**Spatial and temporal separation of toothed whales in the western North Atlantic**

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**Text S1.** Visualization of Smooth Term Interactions

Our continuous covariates were included in the generalized estimating equation generalized additive models (GEEGAMs) as smooth terms, so to plot interactions between terms we extended the typical approach for plotting interactions between continuous and factor variables, or between two continuous variables. This typical approach consists of multiplying the values of one interacting term by a particular value of the other interacting term. Smooth terms differ from simple continuous variables in that smooth terms are represented inside the model by a basis which has length (rows) equal to the number of observations, and a second dimension (columns; *n*) determined by the number of knots or degrees of freedom chosen by the analyst. We chose to use spline basis functions for their good approximation properties across the domain of observed values of a term [1]. The smooth function of a term (*f(x)*) is the linear combination of these columns with their associated model coefficients:

$$f(x) = \sum_{i=1}^{n} b_i(x)\beta_i \tag{1}$$

where $b_i$ is the $i^{th}$ basis function and $\beta_i$ is the coefficient for that function estimated by the model. Basis functions may be a constant, a line, or a curve, and so their linear combination can result in very complex curves. More basis functions results in a more wiggly fit to the data, while fewer basis functions results in a higher degree of smoothing. In this way both the smooth terms, and the GAM (or GEEGAM, in this case) within which they are additively combined, can capture nonlinear relationships while remaining linear models [2].

We observed that interactions of smooth terms are represented inside the model matrix as the elementwise product of each column of one interacting term with each column of the other interacting term. Each of our smooth terms was represented by three basis functions, so an interaction between two terms therefore resulted in nine interaction basis functions. We inspected the model matrices to determine the order of these products and understand how they corresponded to their associated coefficients (i.e. for an interaction between NT and JD, the first column of JD was multiplied by each column of NT to yield three new columns, and then the second column of JD was multiplied by each column of NT to yield the next three columns, etc.).

To visualize interactions between a continuous variable ("target" term) and either a factor or another continuous variable ("interacting" term), one particular level/value of the interacting term is selected at which to visualize the shape of the target term. Since each row of the basis functions for smooth terms represents a single observation of that term, we were able to identify rows corresponding to points of interest across the cycles of interacting terms. We then multiplied an interacting term row of interest by all rows of the basis functions of the target term, analogous to multiplying one value/level of an factor/continuous interacting term by the entire vector of values of a continuous target term.

For example, to visualize the diel pattern (target term) at a particular point in the seasonal cycle (interacting term) we first identified a row in the JD basis functions corresponding to the Julian day of interest. Next, interaction basis functions were computed by multiplying all rows of the NT basis functions by the selected row of the JD basis function. The contribution of the interaction of NT and JD, at that given

value of JD, was then computed as the linear combination of the NT:JD interaction coefficients and the interaction basis functions. To plot the diel pattern as influenced by this interaction we summed this interaction term with the smooth function of NT. In the case of significant interactions between NT and both JD and MPh, the diel pattern at specified points in both the seasonal and lunar cycles were computed as the sum of the smooth function of NT with both the NT:JD interaction term for the Julian day of interest and the NT:MPh interaction term for the moon phase of interest. To plot the lunar patterns during daytime and nighttime in the case of a significant NT:MPh interaction, we averaged the interaction terms across all values of NT representing daytime, and separately across all values of NT representing nighttime, and added each interaction term separately to the smooth function of MPh. To plot seasonal patterns in the case of a significant NT:JD interaction, we averaged the interaction term across all values of NT and summed this with the smooth function of JD. The means of the smooth functions of non-target terms were also added in, as is the convention for partial residual plots.

## LITERATURE CITED

[1]     Wang W, Yan J (2021) Shape-Restricted Regression Splines with R Package splines2. J Data Sci 19:498–517

[2]     Hastie TJ, Tibshirani RJ (1986) Generalized additive models.

Table S1. HARP deployment information at Western North Atlantic acoustic monitoring sites

