OCS Study
BOEM 2017-017

Marine Arctic Ecosystem Study—
Pilot Program: Marine Mammals Tagging and Tracking

US Department of the Interior
Bureau of Ocean Energy Management
Alaska Region

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Disclaimer

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Report Availability

To download a PDF file of this Marine Arctic Ecosystem Study—Pilot Program: Marine Mammals Tagging and Tracking report, go to the US Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program Information System website and search on OCS Study BOEM 2017-017.

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Abbreviations

BOEM	Bureau of Ocean Energy Management
DCDD	Depth Corrected Dive Duration
CTD	Conductivity, Temperature, Depth
DIC	Deviance Information Criterion
MARES	Marine Arctic Ecosystem Study
NSB	North Slope Borough
ONR	Office of Naval Research
SMRU	Sea Mammal Research Unit
TAD	Time Allocated at Depth

1.0 CHAPTER 1—OVERVIEW

1.1 BACKGROUND

The Department of the Interior, Bureau of Ocean Energy Management (BOEM) and its partners seek to advance knowledge of the Arctic marine ecosystem. The Marine Arctic Ecosystem Study (MARES) stems from increased attention on climate change, energy development, and related sustainability issues in the Arctic region. Results from this study are intended to inform government, industry, and communities on regulatory needs, operational challenges, and resource management and provide important context for economic development, environmental protection, sustainability of local communities, and health and safety.

The initial focus of MARES was the US and Canadian Beaufort Sea from Utqiaġvik (formerly Barrow), to the McKenzie Delta, but subsequent modifications focused the study on the eastern Beaufort Sea shelf only from Kaktovik to the McKenzie Delta coastline to a depth of 1,000 m. The overarching scientific goal of MARES, as initially envisioned, was to increase our understanding of the impact of physical drivers (ocean, ice, atmosphere) on the trophic structure and function of the marine ecosystem on the Beaufort shelf with special attention on the implications on marine mammals and local communities. The intent was to implement an integrated, multidisciplinary study combining retrospective analyses, field studies, modeling, and synthesis spanning atmosphere, ice, physical, chemical, and biological oceanography from benthos to fish, marine mammals, and people.

1.2 MARINE MAMMAL PILOT PROGRAM PURPOSE AND GOAL

One of the first components of the overall study was a marine mammal tagging and tracking pilot program funded through the National Ocean Partnership Program by BOEM, Shell, and the Office of Naval Research. Started in 2015, the pilot program was funded with a one-year field season focused on refining capture, tagging, and data collection methods and developed as a precursor to a larger-scale two-year marine mammal field program that would focus on habitat use patterns and impacts of changes to the marine ecosystem. Subsequent cancelation of the main marine mammal field program, however, prompted a detailed data analysis of pilot program results as a stand-alone product. That analysis forms the basis of this report.

Thus, this report constitutes the final technical report (replacing deliverable 5.0 K—Synthesis Report) for the work performed under task order M15PD00015 or "Task Order 2" which falls within the broader scope of ID/IQ contract M14PC00008.

1.3 APPROACH

Stantec partnered with the North Slope Borough's (NSB) Department of Wildlife Management to develop and refine capture and tagging methods for studying habitat use by Arctic marine mammals. The NSB already was tagging spotted seals in an effort funded through the NSB-Shell Baseline Studies Program and permitted by the National Marine Fisheries Service through the Alaska Department of Fish and Game. They also had existing relationships with local seal and whale hunters throughout the region. Therefore, we combined field efforts with the NSB to avoid overlap and capitalize on synergies and existing relationships. MARES investigators conducted all data analyses and reporting.

1.4 OBJECTIVES

Specific initial objectives for the marine mammal pilot program were to:

1. Establish relationships within the Native Alaska communities where tagging was to take place
2. Test instrumentation, sensors, and tag communication protocols
3. Capture and tag seals and belugas
4. Refine capture and tagging methods, tag deployment, and data recovery

We also added:

5. Analyze tag data and—to the extent possible—infer movement and habitat use patterns
6. Determine whether oceanographic data collected *in situ* by tags attached to diving seals could be used to characterize water conditions in which seals preferentially forage

Chapter 2 summarizes efforts and findings related to objectives 1–4. Chapters 3 and 4 address objective 5 by presenting results of the analysis of tagging data with respect to surface movements and dive behavior, and Chapter 5 addresses objective 6 by examining the environmental parameters collected. Chapter 6 summarizes the main conclusions from Chapters 2 to 5.

2.0 CHAPTER 2—STUDY DESIGN AND IMPLEMENTATION

This chapter summarizes efforts and findings related to objectives 1–4. Specifically, this chapter details information on community consultations, permits required, tags, and capture methods and locations.

2.1 COMMUNITY CONSULTATIONS

Feedback on the marine mammal tagging component of MARES—including species of interest and proposed capture and tagging locations—was received during community consultations during the fall and winter of 2014/15. Stantec and NSB researchers consulted with the communities of Point Lay, Wainwright, and Utqiaġvik, and with the NSB Department of Wildlife Management and the Ice Seal Committee. Based on community feedback and taking advantage of ongoing marine mammal tagging efforts, seals were tagged in the northern Chukchi Sea and around Utqiaġvik. In anticipation of increasing overlap with the MARES' eastern Beaufort Sea field efforts in 2016 and 2017, Stantec also consulted with the Kaktovik City Council, the Kaktovik Village Council, the Inuvialuit Game Council, and the Fisheries Joint Management Council. A summary of consultation meetings is provided in Appendix I.

Support for seal studies was received from all groups, with the Kaktovik Village Council passing a motion to support seal tagging studies in their area. Some members of the Ice Seal Committee expressed interest in expanding seal tagging efforts farther south in the Chukchi Sea. Some concerns were expressed regarding belugas, and it was agreed that any beluga tagging effort would only occur in conjunction with existing NSB plans in Point Lay and not as part of a separate effort.

Following these consultations and discussions with partners, the Marine Mammal Tagging and Tracking Pilot Program focused on catching and tagging beluga whales (*Delphinapterus leucas*), bearded seals (*Erignathus barbatus*), and spotted seals (*Phoca largha*) between Point Lay and Dease Inlet (Figure 1).

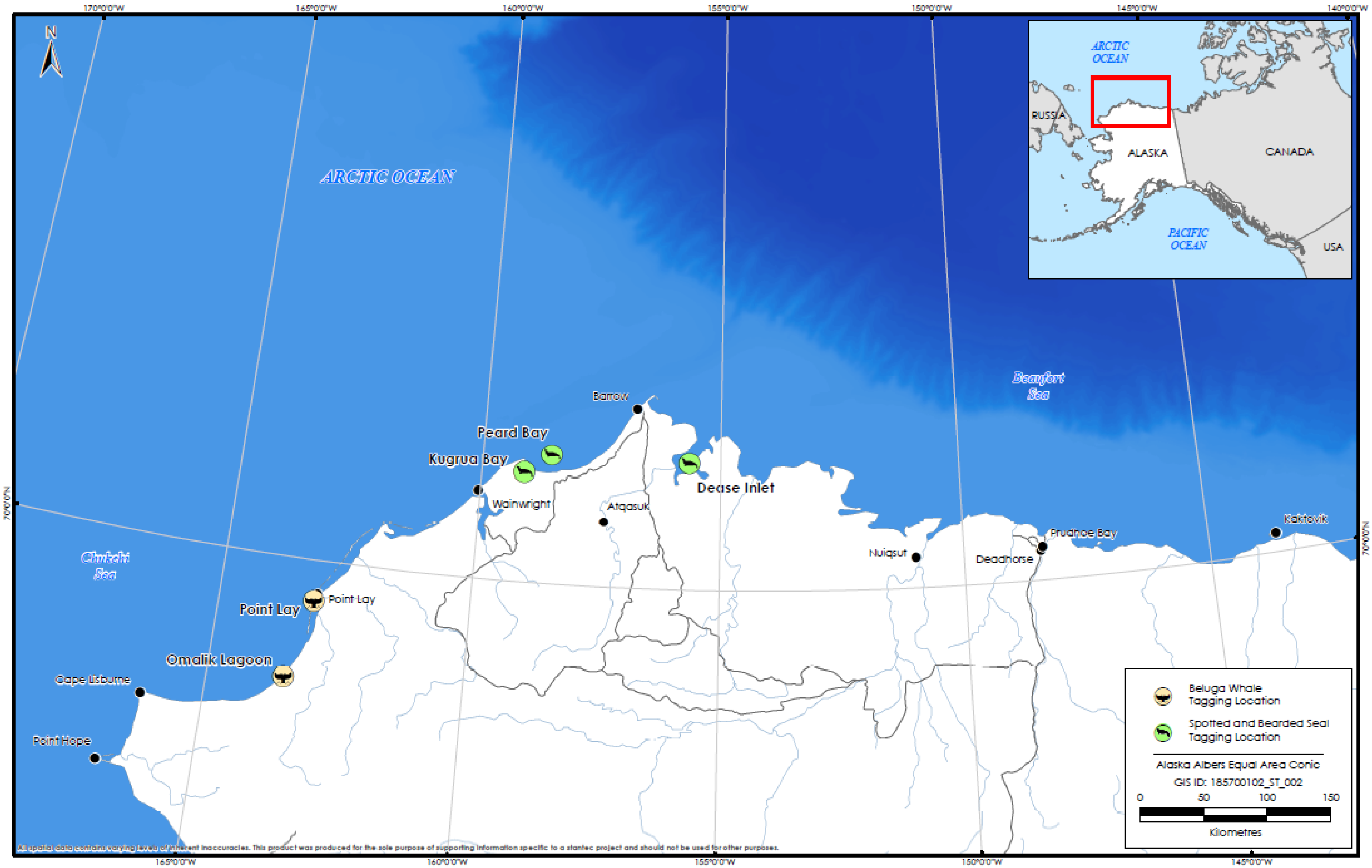

Figure 1 Map of study area with planned tagging locations for seals and belugas

Follow-up meetings were initially planned for Point Lay, Utqiaġvik, Kaktovik, and the Alaska Native Organizations and co-management groups (e.g., Ice Seal Committee, Beluga Whale Committee), as well as with Tuktoyaktuk, Inuvik, and Aklavik, and Canadian First Nations organizations (e.g., Hunters and Trappers Associations, Inuvialuit Game Council, Fisheries Joint Management Council). These meetings were to occur prior to and after the main tagging program in 2016 and 2017. Due to the cancelation of the main field program and the failed beluga tagging effort (see Section 2.3.2 below), follow-up meetings were only conducted in Utqiaġvik and with the NSB in the summer of 2016 and with the Ice Seal Committee at their annual meeting in Anchorage in June 2016. The preliminary results presented at the time, which were mostly focused on movements depicted as sequential surface locations and inferred foraging and transiting, were well received and much interest was expressed by the NSB to continue these collaborative efforts with Stantec in the future.

2.2 TEST INSTRUMENTATION, SENSORS, AND TAG COMMUNICATION PROTOCOLS

We sought to extend knowledge of important foraging areas of Arctic marine mammals, expanding on previous movement data (e.g., Lowry et al. 1998; Suydam et al. 2001; Boveng and Cameron 2013; Martinez-Bakker et al. 2013), by using animal-borne sensors—Sea Mammal Research Unit (SMRU) Conductivity, Temperature, Depth (CTD)-fluorometer tags. These tags weigh approximately 680 g, measure 11.5 x 10 x 4 cm, and record water temperature, salinity, and fluorescence (a proxy for chlorophyll-a) (Figure 2). The SMRU tags transmit—via ARGOS satellites—the animals' locations (including location uncertainty as classified by ARGOS, CLS 2016), dive profiles, and water characteristics.

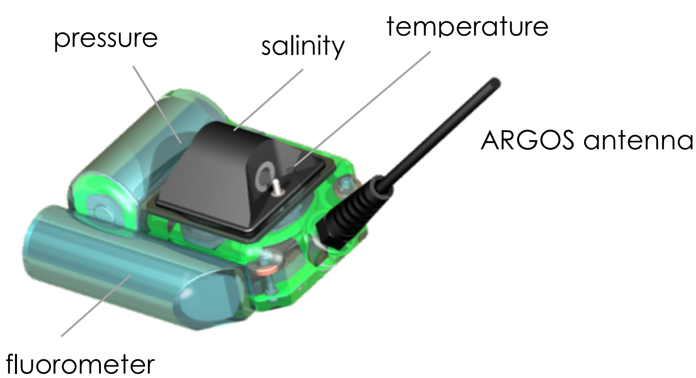

Figure 2 Artist rendition of SMRU CTD-Fluorometer Tag with sensor labels (SMRU 2016)

Location and dive date were transmitted when the animal was at the surface and the SMRU tags connected to the ARGOS satellite (up to 10 times a day at this latitude). Dive recording started when sensors were wet for 8 seconds and deeper than 1.5 m. Dive shape was transmitted using the broken stick algorithm (Fedak et al. 2001) resulting in four inflection points describing the shape of the dives.

Oceanographic data were transmitted only for the deepest dive within every 12-hour period (Photopoulou et al. 2015) to increase tag longevity and address bandwidth limitations when transmitting data. Data were collected on ascent with a 10-m delay; i.e. collection only started once animals were 10 m off the bottom and ascending to prevent data collection during what could be time at the bottom of the dive. If dives were less than 10 m, no oceanographic data was collected. Once activated, CTD and fluorometer sensors sampled the water column every second. Eighteen points from the dive were transmitted via satellite: 14 evenly distributed between the minimum and maximum depth (-10 m), and 4 standard points, namely minimum and maximum depth, and minimum and maximum temperature. The high resolution CTD/Fluorometry measurements and dive profiled information were stored on the tag and could be downloaded in the unlikely event that a tag should be retrieved (e.g., by hunters). Data were accessible in near-real time (typically within a few hours of transmission) via the password protected SMRU online system.

The pilot project was intended to field-test the tag communication protocols and the efficacy of CTD-fluorometer tags for determining habitat selection by ice seals and belugas. Chapters 3 to 5 detail the usefulness of these tags for determining habitat use. In relation to sensors protocols, however, we note the following recommendations:

- To provide a more accurate characterization of vertical movement, more than four inflection points should be incorporated into the broken-stick algorithm. Discussion with the manufacturer should take place to determine the trade-off between increasing inflection points while still considering battery life and satellite transmission requirements.
- To better characterize vertical habitat use, the algorithm that only starts to record profiles once the seal is 10 m above their maximum dive depth and returning to the surface should be amended. Although the current protocol safeguards that oceanographic data are not collected while the seal is still at the bottom of the dive—and recognizing these data take up much of the storage and battery life—it would be beneficial to have oceanographic data associated with the bottom of dives. Trade-offs between minimum dive depth and data storage and transmission should be discussed with SMRU.

Discussion with SMRU regarding some of these points started but were halted when the main field program was canceled.

2.3 CAPTURE AND TAGGING

2.3.1 Permitting

Seal and beluga whale tagging was authorized under National Marine Fisheries Service permits No. 15324-01 and 14610-04, respectively, held by Alaska Department of Fish and Game. Additional authorizations were provided by ONR. Procedures for capture and handling of animals followed permit specifications and the Alaska Department of Fish and Game Institutional Animal Care and Use Committee permit submitted to BOEM and ONR.

2.3.2 Beluga Whales

As part of the collaborative efforts between Stantec and the NSB, the NSB team planned to capture and tag beluga whales in conjunction with the summer subsistence hunt at Point Lay, Alaska. Past tracking by the NSB showed that whales tagged at Pt. Lay travelled into the eastern Beaufort Sea (Suydam et al. 2001), suggesting that continued focus on belugas in this region could provide movement and environmental data within the eastern Beaufort Sea MARES study area.

Capture and tagging of beluga whales in Point Lay depends on the subsistence hunt in which whales are driven into shallow lagoons. Some of those whales are not harvested and are available for tagging with the aid of local hunters.

Tagging was planned for early July 2015, the time of year when beluga whales historically migrate through this area of the Chukchi Sea (Frost and Lowry 1990). Unfortunately, and to the great surprise of hunters and the local community, the belugas migrated past Point Lay 2.5 weeks earlier in 2015 than at any time in the previous 25 years (per traditional knowledge). Consequently, the belugas migrated past the study location before the team was mobilized. The team subsequently travelled south to Omalik Lagoon (Figure 1) to search for beluga whales, but none were sighted. Additional plans to tag beluga whales later in the summer near Utqiaġvik were abandoned when a dead beluga, which had been tagged a decade earlier, washed up in Cook Inlet with signs of necrosis around the tag attachment site, prompting concerns about the impacts of tagging. Based on these events and the cancelation of the main MARES marine mammal tagging program, efforts to tag beluga whales were halted and are not discussed further in this report.

2.3.3 Seals

Tagging focused on concentrations of seals accessible from Utqiaġvik. Spotted seals were tagged in mid- to late-August 2015, while bearded seals were tagged at the end of August, based on local knowledge of movements by juveniles into inlets and rivers at that time of year (Burns 1981).

Seals were captured using tangle nets deployed from a vessel or from the shore. The nets (50 m long by 8 m deep) were made from braided monofilament, 20 cm mesh size with a light lead line so that entangled seals could easily surface to breathe (Figure 3). Once the net was deployed, the vessel moved away from the immediate area, and the tagging crew monitored the net continuously. Entangled seals were measured, weighed, and tagged on board the vessel or on shore. Approximate straight and curvilinear lengths (cm) were recorded, along with the hip, maximal, and auxiliary girth. Weight (kg), was obtained using a hanging spring scale. Seals were restrained manually and with a hoop net. Visual signs of stress (e.g., changes in breathing rate) were monitored during handling. The seals' eyes were covered with fabric during handling to reduce stress. Tagging was conducted in an efficient manner to minimize handling time and expedite release of the animal. No sedation was used during handling.

Figure 3 Tangle net used for bearded and spotted seal captures
(Photo by Rowenna Gryba)

Each seal was fitted with a SMRU CTD-fluorometry ARGOS satellite tag (Figure 4), which was attached with five-minute epoxy to the hair between the shoulder blades. This method of attachment allows for the tags to be shed during the subsequent spring molt. As part of the NSB tagging program, a “smart position and temperature” (SPOT) tag was also attached through the webbing of the hind flipper. We only report data from the CTD-fluorometer tags herein; data from the SPOT tags will be reported by the NSB. Tagged seals were released at the capture location, typically within one hour of capture.

Figure 4 Spotted seal with CTD-fluorometer tag
(Photo by Rowenna Gryba)

2.3.4 Refining Capture and Tagging Methods

One of our objectives was to document and subsequently implement lessons learned during capture and tagging during this program. We expanded this concept by also organizing and leading a workshop on seal capture, handling, and tagging methods at the Society of Marine Mammalogy Biennial Conference on December 12, 2015. The workshop provided an opportunity for researchers from around the world to share methods and best practices in field studies of polar seals. A summary of the discussion is provided in Appendix II.

Several insights gained during the capture and tagging efforts can inform future efforts:

- Restraining seals in hoop nets lessened the likelihood of escape during transits to shore
- Bearded seals were available for capture in Dease Inlet and within rivers in the area
- Juvenile bearded seals were easily handled and tagged without need of anesthesia
- Based on local knowledge of animal movement and availability for capture in the vicinity of Utqiaġvik, Alaska, there are likely two good time periods for tagging bearded seals in the future: early summer (June) and late summer (August)

3.0 CHAPTER 3—BEARDED AND SPOTTED SEAL FORAGING INFERRED FROM SURFACE MOVEMENTS

3.1 INTRODUCTION

Spotted and bearded seals are ice-associated pinnipeds and typically classified as pelagic and benthic foragers, respectively (Burns 1981; Stirling et al. 1982; Bukhtiyarov et al. 1984; Kingsley et al. 1985; Dehn et al. 2007). Based on their preferred foraging zones, it can be assumed that the two species target different regions and/or specific locations in the Arctic for foraging. Conversely, at a regional scale, surface movements during certain times of the year may be similar across species and related to general environmental conditions such as the location of the ice edge or the overall productivity of a region, but at a finer scale, movement patterns may reflect foraging activities. Movement data—collected via satellite tags—can be used to infer foraging and transiting through Bayesian state-space modeling (e.g., Jonsen et al. 2005).

Previous tracking studies have reported movements and regional habitat use by spotted and bearded seals. Satellite-linked transmitters were used to identify sequential haul-out locations of spotted seals (Lowry et al. 1998). Boveng et al. (2013) used state-space modeling to describe regional trends in resting, foraging, and transiting by bearded seals tagged in Kotzebue Sound. The frequencies of those behaviors differed between bearded seals that migrated through the Chukchi/Beaufort Sea and those that remained in the northeast Chukchi Sea. McClintock et al. (2015) coupled the same bearded seal data with satellite tracks of Hawaiian monk seal (*Monachus schauinslandi*) to explore approaches to correcting ARGOS location errors. Although those studies provided valuable information on spotted and bearded seal movements, they could not describe habitat at a fine scale. McClintock et al. (2017), however, elaborated on their analysis of bearded seal movements to expand beyond differentiating foraging from transiting. Their approach identified additional behaviors by combining data on location, diving, land cover, bathymetry, and sea ice cover.

The analysis presented in this chapter focused on whether surface movements—based on successive locations when animals surface—can indicate foraging hotspots and, if so, whether foraging can be inferred from surface movements for animals feeding mainly in the water column (spotted seals) and those feeding primarily on the bottom (bearded seals). We used state-space models to determine when and where seals were traveling and foraging (Jonsen et al. 2005). State-space models of surface movements have been used to infer when marine mammals are foraging or transiting based on surface movement characteristics (Cotté et al. 2015) and fine-scale movements within individual dives (Simpkins et al. 2001a). In our study, foraging was inferred but not confirmed through independent data (e.g., video or accelerometers indicating foraging or prey capture events). Rather, we inferred foraging based on fine scale surface movements (area restricted search). The method expands the use of foraging activity to identify important areas within and across species. Given the limited number of animals in this pilot study (n = 5), we focused on elaborating analytic methods appropriate to these species. Whereas this chapter focuses on an analysis of surface movement, chapters 4 and 5 add vertical and environmental dimensions, respectively.

3.2 METHODS

3.2.1 Capture and Tagging

Spotted and bearded seals were captured and tagged between mid-August and mid-September in Dease Inlet and Kugrua Bay (Chapter 2; Figure 1). Capture and tagging was carried out cooperatively with NSB scientists and Native subsistence hunters using methods described in Section 2.3.3.

3.2.2 Data Analysis

State-space models, using a Bayesian framework, were used to infer area-restricted search at the surface and transiting behavior following methods outlined in Jonsen et al. (2005) and Jonsen (2016). State-space models allow interpretation of movement dynamics (e.g., differences in turning angle; directional persistence) and associated observations of locations), while accounting for associated errors to identify 'hidden' behaviors. The Bayesian analysis incorporated the variability in the movement and the location data.

A hierarchical approach was taken for each species (Jonsen 2016), to "borrow strength" between animals by assuming movement parameters are the same between animals, while still inferring behaviors separately for each animal. The models used two different correlated random walks to describe movement dynamics. The correlated random walks differentiate between periods of fast directed movement (transiting behavior) and periods of slower movement with increased changes in course direction (area-restricted search) that are generally interpreted as foraging behavior (Jonsen et al. 2005). The method also models the probability of switching between these two behaviors.

State-space models do not require the identification of *a priori* thresholds to define movement as transiting or area-restricted search; rather, they depend on the data and the differences in parameter distributions to infer behaviors. The models describing the movement dynamics are linked to the observed data through another model - the measurement equation. This equation incorporates distributions of error associated with the different levels of ARGOS location quality to provide estimates of corrected locations, down-weighting the influence of low quality locations on the resulting animal track (Jonsen et al. 2005).

The modeling was completed using the statistics program R 3.3.1 (R Core Team 2016) with R package "bsam" (Jonsen et al. 2005, 2016). The package calls the software *Just Another Gibbs Sampler* (JAGS; Plummer 2003) and provides a Bayesian simulation analysis using Markov Chain Monte Carlo methods. The Bayesian analysis predicted *a posterior* distribution based on the combined distributions of the model parameters and states based on the data. The posterior distributions were estimated using two Markov chain Monte Carlo simulations with a burn-in of 20,000 samples (number of samples during the adaptation phase of the modeling) and 40,000 iterations (number of posterior samples after burn-in). To improve model performance during posterior sampling, the chains were thinned so that 1 in every 10 samples was retained. The time step selected for each species was dependent upon the number of locations and model convergence.

