Scottish Government
Riaghaltas na h-Alba
gov.scot

Determining the Water Column Usage by Seals in the Brims Lease Site

Scottish Marine and Freshwater Science Vol 8 No 22

C Evers, C Blight, D Thompson, J Onoufriou and G Hastie

marine scotland

Determining the Water Column Usage by Seals in the Brims Lease Site

Scottish Marine and Freshwater Science Report Vol 8 No 22

Clair Evers, Clint Blight, Dave Thompson, Joe Onoufriou and Gordon Hastie

Published by Marine Scotland Science
ISSN: 2043-772
DOI: 10.7489/2008-1

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes the results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out for Marine Scotland under external commission.

Determining the water column usage by seals in the Brims lease site

Clair Evers, Clint Blight, Dave Thompson, Joe Onoufriou and Gordon Hastie

Sea Mammal Research Unit
Scottish Oceans Institute,
University of St Andrews, St Andrews, Fife, KY16 8LB, UK

Executive Summary

The report describes how adult harbour seals and grey seal pups use the water column within the Brims lease site.

1. Telemetry data from 12 adult harbour seals and seven grey seal pups diving within the Brims lease site were analysed to extract descriptors of dive behaviour.
2. Dive data were summarised to provide estimates of the proportion of time seals spent at different depths relative to the sea surface and relative to the seafloor. In addition to estimates of the proportion of time at depth, the number of times seals transited through different depth bins relative to the sea surface and seafloor was also determined.
3. Water depths at dive locations were estimated from high resolution bathymetry data corrected for tide height at that time and place.
4. Harbour seals spent approximately 31 % of their time at intermediate depths between 10 m to 25 m from the surface, with a secondary but less pronounced peak between 75 m and 80 m from the surface. When expressed as a distance from the seafloor, harbour seals spent the highest proportion of time within 5 m of the seafloor (mean = 0.16; 95 % CIs: 0.04-0.46) with a secondary peak between 65 m and 70 m from the seafloor (mean = 0.12; 95 % CIs: 0.03-0.26) indicating a significant amount of mid water swimming by harbour seals at this site. Harbour seals spent on average 12.8 % of their time in the band between 5 m and 25 m above the seafloor.
5. For grey seal pups, the proportion of time spent in depth bands decreases monotonically with depth and the amount of time spent close to the seafloor was lower than in harbour seals. Grey seal pups spent on average 6.5 % of their time in the band between 5 m and 25 m above the seafloor.
6. Harbour seals in the Brims site entered or transited through the zone between 5 m and 25 m from the sea floor on approximately 27 % of dives. Grey seal pups entered the depth bands closest to the seafloor less frequently than did the harbour seals.

Contents

Introduction

The development of offshore renewable energy projects is rapidly gaining momentum. Although offshore wind is now a well-developed industry, due to their inherent spatial and temporal predictability, tidal currents as a source of energy are proving attractive to developers. Tidal stream energy converters (tidal turbines) that extract energy from moving water are being considered for installation in many coastal areas around the UK (Carbon Trust, 2010); these are generally subsurface, seabed mounted devices, and while many designs exist, they typically have spinning horizontal axis blades.

There is increasing evidence that tidally energetic areas can also be important foraging locations for marine mammals (Benjamins *et al*., 2015; Hastie *et al*., 2014) and the potential spatial and temporal overlap between turbines and marine mammals has led to concerns about environmental impacts. Concerns derive primarily from the potential for direct physical interactions between turbine structures and marine mammals resulting in physical injury or mortality to marine mammals (Wilson *et al*., 2007). Other concerns include potential spatial avoidance caused by turbine operational noise; for example, Hastie *et al.* (2017) found that harbour seals exhibited significant avoidance when exposed to controlled playbacks of turbine noise, and Sparling *et al*. (2017) showed that transits past a commercial scale tidal turbine decreased significantly when the turbine was operational.

Collision risk modelling is a common approach used to estimate the frequency of potential encounters or collisions between turbines and animals over a period of time (Band, 2000; 2012; Scottish Natural Heritage, 2016). These models utilize a series of information on animal behaviour and the operational and structural characteristics of the turbines. For example, swimming speed, depth distribution, animal density, blade thickness and rotational speed are all parameters in collision risk models. By setting thresholds for which collisions may result in mortality, potential population level consequences can also be explored. This is particularly important for species that are experiencing declines in population numbers. For example, a relatively large number of tidal developments are currently being considered for consent in coastal waters around Orkney and the Pentland Firth; an area which has seen a dramatic decline in harbour seal (*Phoca vitulina*) numbers over the past 20 years (SCOS, 2016).

As marine mammals spend the majority of their time below the sea surface, it can be challenging to collect the data required to parameterize collision risk models. However, advances in animal borne telemetry (Hastie *et al*., 2014; Thompson *et al*., 2016) mean that data on the horizontal and vertical movements of individuals can now be collected in relatively high resolution. This potentially allows the spatially explicit use of the water column to be accurately determined. By investigating dive behaviour and the preferred water depths of seals, it is possible to begin to predict where in the water column the potential for interactions between seals and turbines may exist.

This study provides information on the usage of the water column by harbour and grey seals (*Halichoerus grypus*) within the Brims tidal energy lease area, located between Orkney and the north coast of Scotland. Animal borne telemetry tags were used to estimate the proportion of time that seals spend at different depths in the water column, expressed in terms of proportion of time at depth, proportion of time within defined distances of the sea bed and the proportion of the water column used. The results can be used to inform collision risk models for seals which can help developers and regulators make informed decisions regarding the environmental risks associated with tidal turbine operation in the Brims site.

Methods

Animal-borne Global Positioning System/Global System for Mobile (GPS/GSM) tags were deployed on harbour and grey seals around Orkney and the north coast of Scotland over five different years (2010, 2011, 2014, 2016 and 2017). Seals were captured whilst hauled out on intertidal rocks or in the water close to haul-out sites and anesthetised with Zoletil® with or without pre-med Hypnovel®. Capture and handling procedures are described in more detail by Sharples *et al.* (2012). The tags were attached to the fur at the back of the neck using 2-part epoxy or Loctite® 422 Instant Adhesive. All procedures were carried out under Home Office Animals (Scientific Procedures) Act licence numbers 60/4009 and 70/7806. The tags attempt to record GPS quality at-sea locations at regular intervals using a Fastloc hybrid protocol (McConnell *et al.,* 2004) and transmit data to shore using the GSM mobile phone network. These tags also provide depth measurements throughout the duration of the seals' dives; a pressure sensor on the tag provides depth readings at either nine or 23 time intervals (depending on the tag model) distributed equally in time throughout each dive. Telemetry data were compiled for all tagged seals (13 adult harbour seals and seven grey seal pups) that used the Brims lease area (Lat: 58.749- 58.771, Lon: 3.314- 3.176, Figure 1), during five different years (Table 1). The location and depth data were analysed to obtain proportion of time spent at different depths from the sea surface and seafloor within the lease area.

Location and dive data

Location data were initially cleaned to remove inaccurate locations, as well as erroneous locations, using thresholds of residual error, a measure of location quality supplied by the Fastloc GPS algorithm (residuals < 200) and the number of satellites (> 5), as per Russell *et al.* (2011). Additionally, speed of movement over the ground was calculated between locations and any with unrealistic speeds (> 9 ms^{-1}) were assumed to be erroneous and removed. This conservative speed threshold accounted for the summed effect of the maximum expected speed of free-ranging harbour seals (~3 ms^{-1}, Gallon *et al*., 2007) and the maximum sustained current speeds estimated for the Pentland Firth (~4 ms^{-1}, Price *et al.*, 2015). The filtered data were used to generate a series of location estimates at one minute intervals by linearly interpolating between GPS location fixes. For various reasons, location fixes may be missed so that the time series is irregular and includes long gaps that would be interpreted as long straight-line travel periods and may mask significant movement patterns. Therefore, interpolated data points relating to gaps of greater than 55 minutes in the GPS time series were removed from the analyses. The maximum value of 55 minutes was used as the multi-modal distribution of time intervals between locations (prior to interpolation and filtering) shows a peak at 60 minutes (Figure 2) resulting from a switch in transmission schedule when seals haul out. All analyses were conducted using the R statistical framework (R Core Development Team, 2016).

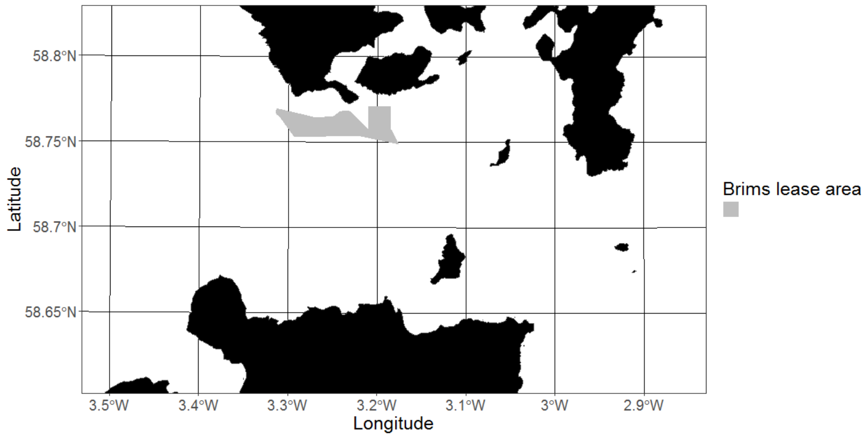


Figure 1. Location of the Brims lease site. Map is projected in UTM 30N.

Table 1. Summary of seal telemetry data that occurred within the Brims lease site, including an individual identifier for seal ID and the species. Pv refers to harbour seals (*Phoca vitulina*) and Hg refers to grey seals (*Halichoerus grypus*).

				Tagging details				
Seal ID	Species	Date	Lon	Lat	Location	Sex	Age	Mass (kg)
vf03-469-17	Pv	02/05/2017	-2.6	59.200	South Orkney	F	Adult	104.2
vf01-264-16	Pv	19/04/2016	-2.6	59.200	South Orkney	F	Adult	83.8
vf01-261-16	Pv	14/04/2016	-2.6	59.200	South Orkney	M	Adult	99.4
vf01-259-16	Pv	11/04/2016	-2.6	59.200	South Orkney	F	Adult	94
vf01-258-16	Pv	15/04/2016	-2.6	59.200	South Orkney	M	Adult	78.8
vf01-257-16	Pv	15/04/2016	-2.6	59.200	South Orkney	F	Adult	86.6
vf01-256-16	Pv	19/04/2016	-2.6	59.200	South Orkney	F	Adult	96.8
pv57-200-14	Pv	02/10/2014	-2.6	59.200	South Orkney	F	Adult	93.5
pv24-622-11	Pv	31/03/2011	-3.31	58.644	Pentland Firth	M	Adult	91.4
pv24-580-11	Pv	29/03/2011	-3.31	58.644	Pentland Firth	F	Adult	89.0
pv24-541-11	Pv	30/03/2011	-3.31	58.644	Pentland Firth	M	Adult	96.8
pv24-151-11	Pv	25/09/2011	-3.31	58.644	Pentland Firth	M	Adult	84.8
pv24-112-11	Pv	24/09/2011	-3.31	58.644	Pentland Firth	M	Adult	92.8
hg30-17-10	Hg	12/12/2010	-2.6	59.200	Stroma, Orkney	M	Weaned Pup	~40
hg30-14-10	Hg	12/12/2010	-2.6	59.200	Stroma, Orkney	F	Weaned Pup	~33
hg30-12-10	Hg	12/12/2010	-2.6	59.200	Stroma, Orkney	F	Weaned Pup	~38
hg30-11-10	Hg	12/12/2010	-2.6	59.200	Stroma, Orkney	M	Weaned Pup	~45
hg30-06-10	Hg	14/12/2010	-2.6	59.200	Stroma, Orkney	M	Weaned Pup	42.0
hg30-04-10	Hg	14/12/2010	-2.6	59.200	Stroma, Orkney	F	Weaned Pup	35.5
hg30-01-10	Hg	12/12/2010	-2.6	59.200	Stroma, Orkney	M	Weaned Pup	~35