| Site | Deployment | Latitude | Longitude | Depth (m) | Data Start Date | Time | Data End Date | Time |
|---|---|---|---|---|---|---|---|---|
| Heezen Canyon (HZ) | 1 | 41°03.71' N | 66°21.10' W | 883 | 4/22/2016 | 18:00:00 | 6/19/2017 | 7:05:06 |
| | 2 | 41°03.70' N | 66°21.09' W | 885 | 7/9/2017 | 0:00:00 | 1/13/2018 | 15:25:06 |
| | 3 | 41°03.70' N | 66°21.09' W | 885 | 6/11/2018 | 17:59:59 | 5/10/2019 | 6:33:44 |
| Oceanographer's Canyon (OC) | 1 | 40°15.80' N | 67°59.17' W | 448 | 4/24/2016 | 5:59:59 | 5/18/2017 | 6:37:35 |
| | 2 | 40°15.80' N | 67°59.18' W | 447 | 7/6/2017 | 23:59:59 | 4/16/2018 | 5:56:18 |
| | 3 | 40°13.80' N | 67°58.68' W | 882 | 6/10/2018 | 6:00:00 | 5/19/2019 | 4:33:45 |
| Nantucket Canyon (NC) | 1 | 39°49.94' N | 69°58.93' W | 894 | 4/21/2016 | 18:00:00 | 5/24/2017 | 14:53:51 |
| | 2 | 39°49.96' N | 69°58.92' W | 894 | 7/16/2017 | 18:00:00 | 6/9/2018 | 13:02:36 |
| | 3 | 39°49.98' N | 69°58.92' W | 894 | 6/10/2018 | 0:00:00 | 6/3/2019 | 4:43:45 |
| Babylon Canyon (BC) | 1 | 39°11.46' N | 72°13.72' W | 999 | 4/20/2016 | 18:00:00 | 6/10/2017 | 23:04:05 |
| | 2 | 39°11.43' N | 72°13.63' W | 1003 | 6/30/2017 | 12:00:00 | 6/3/2018 | 11:31:21 |
