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Census of New Zealand Fur Seals on the West Coast of New Zealand's South Island

Report prepared for

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1. Introduction

The New Zealand fur seal *Arctocephalus forsteri* breeds around New Zealand and its offshore islands, and along the coastline of southern Australia. They are the most common seal in New Zealand waters and have had a long association with humans. Originally exploited for meat, oil, fur, and leather by early Polynesian arrivals to New Zealand (c. 1000 AD) and Europeans (c. 1792) (Lalas and Bradshaw 2001), New Zealand fur seals received full protection under the New Zealand Marine Mammals Protection Act of 1978 (Boren et al. 2006). As a result the NZ fur seal has now successfully begun to recolonise areas of its former range. A reliable estimate of the current total population within the New Zealand region is unknown, but ~100,000 individuals was suggested by Harcourt (2001). The last comprehensive survey of the population of NZFS was conducted in 1973 by Wilson (1981), who generated a single population estimate for the entire New Zealand region of 39,000 animals (range 30,000 – 50,000).

Over the last 30 years the distribution of fur seals has rapidly expanded along much of the New Zealand coastline, with breeding colonies and haul-outs (non–breeding colonies) re-establishing around the South Island, and into the North Island. As fur seal populations recover from exploitation and increase in distribution and number it is likely that increasing levels of interaction between seals and humans will also be observed. Of concern are the interactions between seals and fisheries, which include the perceived consumption of target species, the destruction of fishing gear, and the incidental death of seals in fishing operations (Lalas and Bradshaw 2001; Boren et al. 2006). There is currently little reliable information available to managers of the impacts of fur seal - fishing operations at the population level within New Zealand, and on the West Coast of the South Island (WCSI) in particular. Since large trawl fishing operations occur in the water off the WCSI, knowledge on the population size of fur seals has been identified as a priority.

Since the 1990s, the Department of Conservation (DOC) has monitored fur seal pup production at three WCSI indicator breeding colonies (Wekakura Point, Cape Foulwind, Open Bay Islands). The unpublished data from these surveys suggest that there has been a decline in population numbers at these rookeries. The causes of this purported decline are uncertain but could be attributed to cyclic weather events (El Niño, La Niña), fisheries bycatch, emigration, or a combination of these. However, in the absence of published peer reviewed research it is not possible to say with certainty whether the WCSI fur seal population is increasing, static, decreasing, or redistributing (M.Cawthorn personal observation).

In December 2008 we were contracted to undertake a photographic census of fur seals on the WCSI. Specifically, we were tasked to:

1. Complete a point count of New Zealand fur seals from Farewell Spit to Puysegur Point and Solander Island inclusive, including the Open Bay Islands, using photographic techniques to record the extent of all identified rookeries and congregations. Areas of Fiordland where aerial survey techniques were considered to be ineffective due to the nature of the terrain were excluded from the survey;
2. Correlate results with New Zealand Department of Conservation (DoC) ground counts at three specified breeding colonies (i.e. Wekakura Point, Cape Foulwind and Open Bay Islands);
3. Document the full range of distribution of fur seals along the WCSI, excluding Fiordland; and
4. Provide advice on the effectiveness of photographic census techniques for monitoring New Zealand fur seals on the WCSI and develop recommendations for future monitoring programmes.

The results of the survey were required to provide improved information on the location of fur seal breeding colonies and haul-out areas, and to provide a baseline for comparisons with future breeding colony and haul-out surveys to assess if fur seal distribution is expanding or contracting.

2. Methods

Field Work

We chartered a helicopter from Southern Lakes Helicopters to conduct a photographic survey of seals along the west coast of the South Island of New Zealand from Farewell Spit to Puysegur Point and Solander Island, excluding Fiordland. The aircraft, a single-engined Robinson R44 helicopter, was piloted by Mark 'Cannibal' Hayes (Southern Lakes Helicopters and Heliworks). On board were Barry Baker (photographer and project coordinator) and Martin Cawthorn (marine mammal biologist), whose function was to identify haul-out and colony sites and to record data, leaving the photographer free to concentrate on accurate photographic documentation of each site.

The flight was conducted in late January 2009 to coincide with the time when pupping had finished, but before pups had left colonies. It was envisaged that pups would still have their lanugo (pup coat) and be clearly evident and distinguishable from adults in photographs. The flight was also timed to coincide with on-ground counts of New Zealand fur seals pups scheduled to be carried out by Department of Conservation staff at three locations along the South Island coastline. These surveys commenced on 28 January 2009.

The survey was conducted from north to south because the aircraft was flown from the starboard side, requiring the photographer to be seated on the port side. We selected a weather window for the operation that predicted clear flying conditions with minimal low-level cloud and ground temperatures that would not exceed 20^0C, as pups were likely to seek shelter from the sun on hot days and thus be less visible. Flights were undertaken between 07.30 and 17.00 hours on 25, 26 and 27 January 2009, with photography generally timed to occur between 09.00 to 15.00 hours. Throughout the three days the weather was generally calm, fine and sunny. On a couple of occasions light showers were encountered during the flight but these had minimal effect on visibility. Brief details of the flights are provided in Table 1.