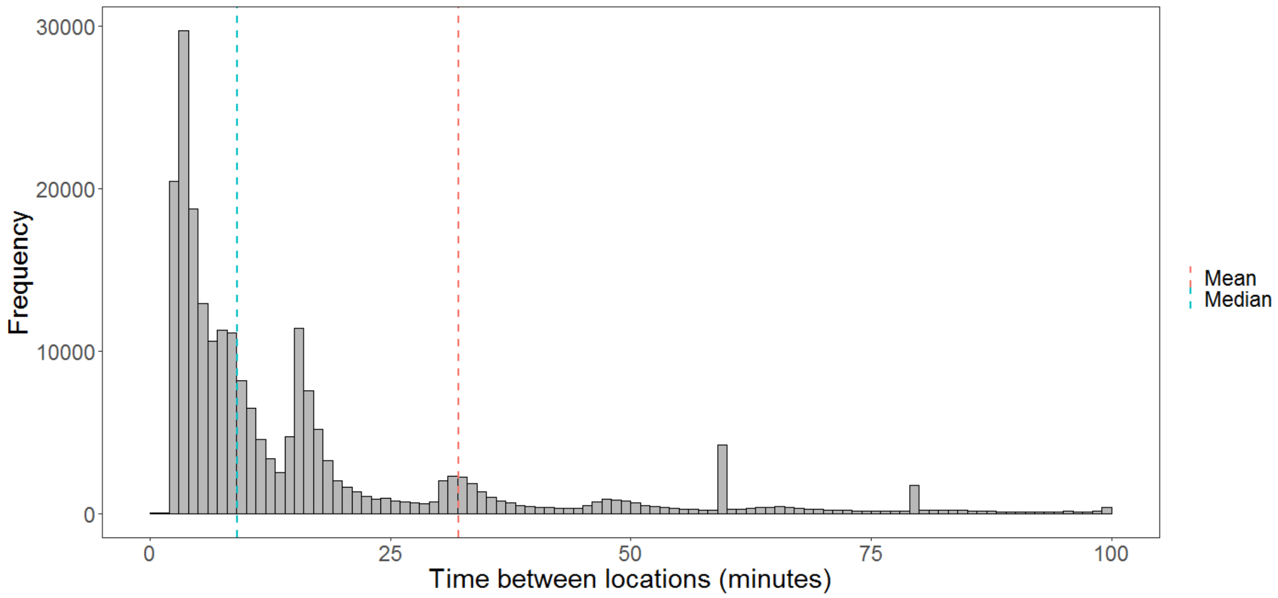


Figure 2. The distribution of time intervals between GPS locations across the entire dataset, prior to filtering out unrealistic speeds and cropping to the Brims site. n=230050 locations.

Depth data were recorded for all dives during which the tag was submerged below a threshold of 1.5 m for a minimum of eight seconds, and ended when the depth reading was above the threshold on return to the surface. Depending on the tag, either nine or 23 depth estimates were provided, evenly spaced in time throughout the duration of the dive.

The location of a seal at any time between location fixes was estimated by linearly interpolating between the cleaned GPS fixes. Dive locations were also assigned by linearly interpolating along those straight-line paths. Matching dive depth to water depth therefore becomes less precise for dives occurring further in time from the GPS fixes. To minimise the potential mismatch between estimated dive location and the bathymetry data, the start and end times of dives were matched to the times of GPS location fixes. If a dive started and ended more than 60 seconds from the closest GPS position fix it was excluded.

To remove any potential bias in time at depth due to differing dive durations, dive depths at one second intervals were derived through linear interpolation between recorded dive depths.

Proportion of time relative to distance from sea surface

The total time and proportion of time spent within 5 m depth bins (spanning 0 to 105 m), in relation to the sea surface, was calculated for all dives for both species. Results are expressed as the total proportion of time for all data pooled and as mean proportions of time (± 95th percentiles) across individual seals.

Proportion of time relative to distance from seafloor

Depths were derived from pressure sensor readings on-board the tag, and are therefore measured relative to the water surface. To provide a measure of the use of the water column relative to the seafloor, which may be more relevant for interactions with bottom mounted turbines, the data were also summarised in terms of distance from seafloor.

High resolution (~2 m) gridded bathymetry data was obtained from Marine Scotland (Marine Scotland, 2013). Within the Brims lease site, depths ranged from 60 m to 125 m (median of 78 m), with the majority of the site being between 60 m and 90 m deep. These depths were relative to Chart Datum (CD) and thus represent the lowest astronomical tide. Depth values relative to Mean Sea Level (MSL) were derived by applying the UKHO VORF LAT correction (UKHO, 2008) for the Brims area to the bathymetric depths relative to CD.

These depth values provide an estimate of the average water column depth at a given location (the midpoint of each dive), but do not account for the depth variation over time caused by the tidal cycle. The National Oceanography Centre (NOC) Hydrodynamics Dynamic Link Library (DLL) (National Oceanography Centre, 2010) was used to generate estimates of the tide height relative to MSL from the harmonics of the High Resolution UK Continental Shelf Model (CS20) which has a resolution of 1/60°lat by 1/40°lon (Proctor *et al.,* 2004). These tidal corrections were then applied to the previously calculated bathymetric depth values relative to MSL, resulting in a more accurate water column depth.

Finally, the water column depth, estimated for the temporal midpoint of each dive, was used to obtain the height above seafloor for each of the measured depths provided by the tags (nine or 23 points depending on tag type). This was achieved by subtracting the measured depths from the corrected water column depth. Dives were then re-interpolated to provide heights above seafloor at one second intervals.

Additional effects due to waves, local barometric pressure changes and storm surges were not included in this analysis. As above, results are expressed as the total proportion of time for all data pooled and as mean proportions of time (± 95th percentiles) across individual seals.

Percentage of water column used

Depending upon how collision risk is estimated, it may be informative to estimate the number of dives on which seals pass through the depth band occupied by turbines. Two approaches were taken.

For each of the dives where high resolution bathymetry data were available (the bathymetry data does not fully cover the Brims area), the maximum dive depth as a proportion of the corrected water depth was calculated.

In addition, the number of transits through particular depth bands may be informative if collision risk is determined by number of events rather than by time spent at a particular depth. So, for each seal recorded diving within the Brims site, the proportion of dives on which it entered and/or transited through a depth band was calculated and then averaged across all seals.

Results

Location and dive data

Of the 20 seals that used the Brims site, 19 dived below 1.5 m for longer than eight seconds (the threshold that triggered a dive being recorded). Therefore, the further analyses of dive behaviour included data from 12 harbour seals and seven grey seals. A total of 944 dives were recorded; 848 by harbour seals and 96 by grey seal pups (Table 2, Figures 3 and 4). The tagged harbour seals spent a total of 60.5 hours within the Brims site while the grey seals spent only 4 hours within the site. The spatial distribution within the Brims site was reasonably uniform across all seals. The harbour seals spent approximately 18 % of their time at the surface and 82 % of their time submerged while diving. Grey seal pups spent less time diving with approximately 35 % of their time at the surface and 65 % submerged; this is primarily due to two of the tagged seals that spent around 2/3 of their time at the surface while in the site.

Table 2. Summary of dive information for each seal within the Brims area.

Seal ID	# of regularized GPS locations	Number of dives	Time submerged (seconds)	Time at surface (seconds)
vf03-469-17	431	56	18408	3428
vf01-264-16	37	4	1652	236
vf01-261-16	440	69	18148	3864
vf01-259-16	328	66	13640	3520
vf01-258-16	53	10	2508	456
vf01-257-16	249	41	9684	2272
vf01-256-16	142	31	5328	1564
pv57-200-14	150	37	6792	1492
pv24-622-11	3	0	NA	NA
pv24-580-11	36	6	1732	260
pv24-541-11	500	89	19492	4416
pv24-151-11	1057	254	45288	12460
pv24-112-11	815	185	32496	8984
hg30-17-10	28	16	508	1028
hg30-14-10	41	14	1936	448
hg30-12-10	50	21	1412	2462
hg30-11-10	29	5	1140	136
hg30-06-10	34	22	1052	820
hg30-04-10	31	12	1472	340
hg30-01-10	20	6	968	236
20 seals	4474	944	183656	48422

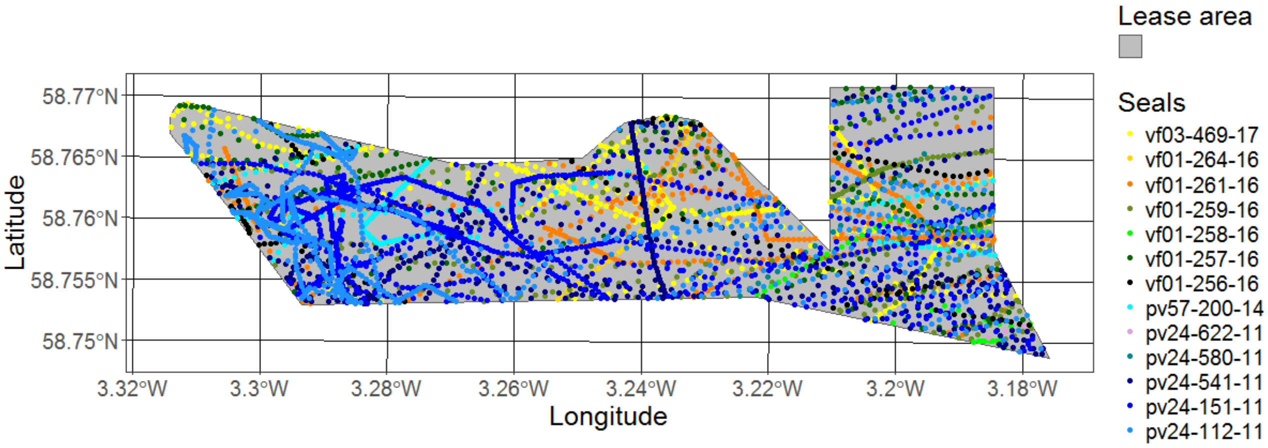


Figure 3. Estimated locations of harbour seals within the Brims lease site. Dots represent interpolated locations at one minute intervals colour coded by individual. Map is projected in UTM 30N. n=4241 interpolated locations.

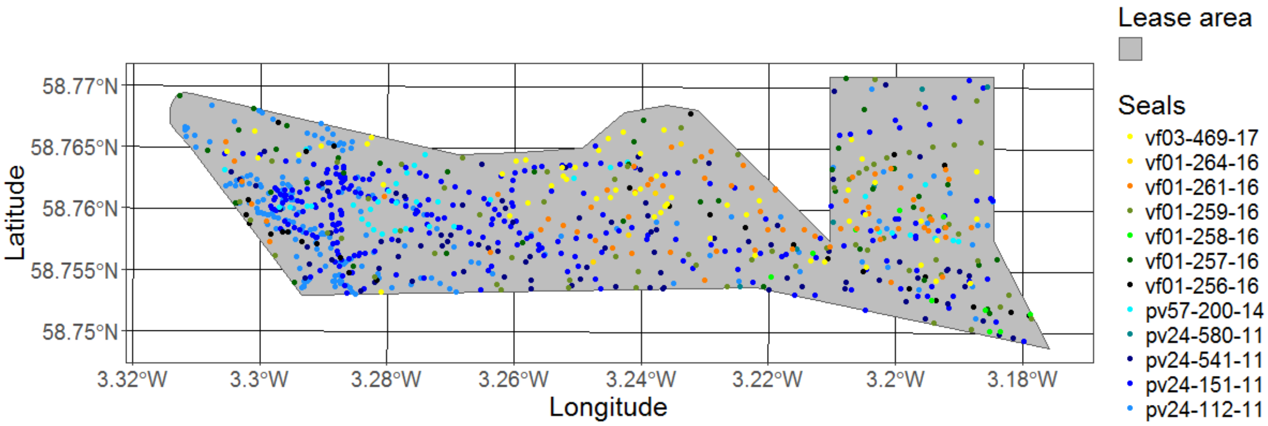


Figure 4. The start locations of harbour seal dives that occurred within the Brims lease site, colour coded by individual. Map is projected in UTM 30N. n=848 dives.