| | 3 | 39°11.52' N | 72°13.64' W | 997 | 6/3/2018 | 12:00:00 | 5/19/2019 | 19:30:00 |
| Wilmington Canyon (WC) | 1 | 38°22.45' N | 73°22.24' W | 1028 | 4/20/2016 | 6:00:00 | 6/29/2017 | 20:57:36 |
| | 2 | 38°22.43' N | 73°22.21' W | 1036 | 6/30/2017 | 0:00:00 | 6/2/2018 | 20:42:36 |
| | 3 | 38°22.40' N | 73°22.19' W | 1045 | 6/2/2018 | 22:00:00 | 5/19/2019 | 8:32:30 |
| Norfolk Canyon (NFC) | 1 | 37°09.99' N | 74°20.00' W | 1028 | 4/30/2016 | 12:00:00 | 6/28/2017 | 18:38:51 |
| | 2 | 37°10.04' N | 74°27.98' W | 992 | 6/30/2017 | 0:00:00 | 6/2/2018 | 16:15:06 |
| | 3 | 37°09.87' N | 74°27.95' W | 1111 | 6/2/2018 | 12:00:00 | 5/18/2019 | 17:46:40 |
| Hatteras (HAT) | 1 | 35°18.11' N | 74°52.74' W | 1194 | 4/29/2016 | 12:00:00 | 2/6/2017 | 8:56:03 |
| | 2 | 35°35.05' N | 74°44.99' W | 1128 | 5/9/2017 | 12:02:54 | 10/25/2017 | 14:11:45 |
| | 3 | 35°35.01' N | 74°44.58' W | 1222 | 10/26/2017 | 12:00:00 | 6/1/2018 | 0:54:59 |
| | 4 | 35°35.39' N | 74°44.86' W | 1327 | 6/1/2018 | 4:00:00 | 12/14/2018 | 14:42:36 |
| | 5 | 35°35.36' N | 74°45.27' W | 1208 | 12/14/2018 | 0:00:00 | 5/17/2019 | 18:17:30 |