All photographs were taken through the open port side of the aircraft using a Nikon D300 digital camera and image-stabilised Nikkor 18— 200 F3.5—5.6 zoom lens. Shutter speeds were set at 1/1000s or faster to minimise camera shake, and every effort made to ensure that the photographs were taken perpendicular to the land surface. In many cases this was not possible because of the topography encountered and permit conditions imposed (see below).The focal length of the zoom lens was not adjusted within each pass sequence over breeding colonies or haulouts. Generally at least two or three passes were made over every large colony encountered to ensure sufficient high-quality photographs were available. From these photographic sequences we produced a complete series of overlapping images that covered the entire area of each colony or haulout identified. Approximately 2,000 digital photographs were taken during the survey flight. All photographs of the colony were saved as fine JPG format files. Most photographs were taken with the zoom lens set at a focal length of between 35 and 50mm. DOC permit requirements for the operation were developed following a pilot flight undertaken on 20 December 2007 (M. Cawthorn unpublished), and required that flights were undertaken at an altitude of no less than 120 m above sea level when operating closer than 150 m horizontally from a point directly above any seal. In practice, we ensured that flights were undertaken at a minimum altitude of 120 m, parallel to the coast and about 150 m horizontal distance from the tide line, and rarely overflew seals directly. The full flight path and altitudes were recorded using a GPS receiver and have been downloaded and archived along with the photographs. A GPS receiver was also connected to the camera, providing positional data for every photo taken. The entire set of photographs were subsequently replicated to ensure that six complete back-up sets existed both on DVDs or hard drives and in at least three different locations.

Table 1. Flight details of survey flights. Temperatures are air temperatures measured by the helicopter's thermometer on liftoff.

Date/Time	Activity	Temperature	Weather Conditions
25 January 2009			
07.30	Left Nelson	18^0 C	fine, wind 5km S
08.05	Farewell Spit	17^0 C	fine
08.56	Landed 15nm north of Karamea to await improvement in light conditions. Refuelled.	17^0 C	fine
09.52	Left 15nm north of Karamea	19^0 C	fine
11.20	Cape Foulwind	17^0 C	fine
11.37	Landed Westport to refuel	19^0 C	fine
13.00	Left Westport	21^0 C	fine
14.14	Landed Hokitika		
15.05	Left Hokitika	19^0 C	hazy
17.36	Land Haast		
26 January 2009			
09.30	Left Haast	18^0 C	hazy
11.09	Landed Kaipo Bay to refuel	19^0 C	hazy
11.20	Left Kaipo Bay		Fine initially, on way encountered low level cloud to 300 ft, light rain at times
12.45	Landed Queenstown		fine weather
27 January 2009			
	Left Queenstown		
10.41	Te Anau	16^0 C	fine
11.38	Chalky Island		fine
12.30	Landed Puyseger Pt to refuel		overcast
12.52	Departed Puyseger Pt		
13.15	Arrived Solander Islands		
13.19	Solander Island commenced photography	18^0 C	fine
13.30	Departed Solander Islands		
14.11	Landed Te Anau	18^0 C	fine

Detecting seals and determining age classes of seals

Detecting seals from aerial photos was a function of both the quality of the photos and the terrain encountered. Poorer quality photographs were usually characterised by low contrast between the seals and substrate, reducing the ability to determine the age class of seals. The age classes of interest were pups and non-pups. These were defined as: **Pups -** typically small and fat, possessing a thick neck, velvet black fur, and a square top to the head when viewed from behind; **Non-pups (or adults) -** generally paler than pups and larger in size.

Although determining age classes of seals is relatively clear cut during on-ground counts, it was considerably more difficult to do this when viewing aerial photographs. We used a suite of morphological and behavioural characteristics to classify seals as being either pups or 'non-pups (Annex 2), after viewing photographs of animals with an experienced seal biologist (David Pemberton). These included pelage colour, head shape, 'vibrissae' or whiskers, posture and thigmotactic behaviour (preferring close physical contact). While pups were small, size could not be used as a diagnostic indicator as weaners (one year old seals) could also be small. These animals tended to have a sleeker look and lacked the 'black velvet' appearance of pups. Older bulls and females were also usually paler in colour. Bulls could often be clearly identified by their occupation of areas which contained grease marks, indicating these sites were regularly used, a habit of territorial males. Grease marks were not often present near pups and females. Also, in late January/early February pups were not expected to be seen in open water.

Terrain quality impacted the detection of seals. We classified each photo montage into the following three photo quality and five terrain categories (Annex 3):

Photo quality —
1. — age classes easily discernable
2. — majority of seals easily discernable. Some difficulty in determining age classes as image soft (pixilated) due to low contrast
3. — age classes not discernable in greater than 50% of small seals because of pixilation or poor contrast, resulting from existing lighting conditions or insufficient magnification in the original photograph.

Terrain quality
1.— light-coloured sandy beach or flat rock platforms ensuring high contrast between seals and substrate
2. — pebble beach, boulder gulches and some crevices where seals cannot hide but rock colour, shadows and shape of substrate make seal detection more difficult than in Class 1 terrain
3.— any substrate where small caves would potentially permit 5% of seals present to be hidden
4.— any substrate where seals are clearly present but the terrain suggests that many seals (5—60%) could be hidden
5.— any substrate where seals are clearly present (i.e. at least one seal observed) but the terrain suggests that most seals (60— 95%) could be hidden. Many Class 5 sites could have been overflown during the survey and seals not detected.

As we had no knowledge of the exact nature of terrain overflown, these terrain categories were assigned on the basis of what could be determined from an assessment of the photos.