Proportion of time relative to distance from sea surface

The distribution of depth records for all dives by harbour seals ranged from 0 m (sea surface) to 103 m with a mean of 30.8 m. The proportion of time spent in 5 m depth bins varied markedly between individuals. The mean proportions of time spent in each 5 m depth bin across all individuals are shown in Table 3 and Figure 5. The highest mean proportion was spent at intermediate depths, with approximately 31 % of their time at depths between 10 m to 25 m from the surface, with a secondary but less pronounced peak between 75 m and 80 m from the surface (Figure 5). There was considerable variation between individual harbour seals (plots of proportion time at depth for individual seals are presented in the Appendix (Figure 15)).

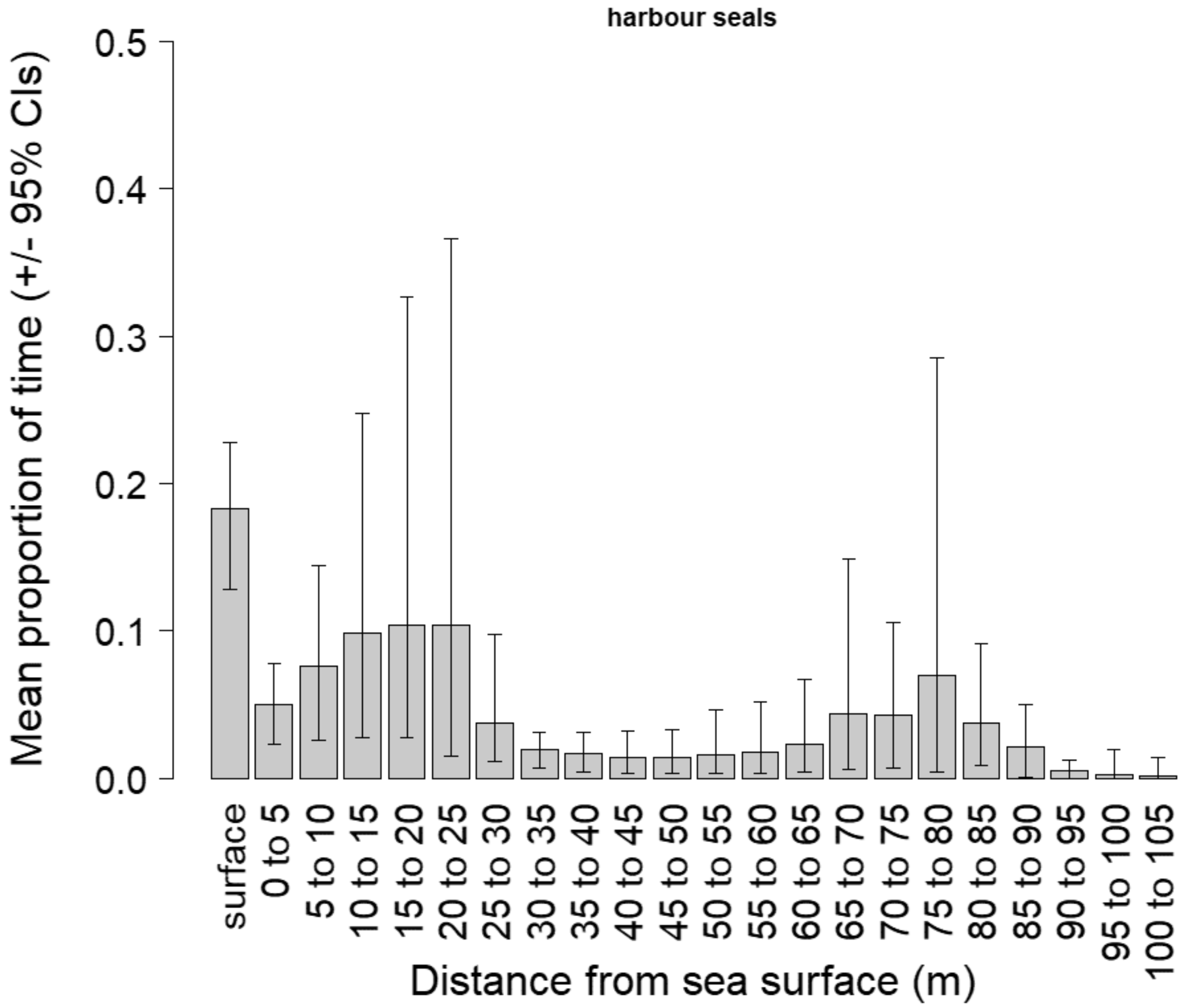


Figure 5. Mean proportion of time spent within each depth bin for all harbour seals. Bars show the 95 % confidence intervals.

Table 3. Mean proportion of time spent within each depth bin relative to the sea surface for all 12 adult harbour seals. n=848 dives.

Distance from sea surface (m)	Mean proportion of time	Standard error
0	0.183	0.010
0 to 5	0.050	0.005
5 to 10	0.076	0.011
10 to 15	0.099	0.020
15 to 20	0.104	0.028
20 to 25	0.104	0.035
25 to 30	0.038	0.008
30 to 35	0.020	0.002
35 to 40	0.017	0.002
40 to 45	0.015	0.003
45 to 50	0.014	0.003
50 to 55	0.016	0.004
55 to 60	0.017	0.005
60 to 65	0.023	0.006
65 to 70	0.044	0.014
70 to 75	0.043	0.010
75 to 80	0.070	0.028
80 to 85	0.037	0.008
85 to 90	0.021	0.005
90 to 95	0.005	0.002
95 to 100	0.002	0.002
100 to 105	0.002	0.002

The distribution of depth records for all dives by grey seal pups ranged from 0 m (sea surface) to 100 m, with a mean of 25.9 m. The mean proportion of time spent in each 5 m bin is shown in Figure 6. Again, there was a large degree of variability between individual grey seals (plots of proportion time at depth for individual seals are presented in the Appendix (Figure 16)). The mean proportion of time in each bin generally decreased as a function of distance from sea surface, with no clearly preferred depth. Similar to harbour seals, proportion of time varied across individuals with some spending more time at mid water depths and others closer to the surface.

It is important to highlight that, because of variations in tidal height, the use of the water column relative to the seabed should not be determined using these distance from the sea surface measurements.

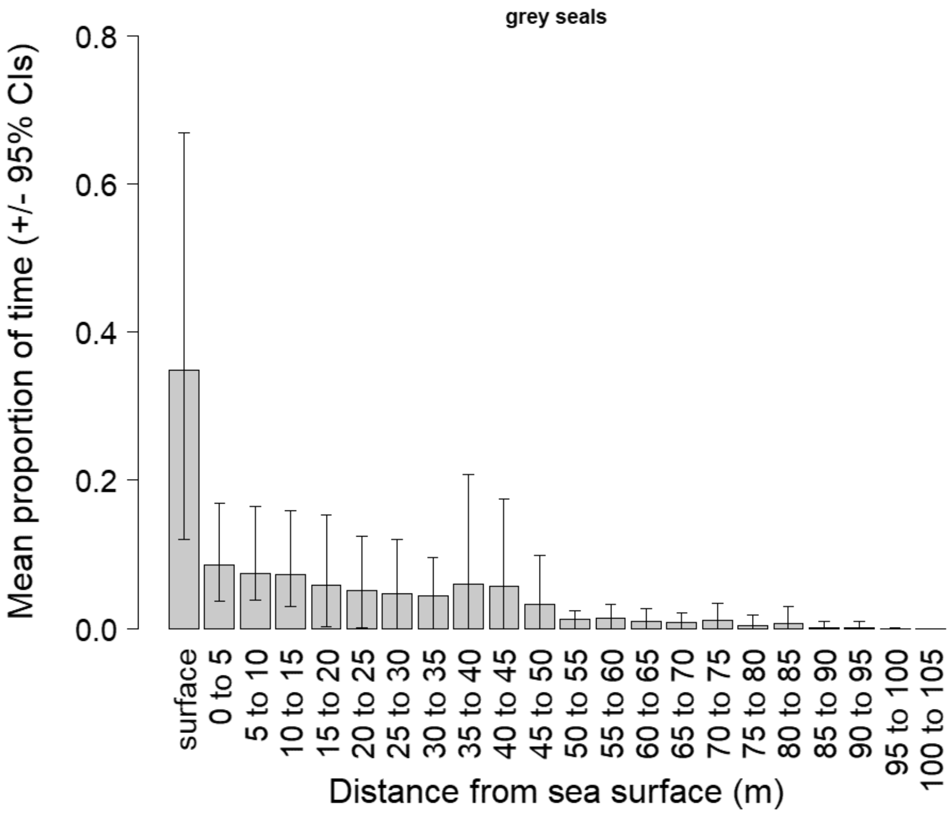


Figure 6. Mean proportion of time spent within each depth bin for all grey seals. Bars show the 95 % confidence intervals.

Table 4. Mean proportion of time spent within each depth bin relative to the sea surface for all grey seal pups. n=96 dives.

Distance from sea surface (m)	Mean proportion of time	Standard error
0	0.348	0.089
0 to 5	0.086	0.020
5 to 10	0.074	0.018
10 to 15	0.072	0.019
15 to 20	0.059	0.021
20 to 25	0.051	0.018
25 to 30	0.047	0.017
30 to 35	0.044	0.015
35 to 40	0.060	0.031
40 to 45	0.056	0.026
45 to 50	0.033	0.014
50 to 55	0.013	0.004
55 to 60	0.014	0.005
60 to 65	0.009	0.004
65 to 70	0.008	0.003
70 to 75	0.011	0.006
75 to 80	0.004	0.003
80 to 85	0.006	0.005
85 to 90	0.002	0.002
90 to 95	0.002	0.002
95 to 100	0.000	0.000
100 to 105	0.000	0.000

Proportion of time relative to distance from seafloor

Assessing dive activity relative to the seafloor requires accurate estimates of the water depth associated with the dive. A total of 20 dives occurred outside of the area covered by the high resolution bathymetry data and were excluded from this analysis, thus, distance from seafloor was estimated for 828 dives. Harbour seal dives within the Brims site occurred over seafloor with reported depths between ~67 to ~96 m, with a mean of ~83 m (Figure 7). Grey seal pups and adult harbour seals generally utilized the same distribution of water column depths (Figure 8).

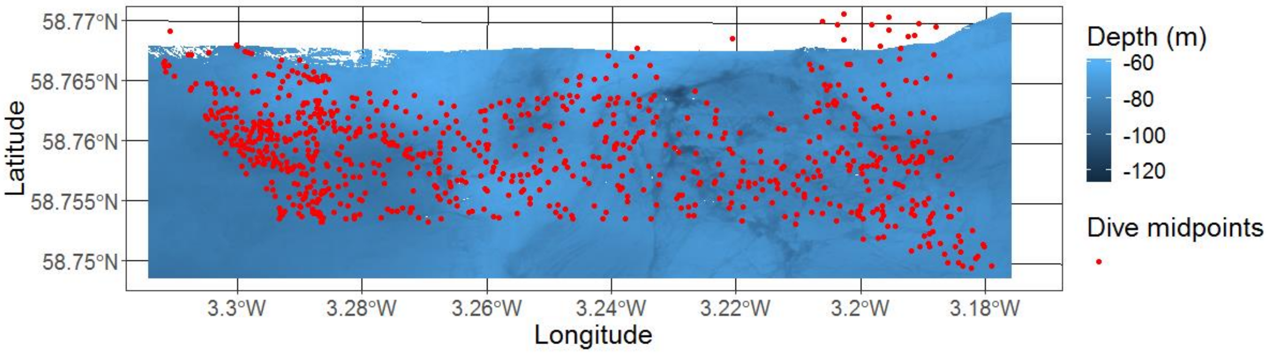


Figure 7. Midpoint locations of each harbour seal dive (in red) overlaid on the high resolution bathymetry data. Note that 20 dives occur outside of the high resolution bathymetry area. Map is projected in UTM 30N. n=848 dives.