| Gulf Stream (GS) | 1 | 33°39.94' N | 76°00.08' W | 926 | 4/29/2016 | 0:00:00 | 6/27/2017 | 18:35:06 |
| | 2 | 33°40.02' N | 75°59.97' W | 932 | 6/28/2017 | 0:00:00 | 6/26/2018 | 11:31:21 |
| | 3 | 33°40.20' N | 75°59.86' W | 933 | 6/28/2018 | 23:59:59 | 6/18/2019 | 14:17:09 |
| Blake Plateau (BP) | 1 | 32°06.36' N | 77°05.66' W | 953 | 4/28/2016 | 12:00:00 | 6/27/2017 | 4:57:36 |
| | 2 | 32°06.42' N | 77°05.41' W | 951 | 6/27/2017 | 12:00:00 | 6/28/2018 | 13:08:51 |
| | 3 | 32°06.32' N | 77°05.44' W | 950 | 6/28/2018 | 0:00:00 | 5/28/2019 | 4:01:15 |
| Blake Spur (BS) | 1 | 30°35.03' N | 77°23.44' W | 1047 | 4/27/2016 | 18:00:00 | 6/26/2017 | 15:22:05 |
| | 2 | 30°34.98' N | 77°23.43' W | 1047 | 6/26/2017 | 18:00:00 | 6/23/2018 | 7:32:33 |
| | 3 | 30°34.98' N | 77°23.40' W | 1047 | 6/28/2018 | 0:00:00 | 6/16/2019 | 20:13:45 |
| Jacksonville (JAX) | 1 | 30°09.11' N | 79°46.21' W | 748 | 4/26/2016 | 18:00:00 | 6/25/2017 | 19:23:35 |
| | 2 | 30°09.16' N | 79°46.19' W | 748 | 6/25/2017 | 18:03:57 | 10/28/2017 | 17:27:48 |
| | 3 | 30°09.14' N | 79°46.24' W | 746 | 6/27/2018 | 0:00:00 | 6/15/2019 | 11:03:45 |
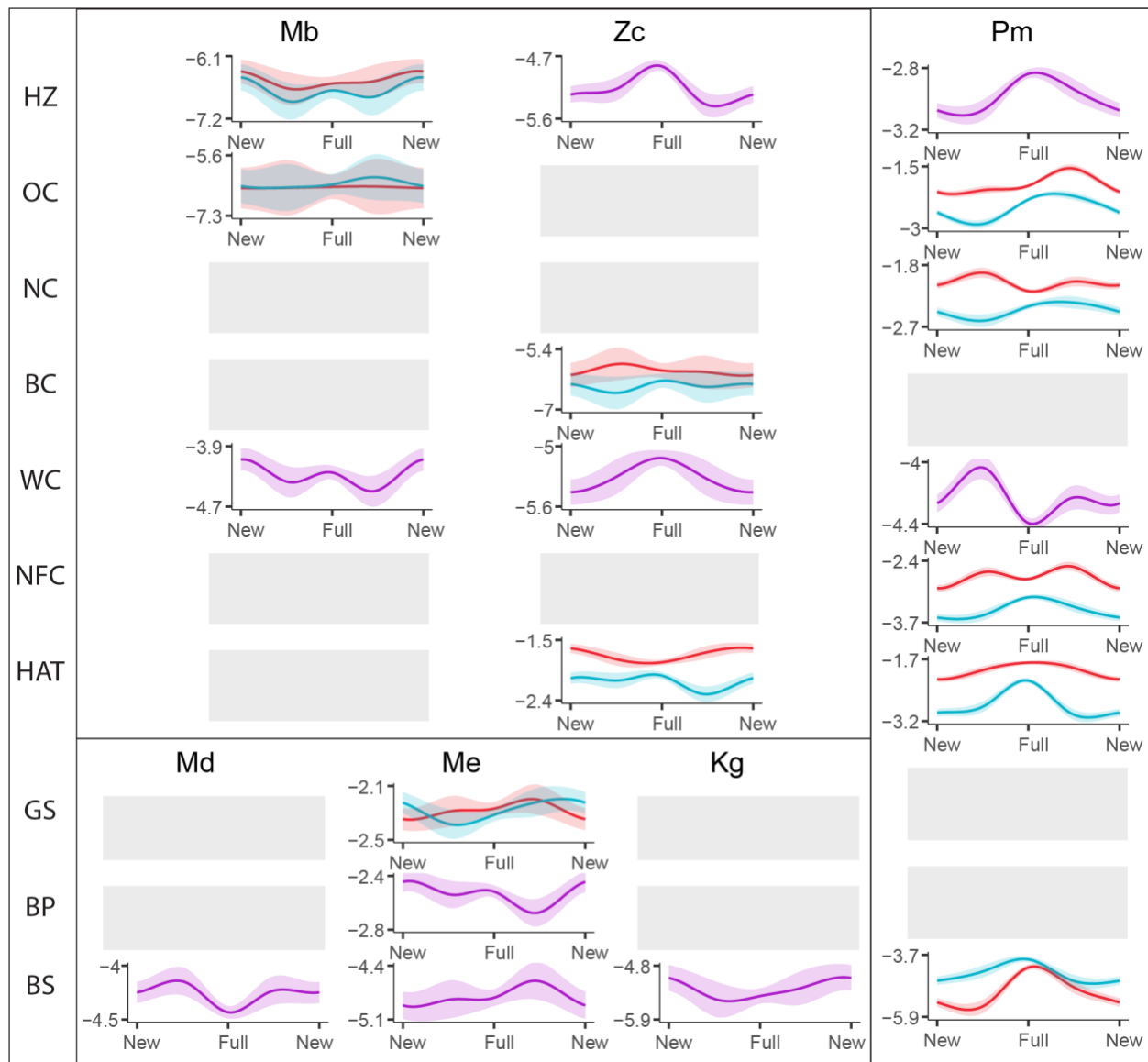
