Harbor Seals *(Phoca vitulina)* in Hood Canal: Estimating Density and Abundance to Assess Impacts of Navy Activities

Report of a workshop held on
15 and 16 October 2015
at National Marine Mammal Laboratory,
Alaska Fisheries Science Center,
NOAA Western Regional Center,
7600 Sand Point Way, NE, Seattle, WA

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Photo Credit:

Harbor seals (*Phoca vitulina*) hauled out on Gertrude Island, Puget Sound, Washington. Photo by Dyanna Lambourn, Washington Department of Fish and Wildlife.

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14. ABSTRACT
The U.S. Navy requires information about the in-water density and abundance of harbor seals (Phoca vitulina) in various parts of Hood Canal, Washington, to evaluate impacts and estimate exposure to Navy activities that may cause acoustic disturbance (e.g., use of sonar, pile driving, and other marine construction). To determine the best approach for estimating in-water density and abundance of harbor seals in Hood Canal using existing data, a workshop was held in October 2015 in Seattle, Washington, and was attended by experts and scientists with experience in the region. Several existing datasets and analytic approaches were discussed, and the workshop participants concluded that the best approach would be to use Navy-funded line-transect aerial survey data (collected from 2013 to 2016 by Smultea Environmental Sciences) from Hood Canal to directly estimate harbor seal density and abundance in the water. A correction factor [trackline detection probability– g(0)] was estimated from dive and surface time data from seal tagging studies, and was used to correct for seals missed on the trackline during surveys. Both conventional and multiple covariate line-transect approaches were applied. The resulting best estimate of density of harbor seals expected to be in the water in the Hood Canal study region was 5.80 seals/square kilometer, with an estimated abundance of 2,009 seals (coefficient of variation [CV] not including g(0) variance = 6.9%; including g(0) variance = 118.6%). We also produced seasonal estimates of density and abundance for six pre-defined sub-regions of Hood Canal. The estimates produced by this work provide a starting point for the Navy to estimate harbor seal exposure to Navy activities in Hood Canal.

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Executive Summary

The U.S. Navy requires information about the in-water density and abundance of harbor seals (*Phoca vitulina*) in various parts of Hood Canal, Washington, to evaluate impacts and estimate exposure to Navy activities that may cause acoustic disturbance (e.g., use of sonar, pile driving, and other marine construction). To determine the best approach for estimating in-water density and abundance of harbor seals in Hood Canal using existing data, a workshop was held in October 2015 in Seattle, Washington, and was attended by experts and scientists with experience in the region. Several existing datasets and analytic approaches were discussed, and the workshop participants concluded that the best approach would be to use Navy-funded line-transect aerial survey data (collected from 2013 to 2016 by Smultea Environmental Sciences) from Hood Canal to directly estimate harbor seal density and abundance in the water. A correction factor [trackline detection probability– $g(0)$] was estimated from dive and surface time data from seal tagging studies, and was used to correct for seals missed on the trackline during surveys. Both conventional and multiple covariate line-transect approaches were applied. The resulting best estimate of density of harbor seals expected to be in the water in the Hood Canal study region was 5.80 seals/square kilometer, with an estimated abundance of 2,009 seals (coefficient of variation [CV] not including $g(0)$ variance = 6.9%; including $g(0)$ variance = 118.6%). We also produced seasonal estimates of density and abundance for six pre-defined sub-regions of Hood Canal. The estimates produced by this work provide a starting point for the Navy to estimate harbor seal exposure to Navy activities in Hood Canal.

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Acronyms and Abbreviations

BSS	Beaufort Sea State
CV	coefficient of variation
km	kilometer(s)
km^2	square kilometer(s)
MCDS	Multiple Covariate Distance Sampling
NAVFAC	Naval Facilities Engineering Command
NMML	National Marine Mammal Laboratory
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
SES	Smultea Environmental Sciences
WDFW	Washington Department of Fish and Wildlife
WRA	Waterfront Restricted Area

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1. Background and Purpose

The U.S. Navy contracted HDR to produce an assessment of harbor seal (*Phoca vitulina*) in-water abundance and densities within Hood Canal, Washington. Hood Canal (**Figure 1**) is a portion of Puget Sound characterized by deep narrow waterways. Based on genetic analyses (Huber et al. 2010, 2012), the National Marine Fisheries Service (NMFS) considers harbor seals inhabiting Hood Canal as a separate stock (Carretta et al. 2015). The U.S. Navy requires information about the in-water abundance and density of this stock to evaluate impacts and estimate exposure to Navy activities involving potential acoustic disturbance of harbor seals (e.g., sonar, pile driving, and other marine construction work). To accomplish this task, investigators with experience conducting telemetry, aerial, vessel and tagging surveys of harbor seals in Hood Canal were convened to review available data sets, chart a path forward on the best way to conduct the analyses, and produce reliable abundance/density estimates (see **Appendix A** for the workshop agenda and **Appendix B** for a list of workshop participants).

The workshop participants reviewed the best available science regarding aerial and vessel survey data potentially relevant to the task (**Table 1**), and identified two different analytical approaches to the problem. One potential approach was to use data collected during seal aerial surveys focused on harbor seal haul-out sites to assess the proportional distribution and density of seals sighted *on land* within six pre-defined sub-regions of Hood Canal (defined for the purposes of this analysis, **Figure 2**), and then use a correction factor to estimate the abundance of in-water animals within each of these sub-regions. An alternative approach involved using aerial line-transect survey data to derive densities of in-water harbor seals for each sub-region, since according to that survey methodology, only sightings of animals observed in the water are used for density estimation. The workshop group ultimately determined that the second approach was more appropriate for the purposes of this analysis, for reasons described further in **Section 3**.

It is important to estimate a variance associated with the density estimates to have some idea of their statistical precision. There is variability associated with each density estimate, as each is estimated from a given sample of survey data. Aerial surveys of hauled-out animals are generally flown on a single day. It is, therefore, sometimes uncertain whether there are replicates of transects from which a sample variance can be calculated. Jeff Laake at the National Marine Mammal Laboratory (NMML), without benefit of evaluating the various data sets, suggested the following points of consideration for variance estimation:

1. The aerial line-transect surveys can provide estimates of variance for density if there are replicate transects in each area.
2. Using a straight proportion of sightings in each area is problematic when mixing vessel and aerial surveys, due to the difference in detection of seals from the two platforms.
3. A variance on harbor seal haul-out aerial survey estimates can be constructed by assuming a binomial distribution for aerial survey counts.