Model convergence was assessed by visually examining the diagnostic plots and through the Gelman-Rubin diagnostic (Gelman and Rubin 1992). If the diagnostic was ≤ 1.1, convergence between chains was assumed (Gelman and Shirley 2011). The model runs were completed on the full tracks for the spotted seals and on three temporal subsets of the data for the bearded seals. Division of the bearded seal data into temporal subsets was necessary due to an 18-day gap in the record for one of the seals. This approach avoided extrapolating surface movement or behavior during the data gap.

State-space model outputs were mapped using ArcGIS 10.1 (ESRI 2012) to visualize areas of transiting and areas of foraging (inferred from area-restricted search). To determine areas that may be important foraging habitat for both species, the state-space model outputs of both species were combined and an Anselin Morans I analysis (Anselin 1995) was performed. Anselin Morans I indicates if a given point is significantly spatially clustered in time and space with other points of the same value; in our case, this involved identifying clusters of inferred foraging. The distance for spatial autocorrelation was set to 18 km so all points had at least one neighbor (the maximum distance between two points in the data was 18 km), and the temporal clustering was set to two weeks.

3.3 RESULTS

3.3.1 Capture and Tagging

Five juvenile seals—three spotted and two bearded seals—were tagged in the vicinity of Utqiaġvik. The spotted seals were tagged in August; two in Dease Inlet and one in Kugrua Bay. Both bearded seals were tagged in Dease Inlet in September (Figure 5; Table 1). The tags transmitted data for 117 to 168 days. Bearded seal tag #5 stopped transmitting on October 6, 2015 but resumed transmitting on October 24, 2015.

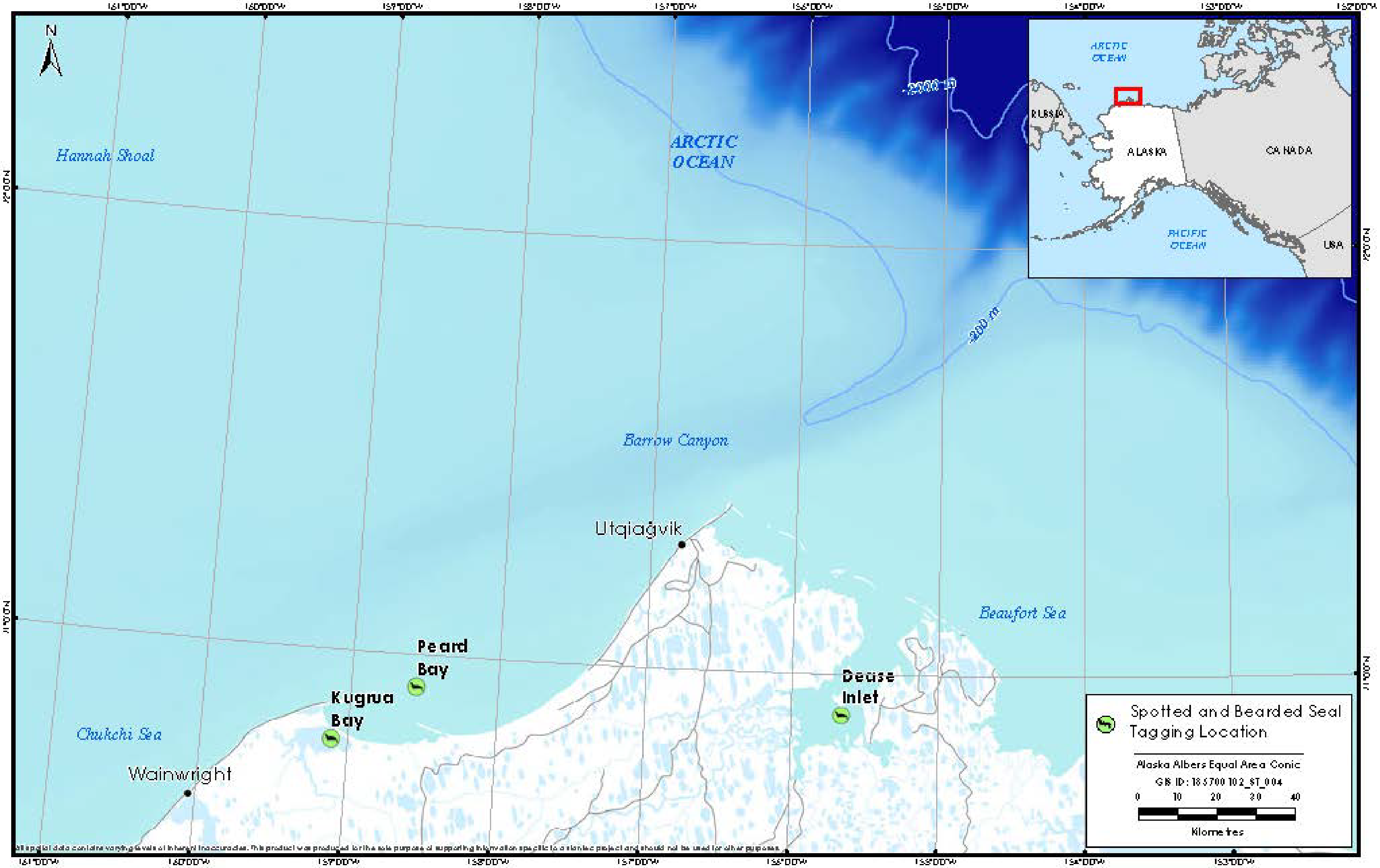

Figure 5 Map of study area with tagging locations

Table 1 Spotted and bearded seal capture dates, approximate morphometric measurements and tag duration

Species	Capture date	Location	Seal ID	Sex	No. Claw Bands	Weight (kg)	Last transmission	Tag transmission (days)
Spotted seal	Aug. 11, 2015	Dease Inlet	4	female	3	66	Dec. 5, 2015	117
	Aug. 13, 2015	Dease Inlet	9	male	5	84	Jan. 11, 2016	152
	Aug. 20, 2015	Kugrua Bay	7	male	3	57	Jan. 3, 2016	137
Bearded seal	Sept. 8, 2015	Dease Inlet	8	male	1	113–125	Feb. 22, 2016	168
	Sept. 17, 2015	Dease Inlet	5	male	0	93	Feb. 26, 2016	144*

NOTE:
*Break in transmission October 6-24, 2015.

3.3.2 Movement Tracks

Movement varied between species and individuals. The larger of the two bearded seals (seal #8) spent more time offshore than did the smaller bearded seal (seal #5) (Figure 6). An opposite result was apparent for the spotted seals, with the two smaller seals (seals #4 and #7) spending more time offshore than the larger seal (seal #9). The seals stayed ahead of the heavy ice (greater than 80% ice cover) or took advantage of open areas through December, with the two bearded seals (the only ones still transmitting past January 11), staying within the ice pack in January and February (Figure 6).

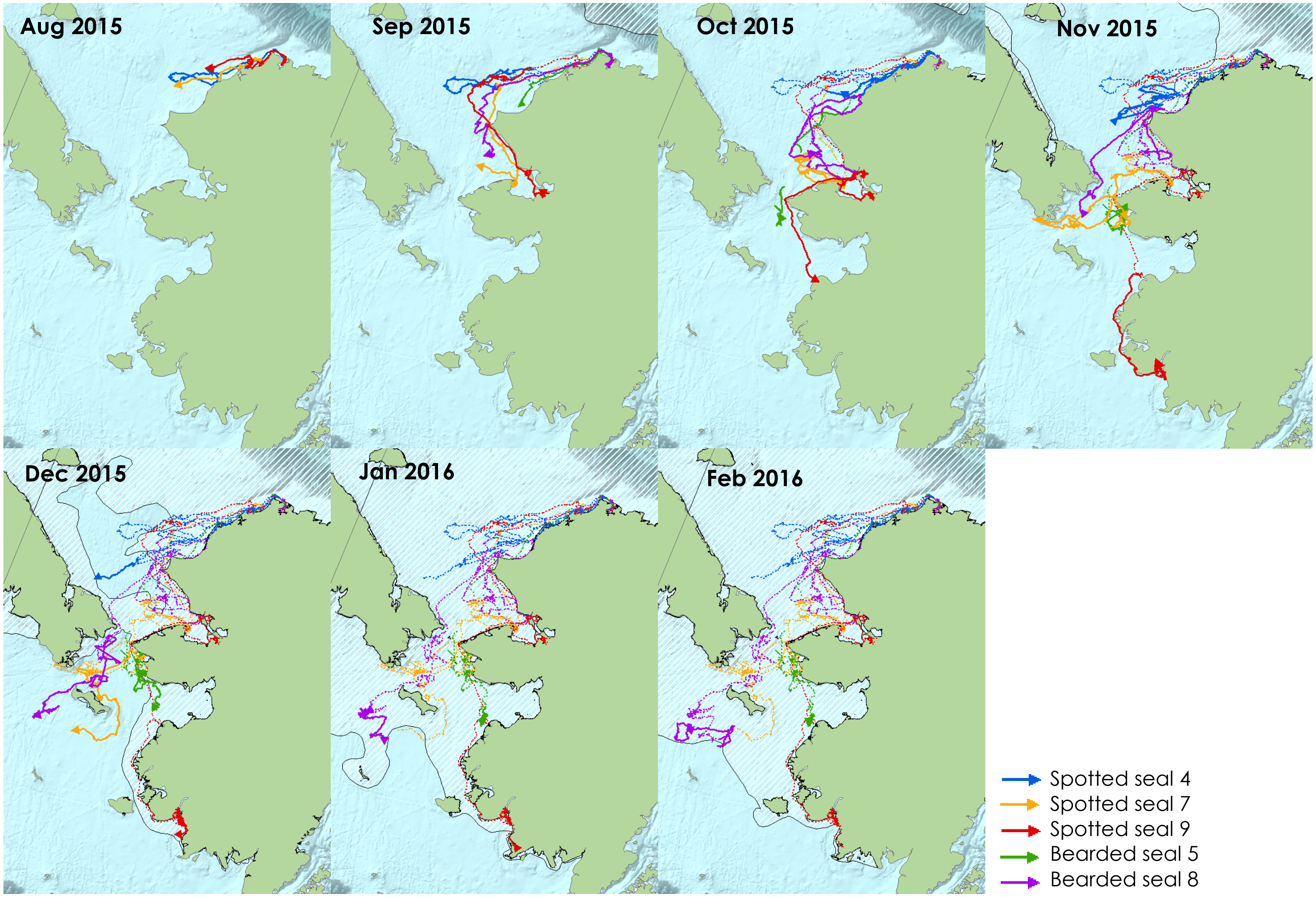

Figure 6 Satellite tracks of tagged bearded and spotted seals from August 11, 2015 to February 26, 2016

Solid lines show the movement of the animal in the identified month, while the dotted lines show the previous month(s) movement. Ice concentrations of >80% shown as white hatching; the ice edge outlined in black. The ice data are plotted for the first of each month (NIC 2016).

3.3.3 Modeling

3.3.3.1 Model Interpretation

The state-space models converged with all Gelman-Rubin values at or below 1.1 for each parameter (Table 2). The distribution between inferred parameters from the state-space model (γ—the move persistence; α—the probability of switching between states) are also summarized in Table 2. Spotted seals had minimal overlap, suggesting the data and random walk models were sufficient to distinguish between inferred transiting and foraging (Table 2). The bearded seals showed overlap between the α parameters and some overlap in the γ parameters in the September-October data but not in the subsequent periods (Table 2). Thus, during the first period, the α parameter was poorly estimated, although there is more persistent direction and speed in the transiting state (γ_1), suggesting differences in movement dynamics during this first period. Excluding the first bearded seal data, both species show a high probability of remaining in either the foraging behavioral state (α_2) or the transiting state (α_1).

Table 2 Gelman-Rubin diagnostic results and posterior median (0.5) and 95% (0.025 and 0.975) credible intervals for parameter estimates from state-space switching models for spotted and bearded seals

Diagnostics	Parameters			
	γ_1	γ_2	α_1	α_2
Spotted seals—Aug. 11–Jan. 11, 2016				
Gelman-Rubin	1.00	1.00	1.02	1.05
Posterior median and credible intervals	0.78 (0.76-0.82)	0.28 (0.22-0.34)	0.96 (0.95-0.97)	0.03 (0.02-0.04)
Bearded seals—Sept. 5–Oct. 5, 2015				
Gelman-Rubin	1.00	1.10	1.04	1.00
Posterior median and credible intervals	0.78 (0.66-0.93)	0.62 (0.04-0.77)	0.69 (0.04-0.99)	0.47 (0.03-0.97)
Bearded seals—Oct. 6–Nov. 30, 2015				
Gelman-Rubin	1.00	1.04	1.01	1.01
Posterior median and credible intervals	0.76 (0.70-0.83)	0.20 (0.02-0.38)	0.99 (0.96-1.00)	0.01 (<0.01-0.06)
Bearded seals—Dec. 1–Feb. 26, 2016				
Gelman-Rubin	1.00	1.03	1.05	1.04
Posterior median and credible intervals	0.60 (0.53-0.68)	0.03 (<0.01-0.13)	0.99 (0.97-1.00)	0.01 (<0.01-0.03)

NOTES:
$_1$ indicates travelling
$_2$ indicates foraging
γ is the degree of correlation in move speed and direction; α_1 is the probability of being in the travelling state at time t, given the same behavior at time t-1; α_2 is the probability of being in the travelling state at time t, given a foraging state at time t-1.

3.3.3.2 Movement Behaviors

The amount of time spent transiting versus foraging varied temporally and spatially among individuals and between species. All three spotted seals spent more time foraging than transiting in September and October while located north of the Bering Strait (Figure and Figure 8). Seal #9 continued this trend through January. Overall, spotted seals foraged along multiple portions of the track north and south of Bering Strait (Figure 8) and foraged earlier than bearded seal, even when accounting for their earlier tagging dates (Figure 7 compared to Figure 9).

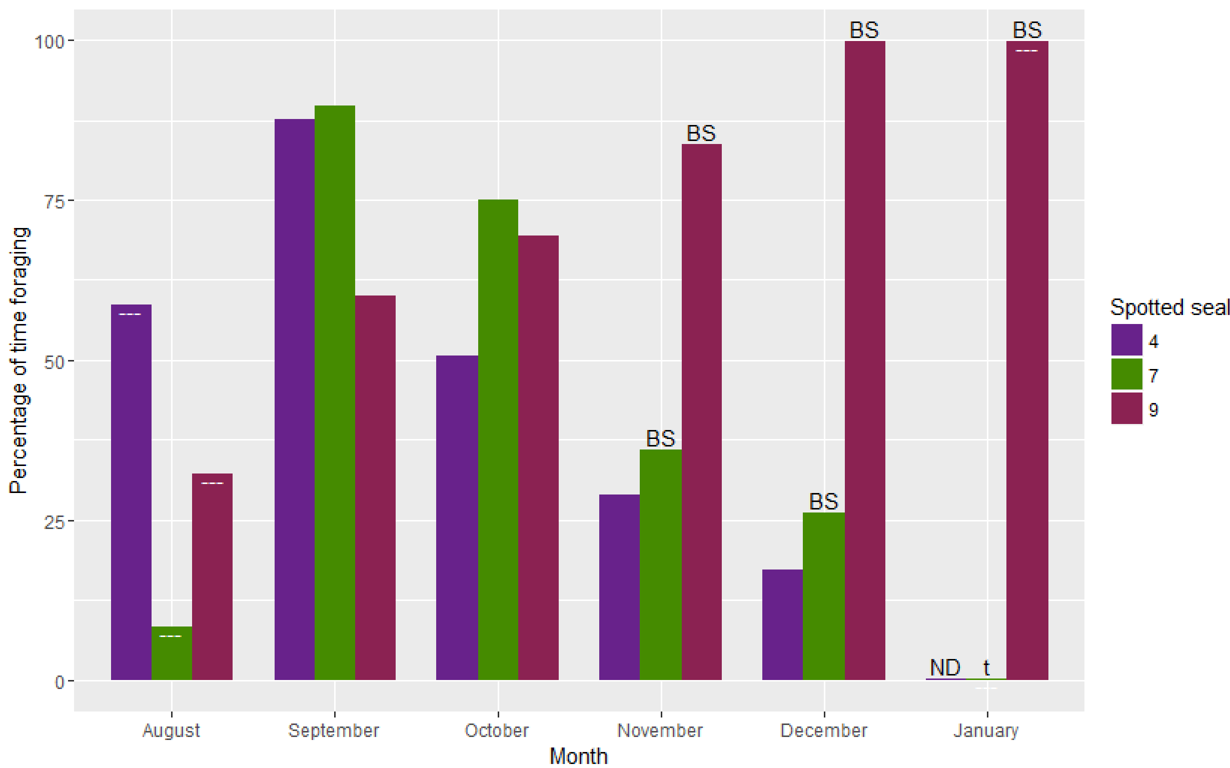

Figure 7 Percentage of time spent foraging by month for spotted seals

BS = months when the majority of time was spent in the Bering Sea; t = seal was only transiting; ND = no data; white dashes indicate partial months.

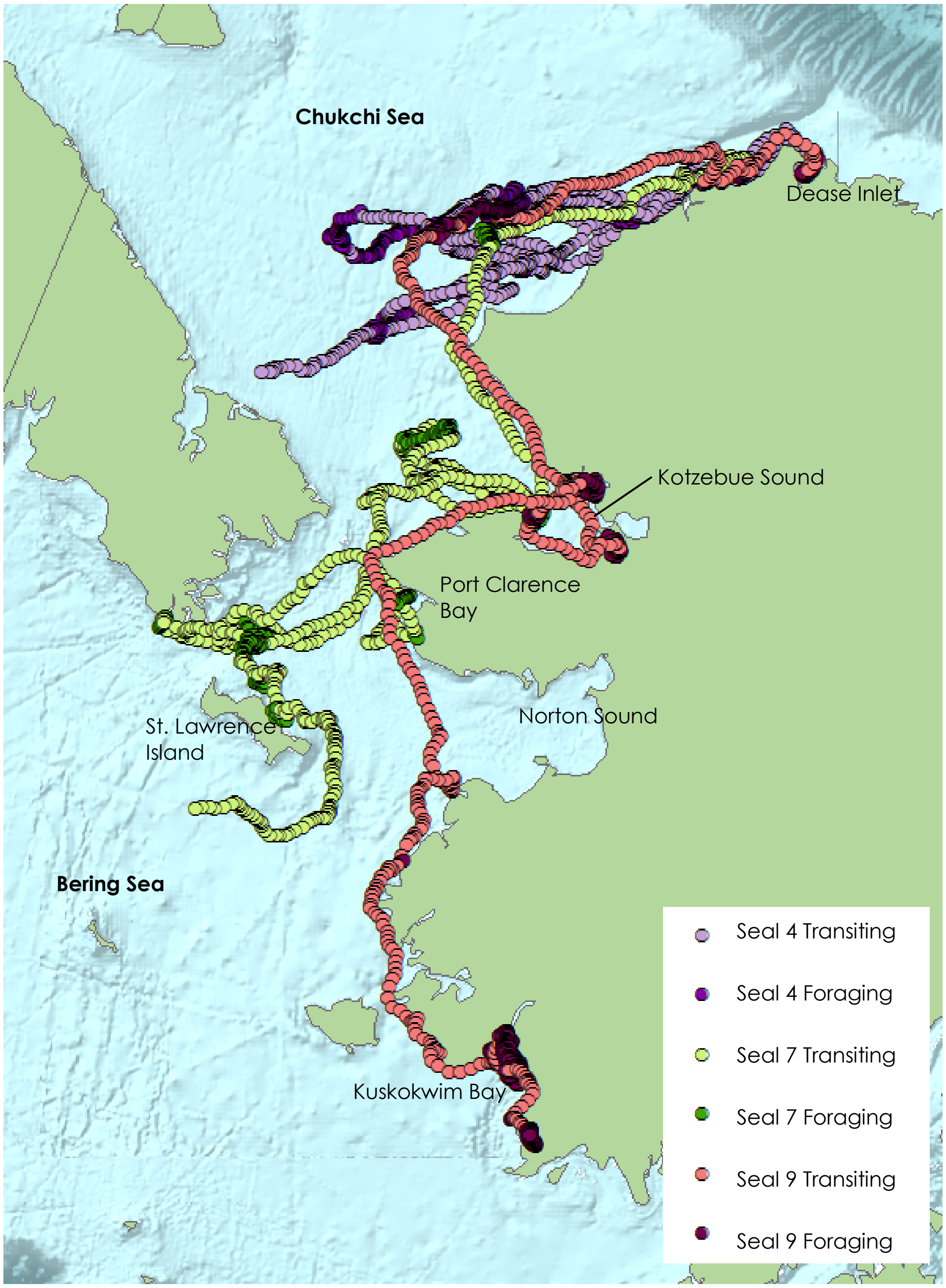

Figure 8 Spotted seal transiting and foraging from hierarchical state-space models

The two bearded seals displayed almost opposite movement behaviors from each other with the larger seal (#8) spending almost all of its time transiting between September and February except for some concentrated foraging in January south of St. Lawrence Island (Figure 9 and Figure 10). Meanwhile, the smaller seal (#5) dedicated almost all of its time to foraging in October, November, January, and February, with November through February spent in or south of Bering Strait. North of Bering Strait, the bearded seals displayed foraging behavior only in the vicinity of Point

Barrow.

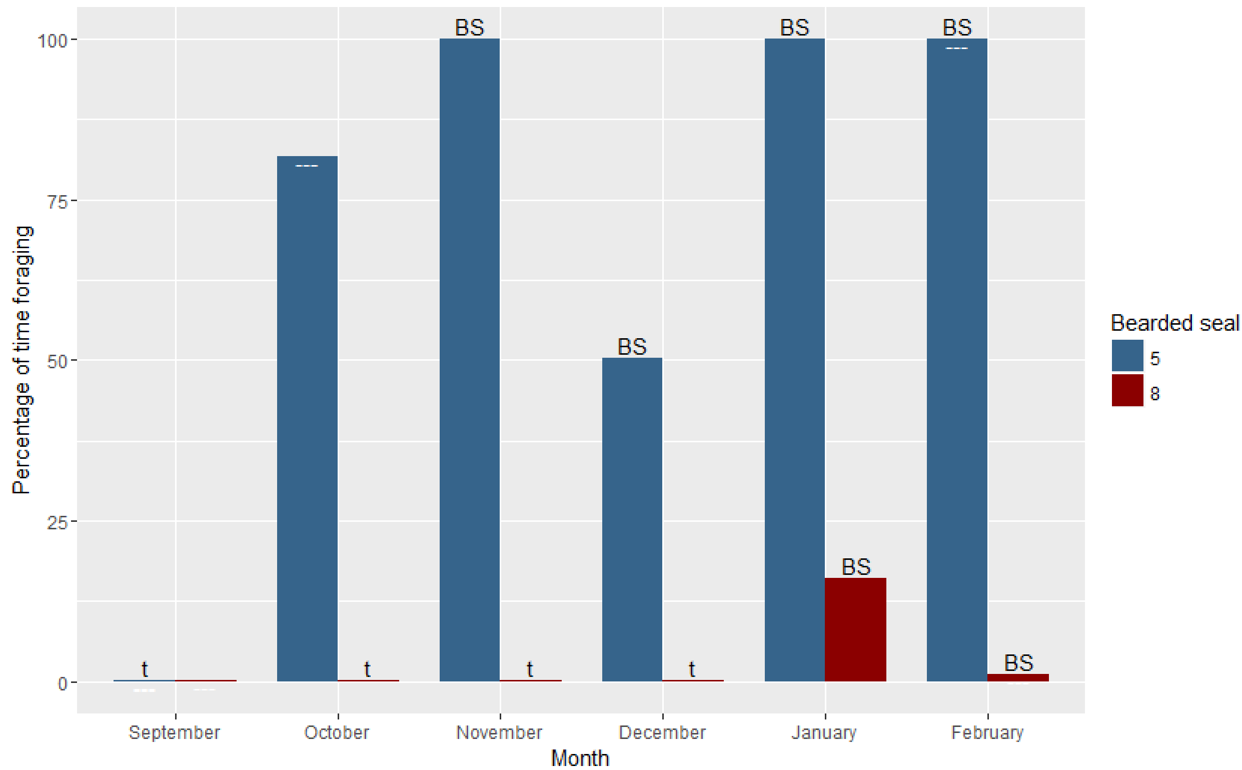

Figure 9 Percentage of time spent foraging by month for bearded seals

BS = months when the majority of time was spent in the Bering Sea; t = seal was only transiting; white dashes indicate partial months.