Fig. S1. Partial fits of moon phase (MP) for the deep diving species. Y-axes give values of s(MP); other terms held constant at their mean values. Shaded regions give 95% confidence intervals; gray blocks indicate no model due to low presence and/or poor performance. Plots showing a single curve (purple) depict the lunar pattern in the absence of significant interactions; plots with two curves depict the lunar patterns in the daytime (red) and nighttime (blue) when there was a significant interaction between MP and normalized time of day (NT). Site name abbreviations as in Table S1. *Mb*: Sowerby's beaked whale; *Zc*: Cuvier's beaked whale; *Md*: Blainville's beaked whale; *Me*: Gervais' beaked whale; *Kg*: *Kogia* spp.; *Pm*: sperm whale.
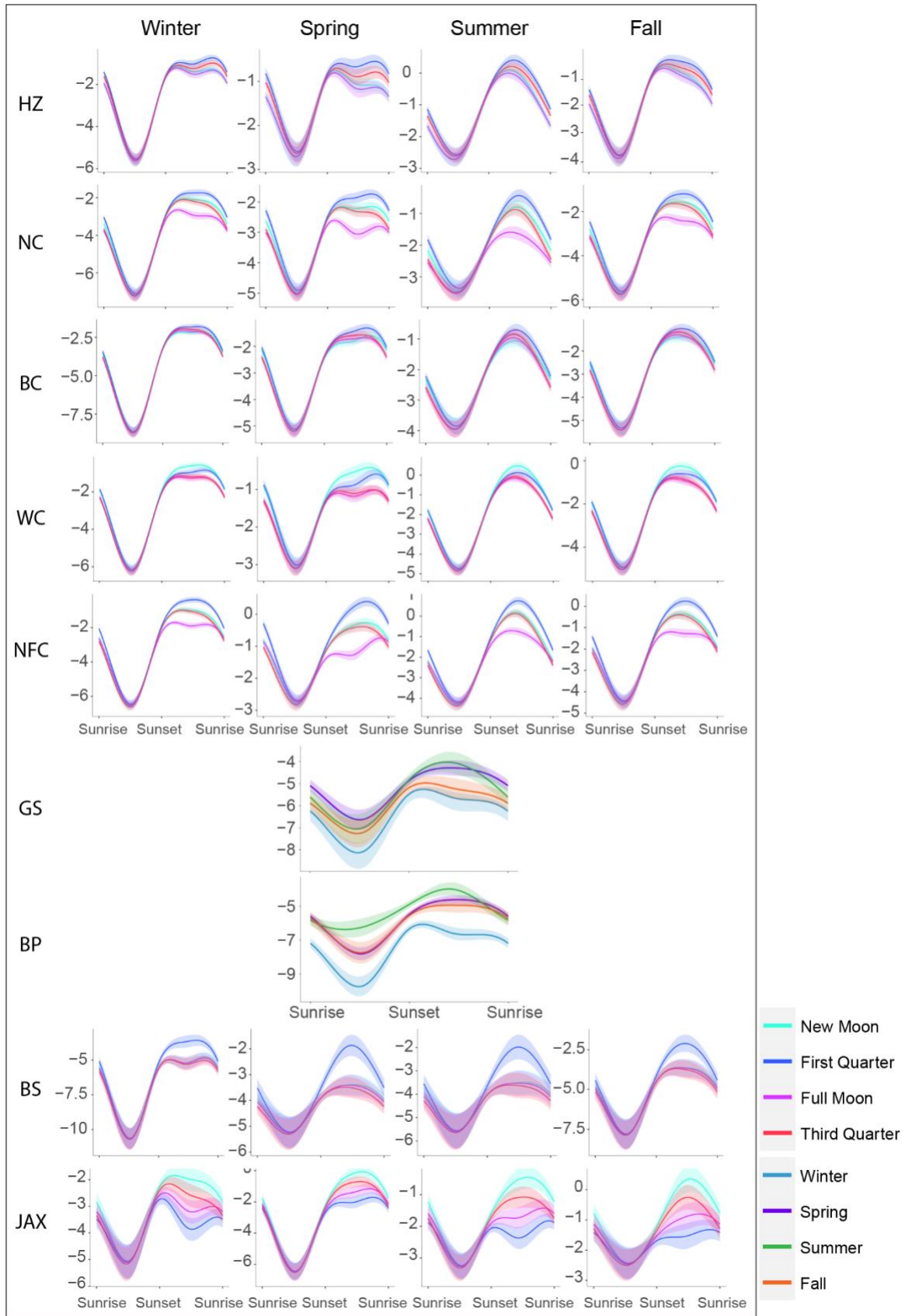
Fig. S2. (previous page) Diel activity patterns for short-beaked common dolphins (*Dd*). Y-axes give values of s(NT). At sites with 4 panels, each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). At sites GS and BP there was no significant interaction between NT and MPh, so only the NT:JD interaction is shown. Site name abbreviations as in Table S1.
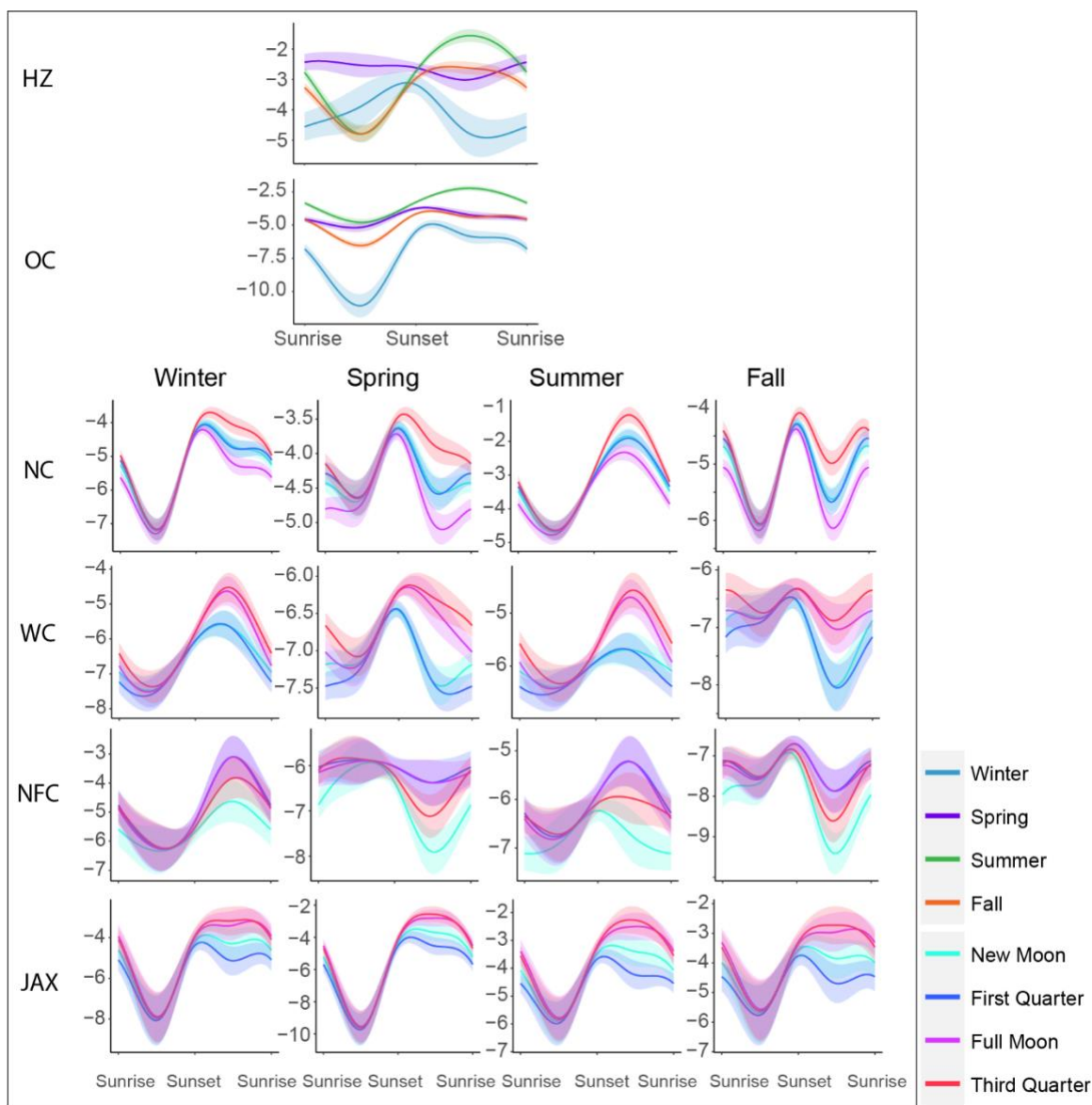