Figure 1. Map of the inland waters of Washington, showing the location of the Hood Canal study area and Naval Base Kitsap at Bangor.

Table 1. Datasets Evaluated, Areas Covered, and Relevant Details of Each.

Sub-region	Area Covered	Survey Type	Survey Platform	Survey Name	Dates	Surveyors	Contractor POC	Navy POC	Notes
1	Hood Canal Bridge	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	
1	Hood Canal Bridge	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	
1	Hood Canal Bridge	Line-transect	Vessel	Bird/Marine Mammal	2012-2016	WDFW	S. Pearson	C. Kunz	
2	Bangor	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	No coverage over Bangor no-fly zone
2	Bangor	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	No coverage over Bangor no-fly zone
2	Bangor	Line-transect	Vessel	JP01† TPP Baseline Surveys	2011	HDR	K. Ampela	A. Balla-Holden	Within no-fly zone, outside WRA
2	Bangor	Line-transect	Vessel	SAIC	2007 & 2008	SAIC		A. Balla-Holden	Within no-fly zone, inside WRA
2	Bangor	Line-transect	Vessel	Bird/Marine Mammal	2012-2016	WDFW	S. Pearson	C. Kunz	Within no-fly zone, outside WRA
2	Bangor	Pile driving monitoring	Pier & Vessel	EHW2-Construction	2012-2014	Hart Crowser	J. Stutes	C. Kunz	Within no fly zone, Inside WRA
2	Bangor	Pile driving monitoring	Pier & Vessel	EHW1-Construction	2011-2012	Hart Crowser	J. Stutes	S. Rainsberry	Within no fly zone, Inside WRA
2	Bangor	Pile driving monitoring	Pier & Vessel	Barge Mooring-Construction	2014	Hart Crowser	J. Stutes	T. Nabors	Within no fly zone, Inside WRA
2	Bangor	Pile driving monitoring	Pier & Vessel	JP01-TPP-Construction	2011	HDR	K. Ampela	A. Balla-Holden	Within no fly zone, Inside WRA
2	Bangor	Haul-out counts	Pier	Haulout Counts	2008-2016	NAVFAC	NA	A. Balla-Holden	Within no fly zone, Inside WRA
2	Bangor	Monitoring during underwater detonation training	Vessel	NWTRC	2012-2015	NAVFAC	NA	A. Balla-Holden	Within no fly zone, outside WRA

Sub-region	Area Covered	Survey Type	Survey Platform	Survey Name	Dates	Surveyors	Contractor POC	Navy POC	Notes
3	Seabeck	Line-transect	Vessel	Keyport Baseline	2012	NAVFAC	NA	A. Balla-Holden	
3	Seabeck	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	
3	Seabeck	Line-transect	Vessel	Bird/Marine Mammal	2012-2016	WDFW	S. Pearson	C. Kunz	
3	Seabeck	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	
4	Dabob Bay to Teku Point	Line-transect	Vessel	Keyport Baseline	2012	NAVFAC	NA	A. Balla-Holden	Partial survey area
4	Dabob Bay to Teku Point	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	
4	Dabob Bay to Teku Point	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	
4	Dabob Bay to Teku Point	Line-transect	Vessel	Bird/Marine Mammal	2012-2016	WDFW	S. Pearson	C. Kunz	
5	Lilliwaup	Line-transect	Vessel	Keyport Baseline	2012	NAVFAC	N/A	A. Balla-Holden	
5	Lilliwaup	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	
5	Lilliwaup	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	
6	Great Bend	Line-transect	Aerial	JP02†/JP04†/KB05‡	2013-2016	SES	M. Smultea	A. Balla-Holden	
6	Great Bend	Haul-out counts	Aerial	JP02†	2013-2014	WDFW	S. Jeffries	A. Balla-Holden	

Key: † Contract N62470-10-D-3011; ‡ Contract N62470-15-D-8006; SES = Smultea Environmental Sciences; WDFW = Washington Department of Fish and Wildlife; WRA = Waterfront Restricted Area; NAVFAC = Naval Facilities Engineering Command.