Counting protocol

We used protocols previously developed for aerial censuses of albatross colonies (Arata et al, 2003; Robertson et al. 2007; Baker et al 2009) and modified them as appropriate for fur seals. Photographic montages of all fur seal breeding and non-breeding (haulout) colonies (Figure 1) were constructed from overlapping photographs using the image editing software package ADOBE PHOTOSHOP (http://www.adobe.com/). Counts of all pups and other fur seals on each montage were then made by magnifying the image to view seals and using the paintbrush tool in PHOTOSHOP to mark each seal with a coloured circle as they were counted (Figure 2). For each image the size of the circle was adjusted for each age class of seal following an initial assessment of the age classes of seals present at the site. A small yellow circle was used for pups and a larger red circle for all other seals. This was subsequently used as an aid in identification of age classes for each photo montage. To assist with counting we used a hand held click counter. Once all seals had been counted on a photo-montage, the file was saved to provide an archival record of the count.

Counts of photo montages were undertaken by one observer only. To estimate counter variability associated with miscounting and misidentifying dark objects such as logs and rocks as seals, and to assess if observer experience increased the effectiveness of detecting seals on photos, we undertook multiple counts of 11 photographs using five observers. The photos selected for this experiment were each numbered 1— 11, and each observer was asked to count the photos in numerical order. Once this was complete, observers then repeated the counts for each image, again carrying out the counts in the same numerical order.

These count data were statistically analysed using Generalised Linear Mixed Models fitted by restricted maximum likelihood (REML), to estimate variances and covariances (Galwey 2006).

Photographic file management

All photographs and details of the flight path has been submitted to the Deep Water Group, Ministry of Fisheries and Department of Conservation. Photos were provided in one directory (NZ fur seals – 2009) with five sub-directories (Original photos, Counted images, Stitched images, Duplicate counts, Seal age classes for ID purposes). The following information is provided to assist others that may wish to access the photos at some stage in the future.

Extensive photo information is superimposed on all digital images taken with the Nikon D300 camera. This includes information on the time and date the photo was taken, the camera and lens used, image quality and size, shooting data (aperture, shutter speed, ISO, exposure correction), and geographic position (latitude and longitude) data where a GPS was connected to the camera. These data can be accessed when the photographic file is opened using Adobe Photoshop or other photographic software, and can be invaluable when analysing photos, building photo montages, or for archival purposes.

Original photographs were saved in the camera with a file name consisting of a prefix 'DSC_ followed by a four-digit number and a three-letter extension 'jpg' that signified the type of file. The initial file number sequence was set to 0001, enabling 9999 photos to be taken before the numbering would be automatically re-set. This was sufficient to ensure each photograph taken during the survey had a unique sequential number. At the completion of field work all files were downloaded to a computer and stored in a separate folder '*Original Photos'*. Some photos were renamed to indicate the colony number and name, and the start and end point of each photographic run for each colony. The original four-digit number was retained in any subsequent renaming of files to permit easy tracking of work flows from the original photos to the stitching and development of photomontages, through to counting of images. File numbering protocols may be best explained in the following table:

Table 2. File numbering protocols for aerial photographs of seal colonies on the West Coast of New Zealand's South Island.

File Name/Number	Process	Explanation
DSC_0177.jpg	Original photo	Camera generated file name with unique sequential number.
DSC_ 0177_Site 4 haulout_Run 1 Start .jpg	File renamed	Some original photos renamed to indicate name of colony and start and end point for the each photographic run at the site. Files stored in directory ***Original Images***
4a (117-120) .jpg	Photo montage	Photos DSC_0117 to DSC_0120 have been copied and stitched to create a photomontage of the site. Photomontage files stored in directory ***Stitched Images***
4a (117-120) count .jpg	Counted image	Stitched image DSC_0177 to DSC_0120 has been duplicated and counted. Duplicate files showing the seals identified and counted stored in directory ***Counted Images***

Ground counts

Ground counts were undertaken at three sites on the West Coast as part of an ongoing Department of Conservation annual monitoring programme. The three sites were Wekakura Point, Cape Foulwind and Open Bay Islands (Taumaka Island). Peterson estimates (Seber 1982) of pup production using mark–recapture techniques were carried out in late January and early February, concurrent with the time of aerial photography. Peterson estimates allow for an accurate assessment of pup production at colonies where pups are able to hide under rocks and in caves. The protocol for the mark–recapture experiments involved marking a subset of pups with tags and comparing the number of marked versus unmarked pups sighted on a walk through the colonies on following days, as described by Shaughnessy et al. (1994), Bradshaw et al. (2000a) and Boren et al. (2006). Walkthroughs involved active searching for pups and were carried out by one observer on five occasions, so that five counts were obtained per colony.

3. Results

Identification of Sites

A total of 33 haulouts and colonies were identified during the survey. A further 3 sites identified during the survey as haulouts were not subsequently found to contain seals following a careful analysis of the photographs taken. Pups were recorded at 19 of the 33 sites (Table 4; Figure 1; Annex 1). The largest colonies were at Yates Point, Chalky Island and Solander Island, each of which contained more than 3,000 seals. Another three sites contained more than 500 seals each — Taumaka, Open Bay Islands; Cascade Point and Long Reef Martins Bay (Table 1, Figure 1).

We did not use pre-existing information on location of sites to influence our search patterns during the survey, with the exception of one site, Wekakura Point, which was one of the long-term monitoring site where on-ground counts were to be undertaken by others. No seals were located during the initial flyover at Wekakura Point, prompting us to return and re-search the site until seals were located. Six other sites known by DOC to contain seals (Kongahu, Wall Island, Charleston, Malcolms Knob, Seal Rocks and Browne Island) were not identified as either haulouts or breeding colonies as a result of this study.

