Supplementary information

Text S1. ODMAP protocol

1.1. Overview

Authorship

Study link: Not applicable

Model objective: Inference and explanation

Focal Taxon: Pygmy blue whale (*Balaenoptera musculus brevicauda*)

Location: Timor Trough and surrounding waters, southeast of Timor Leste

Scale of analysis

Spatial extent: 125, 127.5, -10, -9 (xmin, xmax, ymin, ymax)

Spatial resolution: 1 km

Temporal extent: 2007–2008 **Temporal resolution:** Daily
Boundary: Custom

Biodiversity data

Observation type: Field survey

Response data type: Presence/absence

Predictors

Predictor types: Topographic, habitat, climatic

Hypotheses

Pygmy blue whale favoured areas of elevated productivity in proximity to shelf-incising canyons.

Assumptions

- Relevant ecological drivers (or proxies) are included.
- Detectability does not change spatially or temporally.
- The focal species is at (pseudo-) equilibrium with its environment.
- Sampling is adequate and representative (and any biases are accounted for/corrected).
- Absence points generated for model fitting reflect true absences.

Algorithms

Modelling techniques: Generalised additive models (gam)

Model complexity: We limited the basis size of smooth functions to k = 4 to minimise over-fitting and obtain simple and more ecologically intelligible estimates of species-habitat relationships. We also capped the maximum number of predictors in each candidate model to 3 for the same reasons.

Model averaging: Not applicable

Model workflow: See main text for full details.

Software: R version 4.2.1

Code availability: https://github.com/pjbouchet/timorbw

Data availability: Not applicable

1.2. Data

Biodiversity data

Taxon names: *Balaenoptera musculus brevicauda*

Taxonomic reference system: *Ichihara, 1966*

Ecological level: Individuals

Data sources: Visual observations by trained surveyors onboard seismic vessels (used as platforms of opportunity)

Sampling design: Haphazard, as determined by seismic operations

Sample size: 76

Clipping: Timor Leste

Scaling: Not applicable

Cleaning: Repeat encounters of the same individual within a survey day were discarded, such that only independent sightings identified with certainty were considered. Ad hoc (off-effort) observations without associated measures of effort (i.e., GPS tracks) were excluded from the analysis.

Absence data: Periods of continuous effort with no sightings were treated as absences.

Background data: Absence points were generated within 3 km buffers around vessel tracks, and outside 3 km exclusion zones around each presence point. A total of 1,000 absences were generated and allocated to each daily survey track in proportion to the time spent on effort (in hours) that day.

Errors and biases: Sighting locations were identified with high precision from time-stamped GPS tracks. Misidentification rates were deemed low, as (1) visibility was generally good, (2) blue whales are conspicuous animals, (3) surveys were undertaken by highly trained personnel, and (4) identification photographs were taken in many cases. *Predictor variables*

Bathymetric depth

General Bathymetric Chart of the Oceans (GEBCO; https://www.gebco.net/); 15 arc-sec resolution.

Seabed slope

Calculated from the GEBCO grid as the ‘rise over run’ (in deg) using the slope function in the SDMTools package.

Euclidean distance to major submarine canyons

Based on the classification of submarine canyons of Harris & Whiteway (2011), and calculated using the gDistance function in the rgeos package (Bivand & Rundel 2021).

Remote-sensed sea-surface temperature (SST, in C)

Derived from the U.S. National Aeronautics and Space Administration Multi-scale Ultra-high Resolution dataset (MUR; https://podaac.jpl.nasa.gov/MEaSUREs-MUR) as an analysed product available at 1 km resolution.

Chlorophyll-a concentration (Chl-a, contemporaneous and lagged, in mg.m-3)

Derived from Aqua MODIS satellite imagery (https://oceandata.sci.gsfc.nasa.gov/) at 4 km resolution.

Data sources: See above

Spatial extent: 125, 127.5, -10, -9 (xmin, xmax, ymin, ymax)

Spatial resolution: 1–4 km

Coordinate reference system: WGS84

Temporal extent: 2007-2008 (austral winter, i.e. June to September)

Temporal resolution: Daily

Data processing: Chl-a rasters were gap-filled and upscaled using bilinear interpolation

Errors and biases: Not applicable

Dimension reduction: We capped each candidate model to a maximum of three uncorrelated predictors (|Spearman rho < 0.25|).

Transfer data

Not applicable

1.3. Model

Variable pre-selection: The choice of initial covariates was made as a compromise between their availability and their ecological relevance as indirect proxy of species distributions. Only weakly correlated covariates were included in each model.