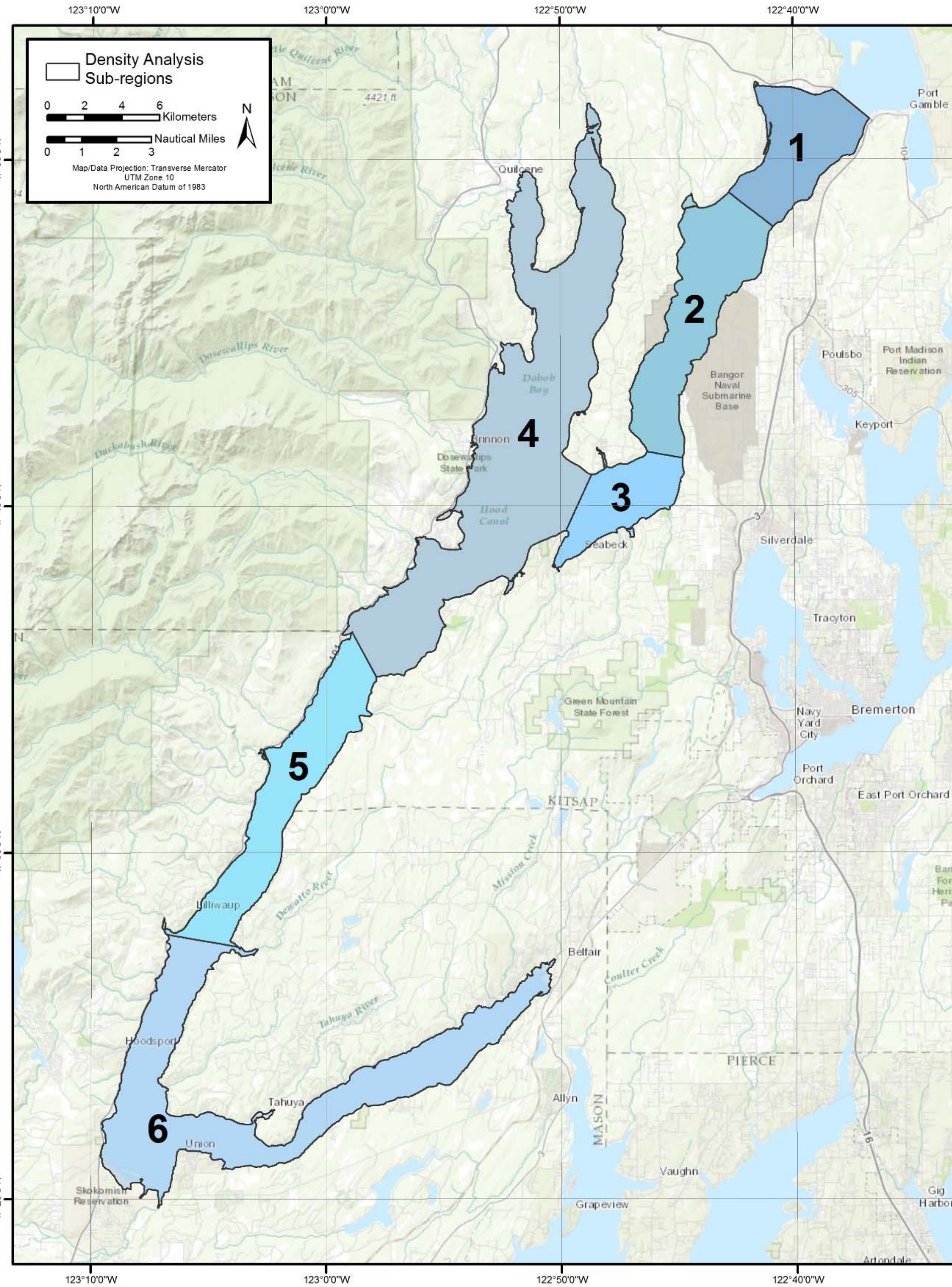

Figure 2. The six density analysis sub-regions. Sub-region 1: Hood Canal Bridge to Navigation Marker #8 and Marker #9; Sub-region 2: Area 1 to Hazel Point to Marker #11; Sub-region 3: Area 2 to Oak Harbor (Marker #12) to Misery Point (Marker #15); Sub-region 4: Area 3 to Trident Head (green Marker #9 to Teku Point); Sub-region 5: Area 4 to Lilliwaup Bay to Duwato Bay; Sub-region 6: Area 5 around the Great Bend to Belfair. Navigational markers correspond to those of NOAA chart 18476.

The Navy has funded several sets of monitoring surveys (aerial line-transect, vessel line-transect, and point-based) in this region; however, there is no comprehensive single survey of the region, due to the no-fly zone around Naval Base Kitsap at Bangor, as well as the presence of other restricted areas related to Navy activities. The resulting "patchwork" of monitoring data collected over the years was reviewed during the NMML-hosted workshop in October 2015 to determine which datasets were most appropriate to use for the analysis (**Table 1**).

Estimates were derived for the number of animals within the six pre-defined geographic sub-regions of Hood Canal, as identified by NMML (**Figure 2**). The sub-regions extend from the Hood Canal Bridge through the Great Bend at the southern extent of the Canal and were designated as follows (navigational marker locations correspond to those of National Oceanic and Atmospheric Administration (NOAA) chart 18476:

- *Sub-region 1:* Hood Canal Bridge to Navigation Marker #8 and Marker #9
- *Sub-region 2:* Area 1 to Hazel Point to Marker #11
- *Sub-region 3:* Area 2 to Oak Harbor (Marker #12) to Misery Point (Marker #15)
- *Sub-region 4:* Area 3 to Trident Head (green Marker #9 to Teku Point)
- *Sub-region 5:* Area 4 to Lilliwaup Bay to Duwato Bay
- *Sub-region 6:* Area 5 around the Great Bend to Belfair.

2. Assessment of Existing Datasets

Table 1 lists all existing Navy-funded line-transect and monitoring survey datasets in the region (at the time of the workshop), each of which provides at least partial coverage of Hood Canal. Twelve survey datasets were identified, which provided coverage of all six sub-regions using various survey methods. These included surveys conducted inside the no-fly zone (both inside and outside of the Waterfront Restricted Area [WRA]) and outside of the no-fly zone (see **Appendix C**). The U.S. Navy and its contractors submitted these datasets for consideration at the workshop.

3. Determination of Best Approach

As described above, the workshop group evaluated a variety of available datasets and identified two potential approaches to the analysis. One approach was to assess the proportional distribution of hauled-out harbor seals sighted within six sub-regions of Hood Canal. Following this approach, proportions of the total sightings within each sub-region would be applied to population estimates of harbor seals for Hood Canal to generate region-specific density estimates. Population estimates would be generated from aerial survey counts of harbor seals at the five major haul-out sites in Hood Canal: (1) Quilcene Bay, (2) Dosewallips, (3) Duckabush, (4) Hamma Hamma, and (5) Skokomish (London et al. 2012; Jeffries 2014). To estimate the proportion of harbor seals in the water, a correction factor would be applied to account for the proportion of animals not ashore while the aerial surveys were conducted.[1] An

[1] It should be noted that Hood Canal harbor seals are unusual, in that they have a higher tendency to haul out at high tide, whereas other harbor seal populations haul out mainly at low tide (London et al. 2012).

alternative approach involved using aerial line-transect survey data to derive densities of in-water harbor seals for each sub-region, since according to that survey methodology, only sightings of animals observed in the water are used for density estimation.

After reviewing the available datasets, along with the strengths and weaknesses of each, the workshop participants concluded that the best approach would be to use the HDR/Smultea Environmental Sciences (SES) aerial transect survey data, collected from 2013 to 2016, as the primary dataset to obtain in-water densities of harbor seals by sub-region in Hood Canal (see Smultea et al. 2015, 2017). This dataset provided a more direct method of obtaining densities in water. However, several key issues required attention:

1. The winter 2016 SES aerial survey data (which doubled survey lines in Hood Canal to increase effort) had to be incorporated into the final dataset and estimates.
2. The seals hauled out on any sand or substrate, which were included in the SES aerial dataset as "in-water" animals, had to be extracted for this analysis (for proper comparisons with haul-out counts).
3. An estimate of $g(0)$ had to be produced and incorporated into the analysis to account for seals that were unavailable to be detected during the surveys due to being on a dive.
4. Sub-region 2 was poorly represented in the aerial surveys (due to the presence of the no-fly zone P-51 around Naval Base Kitsap at Bangor [see **Appendix C**] with no aerial survey effort). Therefore, it was proposed that Washington Department of Fish and Wildlife (WDFW) small-vessel survey data from the no-fly zone off Bangor be evaluated to test the assumption that density of seals in Sub-region 2 can be considered uniform. If so, then the HDR/SES aerial survey could be used for calculating density in Sub-region 2.
5. As a test of the approach, a comparison would at some point be conducted to determine if the total harbor seal numbers, including seals hauled out (based on WDFW aerial survey haul-out counts and thus not counted on SES aerial surveys) is close to estimates of total stock size of seals in Hood Canal.