Counts of Seals – observer effect and calculation of SE

The duplicate count data of 11 photographs using 5 five observers were statistically analysed by fitting the following general linear mixed model:

Seal count=constant + random effect for observer+
fixed effect for photograph +
random observer . photograph effect +
random error (duplicate counts)

These analyses of the count data indicated large observer differences, with the differences not consistent across photos. Such differences are not explained by photo covariates of area, photo quality and terrain type, although all covariates are highly significant. Variance components for total counts of seals were estimated as:

Random term	component	s.e
Observer	222.92	177.21
Observer.Photo_ID	284.17	67.85
Residual (repeat counting)	37.32	7.18

A brief, graphical exploration of the repeat count data, undertaken by David Middleton, is provided at Annex 4.

Shown below are predicted mean counts of total seals for each photograph and associated standard errors. These standard errors are based on 5 observers each reporting two counts for each photo.

Predicted means for Photo_ID — Total Seals

Photo ID	363	626	1027	1726	1871	2057	2144	2691	2799	2908	2959
Means	133.9	22.5	54.44	184.90	102.4	60.8	34.2	85.7	115.90	95.50	54.50
SE	10.25	10.25	10.29	10.25	10.25	10.25	10.25	10.25	10.25	10.25	10.25

As most of the photographs had only one count made by a single observer, confidence intervals for a single count were calculated as Count+/-2*SE where the SE for a single observer reporting one count of total seals will be

Equation 1:

Sqrt(observer variance component + observer.photo variance component + residual variance)
= Sqrt (222.92+284.17+37.32) = 23.33

Variance components for counts of pups were estimated as

Random term	component	s.e
Observer	0	0
Observer.Photo_ID	39.32	9.90
Residual (repeat counting)	13.28	2.55

Predicted mean counts of pups for each photograph and associated standard errors are shown below. As before, these standard errors are based on 5 observers each reporting two counts for each photo.

Predicted means for Photo_ID — Pups

Photo ID	363	626	1027	1726	1871	2057	2144	2691	2799	2908	2959
Means	**1.4**	**2.7**	**16.69**	**86.8**	**34.6**	**23.5**	**4.8**	**14.7**	**25.5**	**26.4**	**8.2**
SE	**3.03**	**3.03**	**3.07**	**3.03**	**3.03**	**3.03**	**3.03**	**3.03**	**3.03**	**3.03**	**3.03**

Applying the same logic to that used above, confidence intervals for a single count were calculated as Count+/-2*SE where the SE for a single observer reporting one count of pups will be:

Equation 2: Sqrt(0+39.32+13.28)) = 7.25

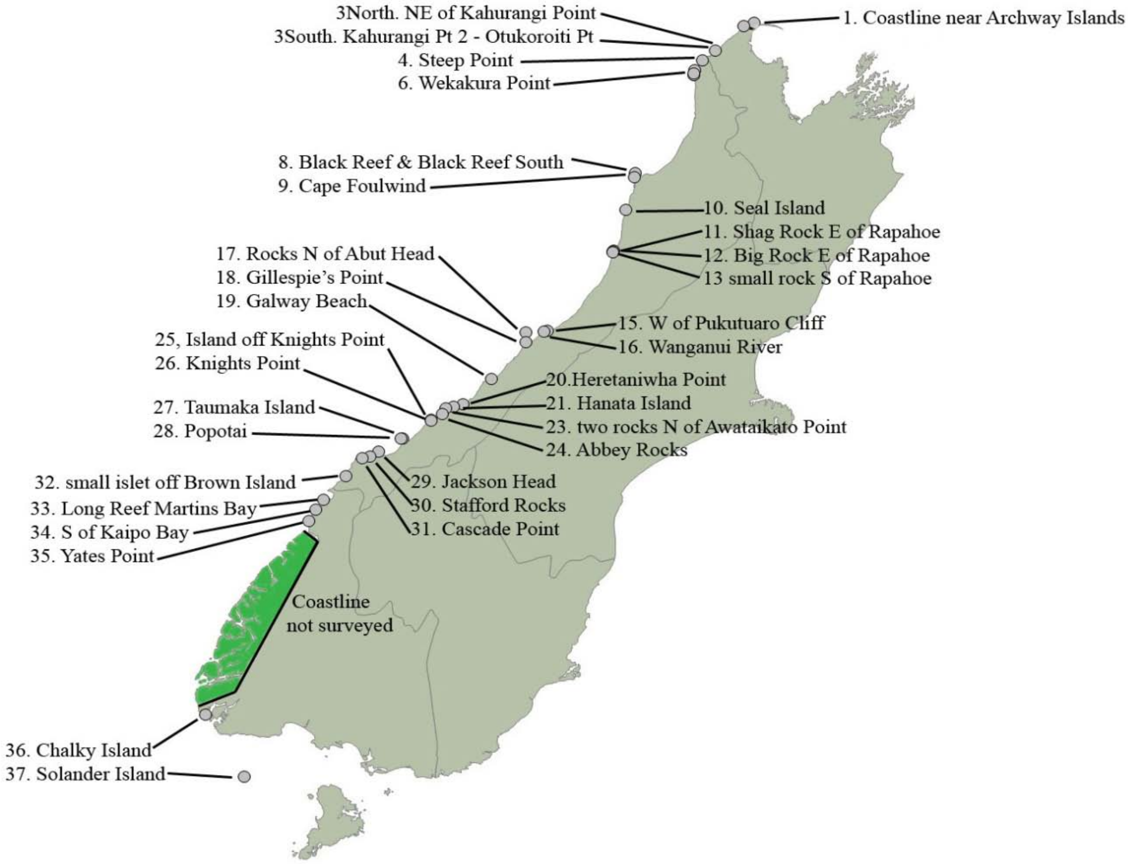

Figure 1. Location of 33 New Zealand fur seal haul-outs and colonies identified during a photographic survey of the west coast of the South Island, excluding Fiordland, in January 2009. Note that sites thought to contain seals at the time of the survey have been excluded if animals were not subsequently identified during photographic analysis.

