Supplementary Material

Seasonal, annual, and decadal distribution of three rorqual whale species relative to dynamic ocean conditions off Oregon, USA

Derville, S.[1,2], Barlow, D. R. [1], Hayslip, C.[1], Torres, L. G.[1]

[1] Marine Mammal Institute, Oregon State University, 2030 SE Marine Science Dr., Newport, OR 97365, United States

[2] French Institute of Research for Sustainable Development, 101 promenade Roger Laroque, 98800 Noumea, New Caledonia

1 Supplementary methods

Unidentified baleen whale classification. To utilize valuable detections of unidentified baleen whales, these sightings were classified into rorquals (blue, fin, or humpback) or gray whale groups using a random forest classifier (*cforest* from R *party* package version 1.3-7) following Roberts et al., (2016). Indeed, few other rorquals use Oregon coastal waters (occasional Sei whale, Minke whales and North Pacific right whales) and gray whales are the only other abundant baleen whale in the area. Gray whales occupy a very different ecological niche than rorquals and surveys were not designed to appropriately sample this species's habitat (Swartz, 2018). The rorqual classification model was used to exclude gray whales from further analyses, and was trained on the depth, distance to shore, month of year, and group size of sightings resolved at species level. The model was built with 1,000 trees and a specific threshold was applied to the receiver operating characteristic curve to classify unidentified baleen whales as rorquals or gray whales. The threshold was selected to limit the false positive rate to 2 % (i.e. proportion of gray whales misclassified as rorquals) in the training dataset, hence ensuring a cautious classification of unidentified baleen whales as putative rorquals.

Availability bias. Distance sampling of cetaceans typically suffers from an availability bias, as animals may be missed by observers when diving underwater (Marsh and Sinclair, 1989). This bias depends on multiple factors (Barlow, 2015), including the animals' diving pattern, and the platform height and speed that determine the 'time window' during which the animal is within a detectable range. The probability P_a of a whale being available for detection was calculated with an equation derived from (Laake et al., 1997; Salgado Kent et al., 2012):

$$P_a = p + (1-p) * exp(-t/d)$$

where p is the expected proportion of time a rorqual species spends at the surface, d is the expected dive duration and t is the time window during which the animal is within a detectable range. The time window t was calculated separately for helicopters and ships, and in the latter case two different speeds (10 and 5 knots) were considered following the equation:

$t = m / s$

where m is the maximum forward distance, fixed here to the platform-specific truncation distance (95 % quantile of the sightings' perpendicular distance values) and s is the speed of the platform.

Dive parameters p and d were derived from the literature, preferentially using tracking data acquired in feeding grounds, over the US west coast and during daytime to account for the strong diel pattern in rorqual diving behavior (Calambokidis et al., 2019; Keen et al., 2019). The proportions of time spent at the surface p were extracted from a tracking study performed on the US West Coast (Calambokidis et al., 2019), which compared the proportion of time three rorqual species spent above 15 m during night and day. The daytime p estimates were used: 0.36 for blue whales, 0.49 for fin whales, and 0.54 for humpback whales. Mean dive durations were extracted from various studies. Blue and fin whale dive durations (5.74 min and 4.78 min respectively) were averaged across two studies conducted in the CCS (Croll et al., 2001; Irvine et al., 2019), which did not differentiate daytime and nighttime dives. Humpback whale dive duration was extracted from tracking data collected on the western South Atlantic population during the feeding season in South Georgia and the South Sandwich Islands, yielding a daytime-only mean dive duration of 2.6 min (Coelho, 2021). Availability P_a was calculated per rorqual species, then averaged across all species to estimate overall rorqual availability. This mean rorqual value was weighted with each species' detection ratio among sightings taxonomically resolved at species-level.

Environmental variables. In addition to the 10 environmental variables used in this study (BBV, ILD, EKE, CURL, SST, SSH, SSTSD, SSHSD, depth, distance to canyons), three other variables were tested in preliminary analyses (Table S3). Remotely-sensed daily chlorophyll-a (CHLA) data were acquired from the Aqua MODIS satellite products at 0.025° resolution to reflect biological productivity in the study system. Weekly CHLA values were generated by averaging daily measurements over the prior seven days, and interpolated to fill small data gaps with a focal mean calculated over a 0.075° square. CHLA layers were log10-transformed following Cimino et al. (2020). Seabed slope was calculated from bathymetry using the *raster r* package (version 3.4-5; Hijmans, 2017) and distance to shore was computed from the Open street map coastline shapefiles. Based on preliminary distribution and cross-correlation analysis, we decided to remove distance to shore, slope, and CHLA from the group of model predictors. Finally, latitude and longitude were purposefully not included as spatial covariates in SDMs to prevent masking of the environmental covariates' effect and impairing the ecological interpretation of model outputs (Becker et al., 2016).