Multicollinearity: Only uncorrelated predictors (|Spearman rho < 0.25|) were considered in each candidate model. *Model settings*

gam: family (binomial), formula (response ~s(chla.max) + s(dcanyonsInc) + s(slope)), smoothTerms (Thin plate splines (bs = "tp"), k = 4), weights (Yes), offset (No), method (REML), select (FALSE)

Model estimates

Coefficients: Not applicable

Parameter uncertainty: Estimated as part of model fitting

Variable importance: Approximate p-values

Model selection

Model selection: Information-theoretic (all subsets)

Model averaging: No model averaging was performed.

Model ensembles: Not applicable

Analysis and Correction of non-independence

Spatial: Spatial autocorrelation in model residuals was assessed using spline correlograms.

Temporal: We used the acf function to plot to estimate temporal correlation in model residuals.

Nested data: Not applicable

1.4. Assessment

Performance statistics

Performance on training data: We used a combination of performance metrics, including the True positive rate, the percentage of deviance explained, the AUC, the TSS, and Sørensen's similarity index.

Plausibility check

Response shapes: Partial response plots

Supplementary figures

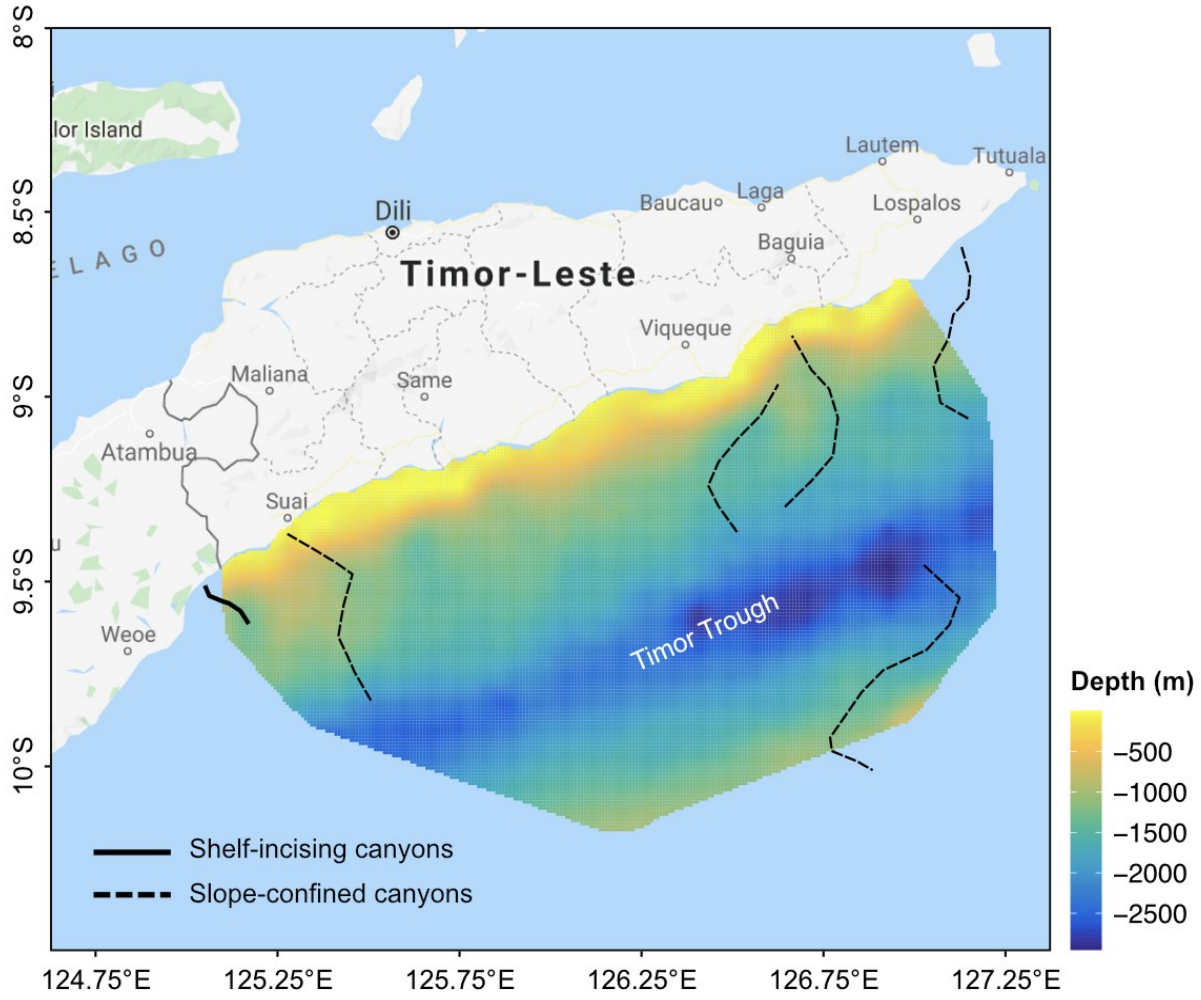

Figure S1: Map of the study area showing the location of both shelf-incising (solid line) and slope-confined (dashed lines) submarine canyons, as delineated in [1].