Figure 2. Photomontage of New Zealand fur seal colonies before (left) and after (right) counting. The larger red circles are animals identified as adult seals, and the smaller yellow circles are pups. The size of the circle used on each photomontage was varied for each image to approximate the size of pups and larger seals, which assisted in detecting pups.

Ground counts

Mean Petersen estimates for seal pups at Wekakura Point, Cape Foulwind and Taumaka Island (Open Bay Islands), based on an initial marking of 217, 167 and 633 animals, were 305, 203 and 941 respectively. These estimates greatly exceeded the estimates of pups derived from counts of aerial photographs (Table 3).

Table 3. Comparison between Petersen estimates of seal pups at three seal colonies on the West Coast of New Zealand's South Island, and estimates derived from analysis of aerial photographs of the same sites.

Site	DOC estimate - ground count	Aerial counts	
	Pups	Pups	Total Seals
Wekakura Point	305	7	182
Cape Foulwind	203	11	70
Taumaka Island, Open Bay Islands	941	443	929

The aerial estimate of pups for Wekakura Point was derived from an area that greatly exceeds that in which the ground counts were undertaken, although some overlap occurred. This was because the boundaries of the ground-count site were not known to the authors at the time of the aerial survey, and had been assumed to be clearly evident from the air. We expected to see well defined colonies from the air but as we approached Wekakura Point it became evident that this was not the case. The ground count site for Wekakura Point extended from Wekakura Point north for 1.5km to just south of Toropuihi Creek. In this area pups were found amongst waist high rocks and in crevices at three rocky promontories referred to as Headland 1 (Wekakura Pt) and Headland 2 and 3. At Headland 2 the pups were more visible sitting on rocks, or in the rock pools. At the northernmost promontory (Headland 3) the pups were 'off the beach amongst large rocks on the shoreward side and difficult to find' (G. Quinn, DOC Karamea, pers.comm). The area identified from the air as comprising the colony commenced just north of Wekakura Point (Headland 2) and extended 3 km south of Wekakura Point to Whakapoai Point. Many (122) of the seals we located were adults hauled out on a sandy beach at Kotaipapa Point, which was south of the DOC monitoring site.

Counts of Seals – analysis of photographs

The quality of most of the photographs was generally good with 118 of 176 (67%) of all photomontages falling into Classes 1 and 2 (Table 4). A Class 3 assessment was assigned to 33% of the photomontages assessed, mainly because significant sections of the areas occupied by seals were in heavy shade, providing poor contrast between seals and substrate, or because there was insufficient magnification in the original photograph, or the angle of the photograph caused a perspective change from foreground to background which made counting difficult. The latter issue was almost entirely due to our decision to not fly directly over any part of a colony.

Terrain Class 4 was assigned to over half (53%) of the 176 photographs or photomontages assessed (Table 4). No photographs were assigned a rating of Class 5, but such sites could have been overflown and seals not detected at the time. At times it was also difficult to make the distinction between terrain quality 4 and 5 as the depth of a cave or gulch, and hence the number of seals that may be hidden, was indeterminable from the photograph. Some of the Class 4 sites could well have been Class 5 sites if assessed from the ground.

Table 4. Summary of photo and terrain quality classes assigned to 176 photomontages or photos counted to assess seal numbers at

Class	**Photo quality**		***Terrain quality***	
	No.	**%**	***No.***	***%***
1	56	0.32	*23*	*0.13*
2	62	0.35	*29*	*0.16*
3	58	0.33	*31*	*0.18*
4	N/A		*93*	*0.53*
5	N/A		*0*	*0*
	176		*176*	

We estimated the total count of fur seal pups and non-pups (adults) at the 33 sites to be 18,503 (95%CI 17,886 — 19,120). Of these, 5,618 (5,463—5773) were assessed as being pups (Table 5).

4. Discussion

Identification of Sites

Our field survey identified a total of 33 sites along the West Coast of the South Island where seals were present, and defined the extent of seal occupation at these sites. Most of the sites containing large numbers of animals were located toward the south of the island and pups were recorded at 19 of the 33 sites (Table 5, Figure 1). The largest colonies were at Yates Point, Chalky Island and Solander Island, each of which contained more than 3,000 seals, while Open Bay Islands; Cascade Point and Long Reef Martins Bay each contained more than 500 seals. While other small sites may have been missed because of the terrain quality overflown (Terrain types 4 and 5) we are confident that we identified all the major sites occupied at the time.