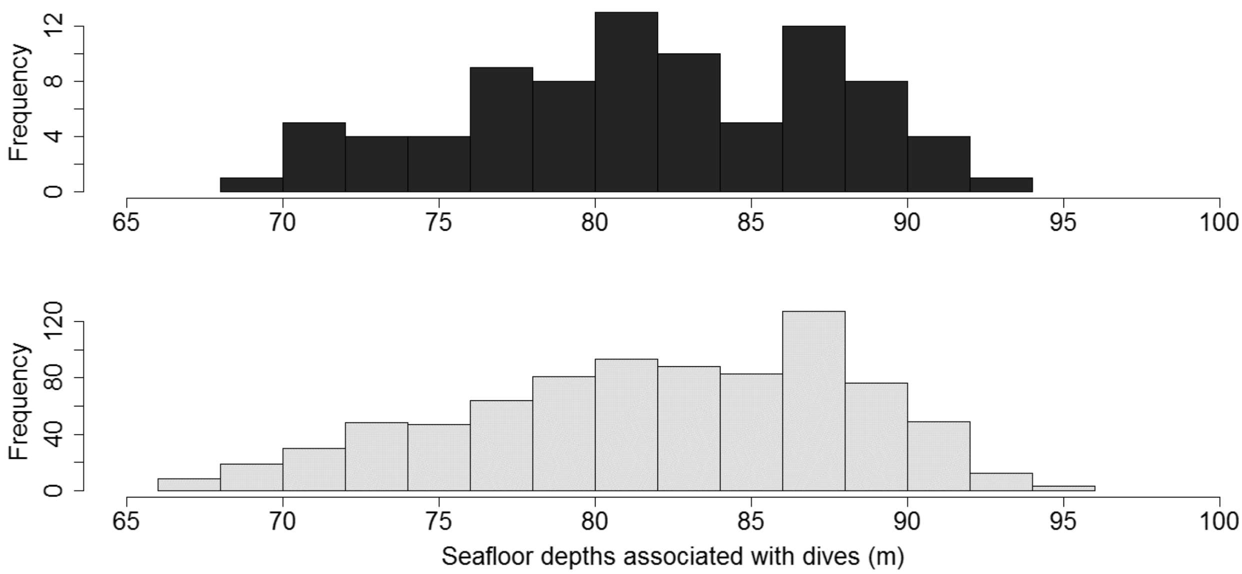


Figure 8. The distribution of seafloor depths associated with dives across the Brims area for grey seal pups (top panel in black, n=84 dives) and adult harbour seals (bottom panel in grey, n=828 dives).

When expressed as a distance from the seafloor, harbour seals spent the highest proportion of time within 5 m of the seafloor (mean = 0.16; 95 % CIs: 0.04-0.46). A secondary peak occurred between 65 m and 70 m from the seafloor (mean = 0.11; 95 % CIs: 0.03-0.23) (Figure 9 and Table 5). This secondary peak is a result of the significant amount of mid water swimming by harbour seals at this site. Harbour seals spent on average 14.8 % of their time in the band between 5 m and 25 m above the seafloor.

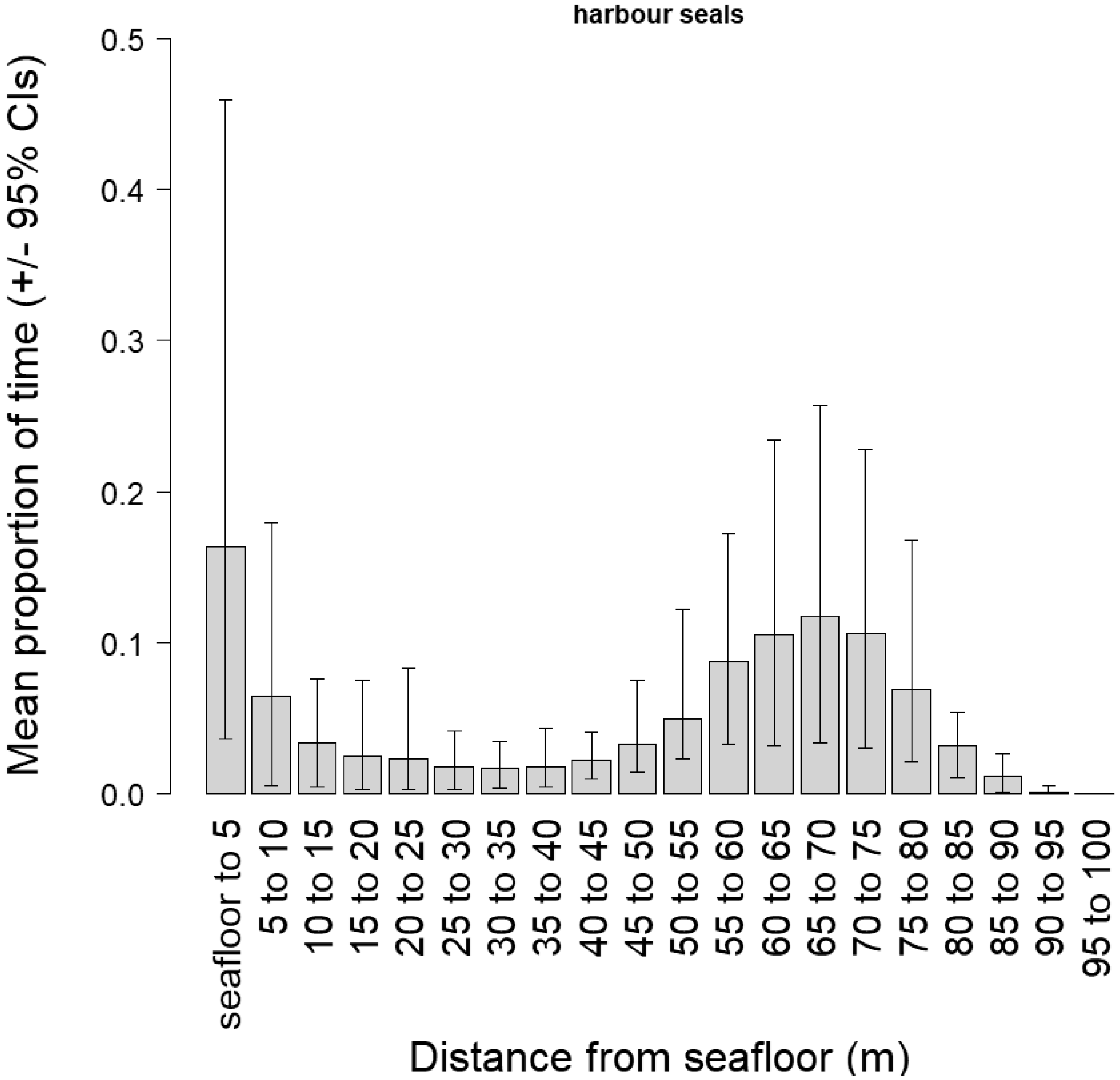


Figure 9. Mean proportion of time spent within each 5 m bin of distance from the seafloor for all harbour seals. Bars show the 95 % confidence intervals.

Table 5. Mean proportion of time spent within each depth bin relative to the seafloor for all harbour seals. n=828 dives.

Distance from seafloor (m)	Mean proportion of time	Standard error
0 to 5	0.163	0.040
5 to 10	0.065	0.017
10 to 15	0.034	0.007
15 to 20	0.025	0.007
20 to 25	0.023	0.008
25 to 30	0.018	0.004
30 to 35	0.017	0.003
35 to 40	0.018	0.004
40 to 45	0.022	0.003
45 to 50	0.033	0.006
50 to 55	0.050	0.010
55 to 60	0.088	0.014
60 to 65	0.105	0.020
65 to 70	0.118	0.020
70 to 75	0.106	0.019
75 to 80	0.069	0.013
80 to 85	0.032	0.004
85 to 90	0.012	0.002
90 to 95	0.002	0.001
95-100	0	0.000

In grey seal pups the proportion of time spent in depth bands decreases monotonically with depth (Figure 6) and as a consequence the amount of time spent close to the seafloor (Figure 10, Table 6) is lower (mean = 0.03; 95 % CIs: 0.0-0.12) than in harbour seals. The grey seal pups spent on average 6.5 % of their time in the band between 5 m and 25 m above the seafloor.

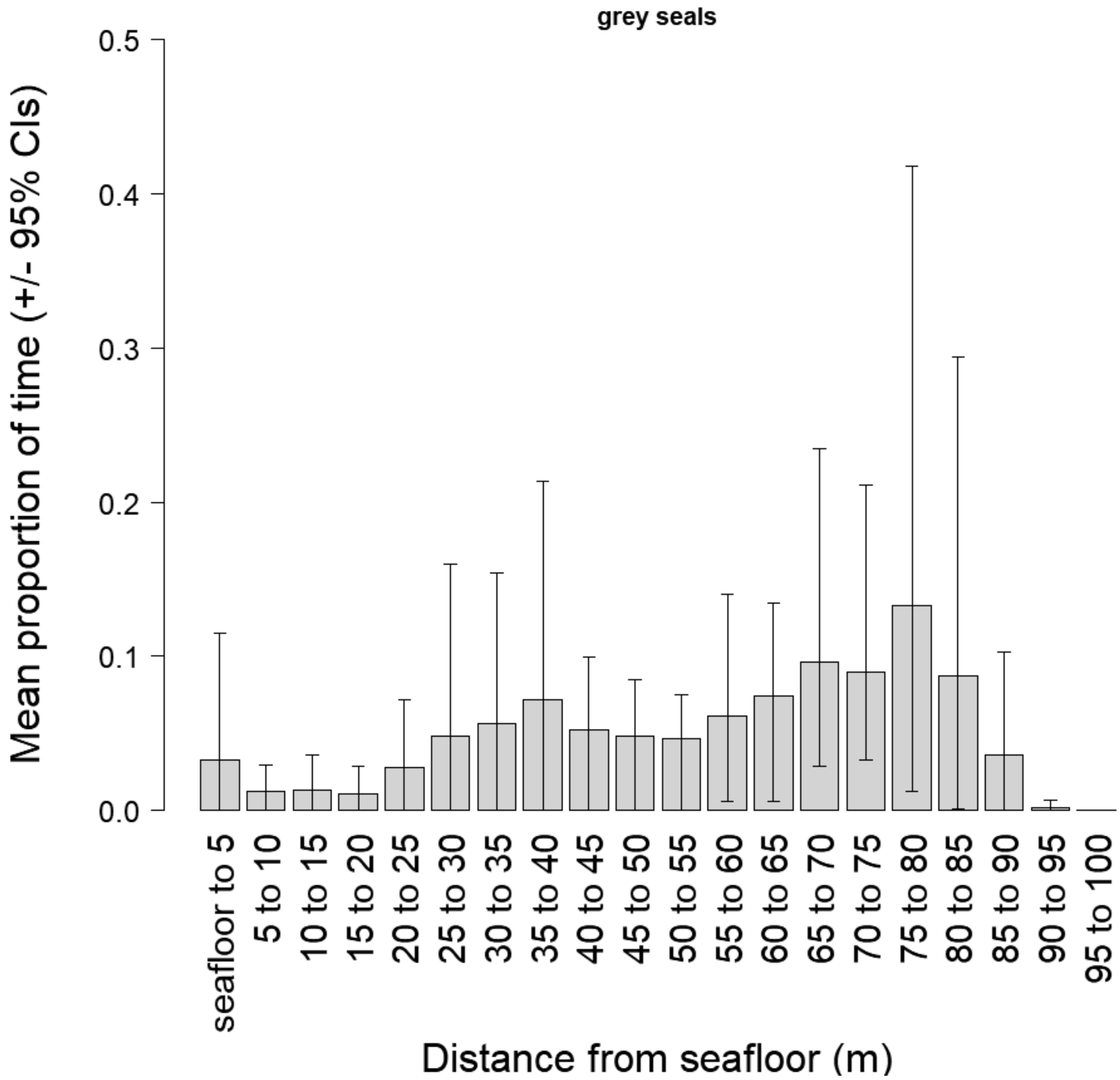


Figure 10. Mean proportion of time spent within each 5 m bin of distance from the seafloor for all grey seals. Bars show the 95 % confidence intervals.

Table 6. Mean proportion of time spent within each depth bin relative to the seafloor for all grey seal pups. n=84 dives.