References

Adams, J., Felis, J. ., Mason, J. W., and Takekawa, J. Y. (2016). Pacific Continental Shelf Environmental Assessment (PaCSEA): aerial seabird and marine mammal surveys off northern California, Oregon, and Washington, 2011-2012. *Resour. Database U.S. Geol. Surv. data release*. doi:10.5066/F7668B7V.

Adams, J., Felis, J., Mason, J. W., and Takekawa, J. Y. (2014). *Pacific Continental Shelf*

Environmental Assessment (PaCSEA): aerial seabird and marine mammal surveys off northern California, Oregon, and Washington, 2011–2012. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM 2014-003.

Barlow, J. (2015). Inferring trackline detection probabilities, g(0), for cetaceans from apparent densities in different survey conditions. *Mar. Mammal Sci.* 31, 923–943. doi:10.1111/mms.12205.

Becker, E., Forney, K., Fiedler, P., Barlow, J., Chivers, S., Edwards, C., et al. (2016). Moving Towards Dynamic Ocean Management: How Well Do Modeled Ocean Products Predict Species Distributions? *Remote Sens.* 8, 149. doi:10.3390/rs8020149.

Brueggeman, J. (1992). *Final report: Oregon and Washington marine mammal and seabird surveys. Prepared for Pacific OCS Region Minerals Management Service*.

Calambokidis, J., Fahlbusch, J. A., Szesciorka, A. R., Southall, B. L., Cade, D. E., Friedlaender, A. S., et al. (2019). Differential Vulnerability to Ship Strikes Between Day and Night for Blue, Fin, and Humpback Whales Based on Dive and Movement Data From Medium Duration Archival Tags. *Front. Mar. Sci.* 6, 1–11. doi:10.3389/fmars.2019.00543.

Cimino, M. A., Santora, J. A., Schroeder, I., Sydeman, W., Jacox, M. G., Hazen, E. L., et al. (2020). Essential krill species habitat resolved by seasonal upwelling and ocean circulation models within the large marine ecosystem of the California Current System. *Ecography (Cop.).* 43, 1536–1549. doi:10.1111/ecog.05204.

Coelho, E. (2021). *Diving behavior of humpback whales (Megaptera novaeangliae) throughout their migratory cycle in the western south Atlantic Ocean*. Master thesis, Universidade Federal de Juiz de Fora, Brazil.

Croll, D. A., Acevedo-Gutiérrez, A., Tershy, B. R., and Urbán-Ramírez, J. (2001). The diving behavior of blue and fin whales: Is dive duration shorter than expected based on oxygen stores? *Comp. Biochem. Physiol. - A Mol. Integr. Physiol.* 129, 797–809. doi:10.1016/S1095-6433(01)00348-8.

Green, G. A., Grotefendt, R. A., Smultea, M. A., Bowlby, C. E., and Rowlett, R. A. (1992). *Delphinid aerial surveys in Oregon and Washington offshore waters, final report. Prepared for the National Marine Fisheries Service, National Marine Mammal Laboratory*.

Harris, P. T., Macmillan-Lawler, M., Rupp, J., and Baker, E. K. (2014). Geomorphology of the oceans. *Mar. Geol.* 352, 4–24. doi:10.1016/j.margeo.2014.01.011.

Irvine, L. M., Palacios, D. M., Lagerquist, B. A., and Mate, B. R. (2019). Scales of Blue and Fin Whale Feeding Behavior off California, USA, With Implications for Prey Patchiness. *Front. Ecol. Evol.* 7, 338. doi:10.3389/fevo.2019.00338.

Keen, E. M., Scales, K. L., Rone, B. K., Hazen, E. L., Falcone, E. A., and Schorr, G. S. (2019). Night and Day: Diel Differences in Ship Strike Risk for Fin Whales (Balaenoptera physalus) in the California Current System. *Front. Mar. Sci.* 6, 1–16. doi:10.3389/fmars.2019.00730.