Counts of Seals – observer effect and calculation of SE

While separating seals from substrate and assigning age classes to animals from aerial photographs is not an easy task, we did not expect our counts would be associated with large observer differences. Four of the observers used for the multiple counts are experienced in counting wildlife from photos and previous analysis of associated observer effects when using experienced observers for counting albatrosses has not led to such problems (Baker et al. 2009). We can only attribute this to the lack of contrast inherent with New Zealand fur seals and the habitats that they choose to occupy in New Zealand. An appropriate approach for future counts would be to use multiple observers to count all photographs and to average count data across all observers and estimate the precision by using Observer plus Observer Photo variance. There were insufficient resources available at this time to adopt such an approach given the large number of photographs that would have required multiple counting. However, we would advocate testing such an approach before embarking on future aerial counts of fur seals on the West Coast of the South Island

Ground and Aerial Counts of Seals

The great disparity between the ground and aerial counts is of concern if aerial photographs are to be used in future population assessment work on the West Coast of the South Island. Much of the difference is clearly due to the effect of terrain quality, although photo quality (including the angle the photos are taken at), would also have a role to play.

For Wekakura Point it would have been impossible for us to detect most of the pups observed by the ground counting team as they were mainly either hiding amongst waist high rocks, in crevices, or off the beach amongst large rocks on the shoreward side and difficult to find (G. Quinn, DOC Karamea, pers.comm). We did not detect any seals on the sites referred to by the ground count team as

‘Headland 2’ and ‘Headland 3’, and only started photography just south of Headland 2 (40.90262^{0}S, 172.09981^{0}E). However, at ‘Headland 2’ pups were reportedly more visibly sitting on rocks or in rock pools. Failure to detect any animals from the air in this area could indicate different behaviour at the time we overflew the colony, which was two days before the ground count commenced. Terrain quality on the section of coastline we photographed averaged 1.6, and never exceeded Class 3, indicating that we failed to assess the habitat correctly from the photographs, particularly in the area where ground counts were carried out. Terrain quality for Cape Foulwind and Taumaka Island, Open Bay Islands, averaged 3.5 and 4, respectively, so it is not surprising that aerial counts were considerably lower than the estimates derived from ground counting.

Photo Quality and Counts of Seals

While photo quality was generally sufficient to permit relatively easy detection of seals from the substrate on which they were resting, poor light on the area of the colony usually led to insufficient pelage contrast and detail. This increased the difficulty of separating pups from other small seals, and most likely increased the probability that seals were not detected. When attempting to photograph an extensive length of coastline over a short period of time, as was the case in this study, it is difficult to ensure that all sites are photographed in ideal lighting conditions. If monitoring was carried out at specific sites only, then an appropriate time for photography that ensured substrates were well lit and not in shadow could be pre-determined. It would also be possible in such situations, and where colony extent was known, to use site-specific photographic approaches i.e. increasing photo magnification through use of greater lens extension, which may have assisted in detecting more animals.

Photo quality was also impacted by our decision to not directly overfly colonies. As a result most photographs were therefore taken at an oblique angle, which meant that many contained a significant perspective change between the foreground and mid ground to background. This was particularly a problem when the colonies extended more than 30 m inland from the shoreline, for example, over rock platforms. It was difficult to apply a consistent size ‘search image’ over such photographs, which was necessary when using size as a guide to separate pups from older seals. This problem could have been overcome to some extent by adopting a higher flight elevation (say 300 m, which would be well within the permit conditions approved for this project) and reducing the horizontal distance from the shoreline, or flying directly over a colony.

The combination of terrain and photo quality clearly impacted the estimation of population size in this study. As a result, the estimated number of seals at the 33 sites (pups 5,618, CI 5,463—5773; total seals 18,503, CI 17,886 — 19,120) must be considered a substantial underestimate of the true population size. While it is usual to apply a correction factor to counts of pups (summarised in Kirkwood et al 2005), we have chosen not to adopt this approach here. The relationship between pup production and population size is variable between species, and is dependent on demographic parameters and population trends, and thus likely to vary over time (Harwood and Prime 1978, Kirkwood et al 2005). Multipliers for New Zealand fur seals have been estimated at 4.23 (Crawley and Brown 1971) and 4.9 (Taylor 1982). We have no basis for applying these multipliers to our data, and given our concerns over observer effect of counts and the level of underestimation due to terrain and other issues, to do so would be misleading. Also important to note is the phase of the moon when the survey was undertaken (new moon) as the number of seals onshore is usually greater under a full moon (Boren unpublished data; Haase 2004).

Future Monitoring using Photographic Census Techniques

The techniques applied in this study would require considerable enhancement before they could be considered suitable for future assessment of New Zealand fur seals on the West Coast of the South Island. It is doubtful if estimation of absolute numbers can be practically achieved given the nature of the terrain occupied by most of the pupping sites we encountered. To do so would require development of correction factors through extensive ground truthing to permit adjustment of aerial counts. It may, however, be possible to use the technique to estimate change over time through the use of relative counts at selected sites (see below). If it is considered desirable to carry out further surveys using aerial photography, it would be necessary to refine field protocols to determine ideal times, flight heights and photographic angles for photographing specific colonies to maximise photo quality.

TABLE 5. Estimates of pups and total seals from 33 colonies and haulouts, derived from aerial photographs, with 95% confidence intervals (CIL, CIU). Photo and terrain quality assessments are mean values derived from the total number of photomontages used to assess each site. Sites 20 and 34 were not photographed as at both only a single seal was observed during the flight.