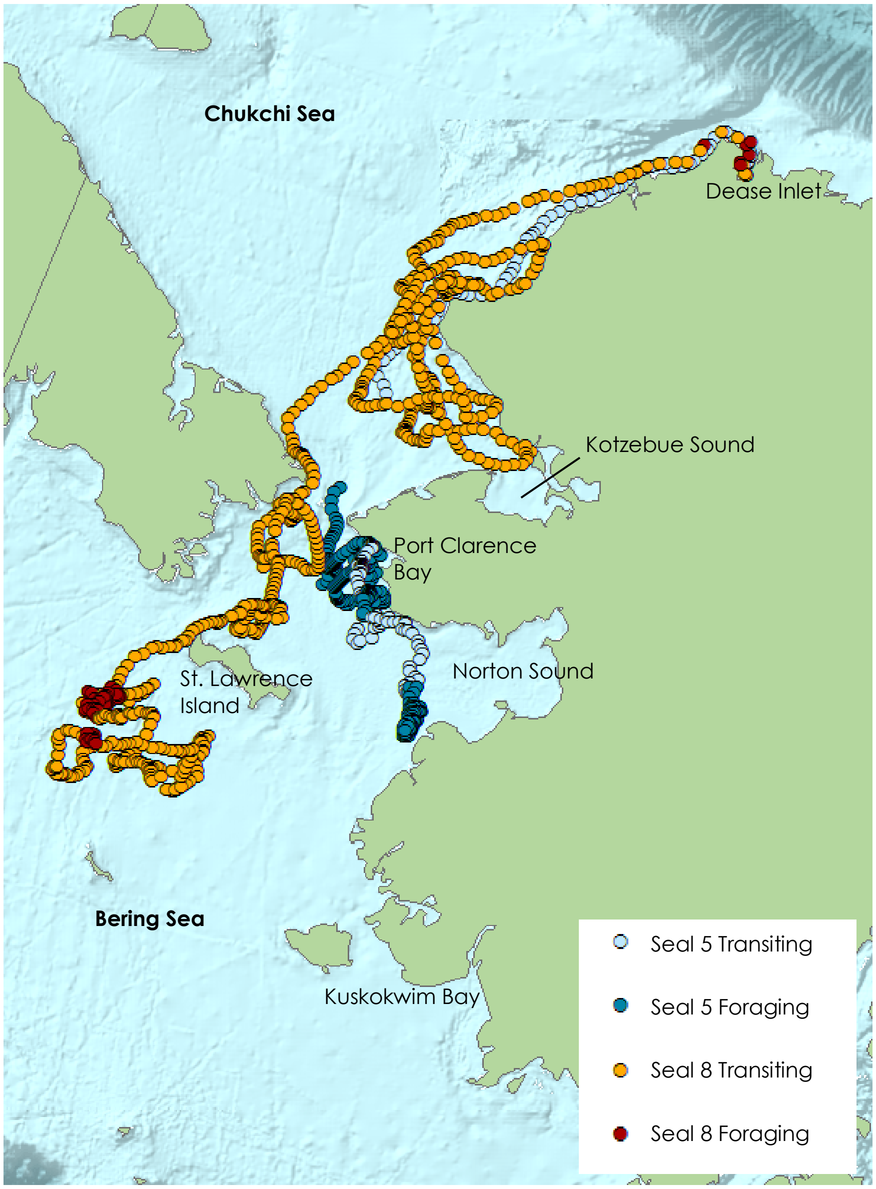

Figure 10 Bearded seal transiting and foraging from hierarchical state-space models

The median dive depths of spotted seals during inferred foraging were greater than during transiting (Figure 11). Median dive depth reflected nearshore movement for bearded seal #5, with shallower median depths for both inferred foraging and transiting. In contrast, bearded seal #8 primarily moved offshore in deeper waters (Figure 10 and Figure 11).

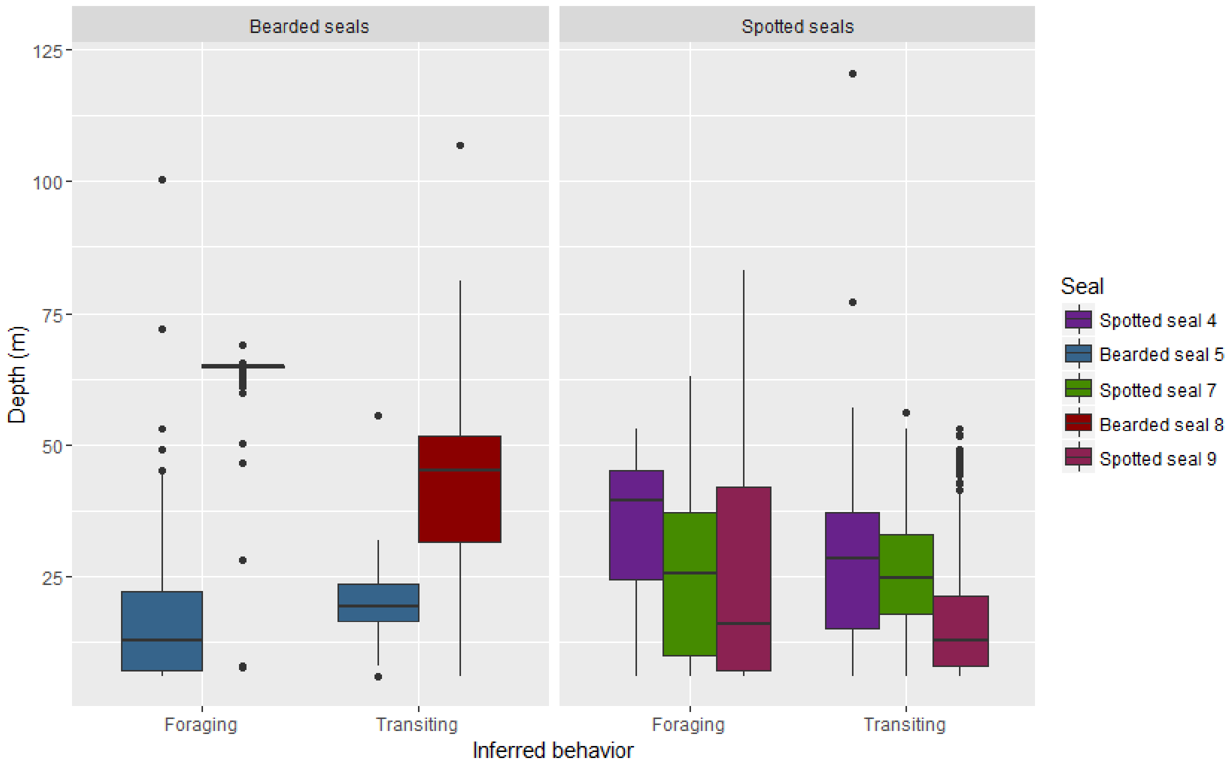

Figure 11 Box plots of dive depths (m) recorded for inferred foraging and transiting from hierarchical state-space models for spotted and bearded seals

3.3.3.3 Foraging Hotspots

The Anselin Morans I analysis highlighted two areas where inferred foraging for both species clustered significantly in space and time: Dease Inlet and south of the Bering Strait near Port Clarence Bay (Figure 12). Other regions with significantly clustered foraging for a single bearded seal included west of St. Lawrence Island and west of Norton Sound. Foraging was significantly clustered for two spotted seals to the west of Point Lay, west of Point Hope, and in Kotzebue Sound (Figure 12).

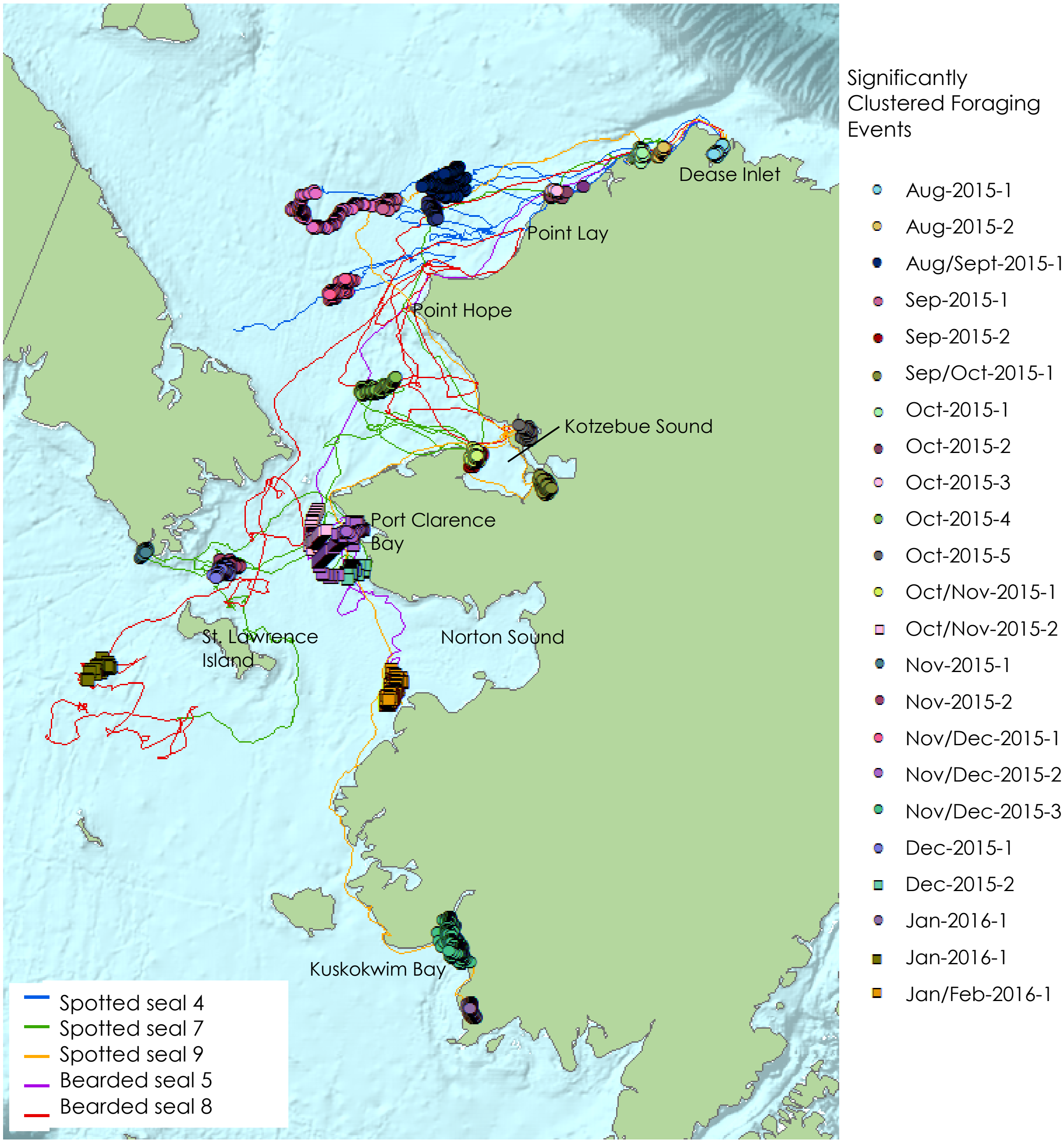

Figure 12 Temporal and spatial foraging clusters of spotted and bearded seals

Spotted seals (circles) and bearded seals (squares) foraging clusters from Anselin Moran's I analysis of state-space model results. Each color indicates a different two-week period of clustered foraging. Integers following the month and year indicate different temporal clusters.

3.4 DISCUSSION

Inferring foraging activity from movement data provides insights into habitat use. The use of surface movements to detect foraging activity (inferred from area restricted search) and directed transiting movement through state-space modeling incorporates variance in movement dynamics and locations. The method inferred areas of foraging, as well as foraging clustered in space and time.

Spotted and bearded seals, like other phocid seals, are capital breeders meaning that they seasonally accumulate and store energy to provision reproduction, a strategy that allows them to segregate breeding and foraging habitats (Costa 1991; Boyd 2000; Houston et al. 2006). Seasonal movements of spotted and bearded seals simultaneously accommodate trade-offs between suitable breeding and foraging sites and movements that are constrained by seasonal ice cover (McClintock et al. 2017).

State-space modeling distinguished between foraging and transiting, showing minimum overlap between parameters for both species. The use of Anselin Moran's I to highlight foraging hotspots could be applied to larger surface movement datasets to further elucidate regional habitat use.

Between August 2015 and February 2016, bearded and spotted seals migrated southward with expanding ice cover. The smaller animals of both species seemed to prefer offshore areas, while the larger seals moved primarily along the coast. That difference in habitat preference needs to be further examined with a larger sample.

Our data suggested that spotted seals foraged throughout their migration but especially in the vicinity of Herald Shoal, west of Point Hope and Kivalina, coastally around Kotzebue Sound, North of St. Lawrence Island, and in Kuskokwim Bay (Figure 8). Except for Dease Inlet and Point Utqiaġvik, the bearded seals did not forage until they reached Bering Strait, with one foraging along the coast of the Seward Peninsula and outer Norton Sound and the other to the southwest of St. Lawrence Island (Figure 10). We hypothesize that benthic community composition and/or sediment type (Grebmeier et al. 2006) may make the Northern Bering Sea shelf preferable foraging habitat for bearded seals.

Significant spatial and temporal overlap in foraging by both species identified Dease Inlet and an area west of Port Clarence Bay as hot spots. Significantly clustered hotspots where bearded seals foraged coincided with bowhead whale core-use areas in Anadyr Strait and Gulf of Anadyr (Citta et al. 2015). Spotted seal forging hotspots overlapped spatially with seabird and marine mammal fall hotpots as identified by Kuletz et al. (2015). Some or all of these locations may reflect important and potentially persistent foraging regions for these species, although this hypothesis should be tested with a larger data set.

We consider improvements to the models by including vertical movements in Chapter 4 and environmental characteristics in Chapter 5.

4.0 CHAPTER 4—INFERRING FORAGING BY SPOTTED AND BEARDED SEALS FROM VERTICAL MOVEMENTS

4.1 INTRODUCTION

Dive shape, duration, and related parameters have been used to infer foraging by marine mammals (e.g., Kelly and Wartzok 1996; Fedak et al. 2001, Simpkins et al. 2001b; Sparling et al. 2007, Heerah et al. 2015, Ramasco et al. 2015). Typically, these types of studies do not directly verify foraging, but rely on behavior and understanding of movement to infer foraging activity. U-shaped dives have been assumed to indicate foraging, since the availability of food extends time spent at depth (Hindell et al. 1991; Thompson et al. 1991; Le Boeuf et al. 1992; Kelly and Wartzok 1996; Fedak et al., 2001). Conversely, V-shaped dives are less informative about activity. Sparling et al. (2007) found that longer dives and longer bottom durations were associated with prey capture for grey seals (*Halichoerus grypus*). Ramasco et al. (2015), however, concluded that dive shapes reflect benthic versus pelagic foraging rather than foraging versus non-foraging dives. Simpkins et al. (2001a) and Heerah et al. (2014), among others, have expanded on the use of dive shapes, distinguishing transiting and searching based on movement patterns including area restricted search. Overall, the use of dive patterns to define foraging activity has had mixed results with variation among species.

State-space models have also been used to infer foraging, typically using surface movement alone to differentiate between transiting—indicated by directed, persistent movement—and foraging—indicated by area restricted search (e.g., Jonsen et al. 2005, Breed et al. 2012, Cotté et al. 2015). Jonsen et al. (2005) found that state-space models using surface movement could identify two behaviors (foraging and transiting) for grey seals and hooded seals, although with variation between individuals. Breed et al. (2012) were able to differentiate between searching and transiting surface movements to define foraging behavior in California sea lions. Simpkins et al. (2001a) used area restricted search to infer foraging within individual dives of ringed seals tracked in three-dimensions. Their method took advantage of restricted movements during the ice-bound season (Kelly et al. 2010) to acoustically track movements at a fine scale, a method not suited to inferring foraging during large scale movements.

We explored the impact of adding vertical movements, obtained with time-depth recorders, on inferring foraging. Surface movements likely reflect responses to large scale environmental conditions (e.g., presence of sea ice), while vertical movements may reflect localized prey availability (Bailleul et al. 2007). Combining movements in both dimensions may, therefore, provide a more complete understanding of foraging patterns. Bestley et al. (2015) explored whether vertical movement patterns can be used to infer shifts between behavioral states and found differences among species.

Here, we explore whether the addition of vertical movements improves the model based only on surface movements (Chapter 3) and influences the spatial and temporal predictions of foraging activities by spotted and bearded seals.

4.2 METHODS

4.2.1 Dive Information

We characterized all dives deeper than 4 m based on time allocated at depth and a depth-corrected dive duration parameter. We also characterized each dive according to dive zone (benthic or pelagic) to explore effects of the zone independent of foraging behavior. As with the state-space model considering only surface movements, we inferred foraging from area restricted search in the model combining surface and vertical movements.

4.2.1.1 Time Allocated at Depth

For each dive, we used mean swim speed (m/s), maximum depth (m), and dive duration (seconds) to calculate time allocated at depth and, thus, distinguish between V-shaped and U-shaped dives (Fedak et al. 2001). We followed Fedak et al. (2001) to determine mean swim speed for each species by plotting time allocated at depth against a range of minimum speeds (0-1.5 m/s, calculated as 2 * maximum depth / dive duration) separately for a suite of *potential* mean swim speeds (ranging from 1-3 m/s). Time allocated at depth is considered independent of the depth:time ratio where the mean swim speed generates a flat line with approximately equal error around it across the range of minimum speeds. The swim speed for which those conditions were met was taken to be the *actual* mean swim speed for that species.

Once the mean swim speed was identified, a subset of dive profiles was randomly selected, visually inspected, and categorized as either U- or V-shaped. The threshold time allocated at depth between U- and V-shaped dives was estimated based on the visual examination of shape. The fraction of each seal's dives that were U- and V-shaped (number U- or V-shaped/total number of dives by that individual) was used as one of the dive parameters to characterize dive behavior. Since these fractions use all data for an individual, no estimates of error are associated with them and are reported as percentage point estimates.

4.2.1.2 Depth-Corrected Dive Duration

Depth-corrected dive durations were estimated using residuals from a linear model of dive duration that included main effects of maximum dive depth and individual seal and an interaction term (maximum dive depth x individual seal). Maximum dive depths were normally distributed for bearded seal; those for spotted seals were transformed prior to analysis to improve model diagnostics and meet normality assumptions. Residuals from these models represent the variation in dive duration after accounting for the effects of depth on dive duration, specific to each individual. Values >1 are longer than expected dives given the observed maximum dive depth, and values <1 are shorter than expected dives.

4.2.1.3 Dive zone (Benthic vs Pelagic)

The dive zone of each dive was classified as either benthic or pelagic depending on the relationship between maximum dive depth and location specific bathymetry. Dives were classified as pelagic when the maximum dive depth was at least 3 m from the bottom; dives were deemed to be benthic when maximum depth was within 3 m of the bottom. The fraction of dives that were benthic and pelagic was calculated for each seal and has no associated error term.

4.2.2 Analysis

We added time allocated at depth and depth-corrected dive duration as covariates to the state-space models that considered surface movement (Chapter 3). Following Bestley et al. (2015), we explored the influence of the dive covariates on switching between foraging and transiting. We used time allocated at depth and depth-corrected dive duration as continuous variables in the models.

We compared the results of state-space models incorporating covariates with those based only used surface movements. Model comparison was conducted by exploring how inclusion of covariates (1) refined the locations and percentage of time spent in inferred foraging and (2) influenced the probability of switching between foraging and transiting and staying in transiting. Model results were mapped, and inferred locations of foraging and transiting were identified with and without the influence of dive profile covariates.

The Deviance Information Criterion (DIC; Spiegelhalter et al. 2002) was calculated for the models with dive covariates to determine which model better represented the data. DIC is similar to the Akaike Information Criterion in that models are penalized for having greater complexity and rewarded for having greater fit. Lower values therefore constitute a better tradeoff of model fit for a given complexity, and the model with the lowest DIC is considered best.

4.3 RESULTS

4.3.1 Dive Characterization

We included dive parameters into the state-space models as covariates by calculating time allocated at depth and depth-corrected dive duration for each dive to a depth greater than 4 m.

Time allocated at depth was based on the mean swim speed for each species; 1.75 m/sec for spotted seals (Figure 13) and 1.5 m/sec for bearded seals (Figure 14)(Fedak et al. 2001).

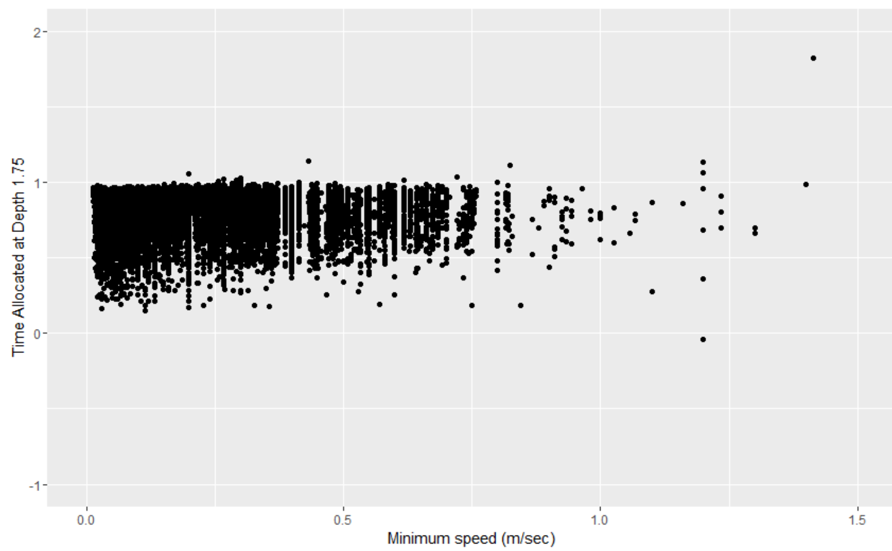

Figure 13 **Spotted seal time allocated at depth by minimum speed**
mean swim speed of 1.75 m/s

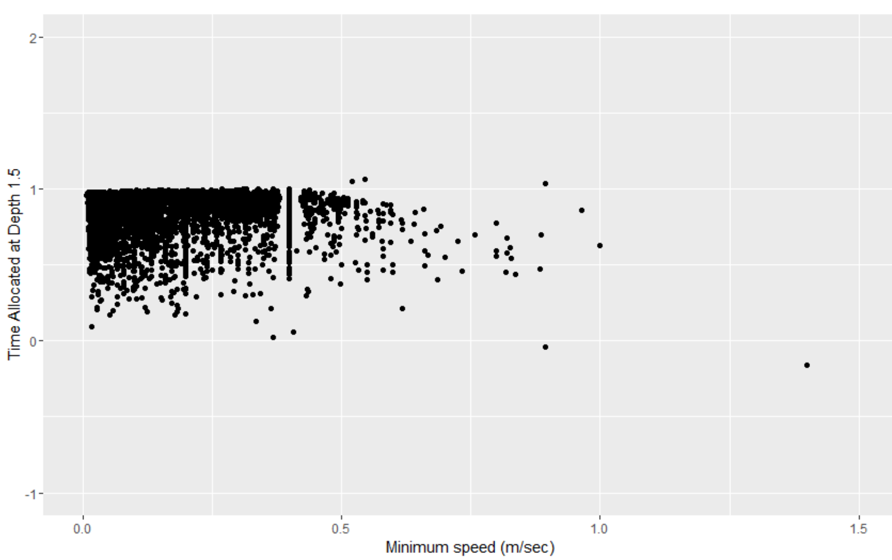

Figure 14 **Bearded seal time allocated at depth by minimum speed**
mean swim speed of 1.5 m/s

A random selection of dives was visually compared to determine the time allocated at depth value thresholds for V-shaped and U-shaped dives. We classified dives with time allocated at depth less than 0.8 as V-shaped dives and those equal to or above 0.8 as

U-shaped (see Figure 15 for an example dive profile).