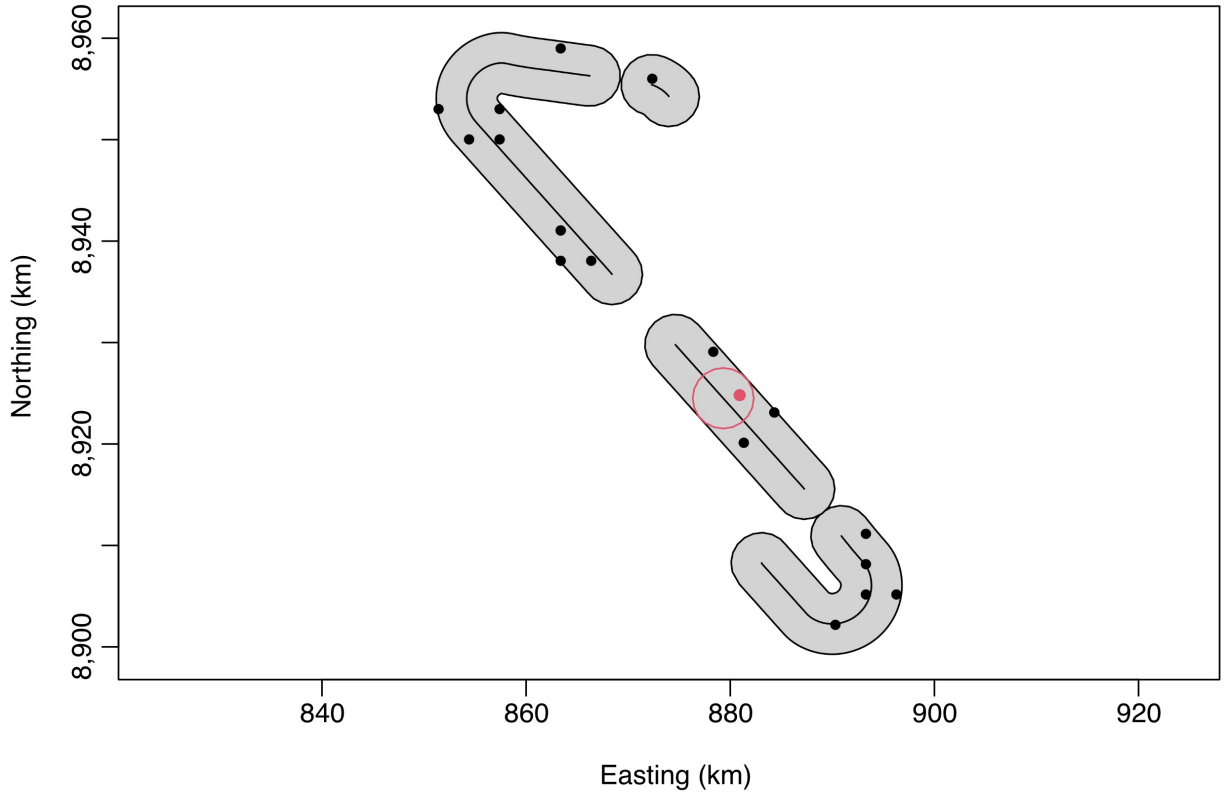

Figure S2: Example buffer around a survey track. Absence points are shown in black and are constrained to lie outside of a 3-km exclusion zone around sighting locations. Presence points are jittered within a 3-km buffer around the vessel's location at the time of encounter (red).