4. Materials and Methods

4.1 Treatment of Seals on Sand- or Mud-Flats in the Analysis

Line-transect analysis is seldom used to estimate density and abundance of pinnipeds, and most studies that use this method involve hauled-out seals on ice in high-latitude areas. There are numerous challenges in estimating numbers for amphibious species, such as pinnipeds, which move regularly between in-water and hauled-out locations. This situation is intensified for harbor seals in Puget Sound, which features a large number of sand- and mud-flats in the intertidal zone, and when used by harbor seals can blur the distinction between animals in water and those out of water.

We assumed that all seals encountered were in one of three categories:

1. "In-water" seals: seals largely submerged in the water (only head sticking out occasionally)
2. "Out-of-water" seals: seals "high and dry" on haul-out areas (islands, rocks, piers, submarines, etc.)
3. "Wet-belly" seals: seals lying on mud or sand flats partially submerged or with "wet bellies."

For this study, we were only concerned with harbor seals, and we had access to additional data from tagging studies to better understand the relative proportions of harbor seals that were in water versus out of water. Since the ultimate goal was to combine the line-transect in-water estimates with haul-out count data to estimate the total size of the Hood Canal harbor seal stock (the only marine mammal in the area with a NOAA stock specific to Hood Canal), we excluded seal sightings in the third category ("wet-belly" seals) from our density estimation of in-water animals. According to NOAA and WDFW haul-out count survey methodology, "wet-belly" seals are considered to be on land; therefore, we excluded this category in the current analysis to avoid potentially double counting these animals.[2]

4.2 Using Aerial Survey Data to Calculate Harbor Seal Density/Abundance in Water

Navy-funded aerial surveys were conducted to estimate in-water density and abundance of marine mammals in Hood Canal from 2013 to 2016 by SES (see Smultea et al. 2017 for detailed information on, and previous analyses of, these surveys). The revised 2016 survey lines in Hood Canal to double survey coverage for the January 2016 survey are shown in **Figure 3**. We used both Conventional Distance Sampling (also known as CDS) and Multiple Covariate Distance Sampling (also known as MCDS) methods to analyze the aerial survey data for estimating density and abundance of harbor seals (see Buckland et al. 2001; Marques and Buckland 2003, 2004). In order to ensure that the assumptions of line-transect methodology were met, the survey data were filtered with the following criteria used to extract data for the final line-transect analyses:

- Only data (e.g., sightings and effort) collected on systematic transect lines (i.e., data during transit and connector effort were excluded)
- Only data collected in Beaufort Sea States (BSS) 0–2
- Only data collected during conditions without significant glare issues (i.e., "hard" glare within which a marine mammal could not be seen, defined as occurring within over 30 percent of each of the three observers' fields of view [0 to 90 degrees left and right of the plane's nose and the belly window view] for over 3 minutes).

[2] Note that in a related report using the same aerial survey data (Smultea et al. 2017) pinnipeds with "wet bellies" were included in that density analysis because of differing methods and study objectives. The reader is referred to the methods section of that report for further details.