Distance from sea floor (m)	Mean proportion of time	Standard error
0 to 5	0.033	0.018
5 to 10	0.013	0.006
10 to 15	0.013	0.006
15 to 20	0.011	0.005
20 to 25	0.028	0.010
25 to 30	0.048	0.023
30 to 35	0.056	0.025
35 to 40	0.072	0.031
40 to 45	0.052	0.016
45 to 50	0.048	0.013
50 to 55	0.046	0.012
55 to 60	0.061	0.018
60 to 65	0.074	0.019
65 to 70	0.096	0.031
70 to 75	0.089	0.025
75 to 80	0.133	0.060
80 to 85	0.087	0.043
85 to 90	0.036	0.016
90 to 95	0.002	0.001
95 to 100	0.000	0.000

Percentage of water column used

When expressed as proportional use of the water column, harbour seal activity shows clear peaks in mid water and near the seafloor. Specifically, when the maximum depth attained on each dive is expressed as a proportion of the local water depth (Figure 11) there are clear peaks in mid water, 51 % of dives reached depths equivalent to between 20 and 40 % of the water depth and 25 % reached depths equivalent to the bottom 10 % of the available water column (Figure 11). While both harbour seal adults and grey seal pups dived to the seafloor, harbour seals adults more frequently utilized 100 % of the water column (Figures 11 and 12).

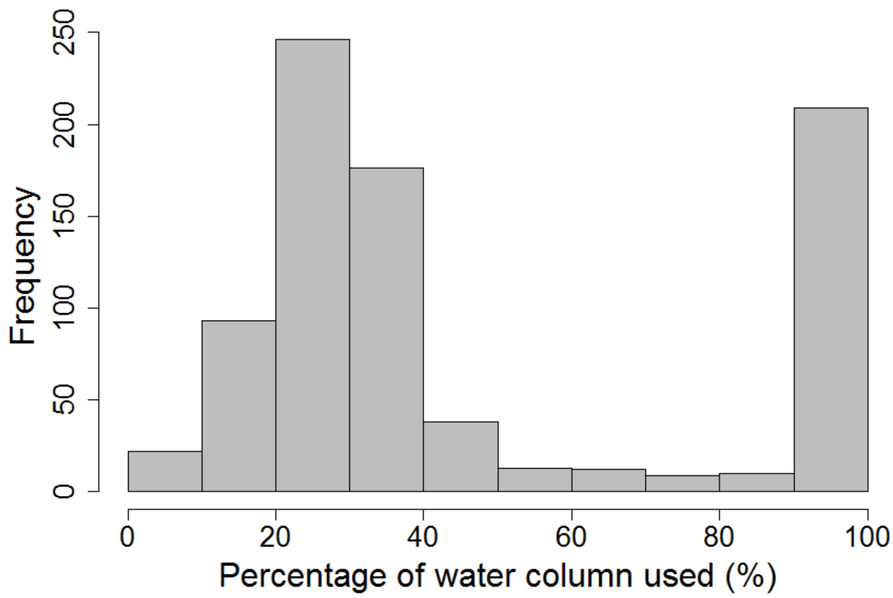


Figure 11. Percentage of water column used across all adult harbour seal dives, i.e. maximum dive depth expressed as a percentage of local corrected water depth. 100 % indicates that the seals reached the seafloor while 0% indicates the seals remained near the surface. n=828 dives.

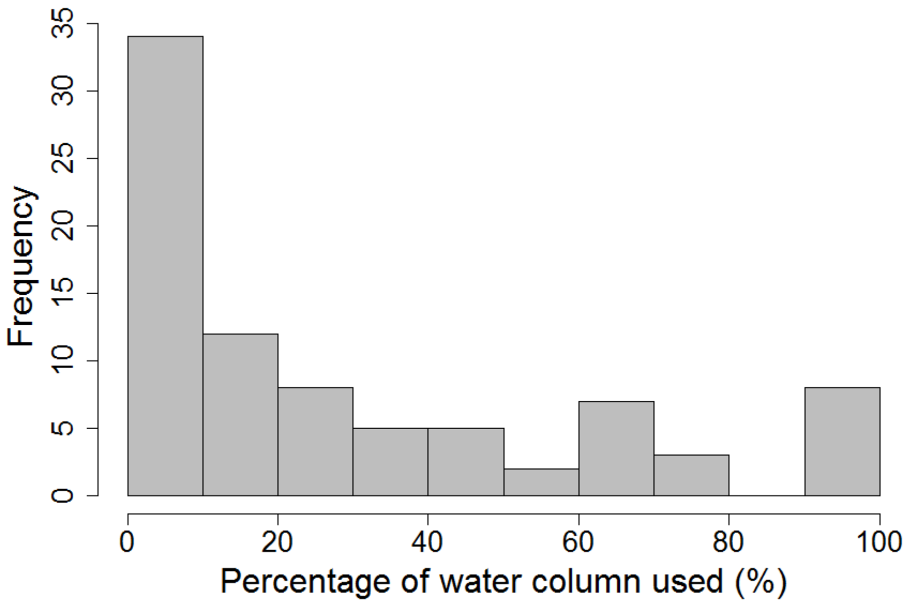


Figure 12. Percentage of water column used across all grey seal pup dives, i.e. maximum dive depth expressed as a percentage of local corrected water depth. 100 % indicates that the seals reached the seafloor while 0 % indicates the seals remained near the surface. n=84 dives.

Transits of depth strata

Collision risk models may require information on number of instances of seals crossing/entering depth strata where they may be at risk of collision with turbine blades. Here information is presented on the proportion of dives recorded within the Brims site in which seals entered each 5 m depth band. These proportions do not take account of the length of time seals spent within the depth band. Figure 13 shows the proportion of dives during which seals swam into and/or through each depth band measured relative to the sea surface for all harbour seal dives and Figure 14 shows the same data for grey seal pup dives. As expected from the depth distribution plots (Figures 5 and 6), the proportion of dives where seals entered deeper depth bands was relatively low.

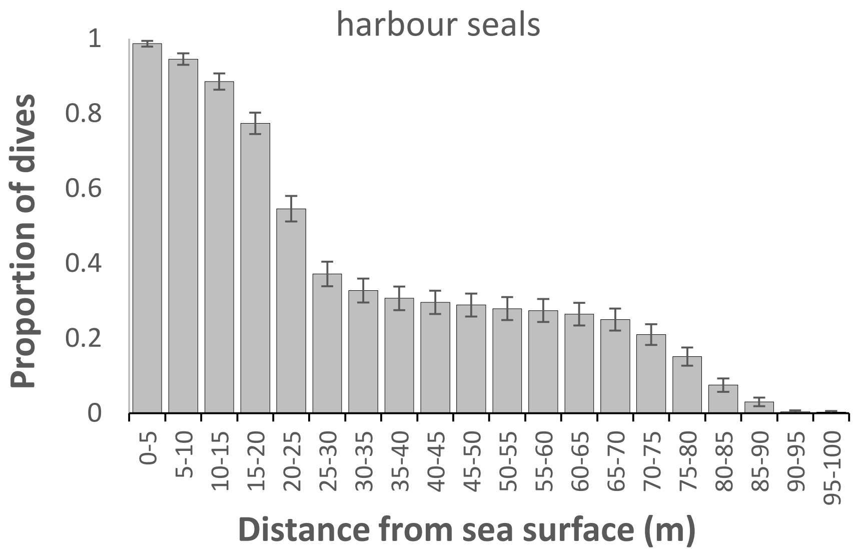


Figure 13. The proportion of dives by harbour seals within the Brims site, during which seals entered and/or transited through particular depth strata relative percentage to the sea surface. Error bars represent 95 % confidence intervals.

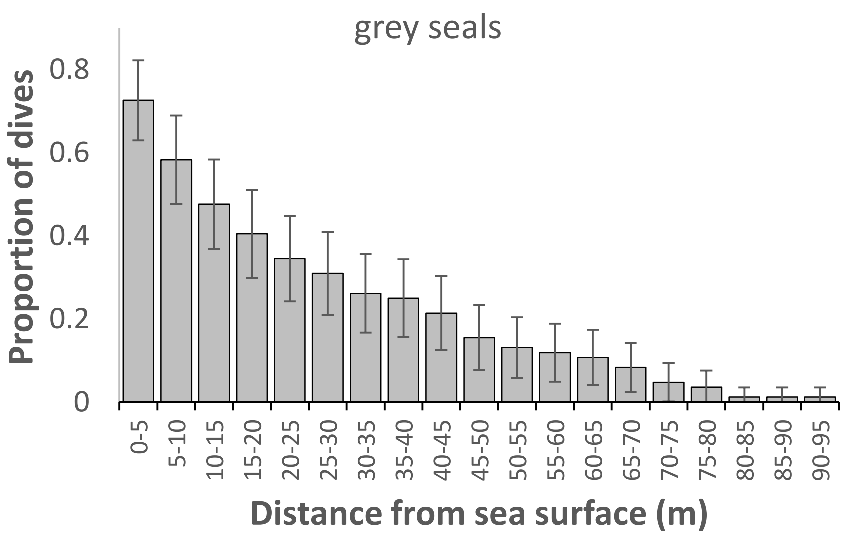


Figure 14. The proportion of dives by grey seal pups within the Brims site during, which seals entered and/or transited through particular depth strata relative percentage to the sea surface. Error bars represent 95 % confidence intervals.

However, in the Brims site where turbines will be fixed to the seabed, the transit rates of interest are likely to be those measured relative to the seafloor. Figure 15 shows the proportion of dives during which seals swam into and/or through each 5 m wide depth band measured relative to the seafloor for all harbour seal dives and Figure 16 shows the same data for grey seal pup dives. In these plots 0 to 5 m represents the depth band nearest the seafloor. The plots have been truncated at 60 m because the zone of interest will be the bottom 30 m to 40 m of the water column and because, at distances greater than 60 m the proportion of dives in which seals entered each bin becomes confounded with the proportion of dives in relatively shallow water (<65 m).

These data suggest that harbour seals in the Brims site enter or transit through the zone between 5 m and 25 m from the seafloor on approximately 27 % of dives (Figure 15 and Table 7).

Grey seal pups entered the depth bands closest to the seafloor less frequently than did the harbour seals (Figure 16 and Table 8).

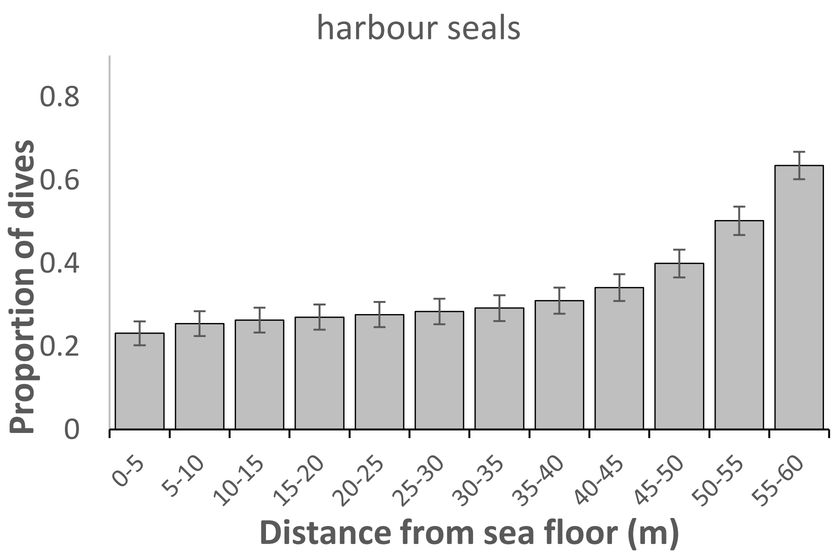


Figure 15. The proportion of dives by harbour seals within the Brims site, during which seals entered and/or transited through particular depth strata, measured relative to the seafloor, i.e. 0 represents the seafloor. Error bars represent 95 % confidence intervals.