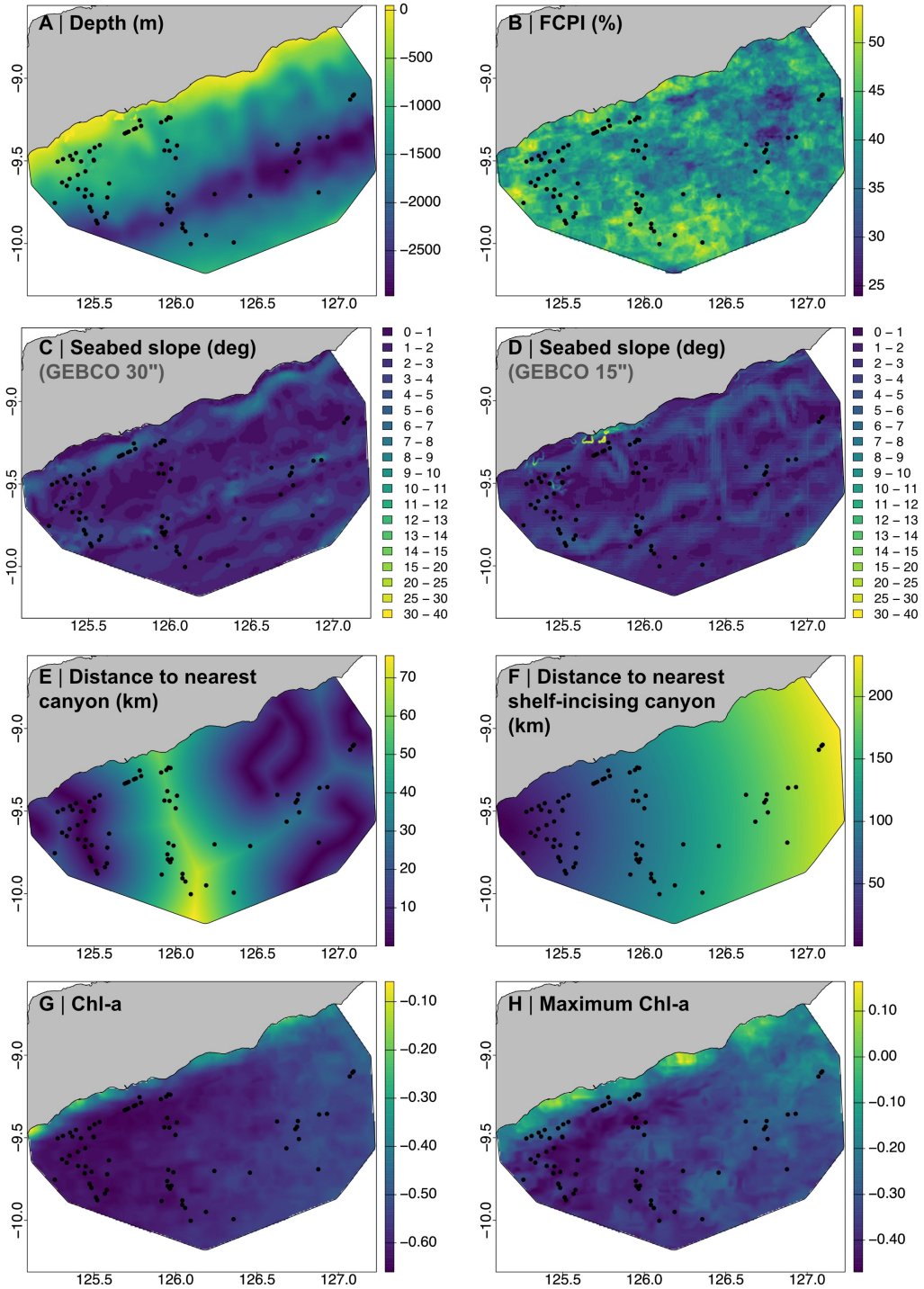

Figure S3: Static and dynamic covariates considered in the generalised additive model of pygmy blue whale (*Balaenoptera musculus brevicauda*) presence within the Timor trough and surrounding waters. FCPI: Frequency of chlorophyll peak index. GEBCO: General Bathymetric Chart of the Oceans. Chl-a: Remote-sensed chlorophyll-a concentration. Dynamic covariates (panels G and H) are shown as means of 10-year climatologies. Whale sightings are overlaid in black.