Fig. S3: Diel activity patterns for Risso's dolphin click type Gg1. Y-axes give values of s(NT). At sites with 4 panels, each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). At sites HZ and OC there was no significant interaction between NT and MPh, so only the NT:JD interaction is shown (MPh held constant at its mean value). Site name abbreviations as in Table S1.
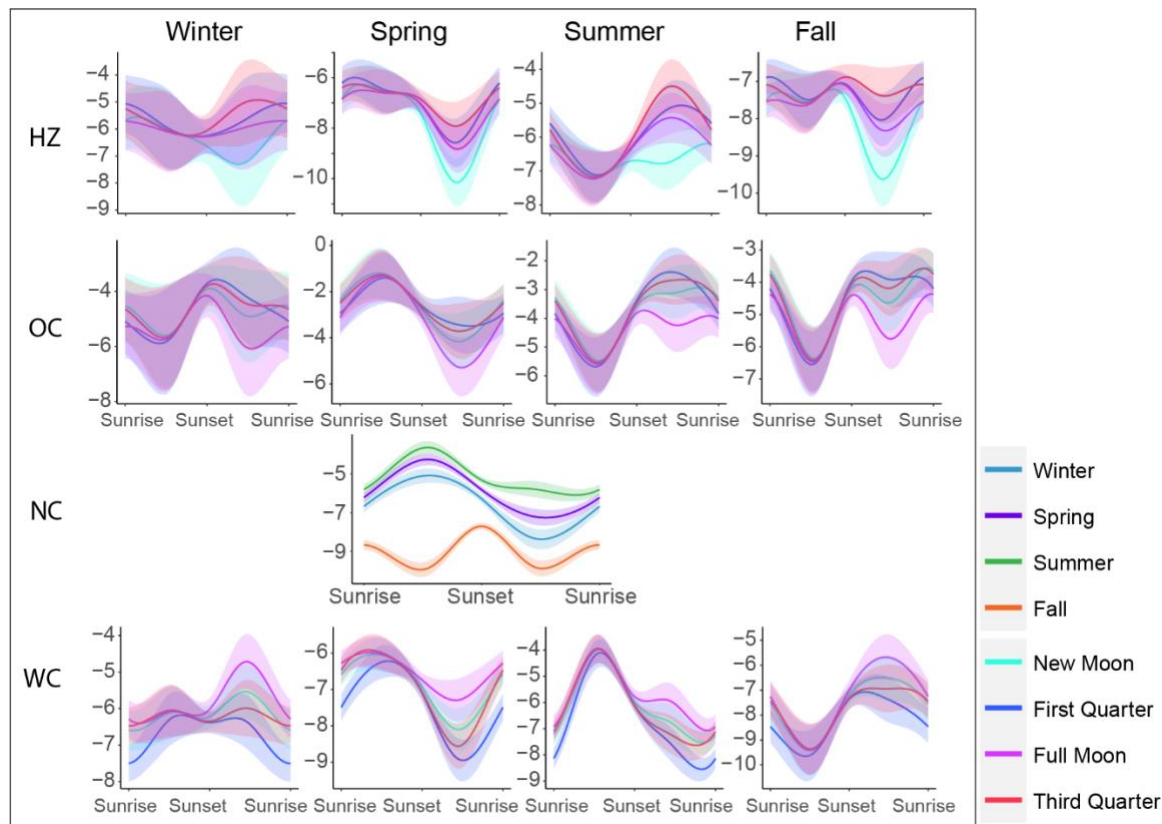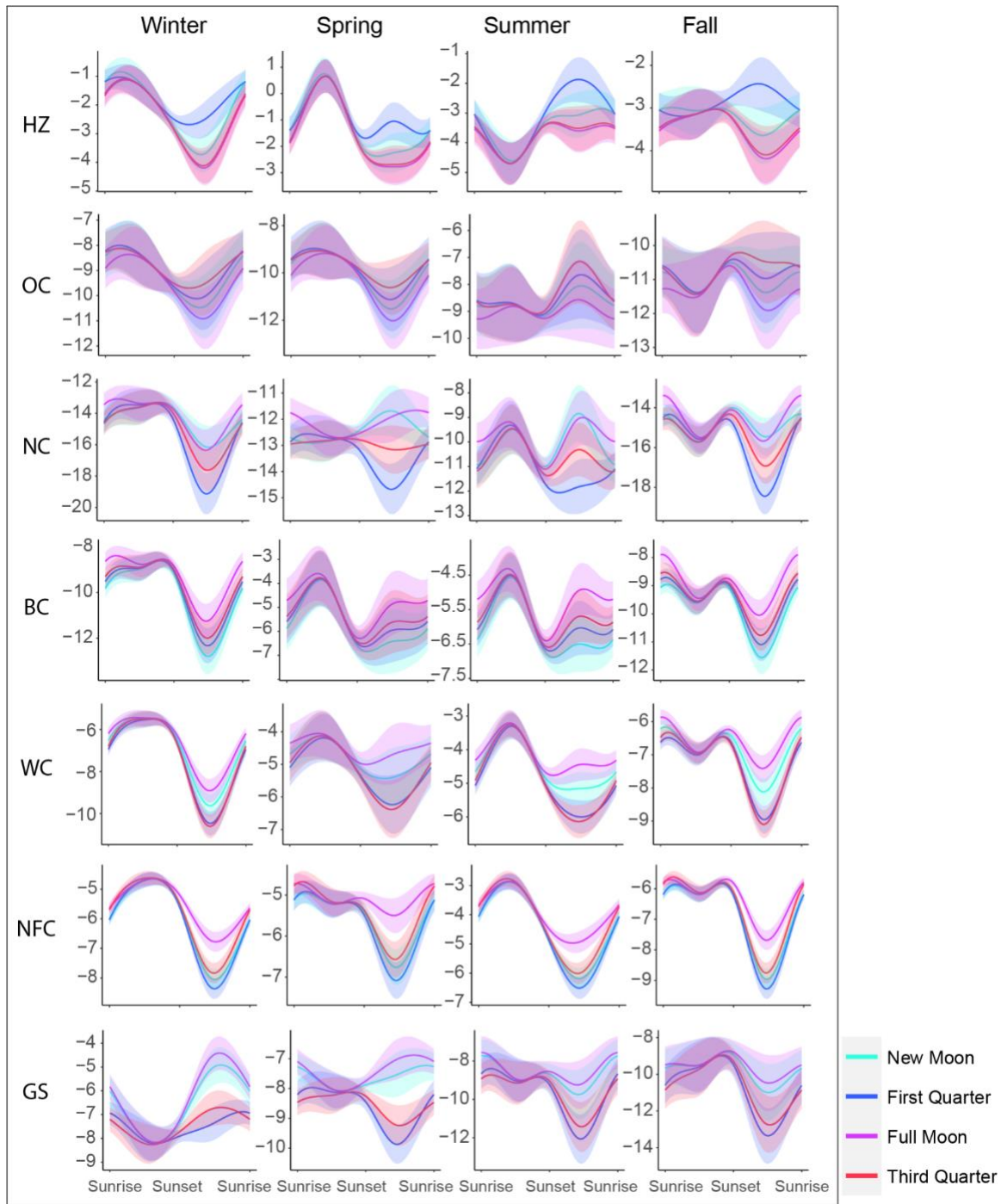
Fig. S4. Diel activity patterns for Risso's dolphin click type Gg2. Y-axes give values of s(NT). At sites with 4 panels, each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). At site NC there was no significant interaction between NT and MPh, so only the NT:JD interaction is shown (MPh held constant at its mean value). Site name abbreviations as in Table S1.