Laake, J. L. ., Calambokidis, J., Osmek, S. D. ., and Rugh, D. J. . (1997). Probability of Detecting Harbor Porpoise from Aerial Surveys : Estimating g(0). *J. Wildl. Manage.* 61, 63–75.

Marsh, H., and Sinclair, D. F. (1989). Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *J. Wildl. Manage.* 53, 1017–1024. doi:10.2307/3809604.

Neveu, E., Moore, A. M., Edwards, C. A., Fiechter, J., Drake, P., Crawford, W. J., et al. (2016). An historical analysis of the California Current circulation using ROMS 4D-Var: System configuration and diagnostics. *Ocean Model.* 99, 133–151. doi:10.1016/j.ocemod.2015.11.012.

Roberts, J. J., Best, B. D., Mannocci, L., Fujioka, E., Halpin, P. N., Palka, D. L., et al. (2016). Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico. *Sci. Rep.* 6, 22615. doi:10.1038/srep22615.

Salgado Kent, C., Jenner, C., Jenner, M., Bouchet, P., and Rexstad, E. (2012). Southern Hemisphere Breeding Stock D humpback whale population estimates from North West Cape, Western Australia. *J. Cetacean Res. Manag.* 12, 29–38. doi:10.31230/osf.io/m94xh.

Swartz, S. L. (2018). “Gray whale: Eschrichtius robustus,” in *Encyclopedia of marine mammals* (Academic Press), 422–428.

2 Supplementary tables

Table S1: Environmental variables tested for inclusion in the rorqual density models. Coastlines used in the maps were acquired from OpenStreetMap (http://openstreetmapdata.com/data/coastlines). Variables with an asterix (*) were not selected in the final models.

Abbreviation	**Variable description**	**Unit**	**Native product resolution**		**Source**
			Spatial	Temporal	
DEPTH	Seabed depth	m	15 arcseconds	-	General Bathymetric Chart of the Oceans (GEBCO) https://download.gebco.net/
SLOPE*	seabed slope	°	15 arcseconds	-	
CANYON	distance to closest canyon	m	-	-	Worldwide geomorphological map (Harris et al., 2014) www.bluehabitats.org
SST	sea surface temperature	°C	0.1°	daily	Regional Ocean Modeling System (ROMS, Neveu et al., 2016) https://oceanmodeling.ucsc.edu:8443/thredds/catalog.html
SSTSD	sea surface temperature standard deviation	-	0.1° (calculated over 3 x 3 cells)	daily	
SSH	sea surface height	m	0.1°	daily	
SSHSD	sea surface height standard deviation	-	0.1° (calculated over 3 x 3 cells)	daily	

EKE	eddy kinetic energy	$kg \cdot m^{2} \cdot s^{-2}$	0.1°	daily	
CURL	wind stress curl	$Newton \cdot m^{-3}$	0.1°	daily	
ILD	isothermal layer depth	m	0.1°	daily	
BBV	bulk buoyancy frequency	s^{-1}	0.1°	daily	
CHLA*	surface chlorophyll-a concentration	$mg.m^{-3}$	0.25°	daily	Satellite product Aqua MODIS (ERDDAP: NOAA NMFS SWFSC) https://coastwatch.pfeg.noaa.gov/erddap/info/erdMBchla1day/index.html

Table S2: Independent rorqual sighting dataset used to validate rorqual density model predictions. References are provided whenever available. HB: humpback whales, BL = blue whales, FI = fin whales, ROR = all rorquals including unidentified whales.