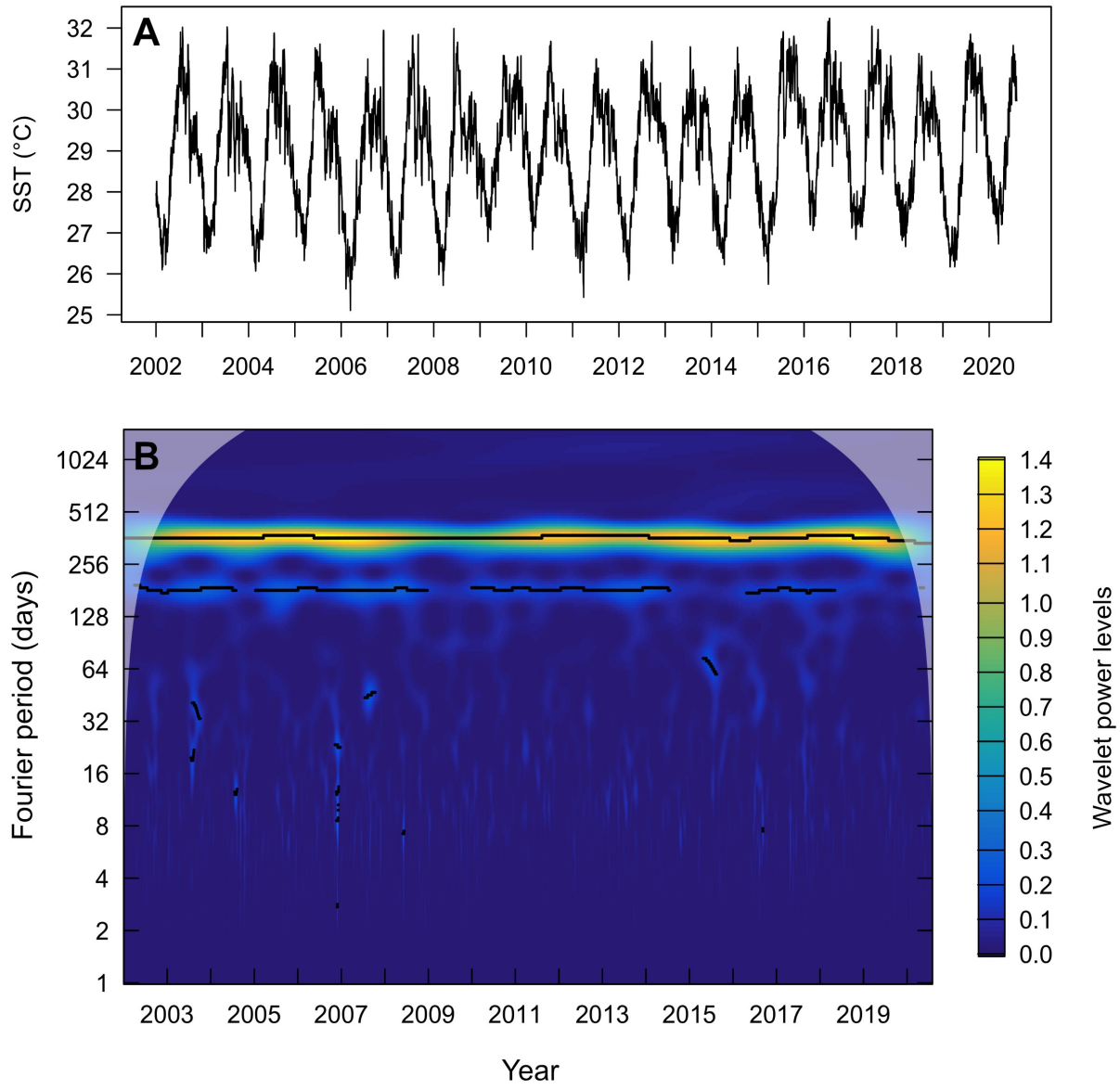

Figure S4: Wavelet analysis of a sea surface temperature (SST, in degrees C) time series. **(A)** Time series of daily SST measurements recorded at a randomly chosen location within the Timor Trough (126.25E, 9.55S) between 2002 and 2020. **(B)** Two-dimensional scalogram of the associated Morlet wavelet power spectrum. The cone of influence (white overlay) defines areas where edge effects become prominent and where data should be ignored. Power values are colour coded from low (dark blue) to high (gold). A signal with a strong periodic component at 365 days is apparent throughout the entire series. A technical description of wavelet power analyses for ecological time series is given in [2].

