red-footed booby	209	358
Total Estimated Number of Birds	**1,147**	**2,109**

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

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

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

[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/