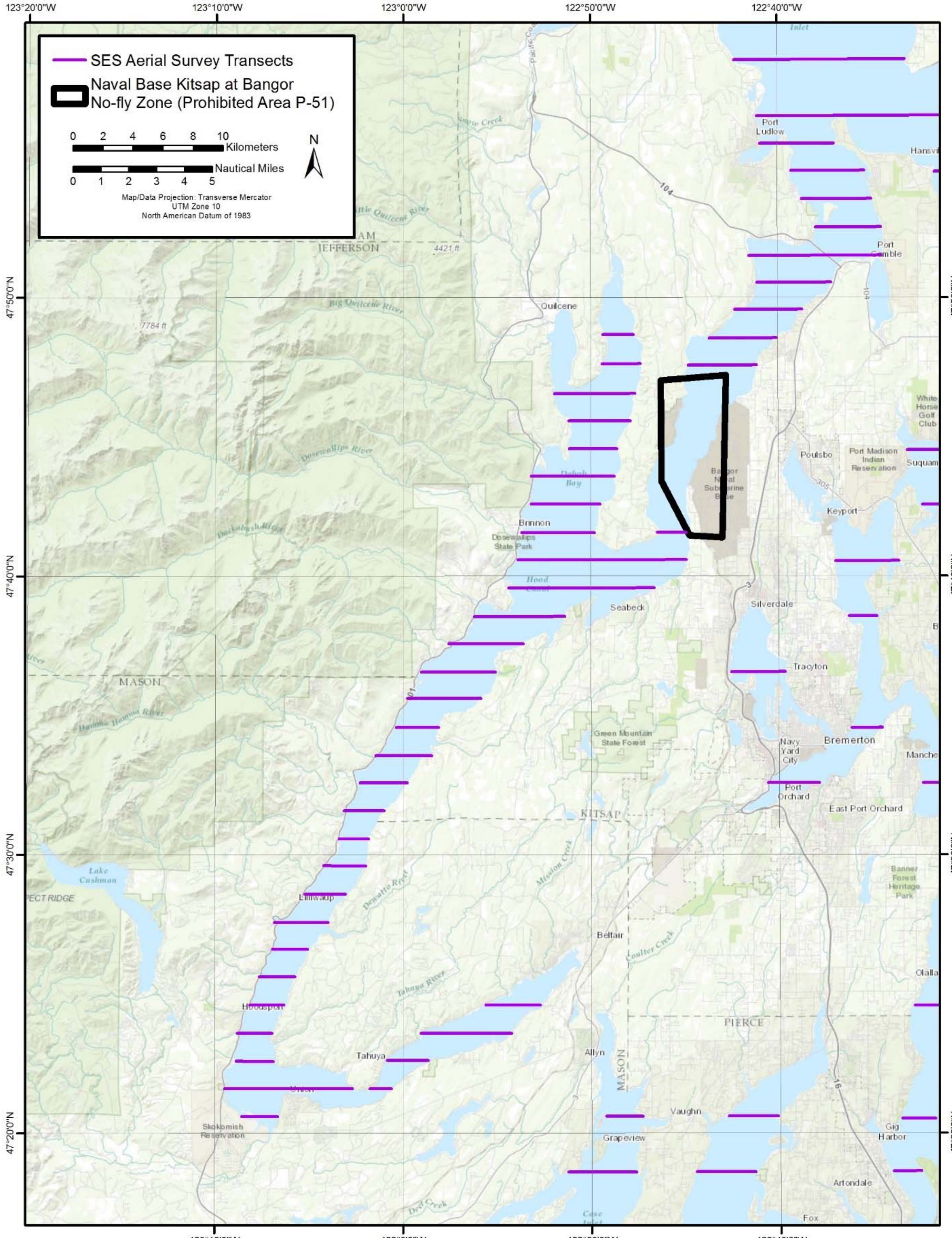

Figure 3. Map of Hood Canal, showing the SES revised aerial survey lines for the 2016 survey in purple. Black polygon is the no-fly zone (Prohibited Area 51) at Naval Base Kitsap at Bangor.

The filtered data were assembled into Microsoft Excel spreadsheets for preparation of the input files, which were analyzed using the software DISTANCE 6.2, Release 1 (see Thomas et al. 2010). Estimates of density and abundance (and their associated coefficients of variation) were calculated using the following standard line-transect formulae:

$$\hat{D} = \frac{n\ \hat{f}(0)\ \hat{E}(s)}{2\ L\ \hat{g}(0)}$$

$$\hat{N} = \frac{n\ \hat{f}(0)\ \hat{E}(s)\ A}{2\ L\ \hat{g}(0)}$$

$$C\hat{V} = \sqrt{\frac{\hat{\mathrm{var}}\,(n)}{n^2} + \frac{\hat{\mathrm{var}}\,[\hat{f}(0)]}{[\hat{f}(0)]^2} + \frac{\hat{\mathrm{var}}\,[\hat{E}(s)]}{[\hat{E}(s)]^2} + \frac{\hat{\mathrm{var}}\,[\hat{g}(0)]}{[\hat{g}(0)]^2}}$$

where *D* = density (of individuals),
n = number of on-effort sightings,
f(0) = detection function evaluated at zero distance,
E(s) = expected average group size (using size-bias correction in DISTANCE),
L = length of transect lines surveyed on effort,
g(0) = trackline detection probability,
N = abundance,
A = size of the survey area,
CV = coefficient of variation,
var = variance.

We produced estimates of density and abundance using the entire filtered dataset (i.e., all surveys and seasons) stratified by survey sub-region, and also produced overall pooled estimates (with the six sub-regions pooled). Although there were six sub-regions of interest (**Figure 2**), due to low sample sizes, sub-regions 1 and 2 had to be pooled for the analyses (resulting in only five sub-regions for the final analysis).

To avoid potential overestimation of group size, we used the size-bias-adjusted estimate of average group size available in DISTANCE, and the variance was calculated using the O2 method available in DISTANCE. To facilitate modeling, the Perpendicular Sighting Distance data were truncated to remove outliers and obtain the best model fit (with lowest CV). The optimal truncation distance was found to be 0.30 kilometer (km). We modeled the data with the half-normal (with hermite polynomial and cosine adjustments) and hazard rate (with simple polynomial and cosine adjustments) models. The model with the lowest value of Akaike's Information Criterion was selected for the final estimates. After conducting experimental analyses using conventional line-transect methods, and the use of several different covariates, we found the best model was obtained from an MCDS approach using the covariates BSS and percentage of cloud cover.

Trackline detection probability [*g(*0)] could not be directly estimated from the data collected in this study, because we did not conduct diving experiments nor use independent observers. Instead, we made use of harbor seal time/depth recorder data from a study provided by K. Wilson (NMML, unpublished data), which were collected from the San Juan Islands area just north of our study area (more information on that study can be found in Wilson et al. 2014). We estimated the trackline detection probability (availability bias portion only) as:

$$\hat{g}(0) = \frac{s+t}{s+d}$$

where *g*(0) = trackline detection probability,
s = average length of time spent at or near the surface,
t = window of time in which aerial observers could detection the animals (10 sec),
d = average dive duration.

Dive and surface times were compiled from the Wilson et al. (2014) dataset. The data were filtered to exclude periods longer than 10 min, as indications are that dives durations longer than 10 minutes are rare, and surface times over 10 minutes may be indicative of seals hauled out (see Suryan and Harvey 1998). Note that there are some potential biases in the data (such as a possible bias resulting from the fact that dives shallower than 5 m were not recorded as dives). However, this dataset provided the most relevant available data for calculation of trackline detection probability for Hood Canal harbor seals.

The resulting estimate of *g(*0) was 0.204, with a standard error of 0.2415. Due to the large variability in dive and surface times, this parameter had a very large variance associated with it (CV=118.0%). So in presenting results, the coefficient of variation that incorporates this variance factor (denoted simply as CV) is provided, as well as the CV that does not include this variance factor (since it was obtained from a study that was not part of the aerial survey project, we call this latter factor CV′).

4.3 Estimating Seasonal Density and Abundance

To obtain seasonal estimates of density and abundance by sub-region, we developed a "seasonal index" corresponding to the proportion of individual seals observed in each season during aerial surveys. We then used this seasonal index as a multiplier to develop the density and abundance estimates by season and sub-region. We used a "marginal model" which assumes that season and sub-region are independent, since analyzing the data by sub-region and then season would have resulted in 16 strata, and there were insufficient numbers of observations in each stratum to proceed with this approach. Seasons were defined as winter (December through February), spring (March through May), summer (June through August), and autumn (September through November).