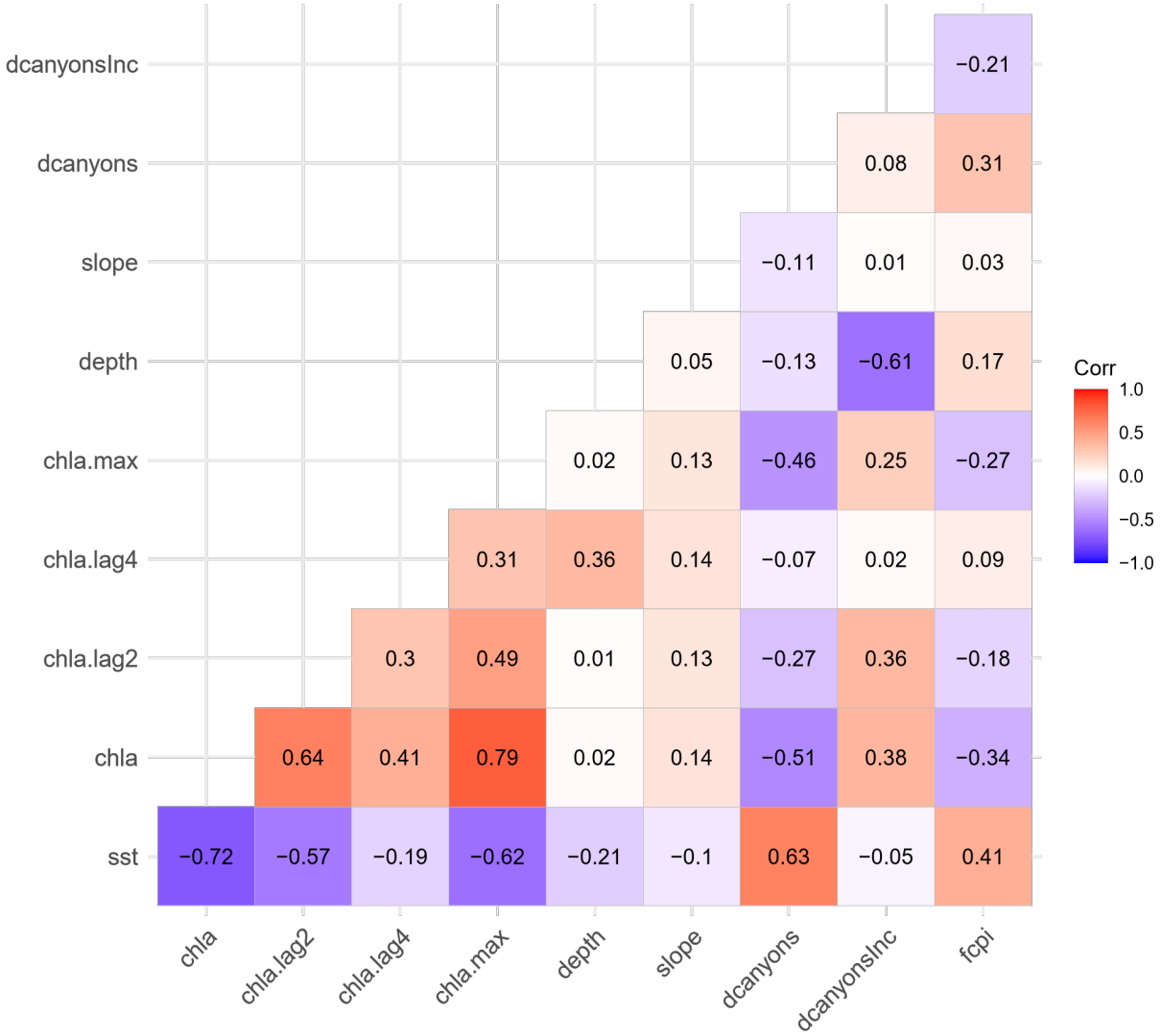

Figure S5: Pearson correlation matrix between candidate explanatory covariates. Sst: Sea surface temperature. Chla: Chlorophyll-a concentration. Dcanyons: Distance to the nearest submarine canyon. dcanyonsInc: Distance to the nearest shelf-incising submarine canyon.