Fig. S5. Diel activity patterns for short-finned pilot whales (*Gm*). Y-axes give values of s(NT). Each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). Site name abbreviations as in Table S1.
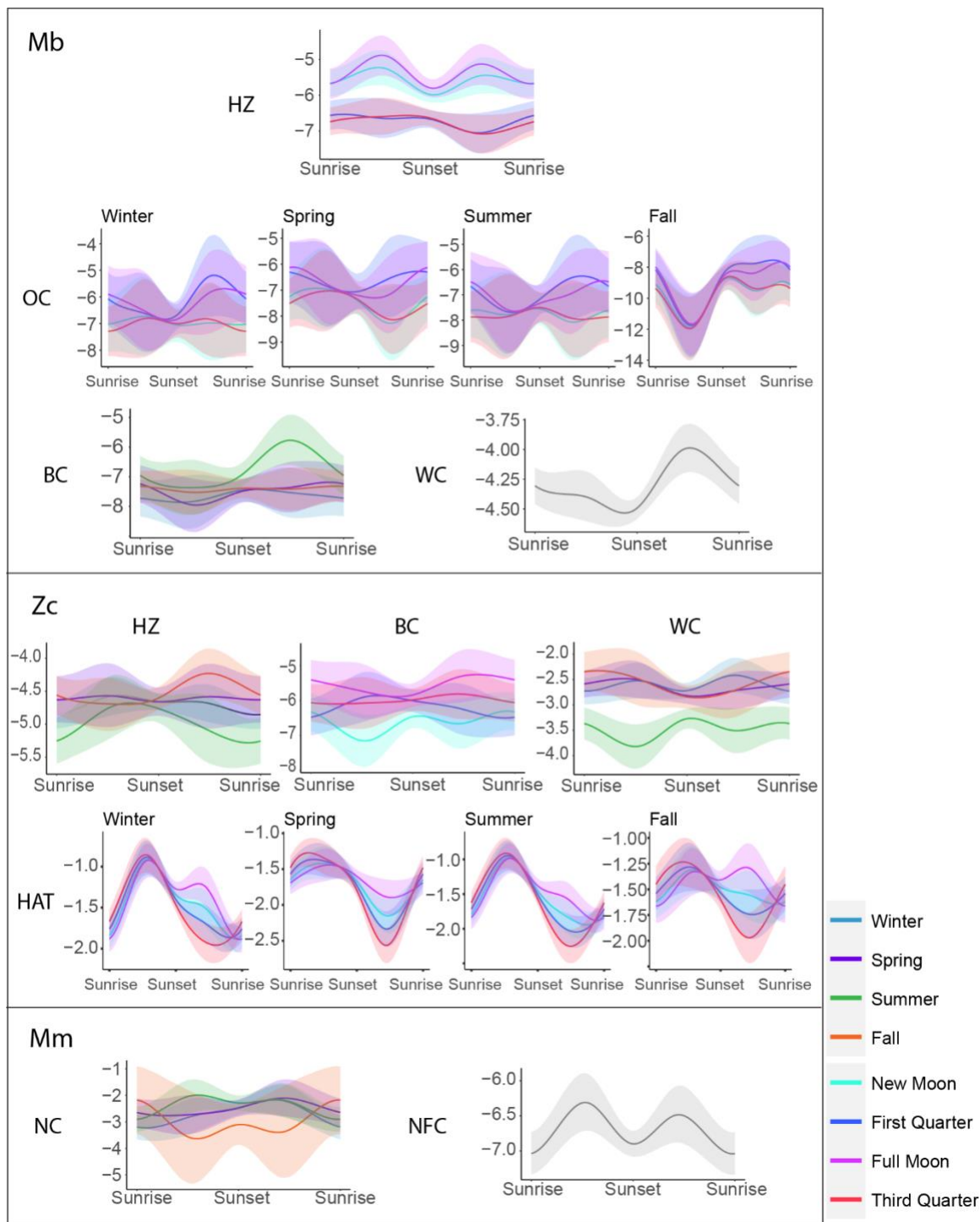
Fig. S6. Diel activity patterns for Sowerby's (*Mb*), Cuvier's (*Zc*), and True's (*Mm*) beaked whales. Y-axes give values of s(NT). For sites with 4 panels, each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). At sites with a single panel the significant interaction (either NT:MPh or NT:JD) is shown by color; if there were no significant interactions the NT pattern is shown in grey. Site name abbreviations as in Table S1.
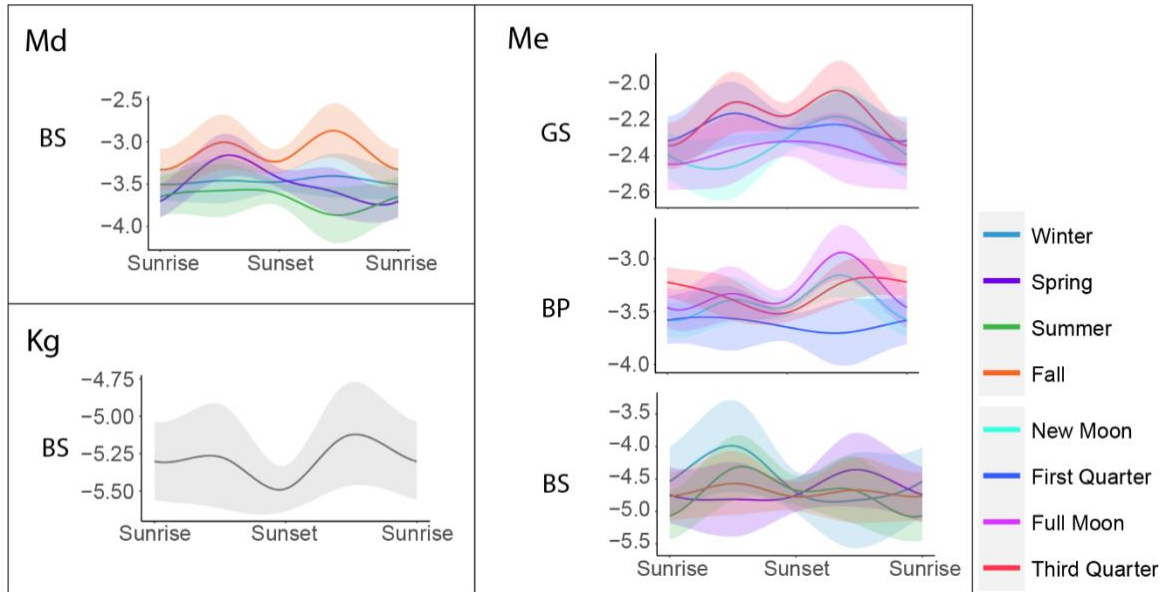