Dataset	**Type**	**Institution**	**Reference**	**Contact**	**Time frame**	**#number of individual whales sighted**			
						HB	**BL**	**FI**	**ROR**
CRC small-boat work	research	Cascadia Research Collective	unpublished	John Calambokidis	2019	193	14		207
DELPHIN surveys	research	NOAA-National Marine Fisheries Service	(Green et al., 1992)	Gregory Green, Jay Brueggeman	1992	29	1		30
GEMM small-boat work	research	Oregon State University	unpublished	Leigh G. Torres	2020	19	51		70
GYREX	research	Oregon State University	unpublished	Lisa Ballance	2021	12			13
ORWA marine mammal and seabird surveys	research	Minerals Management Service	(Brueggeman, 1992)	Gregory Green, Jay Brueggeman	1989-1990	46		19	65
ORWA leatherback surveys	research	NOAA-South West Fisheries Science Center	unpublished	Scott Benson	2021	81	8	20	114
PaCSEA	research	US Geological Survey	(Adams et al., 2016)	Josh Adams[3]	2011-2012	152	16	2	217
Whale Alert and Ocean Alert Apps[1]	opportunistic	Point Blue Conservation Science[2]	http://westcoast.whalealert.org	Jaime Jahncke	2014-2021	69	17		86
Other	opportunistic	Oregon State University	unpublished	Leigh G. Torres	2019-2021	68	14	2	84

[1] Conserve.IO, http://conserve.io/, 1515 N. Swinto Ave, Delray Beach, FL, 33444, United States.

[2] Whale Alert West Coast, 3820 Cypress Drive, Petaluma, CA, 94954, United States.

[3] Also acknowledging: Jonathan Felis (US Geological Survey), John Mason (EI), Jeff Davis (Calibri).

Table S3: Study designs of surveys included in the decadal encounter rate comparison: ORWA and DELPHIN (1989-1992; Brueggeman, 1992; Green et al., 1992), PaCSEA (2011-2012; Adams et al., 2016) and the present study (2016-2021). NA = not applicable, NR = not reported. Distance surveyed refers to systematic on-effort survey time only. Shaded columns indicate the values used to calculate sighting rates per km (distance surveyed) or per km^2 (distance surveyed x effective strip width / 1000).

Survey	Period	Months surveyed	Platform	Altitude (feet)	Speed (knots)	Number of observers	Distance surveyed (km)	Max perpendicular distance (m)	Effective strip width (m)
ORWA	1989-1992	All except Dec and Feb	airplane	200	100	2	40,012	3,400	1,100[a]
DELPHIN	1989-1992	Mar-Apr-May	airplane	530	100	2	15,962	9,200	1,100[a]
PaCSEA	2011-2012	Jan-Feb, Jun-July, Oct-Sep	airplane	86	200	2	26,752	NR	75[b]
Present study	2016-2021	All	helicopter	500	90	1	22,579	6,000	1,100
		Feb-Mar, May, Sep	ships	NA	5 or 10	1 or 2	5,738	16,600	3,170

[a] Effective strip width was not calculated by Brueggeman, (1992) and by Green et al., (1992). Based on their study design and the reported maximum perpendicular distance of detection we decided to apply a conservative ESW equal to that derived from the 2016-2021 helicopter surveys.

[b] The PaCSEA survey was designed to count seabirds within a 75 m strip on each side of the trackline. However, marine mammals observed at further distances were also recorded. These off-strip sightings were included in the sighting rates calculated per km of effort (Figure 2), but not in the sighting rates calculated per km^2 of effort (Figure S8)

Table S4: Variable smooth approximate significance and estimated degrees of freedom (edf) across 10-fold cross-validation runs of each seasonal rorqual density model. Environmental variables: distance to canyons (CANYON in km), seabed depth (DEPTH in m), sea surface temperature (SST in °C) and its spatial standard deviation (SSTSD calculated over 0.3° squares), sea surface height (SSH in m) and its standard deviation (SSHSD calculated over 0.3° squares), eddy kinetic energy (EKE calculated from eastward and northward surface current velocities, kg·m^2·s^{-2}), wind stress curl (CURL in Newton.m^{-3}), isothermal layer depth (ILD in m) and bulk buoyancy frequency (BBV in s^{-1}).