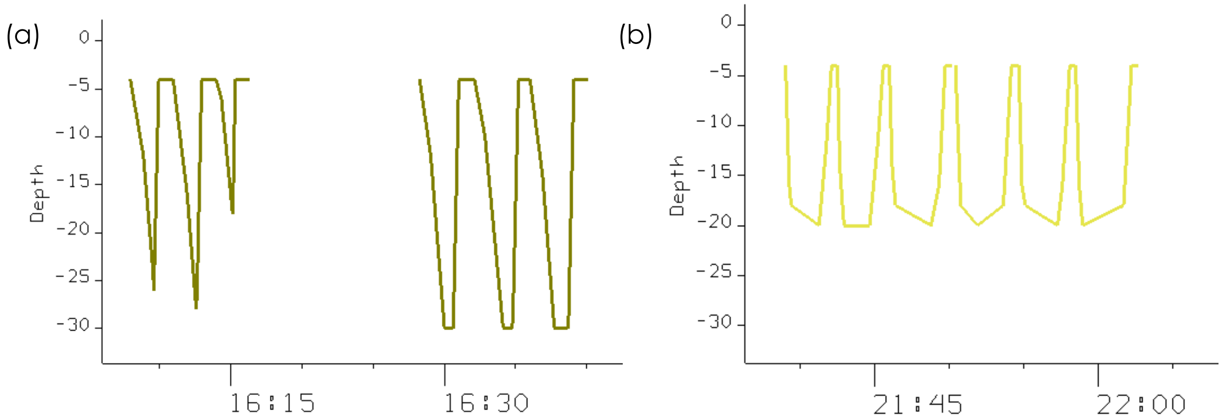

Figure 15 **Example dive profiles**
from spotted seal 7, Oct. 17, 2015
Showing V-shaped dives with time allocated at depth values between 0.45 and 0.65 (a) and U-shaped dives with time allocated at depth values between 0.88 and 0.91 (b).

Most dives by both species were primarily U-shaped and benthic, although bearded seals had higher percentages of both (Figure 16 and Figure 17).

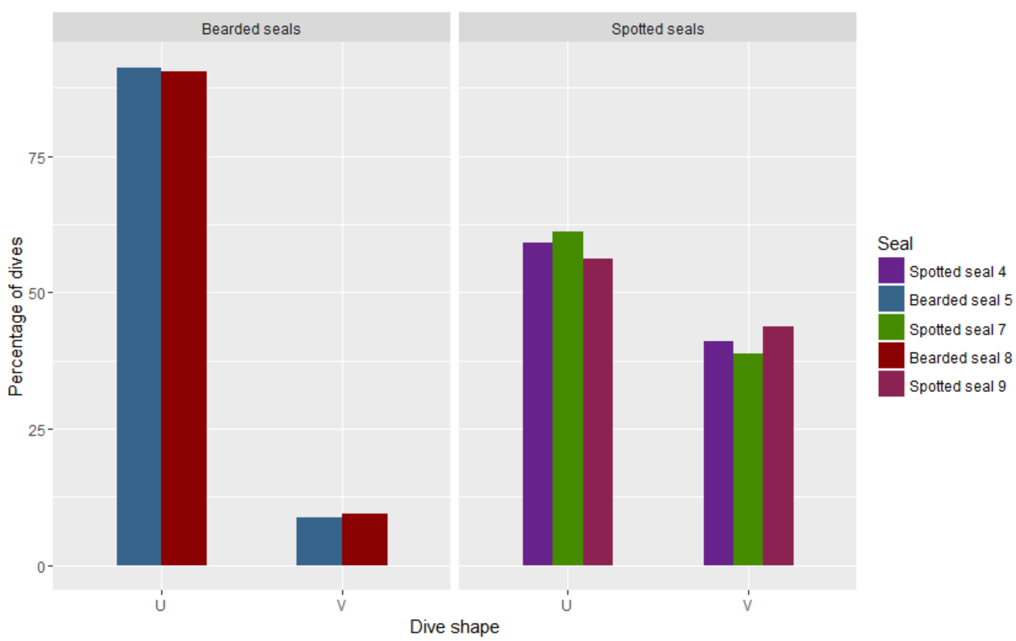

Figure 16 **Percentage of U- or V-shaped dives by species and individual**

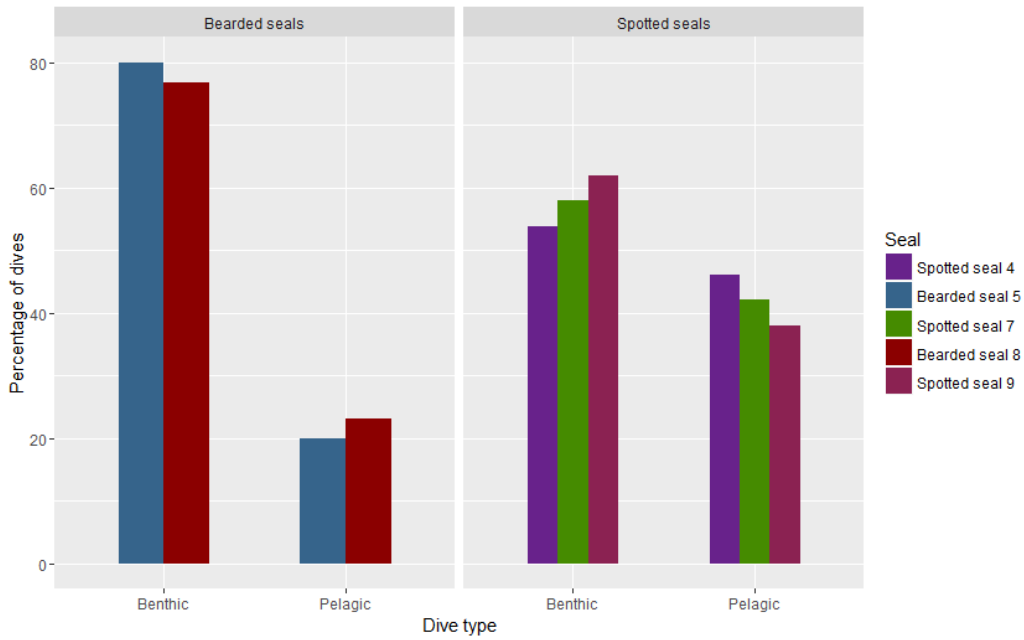

Figure 17 Percentage of benthic or pelagic dives by species and individual

Benthic dives for spotted and bearded seals were predominantly, but not exclusively, U-shaped, while the pelagic dives were primarily V-shaped for spotted seals but U-shaped for bearded seals (Figure 18 and Figure 19).

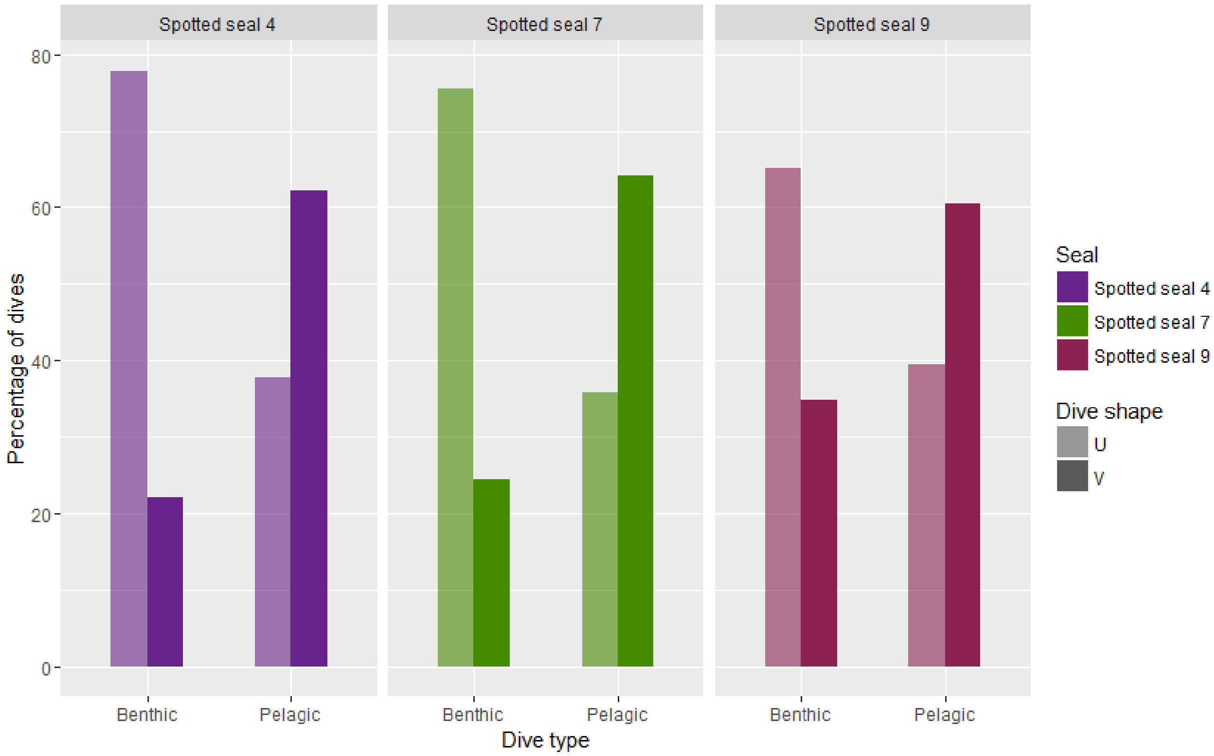

Figure 18 Percentage of benthic or pelagic dives classified as U-shaped and V-shaped dives for spotted seals

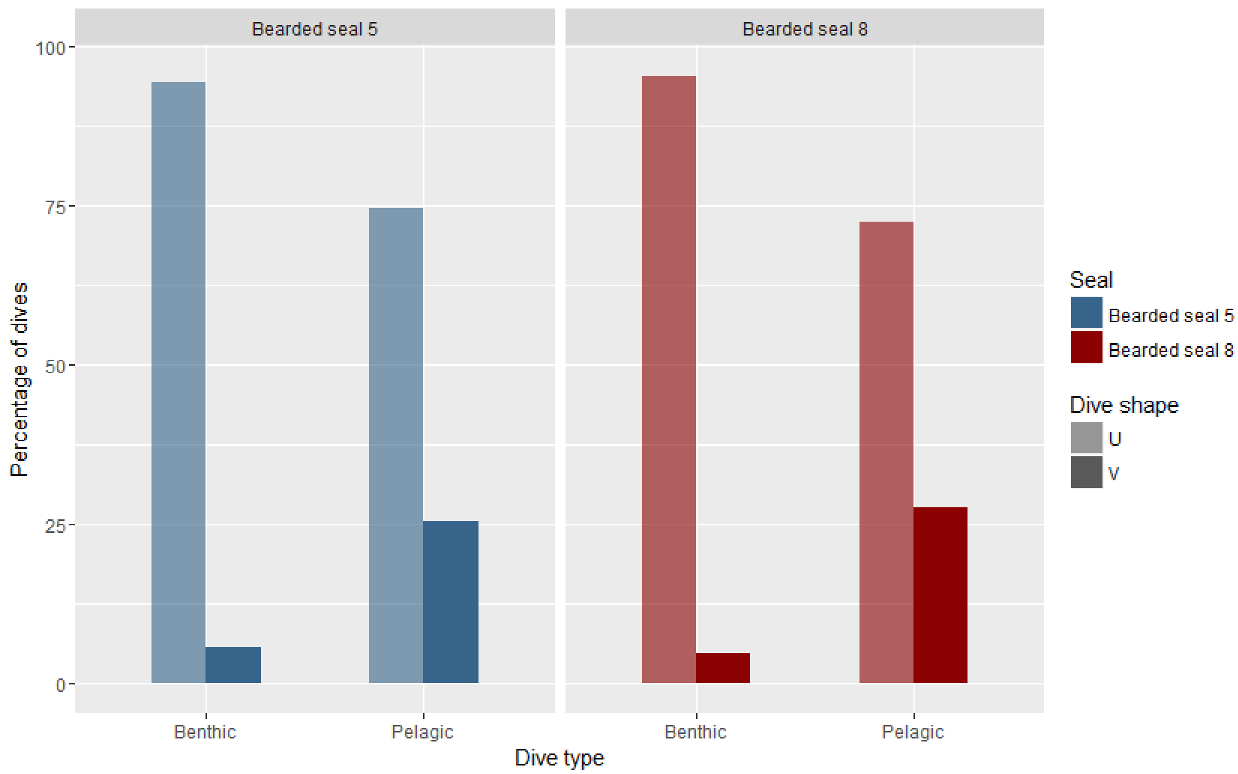

Figure 19 Percentage of benthic and pelagic dives classified as U-shaped or V-shaped dives for bearded seals

U-shaped dives dominated the bearded seal records throughout their tracks with occasional, brief sections of V-shaped dives (Figure 20). The spotted seal tracks show a mix of U- and V-shaped dives with no apparent spatial pattern (Figure 21).

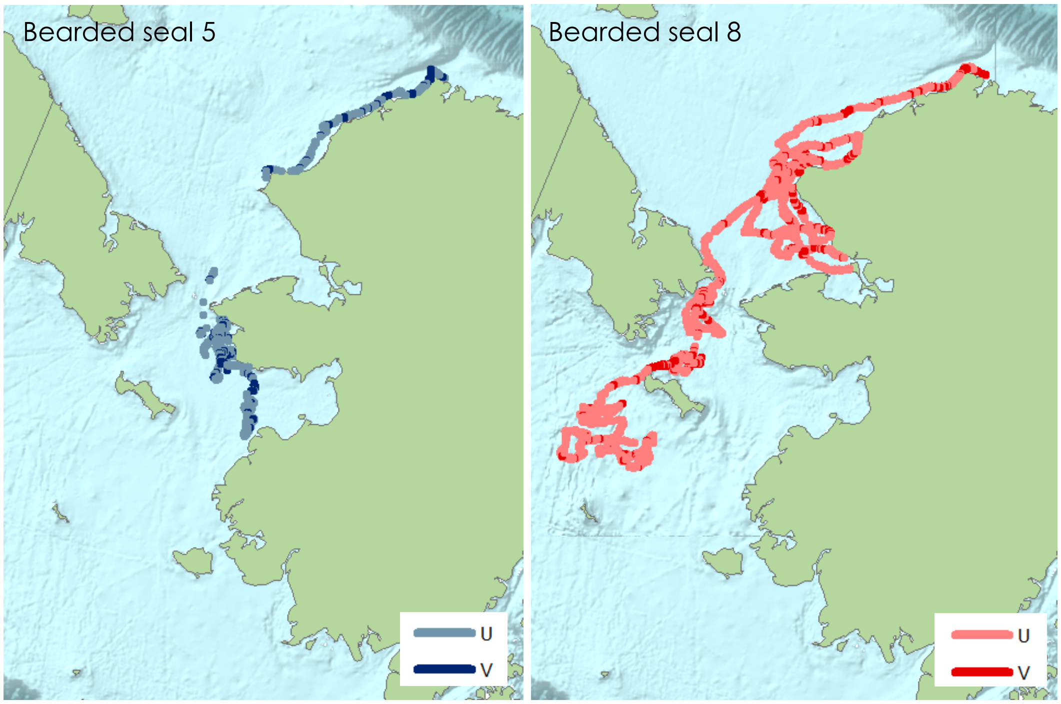

Figure 20 Bearded seal 5 and bearded seal 8 U-shaped and V-shaped dives

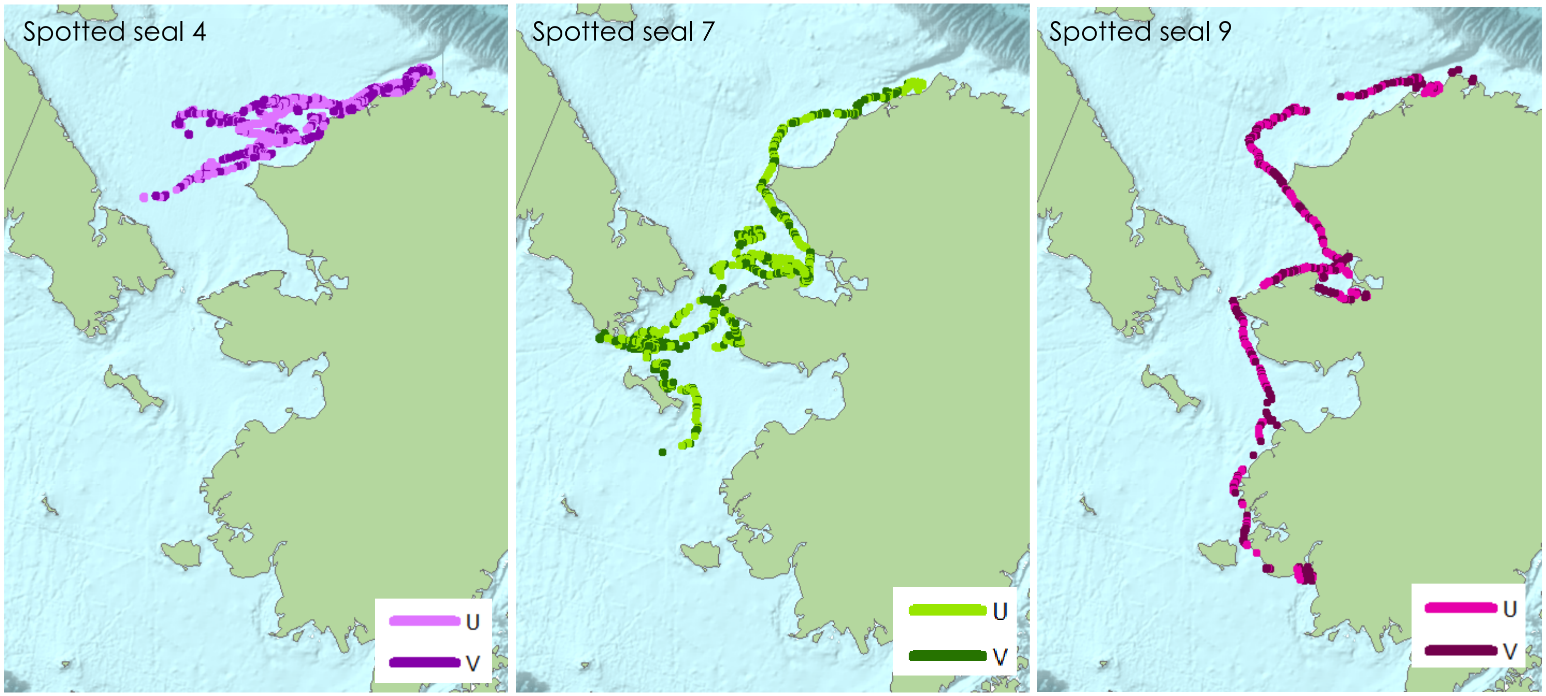

Figure 21 Spotted seal 4, 7, and 9 classified time allocated at depth

4.3.2 Relationship between dive zones and behaviors inferred from surface movements

Dives tended to be benthic for both spotted and bearded seals regardless of whether the seals were foraging or transiting, although bearded seals had substantially more benthic than pelagic dives overall (Table 3).

Table 3 Percentage of pelagic or benthic dives during foraging and transiting modeled using surface movements only.

Model Scenario	Parameter	Spotted seals		Bearded seals	
		Pelagic	**Benthic**	**Pelagic**	**Benthic**
State-space model without covariates	Foraging	38%	62%	14%	86%
	Transiting	41%	59%	14%	86%

Most dives by spotted seals were shallow (<49 m), and foraging dives (as inferred by surface movement) were significantly deeper than transiting dives (Table 4; Figure 22). Bearded seals #5 and #8 traveled predominantly through nearshore and offshore environments, respectively, a difference reflected in significantly different dive depths, whether transiting or foraging in the benthos or pelagic zone (Figure 23). Seal #8's foraging dives were significantly deeper than transiting dives for both pelagic and benthic dives. Seal #5 had similar median dive depths for each behavior regardless of dive zone, but benthic dives during transit were significantly deeper than during foraging.

Table 4 Wilcox rank sum significance (p-value) between median dive depth during foraging and transiting behavior by dive zone (benthic vs. pelagic)

Dive Zone and behavior		Spotted seals			Bearded seals	
		4	**7**	**9**	**5**	**8**
Benthic	Foraging Transiting	<0.01	0.67	0.94	<0.01	<0.01
Pelagic	Foraging Transiting	<0.01	<0.01	0.03	0.80	<0.01

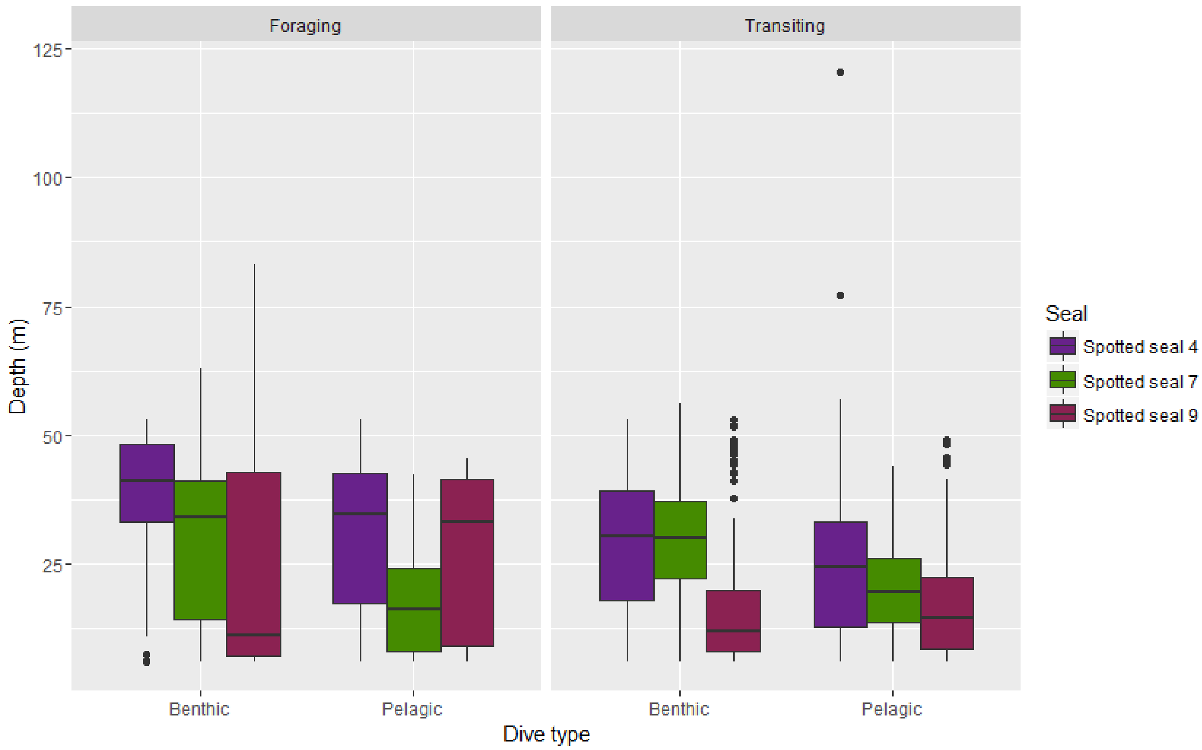

Figure 22 Dive depth for spotted seals during benthic and pelagic foraging and transiting dives

The median is represented by the dark horizontal line, with the box representing the 25th and 75th percentiles, the whiskers representing the 5th and 95th percentiles, and dots showing the outliers.