Fig. S7. Diel activity patterns for Blainville's (*Md*) and Gervais' (*Me*) beaked whales and *Kogia* spp. (Kg). Y-axes give values of s(NT). Colors in each panel show the interaction between either normalized time of day (NT) and Julian day (JD), or NT and moon phase (MPh). If there were no significant interactions the NT pattern is shown in grey. Site name abbreviations as in Table S1.
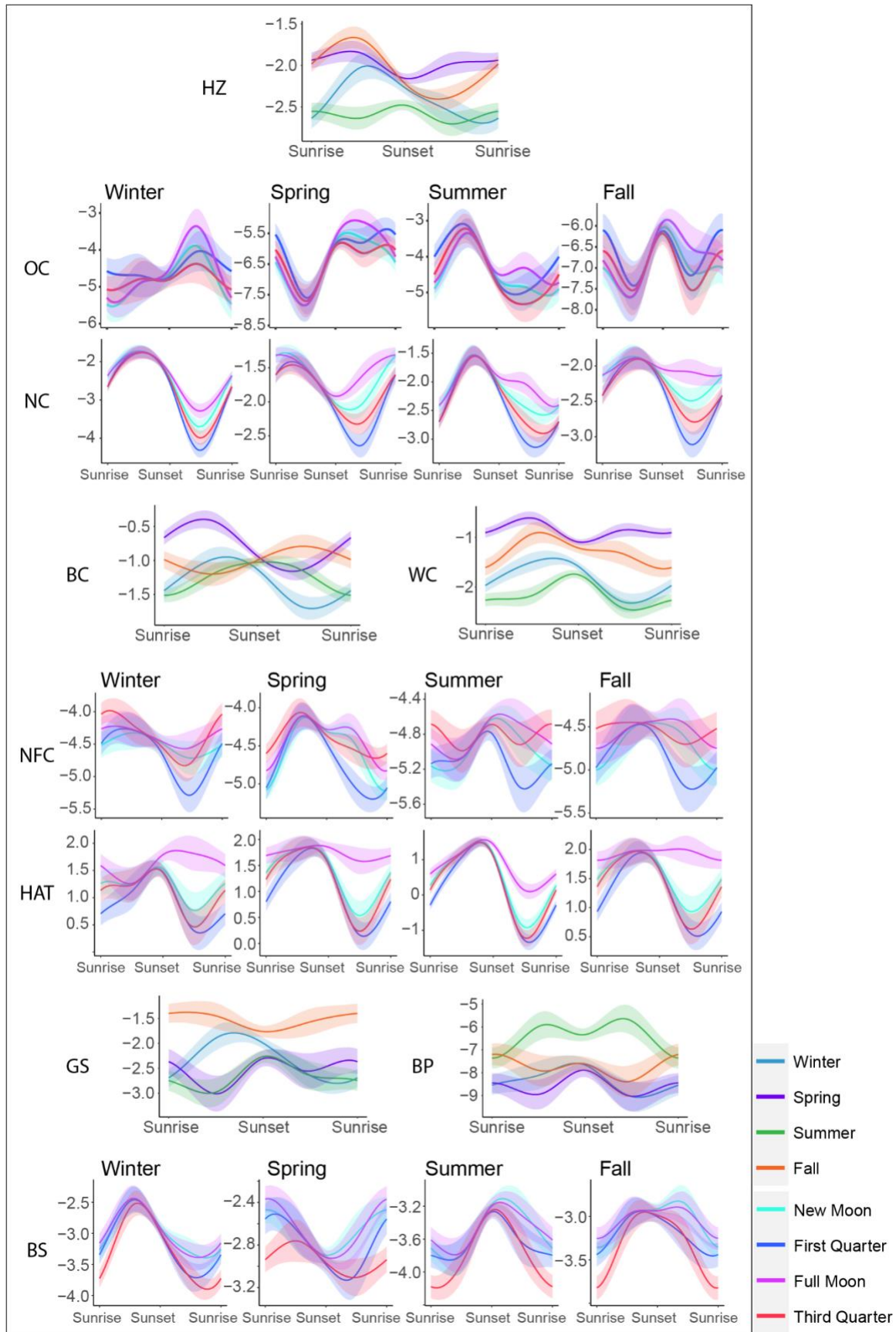
Fig. S8. (previous page) Diel activity patterns for sperm whales (*Pm*). Y-axes give values of s(NT). At sites with 4 panels, each panel represents the interaction between normalized time of day (NT) and Julian Day (JD) at a different point in the seasonal cycle; colors in each panel show the interaction between NT and moon phase (MPh). At sites with a single panel the significant interaction (either NT:MPh or NT:JD) is shown by color. Site name abbreviations as in Table S1.