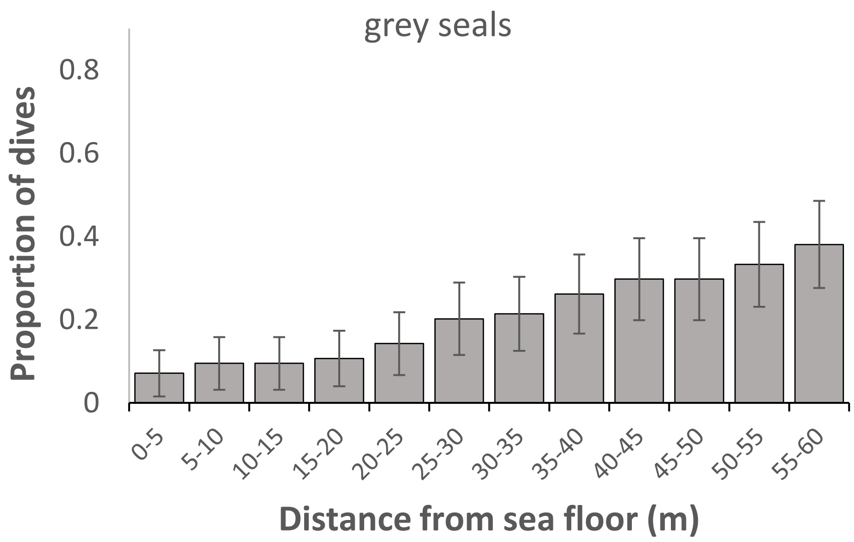


Figure 16. The proportion of dives by grey seal pups within the Brims site, during which seals entered and/or transited through particular depth strata, measured relative to the seafloor, i.e. 0 represents the seafloor. Error bars represent 95 % confidence intervals.

Table 7. Mean proportion of dives on which harbour seals entered or transited through each depth bin, measured relative to distance from the seafloor. N=828 dives

Distance from sea floor (m)	Mean proportion of dives	Standard error
0 to 5	0.23	0.01
5 to 10	0.25	0.02
10 to 15	0.26	0.02
15 to 20	0.27	0.02
20 to 25	0.28	0.02
25 to 30	0.28	0.02
30 to 35	0.29	0.02
35 to 40	0.31	0.02
40 to 45	0.34	0.02
45 to 50	0.40	0.02
50 to 55	0.50	0.02
55 to 60	0.64	0.02

Table 8. Mean proportion of dives on which grey seal pups entered or transited through each depth bin, measured relative to distance from the seafloor n=84 dives.

Distance from sea floor (m)	Mean proportion of dives	Standard error
0 to 5	0.07	0.03
5 to 10	0.10	0.03
10 to 15	0.10	0.03
15 to 20	0.11	0.03
20 to 25	0.14	0.04
25 to 30	0.20	0.04
30 to 35	0.21	0.04
35 to 40	0.26	0.05
40 to 45	0.30	0.05
45 to 50	0.30	0.05
50 to 55	0.33	0.05
55 to 60	0.38	0.05

Discussion

This study reports the diving behaviour of adult harbour seals and grey seal pups in the Brims tidal energy lease site, between Orkney and the north coast of Scotland. Results suggest that harbour seals spend a relatively high proportion of time at mid water depths as well as at depths close to the seafloor. The use of mid water depths appears relatively unusual for this species which is typically considered a primarily benthic forager based on studies in other, non-tidally energetic habitats (Bjorge *et al*., 1995). However, in support of this study, Thompson *et al*. (2016) found that harbour seals within the Inner Sound, another tidally energetic area in the Pentland Firth, also spent a large proportion of their time in mid water depths.

The position of tidal turbines within the water column and the distinctive use of the water column by seals has implications for spatial overlap and hence collision risk. An important point to highlight when interpreting the results presented here is that due to variations in tidal height, the use of the water column relative to seabed mounted turbines should only be made using the distance from the seabed distributions (Figures 9 and 10). Conversely, the use of the water column relative to sea surface located turbines should only be made using the distance from the sea surface distributions (Figures 5 and 6). With this in mind, implications for collision risk depend broadly on the depths at which tidal turbines are located, whether they are fixed to the seabed or are surface floating, and the diameter of the blades, which will together influence the risk depths covered by the swept area of the turbine blades. Overall, the proportion of time spent relative to either the sea surface or seabed, can be used to estimate the density of animals within a zone of risk, and can be used to parameterize collision risk models.

It is clear from the results that there can be marked variation in the diving behaviour of individual seals (see Appendix for individual seal dive behaviour plots) in both harbour and grey seals. The pooled depth distributions for harbour seals shows a clear bi-modal pattern indicating the greatest proportion of time while diving is spent either between the surface and 25 metres depth or between 65 and 80 metres depth. Comparison with the bathymetry data confirms that a significant proportion of the second, deeper peak are benthic dives. Seabed mounted tidal turbines typically have a clearance from the seabed in the order of several metres. This results in the benthic section of dives, which are typically the longest portions of benthic dives, to be out of risk depth. Seals will obviously have to travel through risk depths to reach the seafloor, however as the data suggests, transits through these zones will be relatively rapid. Therefore, dependant on sea depth, harbour seals spend the bulk of their time diving outside of risk zones.

There are several sources of potential error in the data used in these analyses. Large inter animal variations mean that the relatively small sample of seals recorded diving in the Brims site may not be sufficient to adequately describe dive behaviour. For example, the dive behaviour for grey seals is entirely based on a small number of dives by recently weaned grey seal pups during their first few weeks at sea. These data may not be representative of the diving of older, more experienced seals, as diving behaviour in this species changes dramatically in the first three months of independence (Carter *et al.,* 2017). The analyses should be repeated as and when data become available from adult grey seals in this area. The results presented here are for a relatively localised area and the use of the water column by seals in other tidally energetic sites may be markedly different. It would therefore be prudent to investigate dive behaviour of seals in other proposed renewable energy development sites (Band *et al*. 2016). There may be significant uncertainty in the water depth estimates as seafloor depth could only be estimated from the bathymetry associated with the GPS locations where seals surfaced, which could be many metres away from where the seals spent their time in the water column (Thompson *et al.,* 2016).

In summary, harbour seals within the Brims site spent the highest proportion of time within 20 m to 25 m of the sea surface. This suggests that a relatively high proportion of the time was spent in mid-water. When expressed as a distance from the seafloor, harbour seals spent approximately 15 % of their time between 5 m and 25 m above the seafloor. Grey seal pups spent less time at depth in general and only 7 % of their time between 5 m and 25 m of the seafloor. These differences in time spent at depths close to the seafloor were also reflected in the proportions of dives on which seals transited through the lower depth strata, with harbour seals transiting the lowest 25 m of the water column approximately twice as often as grey seals.

Acknowledgements

Telemetry studies were funded by Marine Scotland, Scottish Natural Heritage and NERC. We thank the Instrumentation Group at the Sea Mammal Research Unit, and everyone who assisted during the seal tagging.

References

Band, B. 2000. Windfarms and birds: calculating a theoretical collision risk assuming no avoiding action. Guidance notes series 2000. Scottish Natural Heritage, Battleby.

Band, B. 2012. Using a collision risk model to assess bird collision risks for offshore windfarms. The Crown Estate Strategic Ornithological Support Services (SOSS) report SOSS-02. SOSS Website. www.bto.org/science/wetland-and-marine/soss/projects

Band, B., Sparling, C., Thompson, D., Onoufriou, J., Martin, E. S., and West, N. 2016. Refining Estimates of Collision Risk for Harbour Seals and Tidal Turbines. Scottish Marine and Freshwater Science, **7(17)**, pp. 133.

Benjamins, S., Dale, A. C., Hastie, G., Lea, A., Scott, B., Wilson, B. and Waggitt, J. J. 2015. Confusion Reigns? A Review Of Marine Megafauna Interactions With Tidal-Stream Environments. Oceanographic Marine Biological Annual Review 2015, pp. 1–54.

Bjorge, A., D.Thompson, P. Hammond, M.A.Fedak, E.B.Bryant, H. Arefjord, R.Roen and M. Olsen 1995. Habitat use and diving behaviour of harbour seals in a coastal archipelago in Norway. In: Whales, seals, fish and man. : Proceedings of the International Symposium on the Biology of Marine Mammals in the North East Atlantic. Tromso, Norway, 29 November-1 December 1994. Eds: Blix, A.S., Walloe, L. & Ultang, O. 211:224

Carbon Trust (2006), 'Future marine energy', at: http://www.oceanrenewable.com/wpcontent/uploads/2007/03/futuremarineenergy.pdf.

Carter, M.I.D., Russell, D.J.F., Embling, C.B., Blight, C.J., Thompson, D., Hosegood, P.J. and Bennett, K.J. 2017. Intrinsic and extrinsic factors drive ontogeny of early-life at-sea behaviour in a marine top predator. Scientific Reports, **7**, Article number 15505. DOI: 10.1038/s41598-017-15859-8

Gallon, S. L., Sparling, C. E., George, J., Fedak, M. A., Biuw, M., and Thompson, D. 2007. How fast does a seal swim? Variations in swimming behaviour under differing foraging conditions. Journal of Experimental Biology, **210**, 3285-3294.

Hastie, G. D., Gillespie, D. M., Gordon, J. C. D., Macaulay, J. D. J., Mcconnell, B. J. and Sparling, C. E. 2014. Tracking Technologies for Quantifying Marine Mammal Interactions with Tidal Turbines: Pitfalls and Possibilities. Marine Renewable Energy Technology and Environmental Interactions, Humanity and the Sea (eds. M.A. Shields. & A.I.L. Payne). Springer Science+Business Media, Dordrecht.

Hastie, G. D., Russell, D. J. F., Lepper, P., Elliot, J., Wilson, B., Benjamins, S. and Thompson, D. 2017. Harbour seals avoid tidal turbine noise: implications for collision risk. Journal of Applied Ecology, vol. **Early View**. DOI: 10.1111/1365-2664.12981

Marine Scotland. 2013. Pentland Firth Bathymetric Package. DOI: 10.7489/1213-1

McConnell, B., Beaton, R., Bryant, E., Hunter, C., Lovell, P., and Hall, A. 2004. Phoning home-A new GSM mobile phone telemetry system to collect mark-recapture data. Marine Mammal Science, **20(2)**, 274-283.

National Oceanography Centre (NOC). 2010. Marine Data Products: The NOC Hydro-DLL.

Price, D., Stuiver, C., Johnson, H., Gallego, A., and O'Hara-Muray, R. 2015. The Scottish Shelf Model. Part 2: the Pentland Firth and Orkney Waters Sub-Domain. Scottish Marine and Freshwater Science, **7(4)**, pp. 248.

Proctor, R., Bell, C., Eastwood, L., Holt, J. T., Prandle, D., and Young E. F. 2004. UK Marine Renewable Energy Atlas: Phase 2 - POL contribution. Proudman Oceanographic Laboratory, Internal Document, **No 163**, pp. 26.

R Core Development Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Russell, D., Matthiopoulos, J., and McConnell, B. 2011. SMRU seal telemetry quality control process, SCOS-BP 11/17. Special Committee on Seals: Scientific Advice on Matters Related to the Management of Seal Populations 2011. Sea Mammal Research Unit, University of St Andrews, St Andrews.

SCOS, 2016. Special Committee on Seals: Scientific Advice on Matters Related to the Management of Seal Populations 2016. Sea Mammal Research Unit, University of St Andrews, St Andrews.

Scottish Natural Heritage. 2016. Assessing collision risk between underwater turbines and marine wildlife. SNH Guidance Note. http://www.snh.gov.uk/planning-and-development/renewable-energy/offshore-renewables/marine/

Sharples, R. J., Moss, S. E., Patterson, T. A. & Hammond, P. 2012. Spatial variation in foraging behaviour of a marine top predator (*Phoca vitulina*) determined by a large-scale satellite tagging program. PLoS One, **7**, e37216.