Site No	Site Name	Pups	CIL	CIU	Total seals	CIL	CIU	Photo quality	Terrain quality
1	Coastline near Archway Islands	0			65	0	130	2	2
3 - North	NE of Kahurangi Pt	0			1	0	48	2	1
3 - South	Kahurangi Point 2 - Otukoroiti Pt	63	27	99	171	39	303	3	4
4	Steep Point	25	4	46	122	29	215	2.5	2.5
6	Wekakura Point	7	0	28	182	78	286	2	1.6
8	Black Reef & Black Reef South	18	0	39	346	242	450	2	4
9	Cape Foulwind	11	0	32	70	0	184	2	3.5
10	Seal Island	6	0	21	34	0	100	1.5	3
11	Shag Rock, E of Rapahoe	0			6	0	53	1	2
12	Big Rock, E of Rapahoe	0			14	0	61	1	2
13	small rock S of Big Rock	0			1	0	48	1	2
15	West of Pukutuaro Cliff	16	0	41	272	158	386	1.7	1.8
16	Wanganui River	0			10	0	57	1	3
17	Rocks N of Abut Head	0			24	0	90	1	1
18	Gillespie's Point	3	0	18	107	26	188	1	4
19	Galway Beach	0			93	0	207	1	2.3
20	Heretaniwha Point	0			1	0	48	n/a	n/a
21	Hanata Island	66	41	91	155	74	236	2	4
23	Two rocks, N of Awataikato Point	0			9	0	75	1.5	2
24	Abbey Rocks	12	0	27	28	0	75	3	4
25	Knights Point	0			142	76	208	2	1
26	Island off Knights Pt	13	0	34	69	3	135	2	4
27	Taumaka Island, Open Bay Islands	443	407	479	929	806	1052	1.4	4
28	Popotai	118	93	143	270	189	351	3	4
29	Jackson Head	21	7	36	50	3	97	2	4
30	Stafford Rocks	0			1	0	48	2	2
31	Cascade Point	1,466	1,396	1,536	2,889	2,651	3,127	2.6	3
32	small islet S of Browne Island	0			41	0	107	3	4
33	Long Reef Martins Bay	163	142	184	670	604	736	2.5	4
34	South of Kaipo Bay	0			1	0	48	n/a	n/a
35	Yates Point	1,228	1,166	1,290	3,062	2853	3271	1.2	3.9
36	Chalky Island	832	767	897	4,004	3771	4237	1.88	2.28
37	Solander Island	1,107	1,049	1,165	4,664	4472	4856	2.6	3.7
		5,618	**5,463**	**5,773**	**18,503**	**17,886**	**19,120**		

It would also be necessary to address observer differences in counting seals from photographs. Differences between observer counts will generate variability in the total count, as will misidentification of age classes in pupping sites. Evidence from this study showed that observer effects were high. An appropriate approach for future counts would be to use multiple observers to count all photographs and to average count data across all observers and estimate the precision by using Observer plus Observer Photo variance. Such an approach would need to be assessed prior to committing to establishing a monitoring program based on aerial photographs.

If there is interest in continuing to use this technique, we provide below a recommended strategy for a monitoring program based on our experiences with this project and other monitoring programs for pinnipeds that we have designed.

Potential Approach to Monitoring using Aerial Photography

It is necessary to define the objective of a monitoring program before developing a design, specifically to determine whether the aim is to provide an estimate of population size in a given year, or to detect population change. Whilst appearing similar, the survey methodology may be different to achieve these different aims. For example, if the aim is to estimate population size, then it is necessary to predict populations in areas not sampled. Alternatively, if the aim is to solely quantify change with high precision, then the important design consideration is to essentially re-sample or re-count the same areas from one period of interest (e.g. year) to another. For the latter strategy to be successful, the sample being counted must be representative of the entire population. Re-sampling a number of areas increases precision of estimates when seals show high site fidelity.

Low precision of estimates is associated with a high spread or high variability of repeated estimates; small standard errors and hence tight confidence intervals lead to high precision. Bias refers to consistent divergence of sample estimates from true population parameters. Accuracy in a general sense denotes the closeness of estimates to the exact or true value. The deviation from the scientific true value as a consequence of both bias and random error is a measure of accuracy. A numerical definition of accuracy can be given as the mean square error (MSE) that combines both bias and random error, and is defined as:

MSE= $\left[(Bias)^2 + Variance\right]^{\frac{1}{2}}$

The term accuracy in the above sense has often been misused and confused with precision and lack of bias. We therefore do not use it and prefer to discuss the separate entities of bias and precision.
The protocols presented here aim to detect population change in New Zealand furs seals. Consequently, the approach outlined would monitor change and not estimate total population numbers, including all age classes.

The recommended approach would estimate the number of pups at prescribed sites. From these data it will be possible to track change in populations for NZ fur seals at these sites, allowing inferences about long-term trends to be made. This information should provide a statistical basis for making decisions pertaining to management of these populations.

Suggested approach to monitoring

Select one or more breeding colonies as monitoring sites. Ideally, these sites would have a reasonable annual pup production, with pups occurring in areas that are visible from the air. Suggested sites could include Cascade Point, Yates Point, Chalky Island or Solander Island. At these sites establish boundaries to beaches/areas and document these thoroughly. Boundaries may be naturally defined, or created artificially by use of GPS. These are to be considered the survey units (e.g. beaches, rock platforms or other areas within larger breeding sites). This will then define the statistical population. Thus the survey unit is an area, and the observational unit is a pup, with the survey method yielding a count of pups per area. A minimum of 15 survey units should be counted each year based on the knowledge that the precision of an estimate of 'experimental error' decreases rapidly as the degrees of freedom decrease below 12. Hence, in this case, at least 15 sampling units gives 15 df (at least) for estimating error associated with change in counts between two times with reasonable precision.