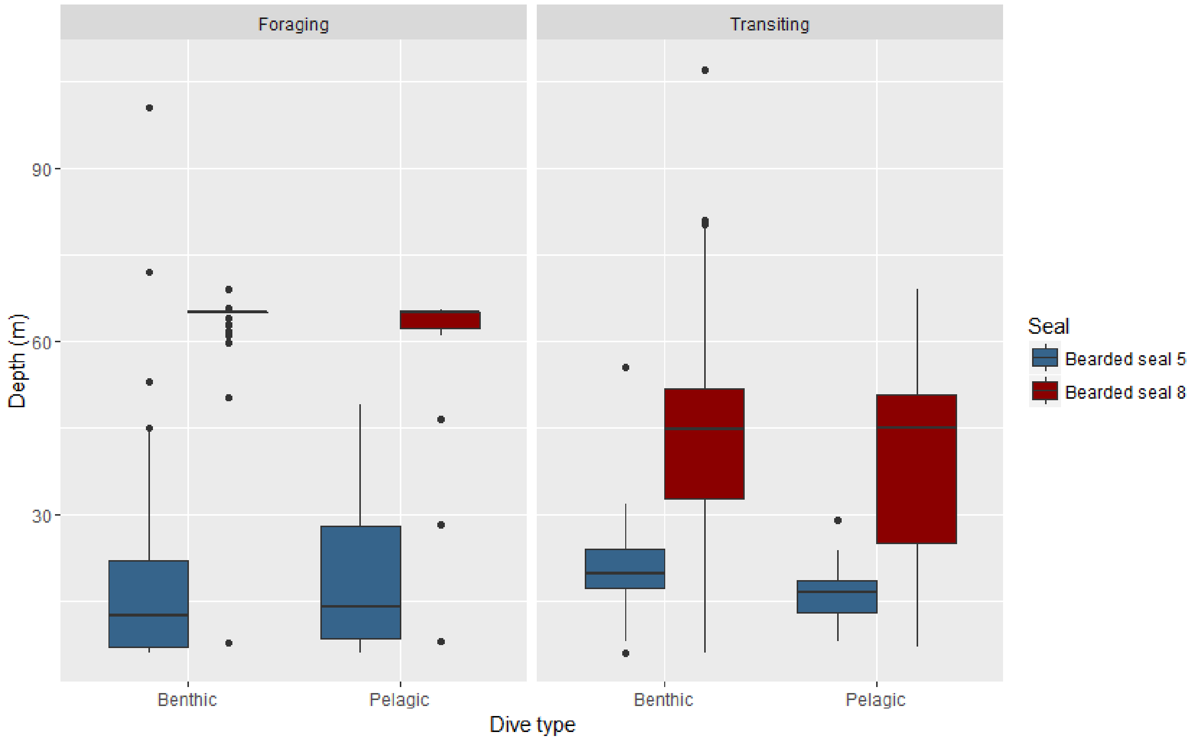

Figure 23 Dive depth for bearded seals during benthic and pelagic foraging and transiting dives

The median is represented by the dark horizontal line, with the box representing the 25th and 75th percentiles, the whiskers representing the 5th and 95th percentiles, and dots showing the outliers.

4.3.3 State-space models with the addition of dive covariates

The addition of dive covariates influenced the modeled locations of inferred foraging. Estimates of time spent foraging were not significantly different between the state-space model results with and without the dive covariates.

4.3.3.1 Model fit

The model that included depth-corrected dive duration as a covariate fit the data better than the model with time allocated at depth, with the exception of the first time period (Sept.–Oct.) for bearded seals (Table 5).

Table 5 DIC values for each subset of state-space model runs for models including dive parameters as covariates. Lowest DIC values are in bold.

	Spotted seals			Bearded seals		
Model Scenario	**Aug. 11–Oct. 1, 2015**	**Oct. 2–Nov. 30, 2015**	**Dec. 1, 2015–Jan. 11, 2016**	**Sept. 8–Oct. 5, 2015**	**Oct. 6–Nov. 30, 2015**	**Dec. 1, 2015–Feb. 26, 2016**
SSM – TAD	-42334	-51325	-13210	**-14797**	-24770	-50199
SSM – DCDD	**-42654**	**-51334**	**-13228**	-14789	**-24777**	**-50209**

NOTES: SSM = state-space model; TAD = Time allocated at depth; DCDD = depth-corrected dive duration.

4.3.3.2 Temporal results

For both species, the inferred amount of time spent foraging was similar for models with and without time allocated at depth and depth-corrected dive duration (Figure 24 and Figure 25).

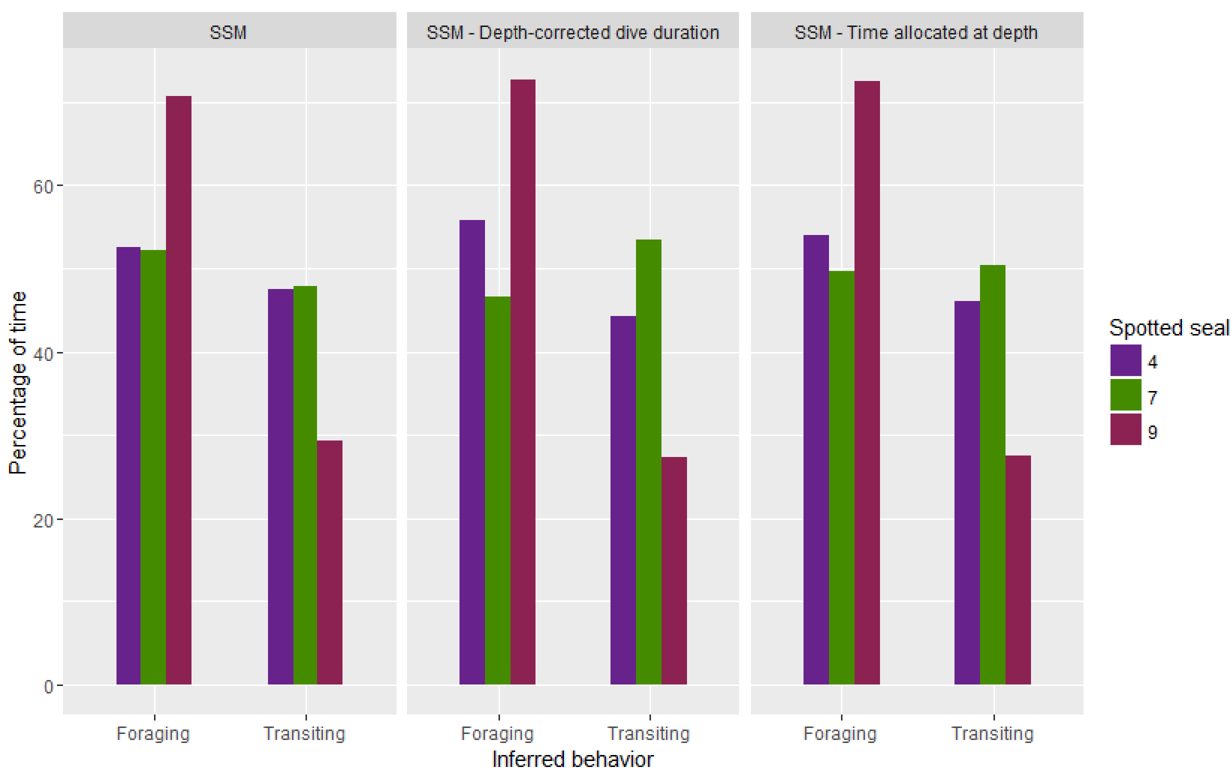

Figure 24 Spotted seal percentage of time spent in foraging and transiting for state-space models (SSM) based on surface movements only, and when adding either time allocated at depth or depth-corrected dive duration as a covariate.

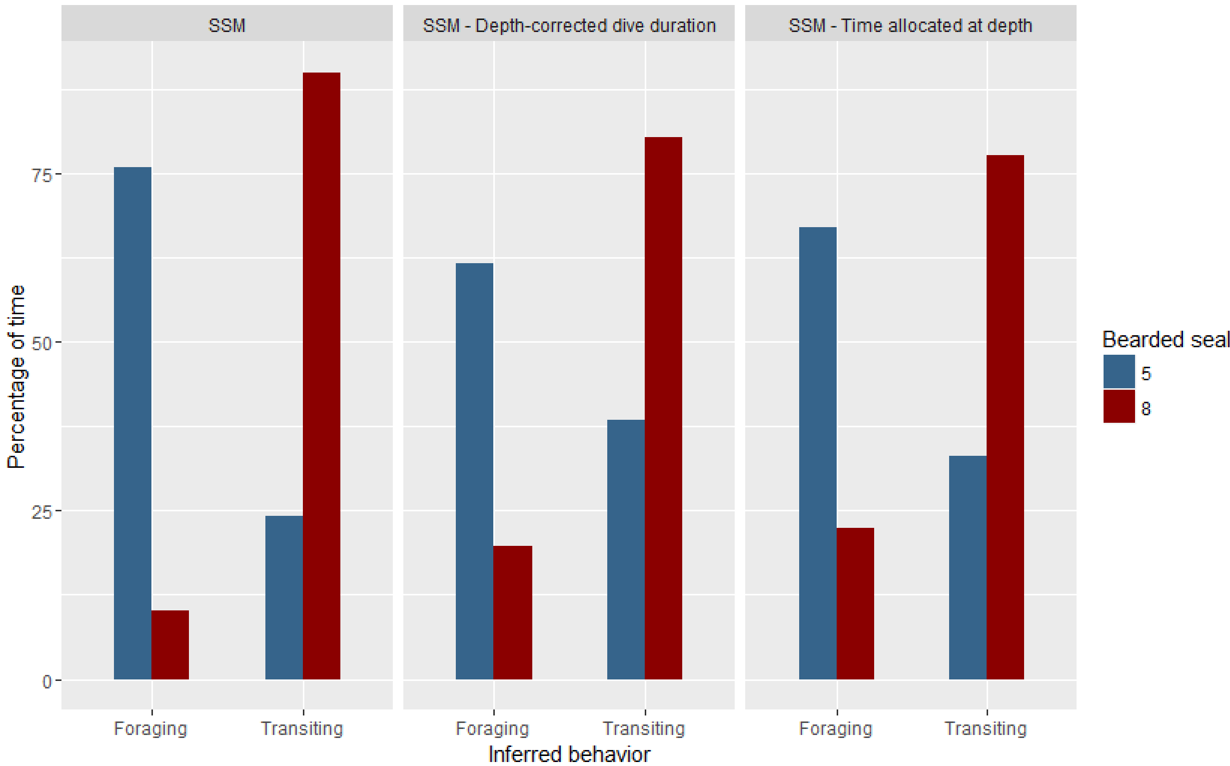

Figure 25 Bearded seal predicted percentage of time spent in foraging and transiting for state-space models (SSM) based on surface movements only, and when adding either time allocated at depth or depth-corrected dive duration as a covariate.

4.3.3.3 Spatial Results

Adding covariates associated with vertical movements altered foraging locations inferred from surface locations alone. For spotted seals, the inclusion of vertical movement covariates had minor effects, adding small foraging locations around Hanna Shoal and in the central Chukchi Sea for seal #4 (Figure 26); just north of the Bering Strait for seal #7 (Figure 27); and one east of Peard Bay for seal #9 (Figure 28). Adding the vertical covariates diminished the inferred foraging areas just south of the Bering Strait for bearded seal #5 (Figure 29) but indicated additional foraging areas west of Wevok, south of Kivalina, and south of Bering Strait for bearded seal #8 (Figure 30).

We conclude that foraging locations are best inferred by models that include depth-corrected dive duration as a covariate (Table 5).

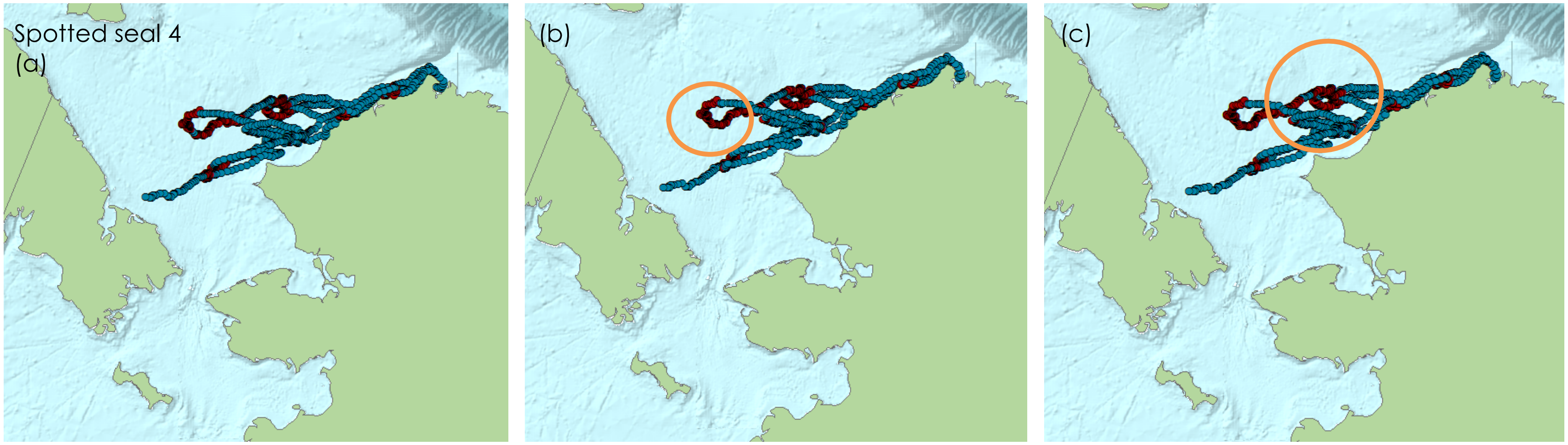

Figure 26 **Inferred foraging and transiting behavior for spotted seal 4 with no covariates (a) and with covariates: time allocated at depth (b), and depth-corrected dive duration (c). Red circles indicate inferred foraging, blue indicates transiting, and the orange circles highlight areas that differed between models.**

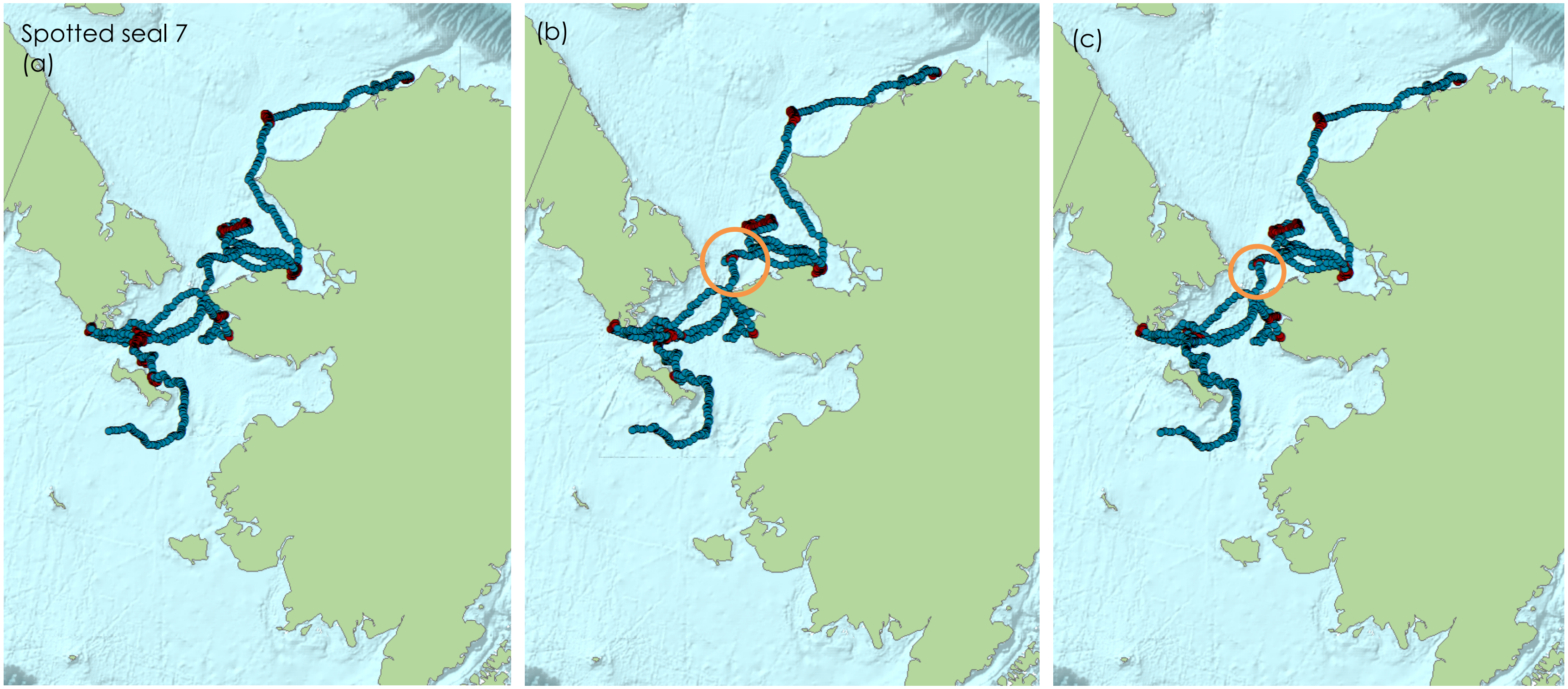

Figure 27 **Inferred foraging and transiting behavior for spotted seal 7 with no covariates (a) and with covariates: time allocated at depth (b), and depth-corrected dive duration (c). Red circles indicate inferred foraging, blue indicates transiting, and the orange circles highlight areas that differed between models.**

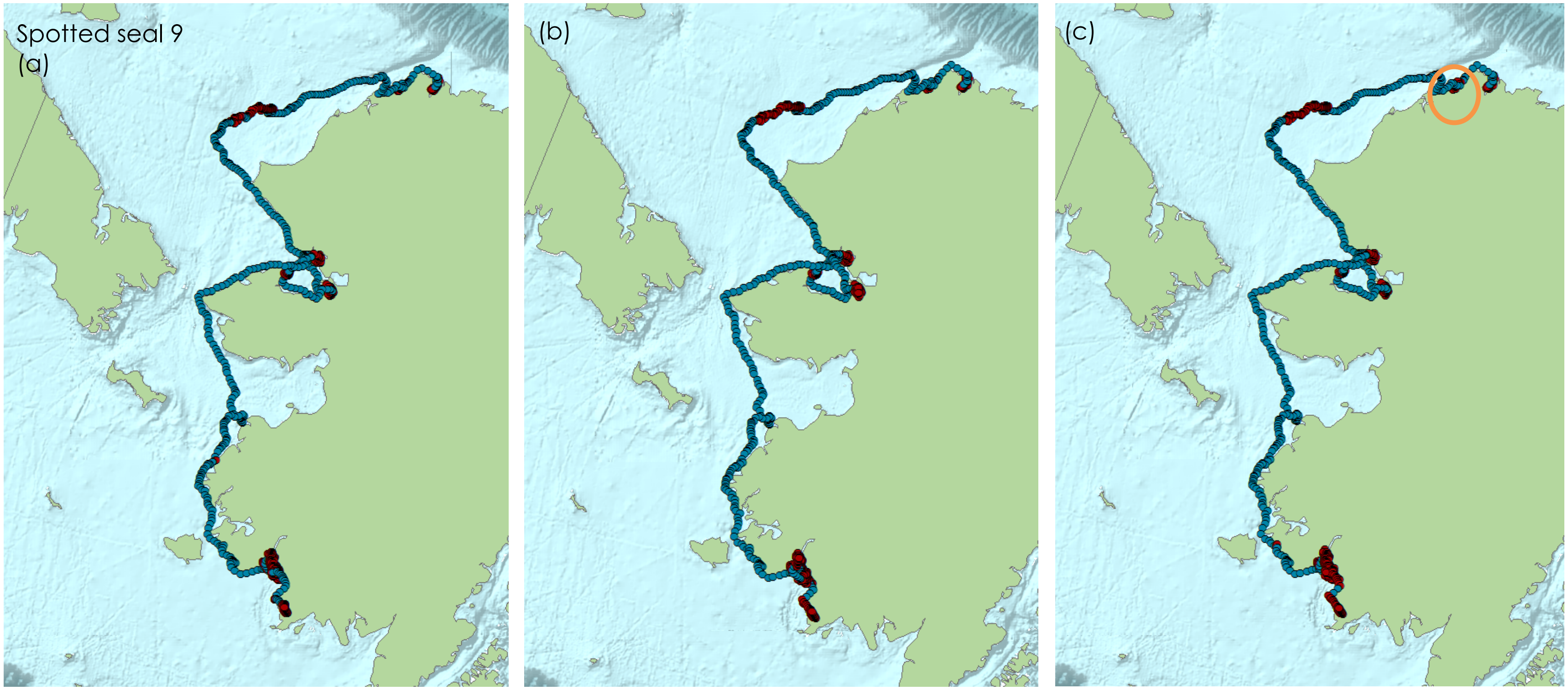

Figure 28 **Inferred foraging and transiting behavior for spotted seal 9 with no covariates (a) and with covariates: time allocated at depth (b), and depth-corrected dive duration (c). Red circles indicate inferred foraging, blue indicates transiting, and the orange circles highlight areas that differed between models.**

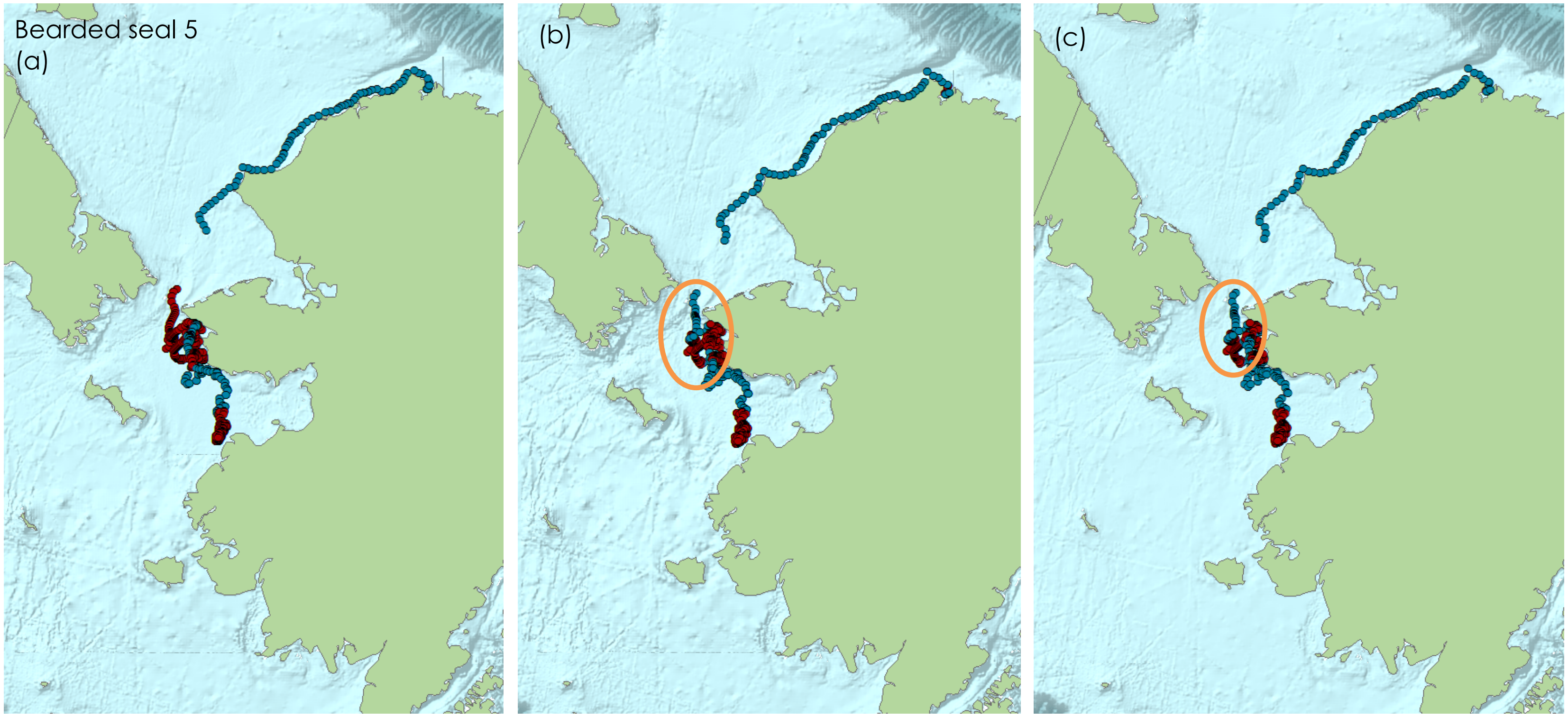

Figure 29 **Inferred foraging and transiting behavior for bearded seal 5 with (a) surface movement only and with covariates (b) time allocated at depth and (c) depth-corrected dive duration. Red circles indicate inferred foraging, blue indicates transiting, and the orange circles highlight areas that differed between models.**