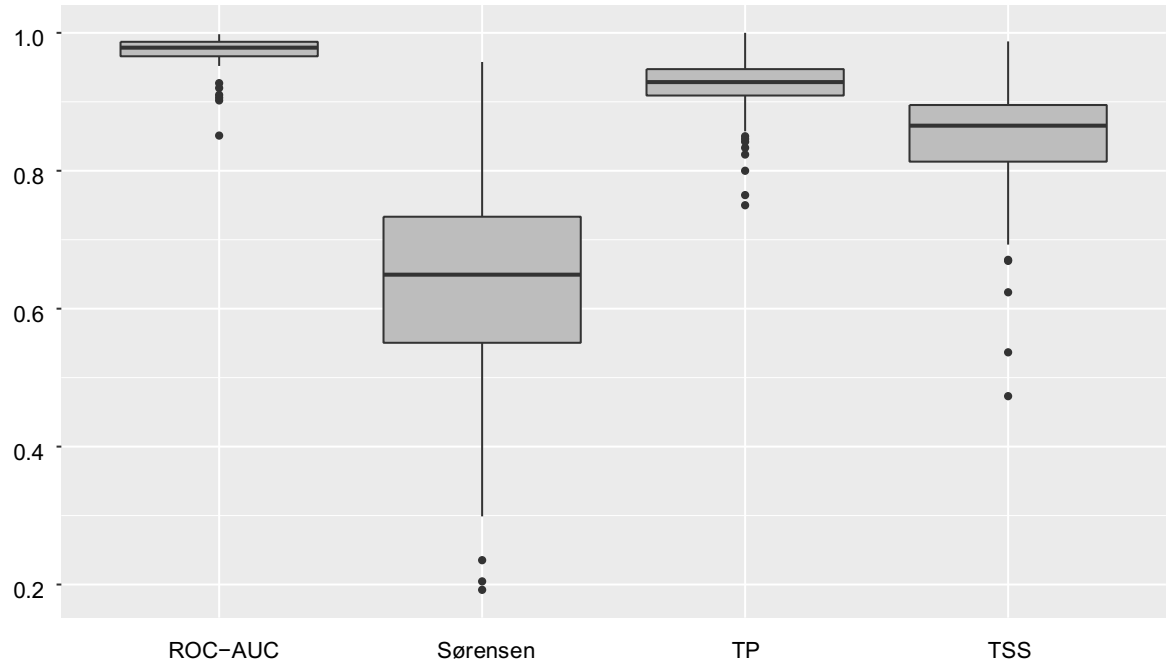

Figure S6: Summary of model performance using block cross-validation. Data were divided into n = 100 pairs of training and testing sets at a ratio of 0.75/0.25, respectively. To account for temporal autocorrelation and ensure independence between cross-validation folds, splitting was performed using blocks of contiguous time that consisted of single survey days [3, 4]. Logistic models were fitted to each training partition, and predictions made on the withheld testing sets. Performance metrics include the area under the curve of the receiver operating characteristic (ROC-AUC), the true skill statistic skill (TSS), the Sørensen index of similarity (Sørensen), and the percentage of sightings correctly predicted as presences (i.e., true positives; TP) [5]. The ROC-AUC is commonly used in ecological modelling, despite having been criticised on various grounds (e.g., [6]). It ranges from 0 to 1, where a value between 0 and 0.5 indicates that the model is worse or no better than random. Typically, ROC-AUC > 0.75 signals good predictive power [7]. The Sørensen index of similarity measures the similarity between predictions and observations. It avoids inflation from true negatives by focusing on true positives, false positives, and false negatives. It also ranges from 0 to 1, where a value of 0 indicates that none of the predictions match the observations, and a value of 1 indicates that predictions match observations perfectly (i.e., no false positives or false negatives) [8]. The TSS accounts for sensitivity and specificity and ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less denote a performance no better than random [1]

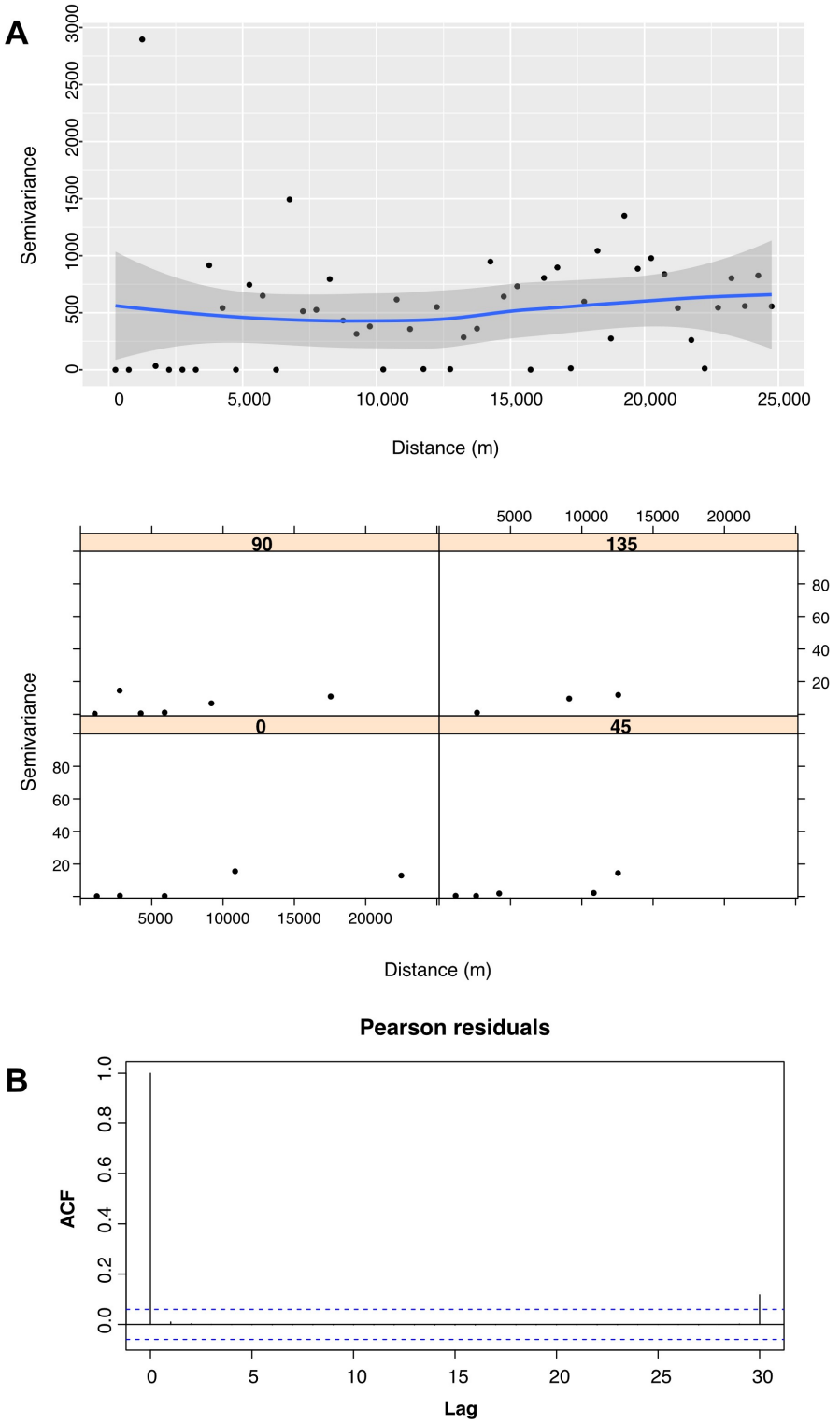

Figure S7: Assessment of autocorrelation in the Pearson residuals from the best-ranked model [9], including **(A)** omni-directional (top) and directional (0, 45, 90, 135 degrees) variograms (bottom), and **(B)** auto-correlation function (ACF) at increasing lags. A smooth LOESS trend has been added to the top plot to aid interpretation.