During late January/early February each breeding season, fly over and photograph each beach/area once and count the number of pups present from photos or photomontages subsequently developed using the Photoshop techniques described in this report. Other seals present could also be counted although these are not the principal subject of the study.

It is recognised that by conducting counts only once during the breeding season that some pups will be missed — some pups will be hidden and not detected, other pups may have died since birth. However, the primary purpose of these protocols is to detect change. Missing pups from year to year will introduce a bias (ie underestimate pup numbers) but if the bias is consistent from year to year, any significant change in pup numbers should be detectable.

Photos should be counted by at least five observers, each of whom should be experienced. The photographer should be familiar with the layout of the beaches and areas within the breeding colonies are located, which can be ascertained from examining photographs taken from previous years. Continuity of photographic and counting personnel between seasons will help ensures that: 1) areas are photographed in a consistent manner, 2) seals should be disturbed less, and 3) observer variability should be reduced.

Field protocols for photographing seals will be defined each year by permits issued by the managing authority (DOC) and adhered to by all survey participants. It is important that both field and counting protocols are well documented and understood by all involved.

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Annex 1. Sites of haulouts and breeding colonies of New Zealand fur seals identified in an aerial survey undertaken in January 2009.

Site No	Site Name	Photo numbers	Start Latitude	Start Longitude	Finish Lat	Finish Long
1	Coastline near Archway Islands	DSC 3-30	40.49818	172.71314	40.49596	172.68751
3 North	NE of Kahurangi Pt	DSC 49 - 52	40.72517	172.31249	40.72517	172.28765
3 South	Kahurangi Point to Otukoroiti Pt	DSC 56 - 114	40.80270	172.18426	40.81752	172.17029
4	Steep Point	DSC 117 - 132	40.88580	172.10552	40.89959	172.09759
6	Wekakura Point	DSC 324-385	40.91041	172.09596	40.94079	172.09504
8	Black Reef & Black Reef South	DSC 459-508	41.73053	171.46943	41.73053	171.46943
9	Cape Foulwind	DSC 513-627	41.76413	171.45320	41.76413	171.45320
10	Seal Island	DSC 635-664	42.02867	171.36383	42.02867	171.36383
11	Shag Rock, E of Rapahoe	DSC 720	42.36858	171.22055	42.36858	171.22055
12	Big Rock, E of Rapahoe	DSC 725	42.37388	171.2186	42.37388	171.21860
13	small rock S of Big Rock	DSC 729	42.37643	171.21789	42.37643	171.21789
15	West of Pukutuaro Cliff	DSC 733 - 775	43.01655	170.49803	43.01729	170.48695
16	Wanganui River	DSC 777-780	43.02154	170.46071	43.02187	170.45883
17	Rocks N of Abut Head	DSC 785 - 788	43.02311	170.26608	43.02329	170.26130
18	Gillespie's Point	DSC 791-808	43.10653	170.26439	43.10816	170.25890
19	Galway Beach	DSC 845 - 882	43.39409	169.88138	43.39384	169.87923
20	Heretaniwha Point	DSC 932-992	43.59446	169.56228	43.59000	169.54906
21	Hanata Island	DSC 1017-1043	43.61749	169.45799	43.63167	169.62460
23	Two rocks, N of Awataikato Point	DSC 1045 -1047	43.62221	169.37653	43.64119	169.37160
24	Abbey Rocks	DSC 1049-1059	43.66817	169.33361	43.66814	169.21455
25	Knights Point	DSC 1080-1110	43.71770	169.21286	43.71848	169.20760
26	Island off Knights Pt	DSC 1124-1129	43.71932	169.20832	43.71857	169.21058
27	Taumaka Island, Open Bay Islands	DSC 1138-1241	43.85854	168.89013	43.86281	168.87990
28	Popotai	DSC 1399-1425	43.85981	168.87526	43.86330	168.87793
29	Jackson Head	DSC 1468	43.95796	168.62517	43.95796	168.62517
30	Stafford Rocks	DSC 1471	43.99098	168.52903	43.99098	168.52903
31	Cascade Point	DSC 1714-1888	44.00748	168.44369	44.01133	168.36990
32	small islet S of Browne Island	DSC 1906 - 1909	44.14230	168.25065	44.14085	168.25170
33	Long Reef Martins Bay	DSC 1934-1949	44.32807	167.99720	44.32672	167.99453
34	south of Kaipo Bay	no photos	44.41058	167.90723	44.41058	167.90723
35	Yates Point	DSC 2029 - 2264	44.49538	167.82062	44.50711	167.82611
36	Chalky Island	DSC 2656-2819	46.03619	166.51421	46.05220	168.53660
37	Solander Island	DSC 2885-2995	46.56957	166.89002	46.56794	166.89390

Annex 2. Examples of age classes of New Zealand Fur Seals


Pup
Bull
Mum and pup


Mum and pup
Mum and pup
Pups
Pup


Cows
Bull


Cow
Bull
Pup

Annex 3. Examples of Terrain Categories applied to aerial photographs

Terrain Category 1 — flat rock shelf

Terrain Category 1 — sandy beach

Terrain 2_Rock shelf with some shadow & crevices

Terrain 2_Rock with shallow crevices

Terrain 2_Sand rock & boulders

Terrain 3_Rock shelf

Terrain 3_Sand and rocks

Terrain 4_Rock & boulders

Terrain 4_Rocky boulders

Annex 4. Graphical exploration of repeat count data