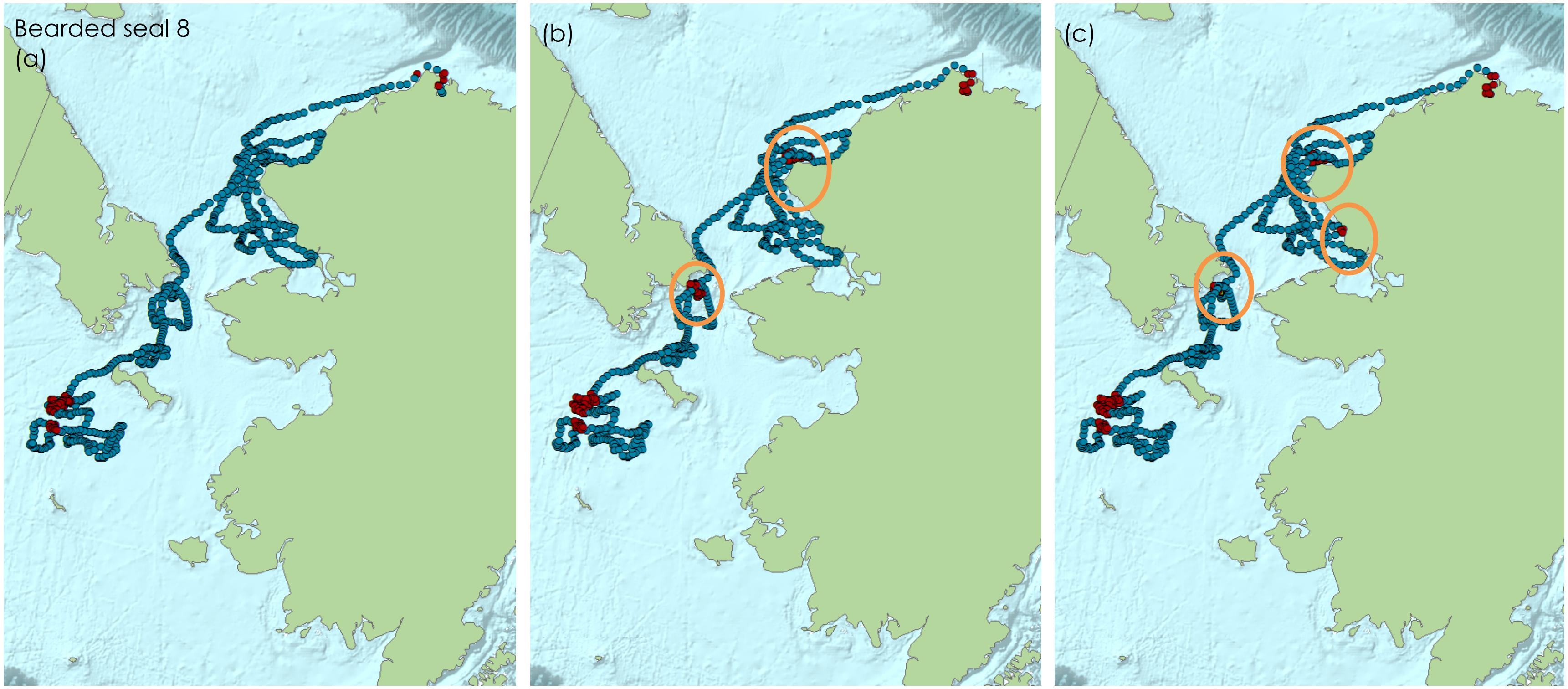

Figure 30 **Inferred foraging and transiting behavior for bearded seal 8 with no covariates (a) and with covariates: time allocated at depth (b), and depth-corrected dive duration (c). Red circles indicate inferred foraging, blue indicates transiting, and the orange circles highlight areas that differed between models.**

4.3.4 Influence of dive covariates on inferred behavioral switching

We explored the influence of the dive covariates on the probability of switching between transiting and foraging considering dive zone and covariate data.

The probability of spotted seals remaining in transit was close to 1 and unrelated to time allocated at depth during pelagic and benthic dives (Figure 31). In contrast, the probability of spotted seals switching from foraging to transiting during pelagic and benthic dives increased from 0 to 0.5 once seals started performing U-shaped dives (i.e., time allocated at depth exceeded 0.8). The distribution of time allocated at depth by spotted seals was similar for both foraging and transiting, although the median time allocated at depth for foraging was lower than for transiting and below the V to U-shaped time allocated at depth threshold of 0.8 (Figure 31).

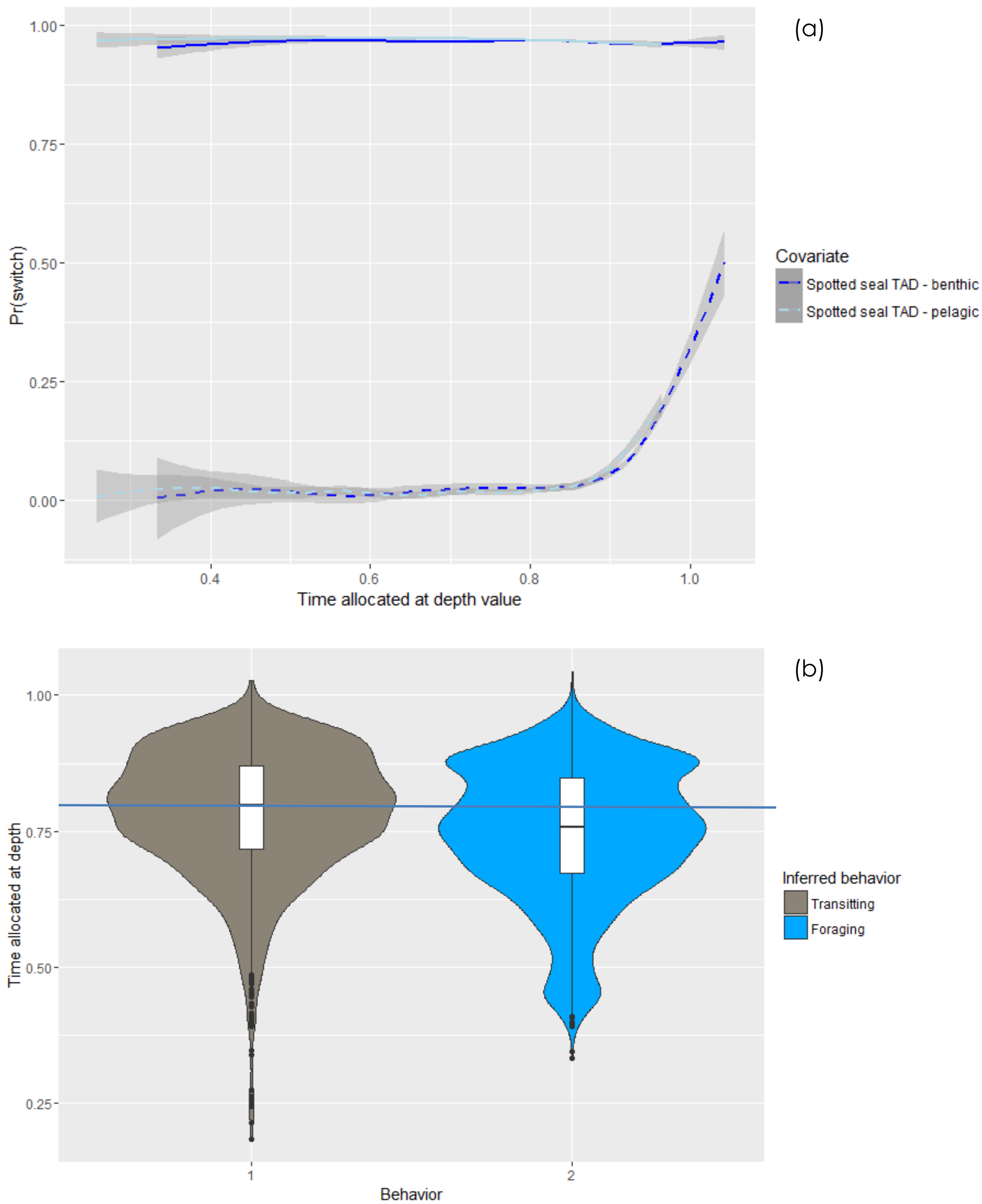

Figure 31 **(a) Estimated relationships between time allocated at depth and probabilities of switching between foraging and transiting for spotted seals. Solid lines = remain transiting; dashed lines = switch from foraging to transiting. (b) The distribution of time allocated at depth for transiting and foraging spotted seals. Transiting (behavior 1) is shown in brown and foraging (behavior 2) is shown in blue, and the blue horizontal line indicates transition from V-shaped to U-shaped dives (TAD~0.8).**

Depth-corrected dive duration had a weak influence on the probability of spotted seals staying in transit or switching to foraging (Figure 32). The distribution of depth-corrected dive duration values varied little between inferred foraging and transiting behaviors with median values hovering right around the expected dive duration based on depth (i.e. depth-corrected dive duration = 0; Figure 32).

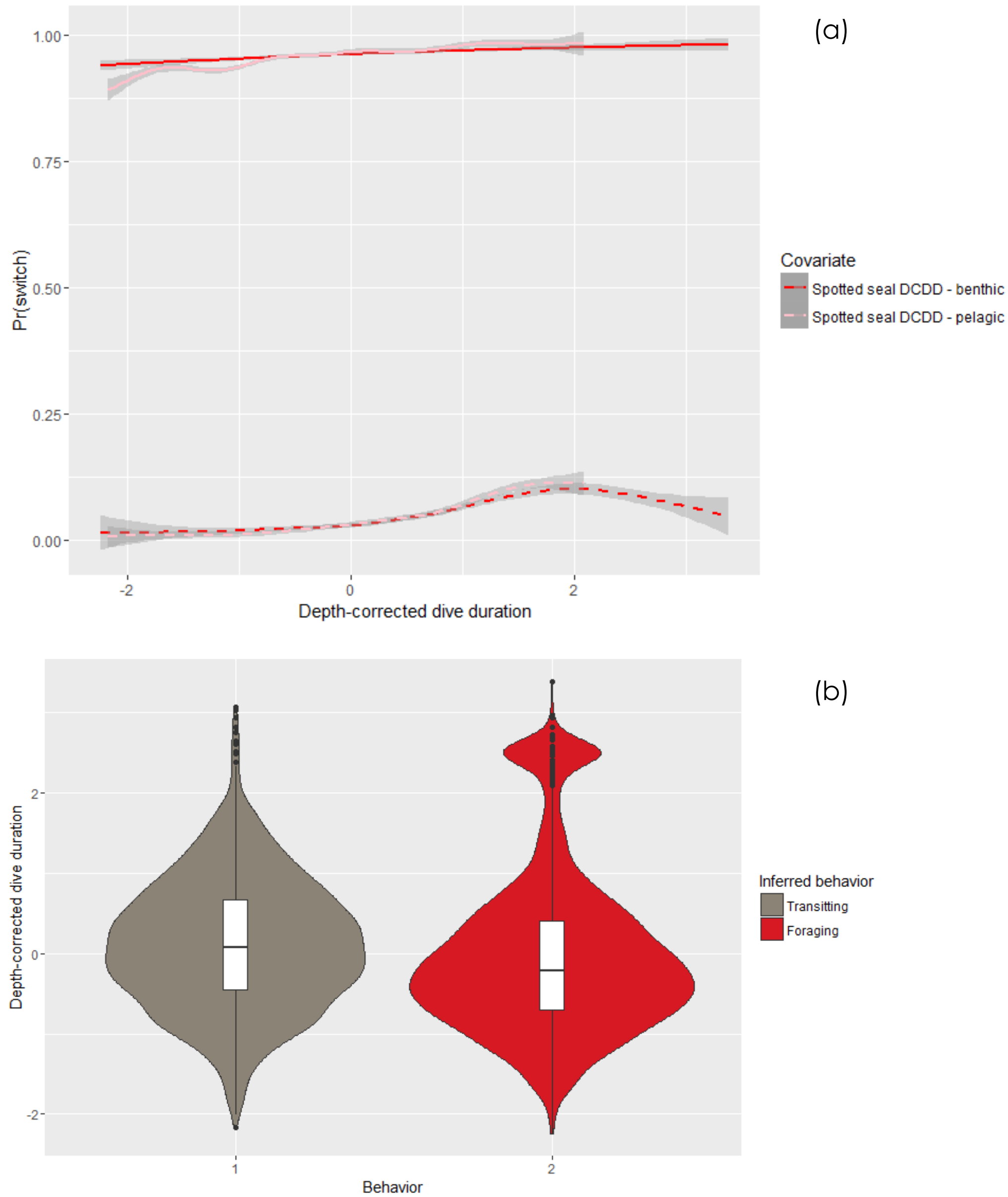

Figure 32 **(a) Estimated relationships between depth-corrected dive duration and probabilities of switching between foraging and transiting for spotted seals. Solid lines = remain transiting; dashed lines = switch from foraging to transiting. (b) The distribution of depth-corrected dive duration for transiting and foraging spotted seals. Transiting (behavior 1) is shown in brown and foraging (behavior 2) is shown in red.**

For bearded seals, the probability of staying in transit varied in V-shaped dives (time allocated at depth < 0.8) but approached 1 in U-shaped dives (Figure 33). Most time allocated at depth values, however, exceeded 0.8 (U-shaped dives; Figure 33), hence the overall influence of time allocated at depth is minimal. The probability of switching from foraging to transiting, however, increased sharply from 0 to 0.5 when time allocated at depth exceeded 0.9 during benthic dives with switching probabilities during pelagic dives remaining low (Figure 31). The distribution of time allocated at depth values was similar between foraging and transiting with medians above 0.9 and most dives being U-shaped (time allocated at depth> 0.8).

The probability of bearded seals remaining in transit was mostly 1 and not influenced by depth-corrected dive duration, whereas the probability of switching from foraging to transiting increased to over 0.25 once corrected-dive duration for both benthic and pelagic dives became longer than the average duration for a given depth (depth-corrected dive duration>0); Figure 34). The distribution of the corrected dive durations was similar between inferred foraging and transiting with median values around zero (Figure 34).

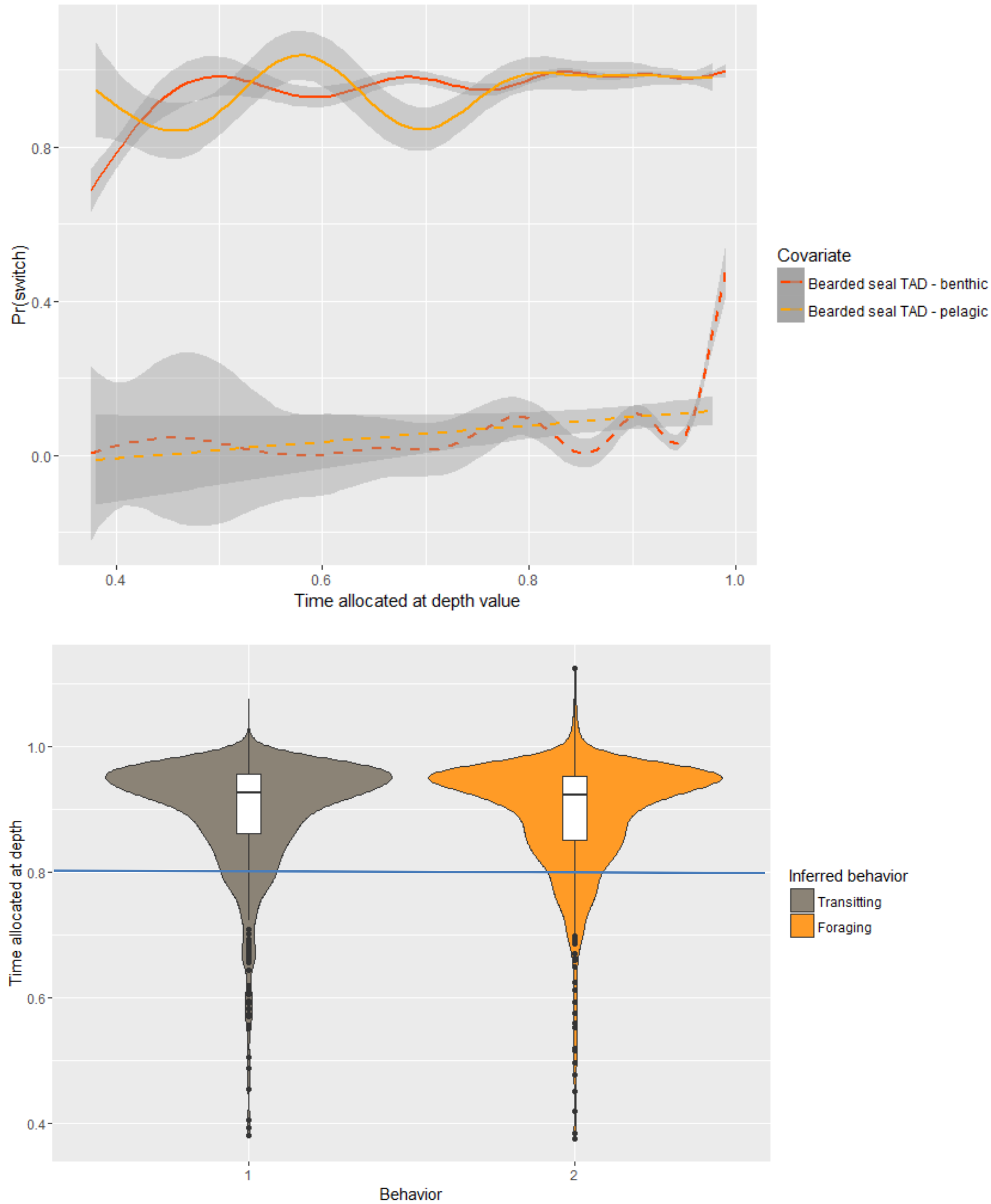

Figure 33 **(a) Estimated relationships between time allocated at depth and probabilities of switching between foraging and transiting for bearded seals. Solid lines = remain transiting; dashed line = switch from foraging to transiting. (b) The distribution of time allocated at depth for transiting and foraging bearded seals. Transiting (behavior 1) is shown in brown and foraging (behavior 2) is shown in orange, and the blue horizontal line indicates transition from V-shaped to U-shaped dives (TAD~0.8).**

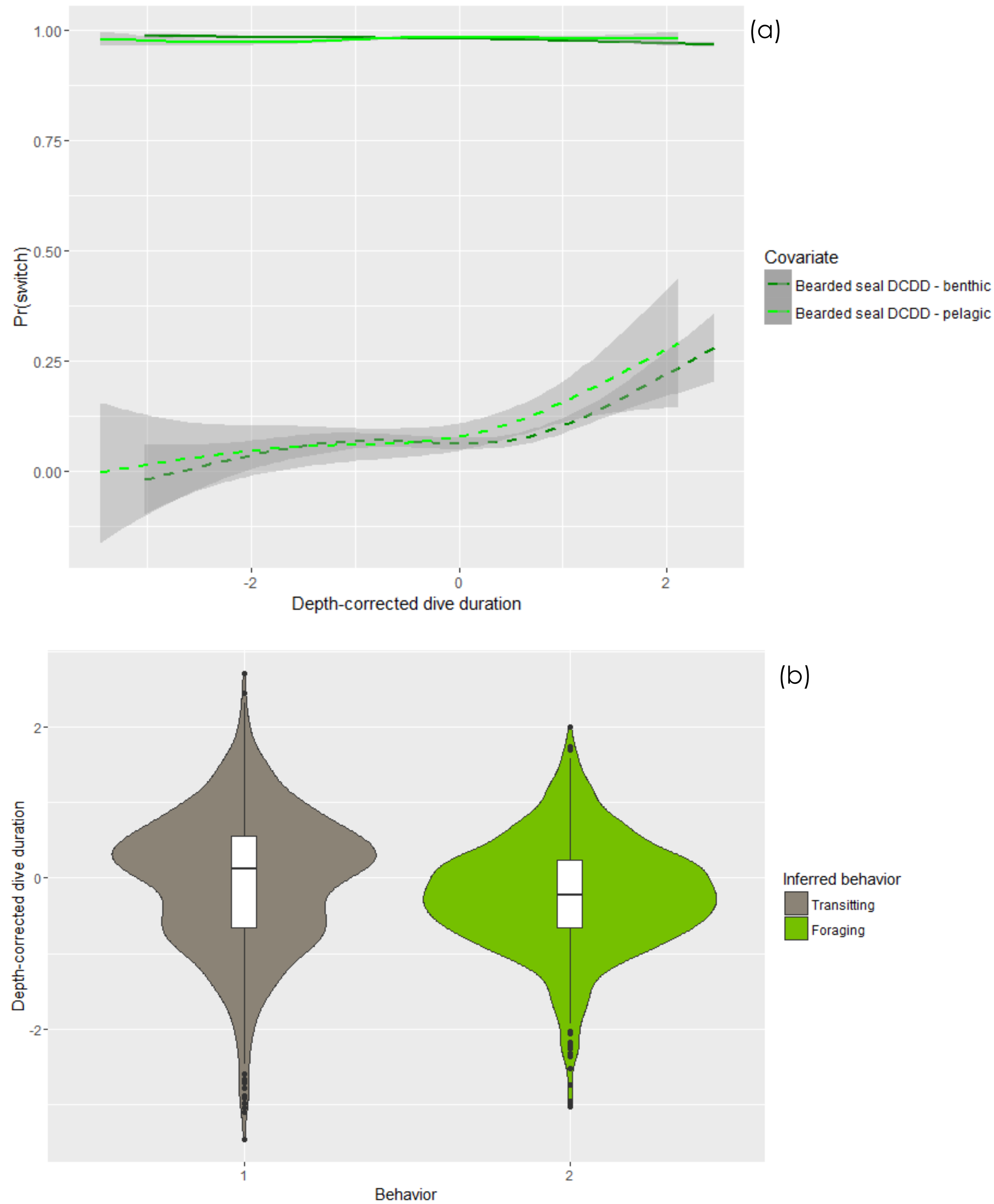

Figure 34 **(a) Estimated relationships between depth-corrected dive duration and probabilities of switching between foraging and transiting for bearded seals. Solid lines = remain transiting; dashed line = switch from foraging to transiting. (b) The distribution of depth-corrected dive duration for transiting and foraging bearded seals. Transiting (behavior 1) is shown in brown and foraging (behavior 2) is shown in green.**

4.4 DISCUSSION

Dive parameters alone are inadequate for inferring foraging, but their addition into state space models refined inferences of foraging based on surface movements.

Dive behaviors for spotted and bearded seals are reflections of their physical as well as biological environments. Spotted and bearded seals stayed on the continental shelf throughout the life of the tags, and a majority of their dives were to less than 50 m. As could be expected for benthic feeders, more than 80% of bearded seal dives were U-shaped and benthic, whereas dive zone (benthic vs. pelagic dives) and dive shape was more evenly split for spotted seals known to forage throughout the water column (Dehn et al. 2007).

For both species, the addition of time allocated at depth and depth-corrected dive duration to the state space model had little effect (10% or less) on the estimated amount of time spent foraging or transiting, but depth-corrected dive duration refined the locations of inferred foraging, most notably for bearded seals.

Measures of time allocated at depth and depth-corrected dive duration had little influence on the probability of bearded and spotted seals switching away from transiting, suggesting that other factors (perhaps environmental) caused the animals to transition into foraging. Conversely, U-shaped dives and depth-corrected dive duration were positively correlated with the probability of seals switching from foraging to transiting behavior. These results suggest that increases in both time allocated at depth and depth-corrected dive duration indicate increasing foraging effort and that this increased effort—caused perhaps by decreased prey abundance—eventually leads to abandonment of foraging as the energetic payoff decreases. Alternatively, it may just be that such increased foraging efforts can only be maintained for so long before some physiological recovery is needed, forcing the seal to abandon their foraging effort.