5. Results and Discussion

5.1 Using Aerial Survey Data to Calculate Seal Density/Abundance in Water

The final estimates of density and abundance were made using MCDS, with the covariates BSS and percentage cloud cover. The chosen model was the half-normal model, with a cosine adjustment (**Figure 4**). The effective strip width was 0.209 km (CV=2.58%). The final estimates of density and abundance for the five sub-regions and the overall study area, along with their relevant components, are presented in **Table 2.** Estimated abundance within the five analyzed sub-regions ranged from 85 to 1,142 seals. The pooled overall (in-water) abundance estimate for Hood Canal was 2,009 seals (CV=118.6%, CV′=6.9%).

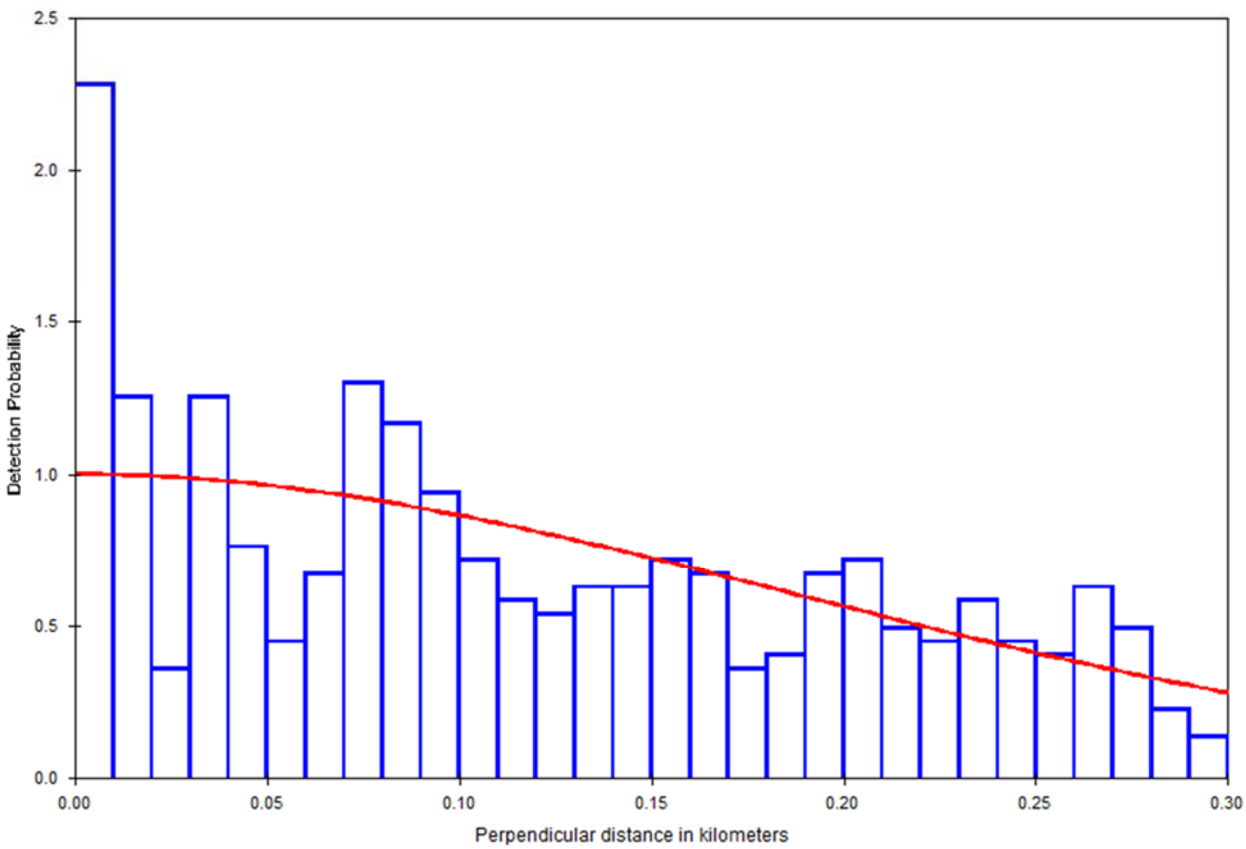

Figure 4. Perpendicular distance histogram and fitted detection function (a half-normal model, with a cosine adjustment).

Table 2. Harbor seal line-transect parameters and estimates of in-water density and abundance for Hood Canal.

Stratum	No. Stgs.*	Effort (km)	Avg. Grp. Sz.	Trackline Detection Prob. – *g*(0)	Individual Density (#/km^2)**	95% CI (Density)	Abundance**	95% CI (Abundance)	% CV	% CV'
Sub-regions 1,2	13	133.8	1.2	0.204	1.16	0.75-1.78	85	55-131	120.3	21.3
Sub-region 3	38	73.7	1.2	0.204	5.93	3.62-9.71	120	73-196	120.6	23.4
Sub-region 4	308	433.1	1.2	0.204	8.77	7.22-10.67	1,142	939-1,389	118.8	9.4
Sub-region 5	71	168.1	1.2	0.204	5.45	3.77-7.89	235	162-340	119.6	17.2
Sub-region 6	100	238.3	1.2	0.204	5.38	4.24-6.84	427	336-542	118.9	11.3
Overall Pooled	530	1,047.0	1.2	0.204	5.80	5.05-6.66	2,009	1,750-2,308	118.6	6.9

* Before truncation; **In-water animals only; does not include hauled-out animals.

It was desirable to produce stratified estimates of density and abundance for sub-regions 1 and 2 (and it was not possible to do this from the aerial survey data alone). Therefore, we used harbor seal sighting rates recorded during the WDFW marbled murrelet vessel surveys as a factor to allocate the pooled estimates from the aerial surveys into the two sub-regions of interest. The resulting estimates are: Sub-region 1, D=0.97 seals/square kilometer (km^2), N=30; Sub-region 2, D=1.34, N=58.

5.2 Seasonal Density and Abundance

The results of the analysis of seasonal density and abundance are shown in **Table 3**. Highest density and abundance were in spring, and lowest were in winter.

Table 3. Harbor seal seasonal estimates of individual density and abundance for Hood Canal.