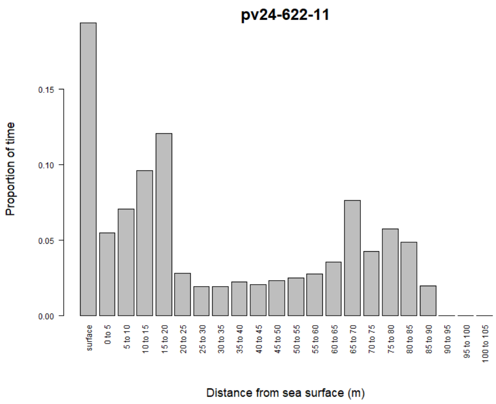
Sparling, C., Lonergan, M., McConnell, B. 2017. Harbour seals (*Phoca vitulina*) around an operational tidal turbine in Strangford Narrows: No barrier effect but small changes in transit behaviour. Aquatic Conservation: Marine and Freshwater Ecosystems, vol Early View, p. 1–11. DOI: 10.1002/aqc.2790

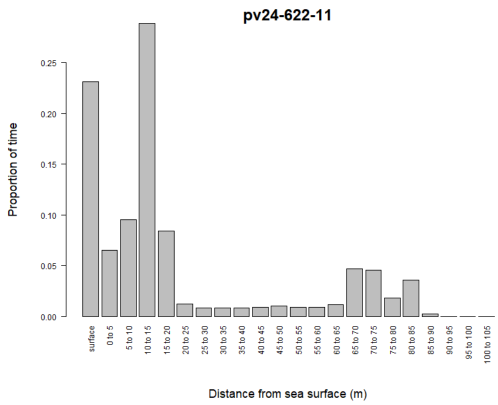
Thompson, D., Onoufriou, J., Brownlow, A. & Morris, C. 2016 . Data based estimates of collision risk: an example based on harbour seal tracking data around a proposed tidal turbine array in the Pentland Firth. Scottish Natural Heritage Commissioned Report No. 900.

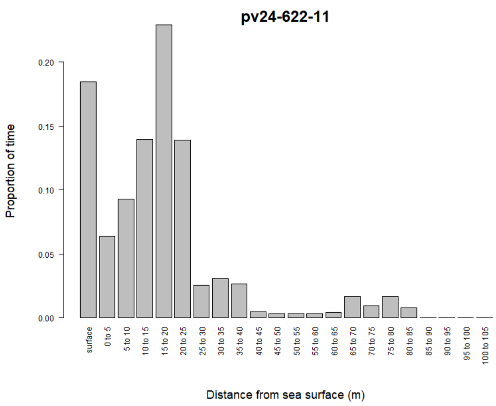
United Kingdom Hydrographic Office (UKHO). 2008. Vertical Offshore Reference Frame (VORF).

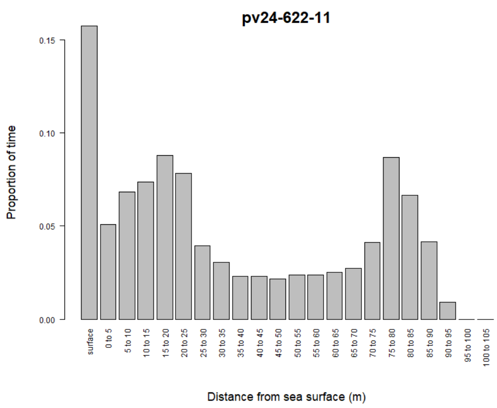
Wilson, B., Batty, R., Daunt, F. and Carter, C. 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive Scottish Association for Marine Science.

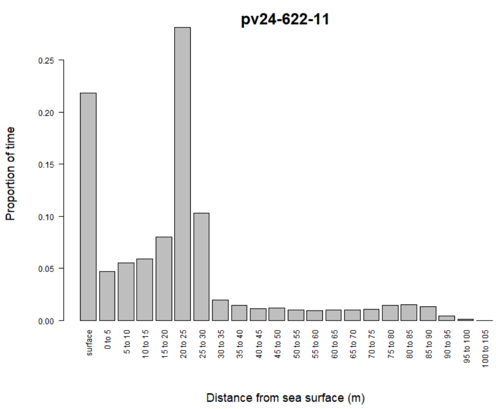
Appendix

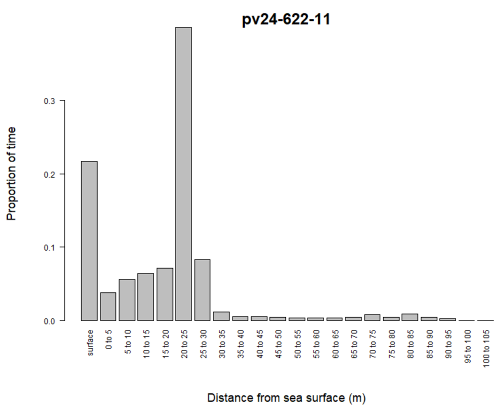

pv24-622-11
Proportion of time
Distance from sea surface (m)


pv24-622-11
Proportion of time
Distance from sea surface (m)


pv24-622-11
Proportion of time
Distance from sea surface (m)


pv24-622-11
Proportion of time
Distance from sea surface (m)


pv24-622-11
Proportion of time
Distance from sea surface (m)


pv24-622-11
Proportion of time
Distance from sea surface (m)

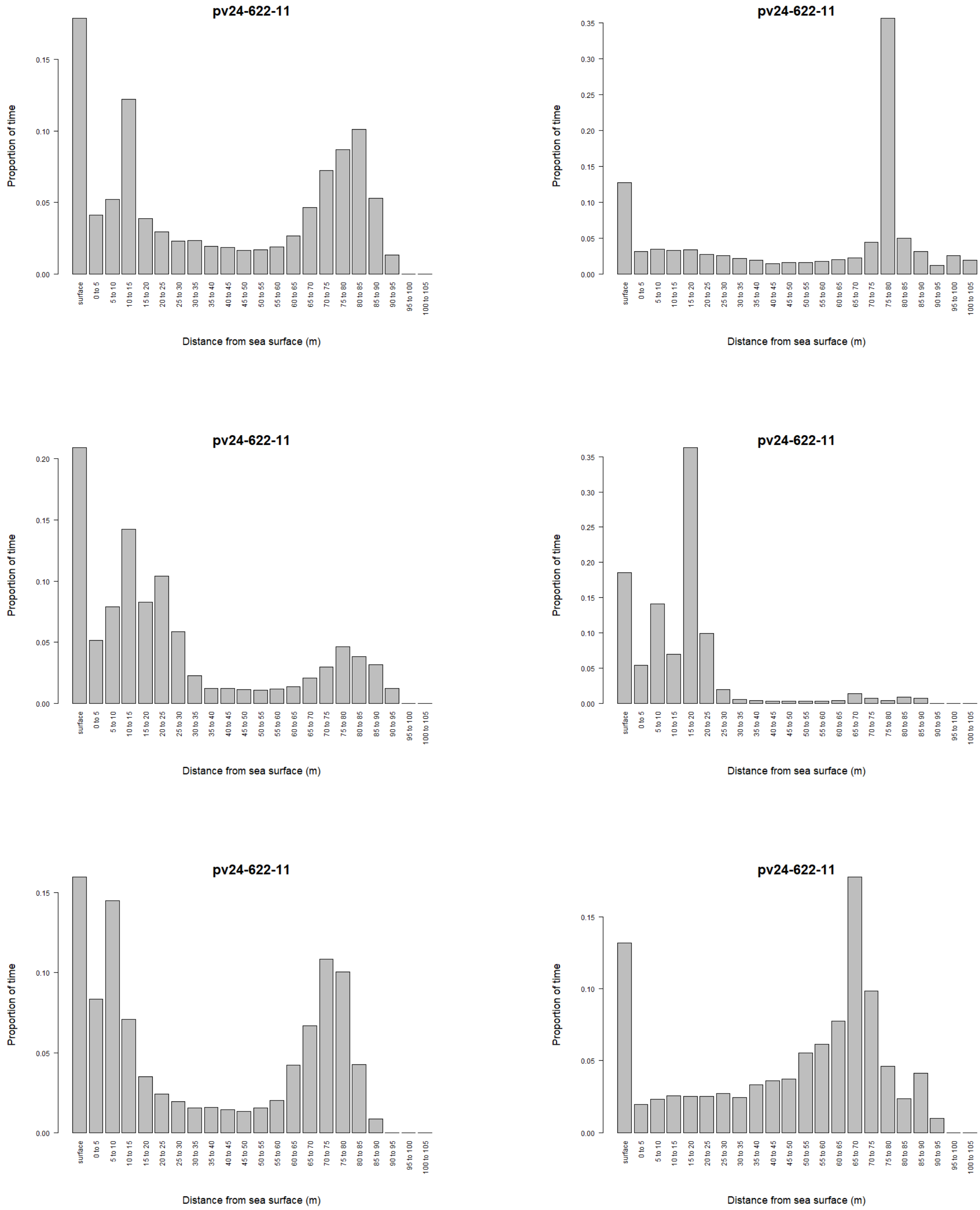


Figure 15. Proportion of time spent within each depth bin relative to distance from sea surface for each of the 12 individual harbour seals.

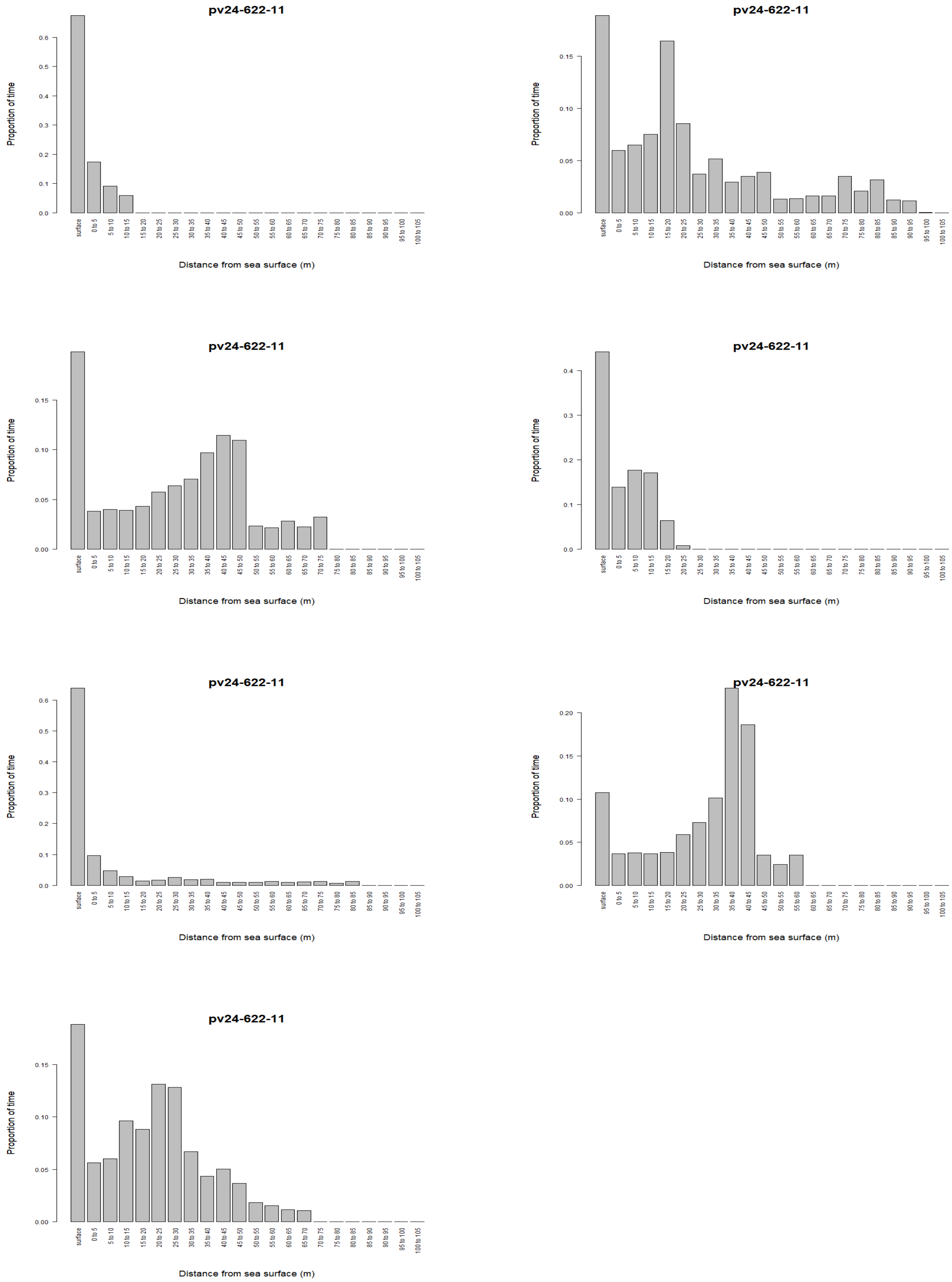
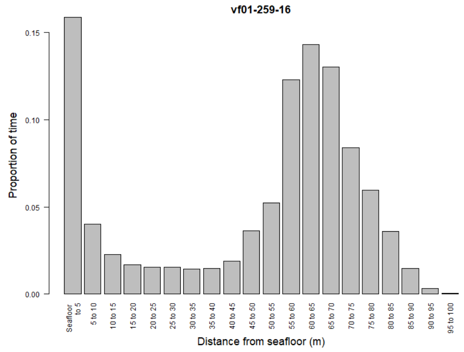
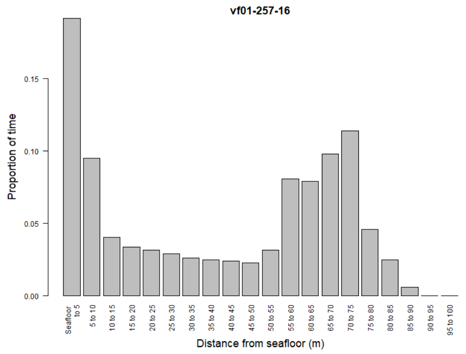
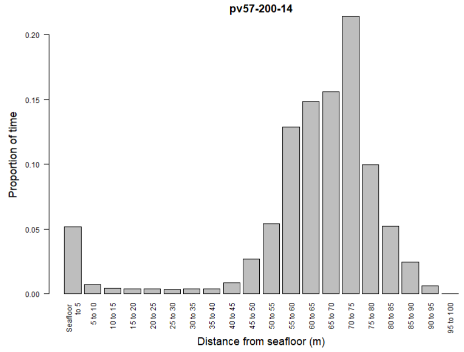
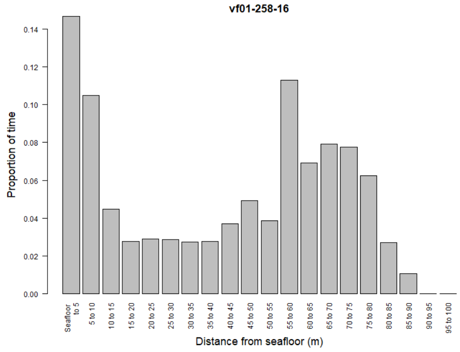