The relationships we observed between surface movements and dive parameter patterns in these five seals suggests a hypothetical behavioral framework relating dives and surface movements to the behavior of spotted and bearded seals (Figure 35).

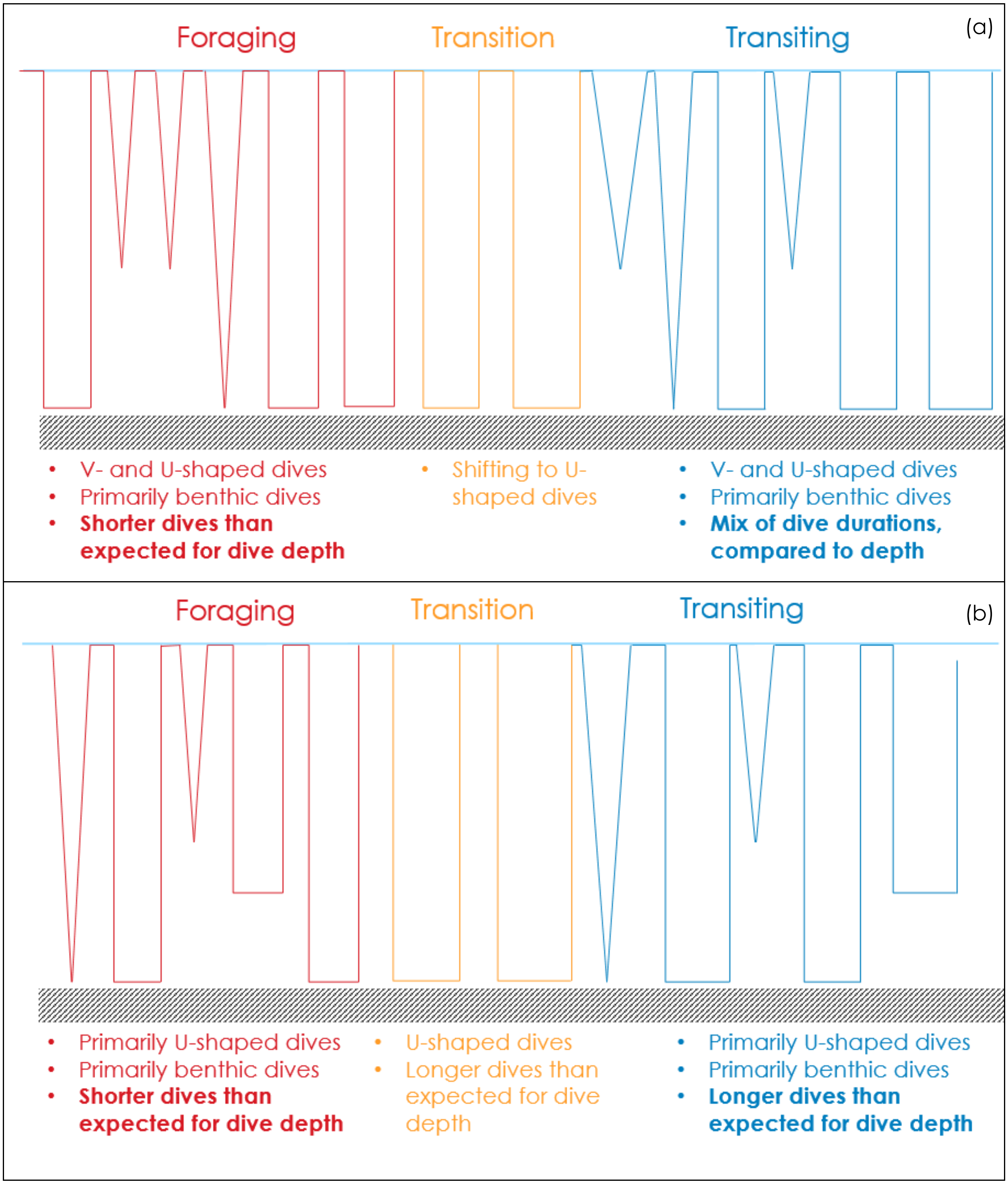

Figure 35 Hypothesized behavioral framework relating diving and surface movements to the behavior of (a) spotted seals and (b) bearded seals.

Future studies with more seals and higher resolution vertical profile data are needed to test the proposed concept. This framework could also be further refined by the addition of environmental data collected during these dives, a topic explored in Chapter 5.

5.0 CHAPTER 5—INFERRING FORAGING WITH THE ADDITION OF *IN SITU* OCEANOGRAPHIC MEASUREMENTS

5.1 INTRODUCTION

Marine resources are highly patchy in space and over time. Areas and/or times of increased productivity and prey concentrations are often driven by upwelling and temperature fronts lasting from a few hours to weeks and sometimes months (Suryan et al. 2006; Gende and Sigler 2006; Sigler et al. 2012). Such peaks in marine resources underpin noticeable increases in the presence of predators (e.g., Steller sea lion distributions associated with persistent forage fish hotspots; Gende and Sigler 2006). Understanding the dynamics of these foraging "hotspots" and "hot-times" can provide insight into the predictability of habitat use by marine taxa, in particular marine mammals, and how that use varies over time to reflect fluctuations in energy demands. Dynamics in habitat use can also inform potential for, and potential effects of, interactions with human activities such as commercial fisheries or subsistence hunters (e.g., Santora et al. 2016).

Marine mammal and seabird movements have been analyzed in relation to environmental data derived from satellite imagery (e.g., surface temperature, surface chlorophyll, sea surface height) (e.g., Block et al. 2011), rather than *in-situ* readings. For species feeding in the water column or on the benthos; however, such approaches are unsatisfactory as they assume a strong relationship between environmental conditions at the surface and those occurring at depth where the animals forage. Historically, the relationship between pelagic and benthic productivity in the Pacific sector of the Arctic has been tightly coupled (Grebmeier et al. 2006). Changing ocean conditions may be shifting some of these relationships, highlighting the importance of linking marine mammal movements to environmental data throughout the water column.

The final objective of our pilot program was to determine whether oceanographic data collected *in situ* by sensors attached to diving seals could be used to characterize water conditions in which seals preferentially forage and, thereby, improve inferences of foraging based on movement patterns (Chapters 3 and 4).

5.2 METHODS

5.2.1 Oceanographic Data

Conductivity, temperature, depth (CTD), and fluorescence data were sampled for dives deeper than 30 m using Sea Mammal Research Unit (SMRU) ARGOS satellite tags attached to 3 spotted seals and 2 bearded seals. The SMRU tags transmitted oceanographic data from the deepest dive within every 12-hour period (Photopoulou et al. 2015). The deepest dive was selected to focus on the most informative dive profile and, thereby, increase longevity of the tags and overcome bandwidth limitations when transmitting data. To further reduce storage requirements, tags were preprogrammed to only record information when the animal was ascending and at least 10 m from their deepest recorded depth (rather than throughout the dive). Once activated, CTD and fluorometer sensors sampled the water column every second, recording temperature, conductivity, fluorescence, and pressure. Data were automatically pared down to 14 readings distributed evenly between the minimum and maximum depth, plus four standard readings: minimum and maximum depth and minimum and maximum temperature. These data were then transmitted via satellite to the SMRU server.

Data were accessible in near-real time (typically within a few hours of transmission). Quality control and analysis of location data were conducted using R 3.3.1 (R Core Team 2016) and ArcGIS 10.1 (ESRI 2012) to remove any obvious outliers. Quality of oceanographic data was further checked by physical oceanographers at Woods Hole Oceanographic Institution and biological oceanographers at the University of Alaska Fairbanks. Salinity and temperature were plotted to identify measurements that were not consistent with those expected from the region during the months when data were collected. The fluorometry data were treated similarly and plotted to identify outliers that were not likely to occur.

5.2.2 Environmental metrics

Prior to exploring links between oceanography and movements (transiting and diving), we derived the following environmental metrics from the data:

- Surface temperature (°C), where the surface was defined as the measurement taken closest to 4 m from the surface
- Surface salinity (Practical Salinity Units; PSU)
- Maximum fluorescence (mV) recorded during depth profile
- Daily distance (km) to the edge of the sea ice pack (i.e., 8–10/10ths of sea ice), calculated in ArcGIS 10.1 (ESRI 2012) using the U.S. National Ice Center Daily Ice Edge data (NIC 2016)
- The water body closest to maximum dive depth. Six water bodies were identified based on salinity and temperature following Pickard (pers comm.; Table 6)

Table 6 Salinity and temperature criteria used to classify water body of dive profiles

Water body	Salinity (PSU) and temperature (°C) criteria
Alaskan coastal water (ACW)	30 ≤ PSU ≤ 32 and 3 ≤ °C ≤ 9
Bering summer water (BSW)	32 ≤ PSU ≤ 33.5 and 3 ≤ °C ≤ 9; or 30 ≤ PSU ≤ 33.5 and 0 ≤ °C ≤ 3
Newly ventilated winter water (NVWW)	31.5 ≤ PSU ≤ 36 and -2 ≤ °C ≤ -1.5
Remnant winter water (RWW)	31.5 ≤ PSU ≤ 33.5 and 0 ≤ °C ≤ -1.5; or 33.5 ≤ PSU ≤ 36 and -1.5 ≤ °C ≤ -1.25
Melt water (MW)	24 ≤ PSU ≤ 30 and -1.5 ≤ °C -1.25 30 ≤ PSU ≤ 31.5 and -1.75 ≤ °C ≤ 0
Atlantic water (AW)	33.5 ≤ PSU ≤ 36 and -1.25 ≤ °C ≤ 9

Environmental metrics were related to the inferred foraging and transiting locations derived from surface movement-only hierarchical state-space models (Chapter 3) using two different approaches. First, we used an *associated behavior approach* and linked environmental metrics to the closest temporal estimate of behavior. This approach only uses a small amount of the inferred behavior predictions (i.e., specifically when a CTD profile was transmitted) but focuses on the inferred behavior most relevant to the associated environmental conditions giving some insight into habitat use by the seals. Second, an *extrapolated environmental data approach* interpolated the oceanographic data to all the inferred behaviors. Here, we linked each behavioral record from the state-space model output with the spatially closest environmental metric (i.e., temperature, salinity and fluorescence). We extrapolated based on space rather than time since water bodies and their characteristics are more likely to be stable in space than in time. For example, a behavior linked to a CTD profile taken 5 km away is more likely to reflect relevant conditions than one taken one week prior to the inferred behavior. Although this second approach effectively smooths potential differences in associations between behavior and oceanographic conditions, it does provide an opportunity to assess the need for, and use of, *in situ* oceanographic data for future studies, where oceanographic data may be collected more frequently.

5.2.3 Modeling

We explored the influence of oceanographic parameters on the probability of switching between transiting and foraging by adding oceanographic variables to the surface movement-only state-space models (Chapter 4). We used logit-linked binomial Generalized Linear Mixed Models (GLMM) with a response of "1" for foraging (i.e., area-restricted search) and "0" for transiting to relate environmental metrics to inferred behaviors. Environmental metrics, time (Julian day or month), and dive characteristics (time allocated at depth, depth-corrected dive duration, and dive zone [benthic vs pelagic], see Chapter 4) were included as fixed effects. We also included random effects of individual on intercept and slopes to account for variation among seals in their responses to environment conditions. We tested for collinearity among fixed effects by calculating pairwise correlations (Zuur et al. 2009).

Models were fit using the *R* package "lmer4" (Bates et al. 2015), and model fits were compared using small-sample Akaike Information Criterion (AICc) calculated using the R package "AICcmodavg" (Mazerolle 2016). Delta AICc was calculated to evaluate model fits. Typically, models with values of delta AICc >10 are considered to have no support (Burnham et al. 2002). P-values were based on asymptotic Wald tests as calculated in 'lmer4' (Bates et al. 2015).

5.3 RESULTS

5.3.1 Associated behavior approach

The majority of the oceanographic data—collected by all five seals throughout the Chukchi and northern Bering Sea—were considered reliable (Table 7).

Table 7 Number of useable temperature, salinity, fluorescence, and full profiles (all three variables) telemetered by the satellite tags.

Individual	Total number of profiles collected	Temperature profiles	Salinity profiles	Fluorescence profiles	Full profiles
Spotted seals					
Seal 4	113	113	113	113	113
Seal 7	121	119	119	95	93
Seal 9	40	40	40	40	40
Bearded seals					
Seal 5	38	21	29	27	16
Seal 8	258	238	234	184	160

Environmental metrics and their link to inferred behaviors varied between species and among individuals (Table 8; Figure 36-Figure 41). For bearded seals, sea surface temperatures differed significantly during inferred foraging and transiting; although inconsistently between the two seals. For spotted seals, surface salinity and maximum fluorescence were significantly higher during foraging than during transiting (Table 8).

Assuming foraging is associated with water characteristics at maximum dive depth, our data revealed different use of water bodies for foraging activity among and within species. Spotted seals primarily foraged in Bering summer water (BSW) with Alaskan coastal water being the second most frequented (Table 8). The bearded seals differed in their preferred use of water bodies: Seal #5 foraged predominantly in Bering summer water while seal #8 foraged primarily in newly ventilated winter water and, to a slightly lesser extent, in remnant winter water.

Table 8 Summary of oceanographic variables and water bodies by individual and behavior for surface movement only state-space models. Values with an asterisk were significantly different between behaviors.

		Surface Temperature (°C)		Surface Salinity (PSU)		Maximum Fluorescence (mV)			Proportion (and number) of dives to each water body at depth					
Individual	Behavior	Median	Interquartile range	Median	Interquartile range	Median	Interquartile range	Primary water body	ACW	AW	BSW	MW	NVWW	RWW
Spotted seals														
Seal 4	Foraging	5.4	0.8–6.9	32.0*	31.7–32.3	1.0*	0.6–1.5	BSW	22% (n = 8)	-	**69% (n = 25)**	3% (n = 1)	-	6% (n = 2)
	Transiting	1.5	0.04–6.2	31.3*	31.0–31.9	0.7*	0.6–0.9	BSW	38% (n = 16)	-	**45% (n = 19)**	10% (n = 4)	-	7% (n = 3)
Seal 7	Foraging	3.8	-0.5–6.9	31.9*	31.5–32.4	2.5*	1.5–2.6	BSW	22% (n = 8)	-	**54% (n = 20)**	3% (n = 1)	13% (n = 5)	8% (n = 3)
	Transiting	3.1	0.8–4.3	31.0*	30.6–31.7	1.7*	1.2–2.2	ACW	**44% (n = 27)**	-	26% (n = 16)	16% (n = 10)	6% (n = 4)	6% (n = 4)
Seal 9	Foraging	6.5	6.1–6.9	31.9*	31.8–32.0	2.2	1.4–2.4	BSW	18% (n = 2)	-	**82% (n = 9)**	-	-	-
	Transiting	6.2	5.6–6.8	31.3*	31.0–31.6	1.6	2.0–2.8	ACW	**53% (n = 8)**	-	47% (n = 7)	-	-	-
Bearded seals														
Seal 5	Foraging	2.8*	1.5–3.0	30.1	28.4–30.3	0.9	0.8–1.0	BSW	12.5% (n = 1)	-	**75% (n = 6)**	12.5% (n = 1)	-	-
	Transiting	-0.9*	-1.4–0.5	30.8	29.8–31.2	0.9	0.7–1.0	MW	12% (n = 1)	-	-	**50% (n = 4)**	-	38% (n = 3)
Seal 8	Foraging	-1.7*	-1.7– -1.6	31.5	31.4–31.7	1.0	0.9–1.4	NVWW	-	-	4% (n = 1)	28% (n = 8)	**57% (n = 16)**	11% (n = 3)
	Transiting	-0.4*	-1.6–3.2	31.8	31.3–32.1	1.2	1.0–2.0	BSW	13% (n = 25)	-	**32% (n = 61)**	14% (n = 28)	15% (n = 29)	26% (n = 50)

NOTES:
Significance was determined using Wilcox rank sum test.
Only those dives with both temperature and salinity values were included in the percentages.

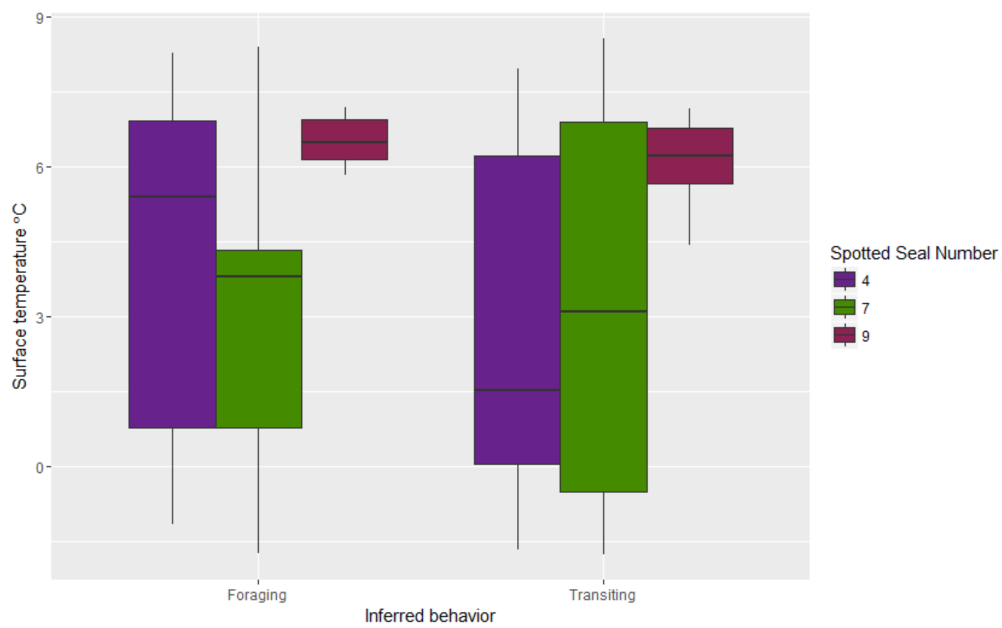

Figure 36 Sea surface temperature associated with inferred surface movement behavior of spotted seals
Thick horizontal line: median value (second quartile); box limits: interquartile range (IQR, i.e. first and third quartiles [Q1 and Q3]); whiskers: extent of most extreme points within 1.5*IQR (i.e., 1.5*[Q3-Q1]) beyond Q1 and Q3; dots: outliers.

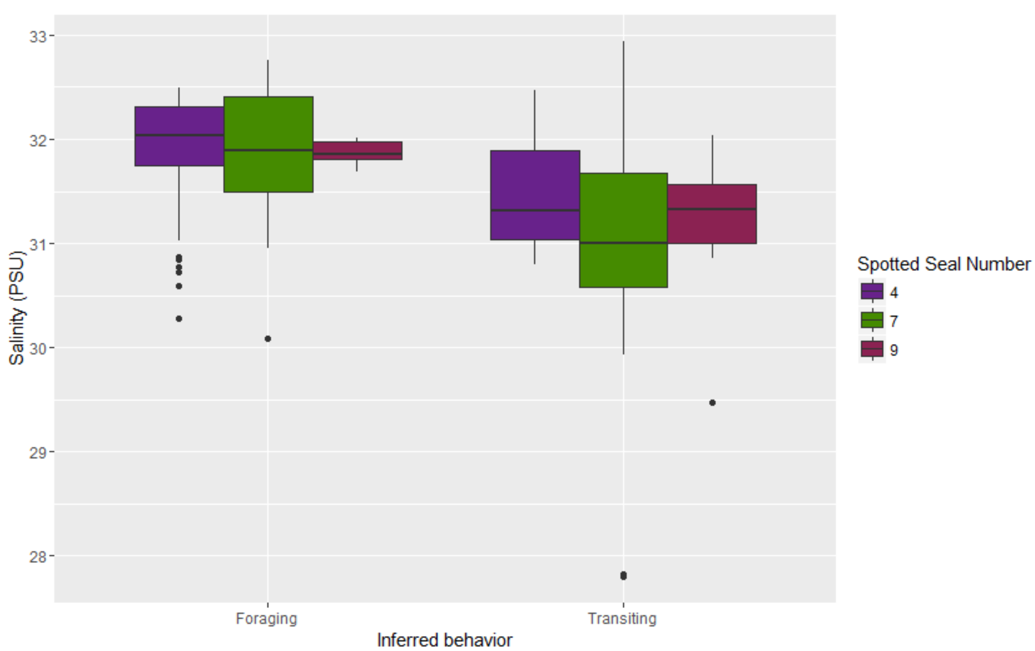

Figure 37 Sea surface salinity associated with inferred surface movement behavior of spotted seals
See Figure 36 caption for further details

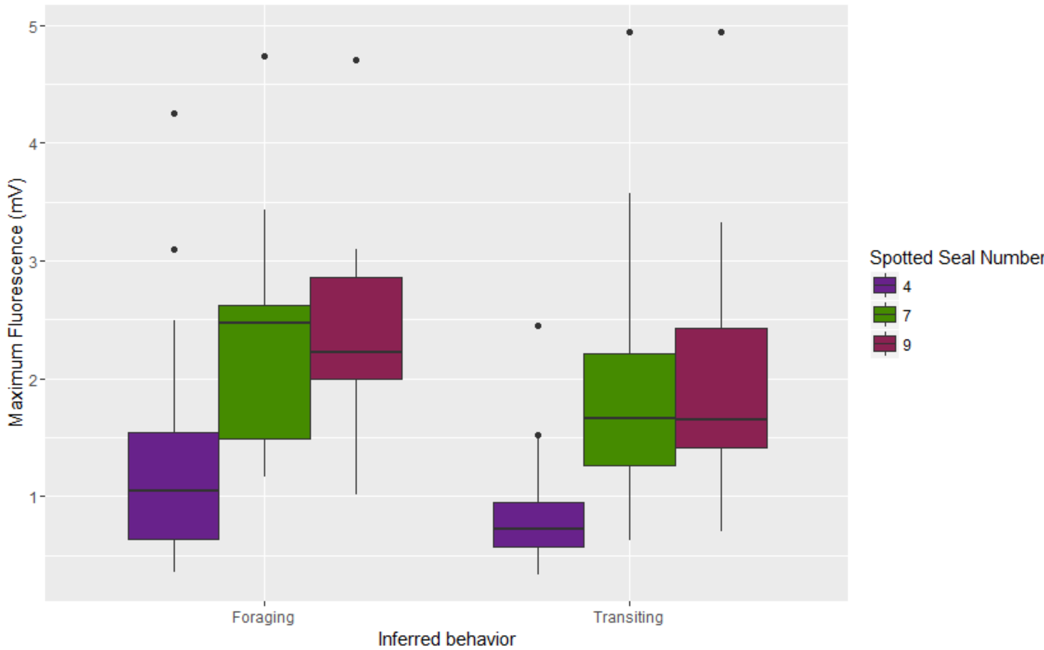

Figure 38 Maximum fluorescence associated with inferred surface movement behavior of spotted seals
See Figure 36 caption for further details

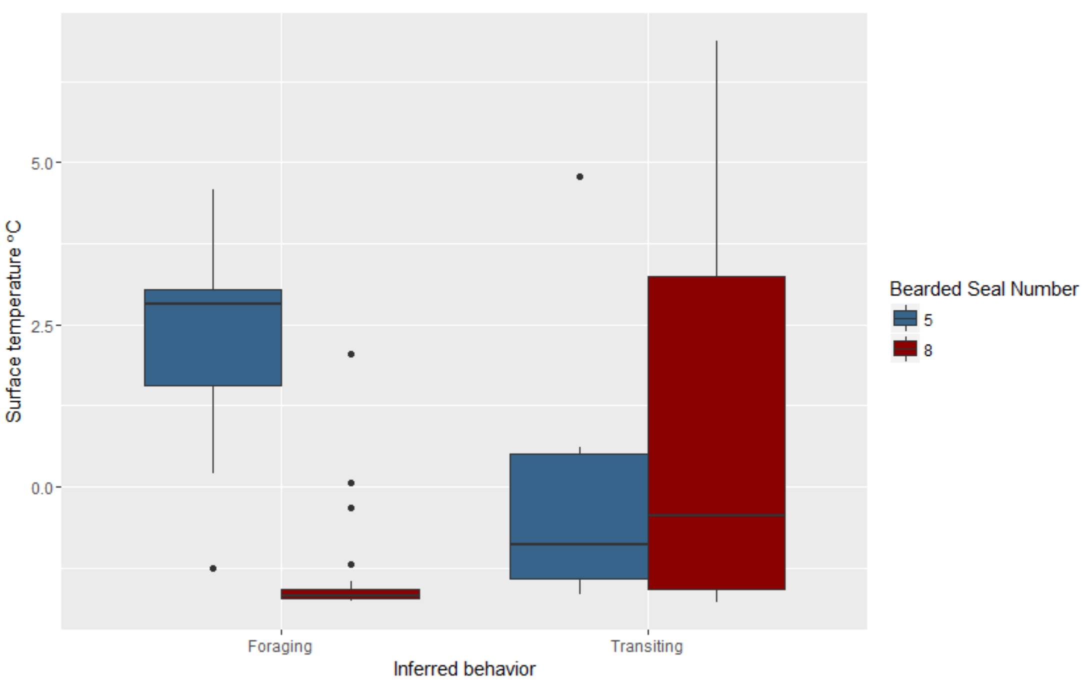

Figure 39 Sea surface temperature associated with inferred surface movement behavior of bearded seals
See Figure 36 caption for further details.