Season	Seasonal Index	Density (#/km2)					Abundance				
		SR 1/2	SR 3	SR 4	SR 5	SR 6	SR 1/2	SR 3	SR 4	SR 5	SR 6
Winter	0.6300	0.73	3.74	5.53	3.43	3.39	54	76	719	148	269
Spring	1.4129	1.64	8.38	12.39	7.70	7.60	120	170	1,614	332	603
Summer	1.2458	1.25	7.39	10.93	6.79	6.70	106	149	1,423	293	532
Autumn	0.7112	0.82	4.22	6.24	3.88	3.83	60	85	812	167	304
	%CV'	21.3	23.4	9.4	17.2	11.3	21.3	23.4	9.4	17.2	11.3

5.3 Estimating Total Stock Size

The analysis described above indicates that, on average, approximately 2,000 harbor seals occur in Hood Canal. Note that these are in-water estimates only and do not represent estimates of total stock size (which includes an unknown hauled-out component). Washington

State harbor seal stocks have generally increased since hunting bounties ended in 1960, and the Marine Mammal Protection Act came into effect after 1972 (Jeffries et al. 2003). However, the current size of the Hood Canal stock has not been presented by NMFS, as there are no official stock size estimates available from the last 14 years. Stock size was estimated to be 1,088 seals in 1999 (Carretta et al. 2015), and was thought to be relatively stable at 1,068 seals in 2002 (London 2006). Based on existing evidence, it is thought to have increased since that time (S. Jeffries, WDFW, pers. comm.), and the current stock size is probably much higher than it was in 2002.

It should be kept in mind that there are challenges in integrating in-water survey data (such as that used in this analysis) with data from more traditional haul-out count surveys in order to estimate the current total stock size for Hood Canal harbor seals. One cannot simply add the in-water estimates produced here to aerial survey haul-out counts, since aerial surveys focusing on "in-water" animals are performed randomly with respect to tide, and pinniped haul-out surveys are typically timed to occur at low or high tide. These different methodologies affect the proportion of seals hauled out and therefore available for observation.

6. Conclusions

This study has produced the first estimates of the density and abundance of harbor seals in Hood Canal waters, stratified by sub-region. These numbers represent an average for all four seasons and for different times of day (excluding nighttime hours). The overall estimate of 2,009 seals (CV′=6.9%), however, should not be considered a stock size estimate, as it does not include a correction for the number of seals hauled out during the aerial surveys.

In practice, determining the number of seals hauled out any given time is quite difficult, as Hood Canal harbor seal haul-out behavior is complex, not well correlated with environmental cycles, and often affected by unpredictable human disturbance factors. The estimates for different sub-regions of the Hood Canal study area provide information that may be useful to the U.S. Navy in estimating incidental exposures of harbor seals from naval activities that involve potential in-water acoustic disturbance (e.g., use of sonar, pile driving, and other marine construction activities).

For the purposes of this analysis, it was necessary to pool data from sub-regions 1 and 2 due to small numbers of seal observations in those areas (especially Sub-region 2, where the "no-fly" zone is located). However, it may be possible to develop separate estimates for these sub-regions in the future. The best option for doing this would be to collect additional data in the areas where there are few data available at present, in order to increase sample sizes and evaluate potential trends. It would also be worthwhile to develop more precise estimates of trackline detection probability [$g(0)$], if appropriate data can be identified. Additional work is also needed to better integrate "in-water" surveys (usually performed randomly with respect to tide), and "on-land" pinniped haul-out surveys (usually timed with a particular tide level).

7. Acknowledgements

This project was funded by Commander, U.S. Pacific Fleet. Many people assisted with this work in various ways, and/or provided data and information essential for its completion. We appreciate the assistance of all those who attended the October 2015 workshop hosted by NMML (see **Appendix B**). We owe special thanks to the SES aerial survey crew for their efforts in collecting and processing these data (D. Steckler and G. Campbell deserve special mention). K. Wilson provided dive and surface time data collected under National Science Foundation award #0550443. S. Jeffries of WDFW, and R. DeLong and J. London of NMML were helpful in organizing the Seattle workshop, and in providing much useful information and data relating to their previous work on harbor seals in Washington. J. Laake provided very helpful suggestions on statistical analysis throughout. Our Navy contacts, R. Uyeyama (Naval Facilities Engineering Command [NAVFAC] Pacific), and A. Balla-Holden (U.S. Pacific Fleet) also assisted in many aspects of this process.

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A

Workshop Agenda

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Appendix A. Workshop Agenda (Workshop Held on 15 and 16 October 2015 at the National Marine Mammal Laboratory, Seattle, WA).

Workshop on harbor seal abundance and density in Hood Canal, Washington

Location: National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, Bldg. 4, 7600 Sand Point Way, NE, Seattle, WA, NMML Conference Room 2039

Time: 15 October 2015 1000 to 1700

16 October 2015 0900 to 1530

15 October

1000 Welcome, our charge and introductions (Bob DeLong)

1010 Why is harbor seal abundance and density of importance to the Navy? (Andrea Balla-Holden)

1030 What is HDR's responsibility to the Navy re: harbor seal densities in Hood Canal? (Kristen Ampela)

1045 What is different about harbor seal biology in Hood Canal that requires unique treatment of survey data to assess abundance? (Josh London and Steve Jeffries)

1115 Why have we chosen six areas within Hood Canal where we will estimate abundance and densities? (Steve Jeffries and Andrea Balla-Holden)

1130 Harbor seal aerial photo surveys 2000 to 2014 available for Hood Canal abundance estimates (Steve Jeffries)

1150 Aerial survey correction factors for Hood Canal aerial surveys (Josh London)

1215 Lunch (NOAA Cafeteria)

1320 Abundance estimates (Steve Jeffries)

1330 Variance estimation procedures for abundance estimates (Tom Jefferson and Jeff Laake)

1400 Harbor seal vessel and aerial transect data in Hood Canal (Kristen Ampela and Andrea Balla-Holden)

1420 Description of surveys within "No-Fly Zone" 2007–2011 survey methodology, effort, sighting data (Kristen Ampela)

1450 Description of HDR Hood Canal and Dabob Bay (Outside No-Fly Zone) vessel survey 2011: survey methodology, effort, sighting data (Kristen Ampela)

1515 Break

1530 Hood Canal and Dabob Bay (Outside No-Fly Zone) 2013, 2014 and 2015 SES aerial line-transect surveys: survey methodology, effort, sighting data (Mari Smultea)

1610 Hood Canal Navy vessel-based line-transect survey – 2012: Survey methodology, effort and geographic coverage, sighting data (Andrea Balla-Holden)

1630 Hood Canal area around Bangor WDF&W vessel line-transect sea bird surveys 2012–2015: survey methodology, effort/geographic coverage, sighting data (Scott Pearson)

1700 Adjourn

<u>16 October</u>

0900 Summary of day one overview (Bob DeLong) and discussion

0940 Which transect survey data are likely to be most useful in assessing proportion of seal population in each geographic area?