Supplementary tables

Table S1: Summary of cetacean sightings made by dedicated marine mammal observers aboard seismic vessels operating in the Timor Trough and surrounding waters in 2007 and 2008. N: Number of sightings. N_{ind}: Total number of individuals. Tallies only include sightings made on effort. The conservation status of each species in the International Union for the Conservation of Nature (IUCN)'s Red List is also indicated (LC: Least Concern, NT: Near Threatened, EN: Endangered).

Species	N	N_{ind}	Status
Common dolphin (*Delphinus delphis)*	1	12	LC
False killer whale (*Pseudorca crassidens)*	1	9	NT
Fraser's dolphin (*Lagenodelphis hosei)*	2	7	LC
Pygmy blue whale (*Balaenoptera musculus brevicauda)*	77	95	EN
Short-finned pilot whale (*Globicephala macrorhynchus)*	1	30	LC
Striped dolphin (*Stenella coeruleoalba)*	1	30	LC
Striped or common dolphin	1	20	-
Unidentified dolphins	7	109	-
Unidentified whale	1	1	-
Unidentified medium whale	1	1	-
Unidentified large whale	7	8	-
Total	**100**	**322**	

Table S2: Observations of fluke-up dives (FUDs) by pygmy blue whales (*Balaenoptera musculus brevicauda*) in the Timor Trough. N: Total number of sightings. N_{ind}: Total number of individuals. N_{adults}: Number of adults. N_{calves}: Number of calves. N_{FUDs}: Number of fluke-up dives. Bathymetric depth is reported in metres.

Date	N_{ind}	N_{adults}	N_{calves}	depth	latitude	longitude	N_{FUDs}
2007-09-04	2	1	1	1,796	-9.93	126.06	3
2007-09-04	1	1	0	1,903	-9.91	126.04	4
2008-07-25	2	1	1	1,713	-9.13	127.07	1
2008-08-09	1	1	0	741.9	-9.24	125.96	1
2008-08-11	2	2	0	1,380	-9.44	125.96	1
2008-08-22	1	1	0	606.9	-9.33	125.69	2
2008-08-22	1	1	0	751.1	-9.40	125.53	1
2008-08-27	1	1	0	1,707	-9.78	125.47	1
2008-08-27	1	1	0	1,416	-9.71	125.44	2
2008-08-28	2	2	0	1,035	-9.64	125.59	1
2008-08-29	1	1	0	947.7	-9.56	125.45	2
2008-08-29	1	1	0	853	-9.61	125.35	1
2008-08-29	2	2	0	866.3	-9.63	125.30	1
2008-08-30	1	1	0	762.8	-9.45	125.39	3
2008-08-30	1	1	0	691.9	-9.47	125.35	2
2008-08-30	2	2	0	484.2	-9.50	125.28	1
2008-08-30	2	2	0	469.4	-9.51	125.26	2
Total	**24**	**22**	**2**				**29**

Table S3: Ten top ranking models from a set of 45 candidate logistic GAMs relating the probability of pygmy blue whale presence to habitat features including: maximum weekly chlorophyll-a concentration (Chl max), average weekly chlorophyll-a concentration at lags of 0, 2 and 4 weeks (Chl, Chl (2w), Chl(4w)), bathymetric depth, seabed slope, distance to the nearest submarine canyon (Canyon), distance to the nearest shelf-incising submarine canyon (CanyonInc) and the frequency of chlorophyll peak index (FCPI). Models are ranked based on their Akaike's Information Criterion scores, corrected for small sample sizes (AICc).

Rank	Depth	FCPI	Slope	Canyon	CanyonInc	Chl	Chl (2w)	Chl (4w)	Chl (max)	AICc	Δi
1			•		•				•	570.19	0.00
2					•				•	640.87	70.68
3	•		•						•	866.25	296.06
4	•								•	914.54	344.35
5			•						•	1,044.90	474.70
6									•	1,085.12	514.93
7		•			•			•		2,537.57	1,967.38
8			•		•			•		2,545.97	1,975.78
9		•	•		•					2,548.91	1,978.72
10			•	•	•					2,549.94	1,979.75

References

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