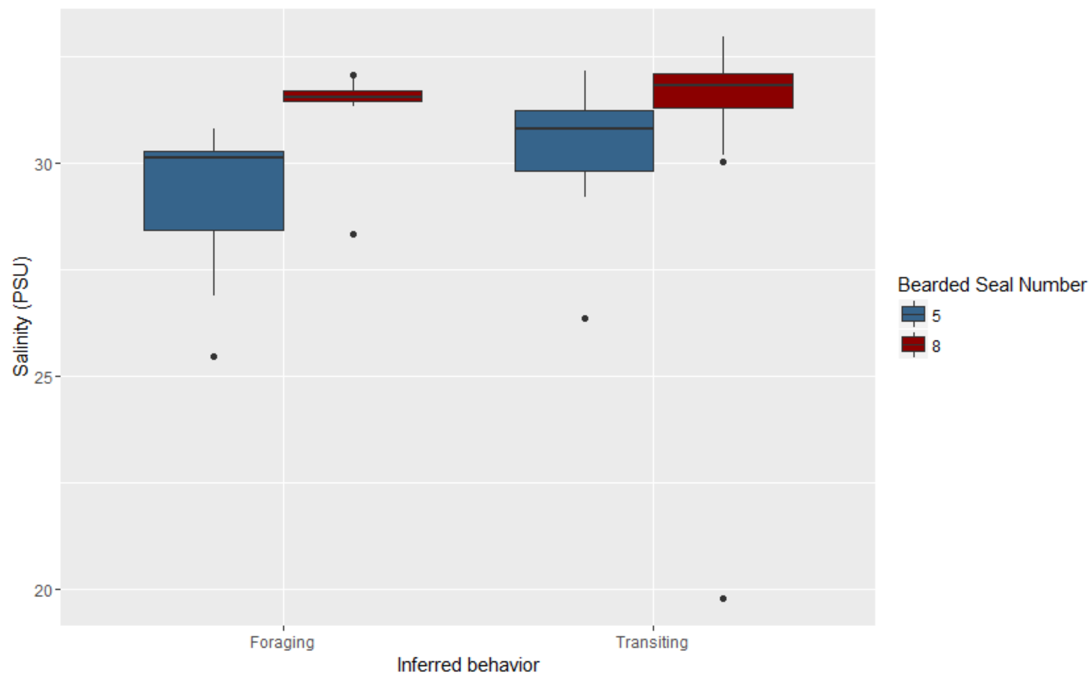

Figure 40 Sea surface salinity associated with inferred surface movement behavior of bearded seals
See Figure 36 caption for further details.

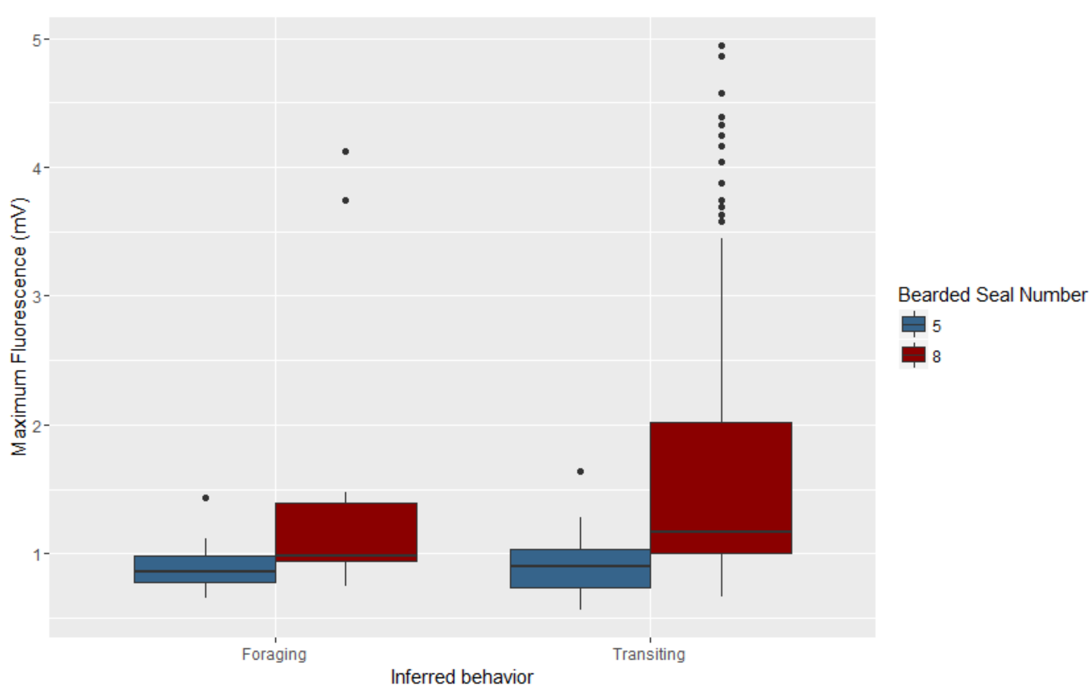

Figure 41 Maximum fluorescence associated with inferred surface movement behavior of bearded seals
See Figure 36 caption for further details.

Modeling the relationship between surface movements, dive parameters and environmental metrics using the associated behavior approach was unsuccessful for both species. The models did not converge due to little difference among the limited number of oceanographic profiles collected by each individual (Table 7). We attempted to overcome this problem by assuming that a water body is the actual target of the foraging dive (and therefore most relevant to the choice of foraging habitat), and we limited environmental metrics to the water body only. For spotted seals, we found significant relationships between foraging and Alaskan Coastal Water (ACW) and Bering Summer Water (BSW) (Table 9). We subsequently attempted to reintroduce at least one of the other dive characteristics parameters described in Chapter 4, however, due to data limitations, none of those models converged. For bearded seals, no models converged.

Table 9 Association between spotted seal foraging behavior and water body using generalized linear mixed models

Water body	Coefficient	Std. Error	P-value
Alaskan coastal water	-1.04	0.27	<0.01*
Bering summer water	1.29	0.34	<0.01*
Melt water	-0.90	0.80	0.26
Newly ventilated winter water	1.26	0.72	0.08
Remnant winter water	0.70	0.65	0.28

5.3.2 Extrapolated environmental data approach

Due to the increased sample size (Table 10), modeling the relationship between surface movement behaviors and environmental metrics using the extrapolated environmental data (i.e., temperature, salinity and fluorescence) approach was possible for both species, although not with all the variables. Models that converged (Table 11 and Table 12) included combinations of dive parameters (i.e., dive zone, time allocated at depth, and depth-corrected dive duration) and environmental metrics (sea surface temperature, sea surface salinity, and maximum fluorescence). No models that included water body converged. Depth-corrected dive duration and surface salinity best predicted spotted seal foraging behavior. The slope for depth-corrected dive duration was significant and negative, indicating increased foraging activity with shorter dive durations, consistent with single prey loading by a pelagic predator and findings presented in Chapter 4. Bearded seal foraging behavior was best predicted by sea surface temperature and maximum fluorescence, both with negative slopes.

Table 10 Sample size for extrapolated environmental data approach

Individual	Temperature profiles	Salinity profiles	Fluorescence profiles	Full profiles
Spotted seals				
Seal 4	1155	1128	1073	1057
Seal 7	1280	1181	928	863
Seal 9	1505	1481	700	676
Bearded seals				
Seal 5	699	411	601	318
Seal 8	828	759	624	576

Table 11 Parameter estimates for spotted seal foraging behavior by environmental metrics and dive parameters using generalized linear mixed models

Model Run	Fixed Effect Variable	Parameter Estimate (SE)	Z-value	p of z-stat	ΔAICc
Spotted seals					
Model 1	Intercept	0.26 (0.26)	1.00	0.32	0
	Depth-corrected dive duration	-0.52 (0.06)	-8.77	<0.01*	
	Sea surface salinity	0.07 (0.04)	1.59	0.11	
Model 2	Intercept	0.17 (0.25)	0.66	0.51	92.5
	Depth-corrected dive duration	-0.52 (0.06)	-8.19	<0.01*	
	Sea surface temperature	0.29 (0.20)	1.45	0.15	
Model 3	Intercept	-0.10 (0.18)	-0.58	0.56	169.7
	Benthic dive	0.35 (0.16)	2.18	0.03*	
	Time allocated at depth (V-shaped)	0.53 (0.07)	7.50	<0.01*	
	Sea surface salinity	0.15 (0.06)	2.51	0.01*	
Model 4	Intercept	0.15 (0.20)	0.75	0.46	193.1
	Time allocated at depth (V-shaped)	0.48 (0.08)	6.29	<0.01*	
	Sea surface salinity	0.09 (0.05)	1.69	0.09	
Model 5	Intercept	-0.08 (0.16)	-0.55	0.58	415.3
	Time allocated at depth (V-shaped)	0.50 (0.07)	7.11	<0.01*	
	Benthic dive	0.25 (0.16)	1.54	0.12	

Table 12 Parameter estimates for bearded seal foraging behavior by environmental metrics and dive parameters using generalized linear mixed models

Model Run	Fixed Effect Variable	Parameter Estimate (SE)	Z-value	p of z-stat	ΔAICc
Bearded seals					
Model 1	Intercept	0.77 (3.37)	0.229	0.82	0
	Sea surface temperature	-0.74 (1.12)	-0.660	0.51	
	Maximum fluorescence	-2.36 (2.51)	-0.941	0.35	
Model 2	Intercept	-0.99 (0.77)	-1.29	0.20	206.0
	Sea surface temperature	-0.98 (0.44)	-2.24	0.03*	
	Sea surface salinity	-0.73 (0.38)	-1.92	0.06	
Model 3	Intercept	-0.82 (0.77)	-1.07	0.28	265.5
	Depth-corrected dive duration	-0.16 (0.23)	-0.69	0.49	
	Sea surface salinity	-0.41 (0.08)	-4.89	<0.01*	
Model 4	Intercept	-0.87 (1.03)	-0.85	0.40	453.1
	Depth-corrected dive duration	0.001 (0.25)	0.01	0.99	
	Sea surface temperature	-1.08 (0.37)	-2.88	<0.01	
Model 5	Intercept	-0.52 (1.14)	-0.45	0.65	545.3
	Depth-corrected dive duration	-0.10 (0.21)	-0.48	0.63	

5.4 DISCUSSION

We successfully collected oceanographic data from animal-borne sensors and created an analytical framework to investigate the relationship between foraging by marine mammals and oceanographic conditions. The framework was implemented using two approaches - associated behavior and extrapolated environmental data. Predictably, more data than collected in this pilot study will be needed to adequately identify variables driving foraging behavior and locations. Nonetheless, trends in relationships for both species were apparent.

Both approaches highlighted the value of adding environmental data to the analysis of habitat selection and the advantage of collecting it *in situ* at the scale relevant to individuals. For example, surface salinity and water column fluorescence were significantly higher when spotted seals were foraging than when they were transiting. Thus, the animal-borne oceanographic sensors may have revealed a preference for pelagic feeding in high productivity waters, and they helped to identify distinct waters bodies (akin to oceanographic stations occupied by ships, e.g., Danielson et al. 2016). Foraging spotted and bearded seals showed an affinity for Bering Sea summer water. Under certain conditions, Bering Sea summer water is associated with high nutrient concentrations and a high overall phytoplankton standing crop biomass (Danielson et al. 2016). Thus, the affinity for Bering Sea summer water may reflect foraging hotspots and hot-times. Deploying oceanographic sensors on foraging marine mammals reveals insights in to habitat selection and, thereby, their likely responses to rapidly changing ocean conditions in the Arctic Ocean.

6.0 CHAPTER 6—CONCLUSIONS

The objectives for this pilot-program were successfully met. We established productive relationships with the North Slope Borough and several native hunters, and we garnered support for our study and approach from the Ice Seal Committee, co-management groups in Canada, and the communities of Wainwright and Kaktovik. We also established effective collaborations with other researchers, thereby minimizing the impact of the research on communities and the animals they rely on for subsistence.

Successful deployment of satellite CTD-fluorometer tags revealed insights concerning tag configuration and communication protocols. Capture methods and locations were also refined by bringing together knowledge and experience from MARES, NSB, and other scientists experienced in capturing and tagging ice-associated seals around the world.

Our analysis using state-space models illustrated the utility of satellite CTD-fluorometer tags to extend inferences of foraging beyond what is possible with surface movements alone. We identified foraging hot spots based on spatiotemporal overlap of foraging bearded and spotted seals. Some of these areas coincided with high prey density and high use areas by other species (e.g., Grebmeier et al. 2015, Ciatta et al. 2015, Kuletz et al. 2015).

Inclusion of dive parameters had little effect on predictions of amount of time spent foraging and in transit, but depth-corrected dive duration helped refine foraging locations. We also demonstrated that dive parameters can provide insights into the probability of switching between foraging and transiting. More frequent and longer than anticipated U-shaped dives were associated with an increased probability of switching from foraging to transiting.

Previous studies of spotted and bearded seals have looked at dive parameters and movement, but not the association of dive parameters with switching between behaviors. Morris et al. (2017) found that spotted seals tagged in the Beaufort and northern Chukchi sea had variable dive depths throughout the year, as they moved into the Bering Sea, but increasing dive depths from summer through to spring. They observed, as did we, frequent benthic dives by spotted seals. Spotted seal tagged in the southern Chukchi Sea exhibited a shift from nearshore to offshore habitat use, through the fall (Lowry et al. 2000). Lowry et al. (2000) linked the preference of spotted seal use of the nearshore in summer and fall with the abundance of prey that was likely present in the nearshore at this time, and the subsequent movement of spotted seals offshore in late fall a result of prey movement offshore. The spotted seals that we tracked behaved differently, with some individuals maintaining a preference for nearshore habitat into the winter.

Foraging by bearded seals has been inferred from movement, dive parameters and environmental data in state space models (McClintock et al. 2017), although using a different method than applied in our study. McClintock et al. (2017) included dive summaries and ice as parameters of six different behavior states and inferred that bearded seals spent 70% of their time foraging in the benthos, based on the model results. Similarly, the bearded seals we tracked foraged benthically 86% of their time. McClintock et al.'s (2017) data were also similar to ours in identifying benthic use during transiting and foraging in similar regions of the Beaufort and Bering seas.

Our pilot program demonstrated that collecting oceanographic parameters *in situ* at a scale relevant to the diving marine mammals can identify water bodies akin to oceanographic stations occupied by ships (e.g., Danielson et al. 2016). We illustrated that animal-borne oceanographic sensors can provide insights in to environmental parameters influencing foraging decisions by spotted and bearded seals. The method revealed that spotted and bearded seals had an affinity to foraging in Bering Sea summer water during their fall and winter movements in the Chukchi and Northern Bering seas. Seal-mounted oceanographic sensors provided finer scale spatial resolution and more direct information about water masses in which the seals foraged than is possible with remote oceanographic sensors. Seal-mounted sensors also provide more continuous data than remote sensors which are disrupted by cloud cover.

Predictably, more data than collected in this pilot program will be needed to fully identify and characterize variables driving the timing and location of foraging by spotted and bearded seals. Yet, the use of oceanographic sensors on marine mammal satellite tags provides an opportunity to explore habitat selection by marine mammals at the scale of identifiable water masses.

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APPENDIX I SOCIETY OF MARINE MAMMALOGY BIENNIAL CONFERENCE ICE SEAL TAGGING WORKSHOP

MARES CONSULTATION MEETINGS JANUARY 2015 TO FEBRUARY 2016 INCLUSIVE

Date	Location	Organization	MARES/Stantec Representative
February 9, 2015	Barrow, AK (USA)	North Slope Borough (NSB) Department of Wildlife Management	Brendan Kelly (MARES), Francis Wiese (Stantec), Rowenna Gryba (Stantec), and from NSB: Harry Brower, Taqulik Hepa, Robert Suydam, Andy VonDuyke
March 4, 2015	Anchorage, AK (USA)	Ice Seal Committee	Brendan Kelly (MARES), Francis Wiese (Stantec), Rowenna Gryba (Stantec),
March 5, 2015	Wainwright, AK (USA)	Wainwright Tri-Lateral Meeting	John Craighead "Craig" George on behalf of MARES
December 18, 2015	Inuvik, NWT (Canada)	Inuvialuit Game Council	Michael Fabijan (Kavik-Stantec)
January 12, 2016	Kaktovik, AK (USA)	Kaktovik City Council, community members, Kaktovik Village Council, Kaktovik Inupiat Corporation	Brendan Kelly (MARES), Rowenna Gryba (Stantec)
January 13, 2016	Winnipeg, MB (Canada)	Fisheries Joint Management Council	Francis Wiese (Stantec)
January 19, 2016	Phone	Kaktovik Village Council	Brendan Kelly (MARES), Francis Wiese (Stantec), Rowenna Gryba (Stantec)
June 8 – 9, 2016	Anchorage, AK (USA)	Ice Seal Committee	Sara Lindberg (Stantec), Andy VonDuyke on behalf of MARES
July 14 and July 15, 2016	Barrow, AK (USA)	North Slope Borough (NSB) Department of Wildlife Management	Rowenna Gryba (Stantec), and from NSB: Taqulik Hepa, Harry Brower, Jr., Billy Adams, John Craighead "Craig" George, Raphaela Stimmelmayr, Robert Suydam, Andy VonDuyke, and interns with the NSB

APPENDIX II BIENNIAL CONFERENCE—SOCIETY FOR MARINE MAMMALOGY 2015 ICE-SEAL TAGGING WORKSHOP

SMM 2015 ICE-SEAL TAGGING WORKSHOP

Saturday, December 12, 2015

The tagging workshop goal was to bring together experts in ice-seal capture and tagging from both the Arctic and Antarctic, to foster collaboration and sharing of 'lessons learned.' The workshop was attended by 35 individuals including tag developers, researchers, and students. Topics covered included capture methods, tag attachment and tag design.

Capture Methods

- Weddell seals lightly sedated during captures, use of head bag (R. Davis)
- Aglu nets use to capture ringed seals, with assistance of trained dogs (B. Kelly)
  - Have also captured bearded seals in the aglu nets (not targeted)
- Ribbon and spotted seals captured using salmon landing nets in marginal ice zone by approaching using zodiacs when animal is hauled out on the ice (travel to region via large vessel) (P. Boveng)
- Adult bearded seals captured using tangle nets, found by searching ice and setting nets near the flow (approach by zodiac but land based). Can spend extended time searching and where to place nets has been done 'randomly' as each attempt has varied and there have been few successful captures (P. Boveng)
- String nets used to capture Sima ringed seals—set in stormy weather and left (M. Kunnasranta)
- Polyethylene nets used to capture near haul outs (M. Kunnasranta)
- Monofilimant tangle nets used to capture juvenile bearded seals with mixed success as net color seems to have an effect on success. Depends on cloud cover, water clarity. Have captured with clear, green colored nets but have had difficulty getting different net materials (L. Quakenbush)
- Pop-up net system designed by SMRU (Simon Wood) to capture harbour seals and grey seals (C. McKnight)
  - Float line replaced with hose, packed into "sausage" and attached to chain laid on the bottom. Triggered remotely (up to 1 km away in calm water or if higher up) and net tacks a couple of second to extend up from the surface. Air ballast blast scars seals into the net.
  - Can be set very close to shore so seals swim directly from haul out into the net
  - Use nylon nets—no cutting and able to roll the animals out of the net
  - Have captured up to 10 seals in one net from a haul out, consider logistics in terms of processing animals if "too successful"
- SMRU developing use of decoys to lay out net (C. McKnight)
  - Remote controlled to lay out net in front of animal/haul-out
  - Currently still working on weighting of the nets to correct small issues with deployment
- Use of decoys to increase capture success/rate?
  - Have used mirrors/ornaments placed on the nest in Finland with success
  - Otters have habituated to decoys very quickly so may or may not work
  - Harbour seal decoy on a platform was not successful but may have been other issues
  - Use of vocalizations for bearded seals has yet to be tried (possibly in the near future) but unsure about behavioural response
  - Use of bait ball in the net? No one has tried yet but might have some potential
- Effect of net color?
  - Hasn't been documented

- Highly variable results based on light and water conditions
- Could try a mixture of net types (attached together)
- Bring a wide range of net types to the field to vary with conditions

Tag Attachment

- Neoprene backing used on tags attached to Weddell seals (R. Davis)
  - Moves with the animal
  - Attached with contact cement (approx. seven month attachment)
  - Contact cement used due to large instrument size
- Warm epoxy plus heat during tag setting (radiant heat source) plus heat packs to warm tagging area (M. Fedak)
- Have tried acetone spray as excellerant for expoxy but makes epoxy brittle and had one month attachment (M. Fedak)
- Loctite 422 can damage skin (C. McKnight).
- Loctite 6851 is working really well (C. McKnight)
- Polyurethane footprint with "legs" spreads out tag footprint—lessens potential damage to fur; tag is attached to mesh and embedded into polyurethane (C. McKnight)
- Drying of fur, or using acetone to clean it is not likely necessary prior to gluing
- Super glue has 30 second dry time and seems to work well
- Tags attached to neoprene (3–4 mm thick; just larger than tag), then attached to animal using thin layer of Loctite 422 on wet fur -> 20–30 second set time; 11 month attachment time; doesn't touch the skin of the animal; neoprene moves with the animal (M. Horning)
- Change in fur color from epoxy/glue observed in some species
- Variation in location of attachment—head vs. back
  - If tag small enough head is good because no bending around attachment area
  - Potential to use two smaller tags that "talk" via Bluetooth (M. Fedak)
- Loctite 481 sets softer than 422
- Sometime bead of epoxy is applied around edge of tag when Loctite used

Sedation

- Light sedation used on Weddell seals during tagging (R. Davis)
- Light sedation used on spotted seals and bearded seals (P. Boveng)
- Mild sedation used by NMML for almost all species (P. Boveng)
  - Choose to use sedation in all cases to minimize handling time
  - Bites from animals not an issue for all species (e.g., bearded seals) but easier to attach tags to calm animals
  - Drugging isn't difficult
- Sedation may manage some risks but may increase other (M. Horning)
  - There do not seem to be any amnesic effects but no long term studies of effects of sedation have been completed
  - Lower fecal stress hormone detected in sedated animals
- Requires vigilance to detect any issues (e.g., apnea)
- Animals that have been sedated have been observed to spend more time on land after tagging (C. McKnight)
- NMML methods: Intermuscular at capture, top ups using IV
- Stable, frequent small doses of valium/cademine work well (R. Davis)
- Overheating can be an issue—minimize by running water or putting ice on flippers

Safety

- Caution required when working with tangle nets—issues can arise quick from current, ice
- Use seatbelt cutters or net cutting knives

Action Items

- Send out email list to group
- Contact Research Nets (Seattle) about net materials (made ringed seal nets for BK)
- Contact SMRU re cost of pop-up nets

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

The BOEM Environmental Studies Program

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.