1000 Useful variance estimation procedures for proportions of seals in geographic areas

Other Data Sets:

1020 Navy pinniped haul-out data at Bangor (2009–2015) (Andrea Balla-Holden)

Bangor Pile driving monitoring data:

1040 2011 Test Pile – HDR (Kristen Ampela)

1100 EHW1 (2011, 2012) HDR (Kristen Ampela)

1120 Break

1140 EHW2 (2012, 2014) Hart Crowser (Andrea Balla-Holden)

1200 Barge Mooring (2014) Hart Crowser (Andrea Balla-Holden)

1200 Discussion of utility of non-line transect data for accomplishing goal

1220 Lunch (NOAA Cafeteria)

1320 Tasks Remaining to prepare data for analysis:

1320 Vessel and aerial survey data

1350 Harbor seal abundance estimates: variance estimates

1430 Other details on how we proceed to estimate the abundance and density of harbor seals within the six geographic areas of Hood Canal

1530 Adjourn

B

Workshop Participants

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Appendix B. Workshop Participants (Workshop Held on 15 and 16 October 2015 at the National Marine Mammal Laboratory, Seattle, WA).

- Kristen Ampela, HDR, Inc.
- Andrea Balla-Holden, U.S. Navy, Pacific Fleet
- Robert DeLong, National Marine Mammal Laboratory, NMFS
- Harriet Huber, National Marine Mammal Laboratory, NMFS
- Thomas A. Jefferson, Clymene Enterprises
- Steve Jeffries, Washington Department of Fish and Wildlife
- Jeff Laake, National Marine Mammal Laboratory, NMFS (via telephone)
- Dyanna Lambourn, Washington Department of Fish and Wildlife
- Josh London, National Marine Mammal Laboratory, NMFS
- Scott Pearson, Washington Department of Fish and Wildlife
- Mari A. Smultea, Smultea Environmental Sciences
- Phil Thorson, SAIC (via telephone)
- Robert Uyeyama, U.S. Navy, NAVFAC Pacific

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C

Survey Effort at Naval Base Kitsap at Bangor and Associated No-Fly Zone

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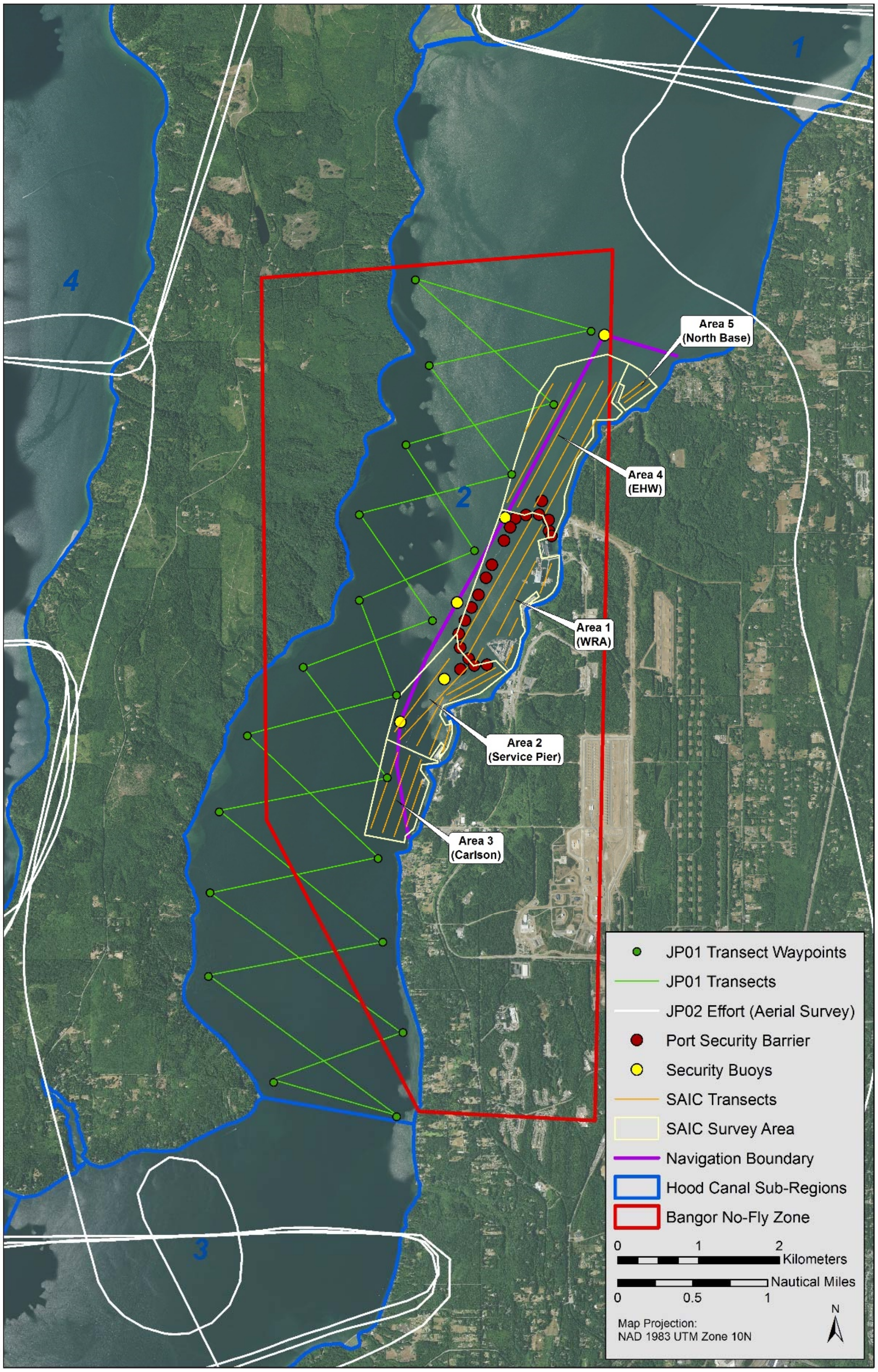
Appendix C. Survey Effort at Naval Base Kitsap at Bangor and Associated No-Fly Zone.



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