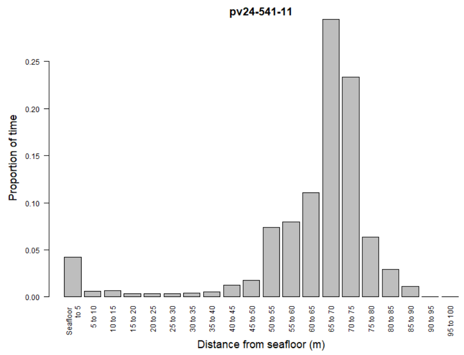
Figure 16. Proportion of time spent within each depth bin relative to distance from sea surface for each of the seven individual grey seals.

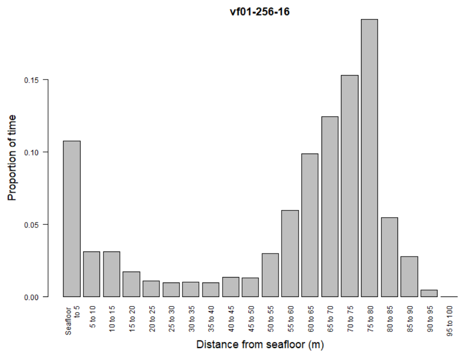

vf01-259-16
Proportion of time
Distance from seafloor (m)


vf01-257-16
Proportion of time
Distance from seafloor (m)


pv57-200-14
Proportion of time
Distance from seafloor (m)


vf01-258-16
Proportion of time
Distance from seafloor (m)


pv24-541-11
Proportion of time
Distance from seafloor (m)


vf01-256-16
Proportion of time
Distance from seafloor (m)

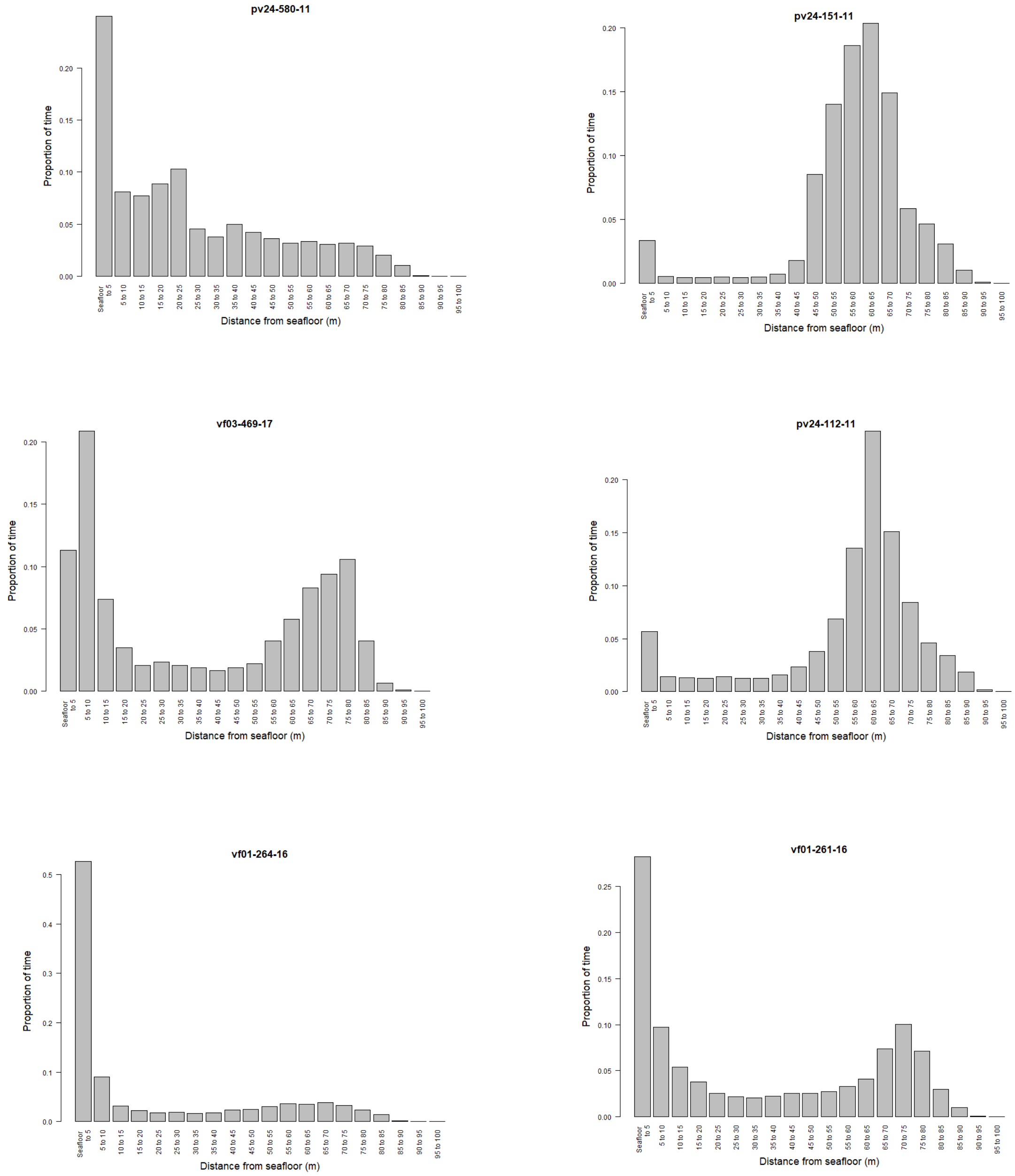


Figure 17. Proportion of time spent within each depth bin relative to distance from seafloor for each of the 12 individual harbour seals.

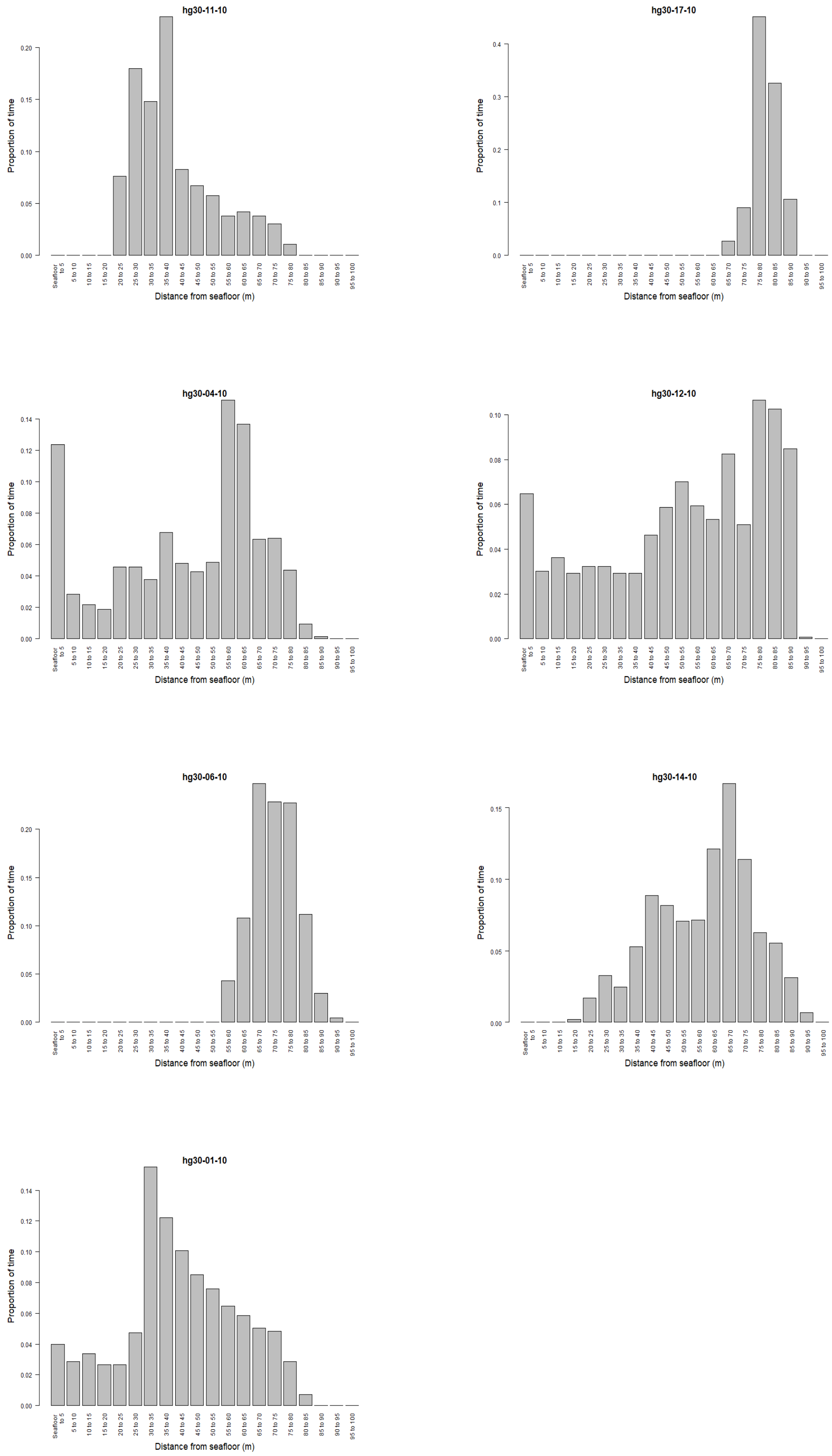


Figure 18. Proportion of time spent within each depth bin relative to distance from seafloor for each of the seven individual grey seals.