season	**variables**	**Number of folds with p-value <0.001**	**Number of folds with p-value <0.01**	**Number of folds with p-value <0.05**	**Mean p-value across 10-fold runs**	**Mean edf across 10-fold runs**	**Max edf across 10-fold runs**
Apr-Jul	DEPTH	10	10	10	0	2.3	2.5
	CANYON	0	0	6	0.084	1.4	1.9
	BBV	0	4	10	0.017	1.9	2.5
	CURL	10	10	10	0	2	2.3
	EKE	0	0	0	0.617	0.1	0.7
	ILD	10	10	10	0	2	2.5
	SSHSD	9	10	10	0	2.6	3
	SSH	0	1	3	0.377	0.5	2.9
	SSTSD	10	10	10	0	3.1	3.4
	SST	10	10	10	0	3	3.6
Aug-Nov	DEPTH	2	7	10	0.011	1.3	1.8
	CANYON	1	3	8	0.037	1.2	3.8
	BBV	8	9	10	0.001	1.5	2.5
	CURL	1	4	9	0.023	2	2.8
	EKE	0	6	9	0.013	1.8	1.9
	ILD	10	10	10	0	2.2	2.4
	SSHSD	10	10	10	0	2.8	3.4
	SSH	0	0	1	0.393	0.5	1.4
	SSTSD	0	0	0	0.578	0.1	0.8
	SST	3	7	10	0.005	1.5	1.9
Dec-Mar	DEPTH	0	1	2	0.326	0.8	1.9
	CANYON	0	0	1	0.364	0.6	2.1
	BBV	0	0	0	0.318	0.7	1.6
	CURL	0	0	2	0.216	0.8	1.9
	EKE	0	0	1	0.336	0.4	2.3
	ILD	0	0	1	0.65	0.2	0.8
	SSHSD	0	2	2	0.386	0.5	2
	SSH	0	2	9	0.032	1.5	2
	SSTSD	0	0	1	0.235	0.4	0.9
	SST	0	0	0	0.802	0	0

Table S5: Variable smooth approximate significance and estimated degrees of freedom (edf) across 10-fold cross-validation runs of species-specific density model. Environmental variables: day of year (YDAY), distance to canyons (CANYON in km), seabed depth (DEPTH in m), sea surface temperature (SST in °C) and its spatial standard deviation (SSTSD calculated over 0.3° squares), sea surface height (SSH in m) and its standard deviation (SSHSD calculated over 0.3° squares), eddy kinetic energy (EKE calculated from eastward and northward surface current velocities, $kg \cdot m^2 \cdot s^{-2}$), wind stress curl (CURL in $Newton.m^{-3}$), isothermal layer depth (ILD in m) and bulk buoyancy frequency (BBV in s^{-1}).

species	variables	Number of folds with p-value <0.001	Number of folds with p-value <0.01	Number of folds with p-value <0.05	Mean p-value across 10-fold runs	Mean edf across 10-fold runs	Max edf across 10-fold runs
Blue whale model	DEPTH	0	1	3	0.263	0.9	1.8
	CANYON	0	1	3	0.256	0.5	0.9
	BBV	1	3	4	0.097	1.4	2.6
	CURL	0	0	0	0.836	0	0
	EKE	0	0	0	0.372	0.4	1.4
	ILD	1	6	10	0.011	1.1	2.1
	SSHSD	0	7	10	0.008	2.1	2.2
	SSH	0	0	2	0.397	0.5	1.5
	SSTSD	0	0	0	0.927	0	0
	SST	10	10	10	0	1.9	2.5
	YDAY	6	7	9	0.013	3.1	3.7
Fin whale model	DEPTH	2	5	5	0.308	1.2	2.8
	CANYON	6	6	6	0.04	1.5	1.9
	BBV	0	0	2	0.357	0.5	1.8
	CURL	0	0	1	0.074	1.7	1.9
	EKE	0	2	7	0.133	0.7	1.5
	ILD	8	8	9	0.015	2.5	3.1
	SSHSD	0	4	6	0.155	1.5	2.2
	SSH	0	0	0	0.399	0.1	0.3
	SSTSD	0	0	0	0.636	0.2	0.7
	SST	2	8	8	0.045	0.9	1.9
	YDAY	1	1	1	0.599	0.3	2.7
Humpback whale model	DEPTH	10	10	10	0	1	1.1
	CANYON	7	9	10	0.002	2.4	2.8
	BBV	8	9	10	0.002	1	1.6
	CURL	9	10	10	0	2	2
	EKE	0	0	1	0.293	0.3	0.8
	ILD	5	9	10	0.003	1.8	2
	SSHSD	10	10	10	0	2.5	3.1
	SSH	0	0	0	0.631	0.1	0.6
	SSTSD	0	0	3	0.179	1.1	1.9
	SST	10	10	10	0	2.4	2.6
	YDAY	10	10	10	0	2.4	2.9

3 Supplementary figures

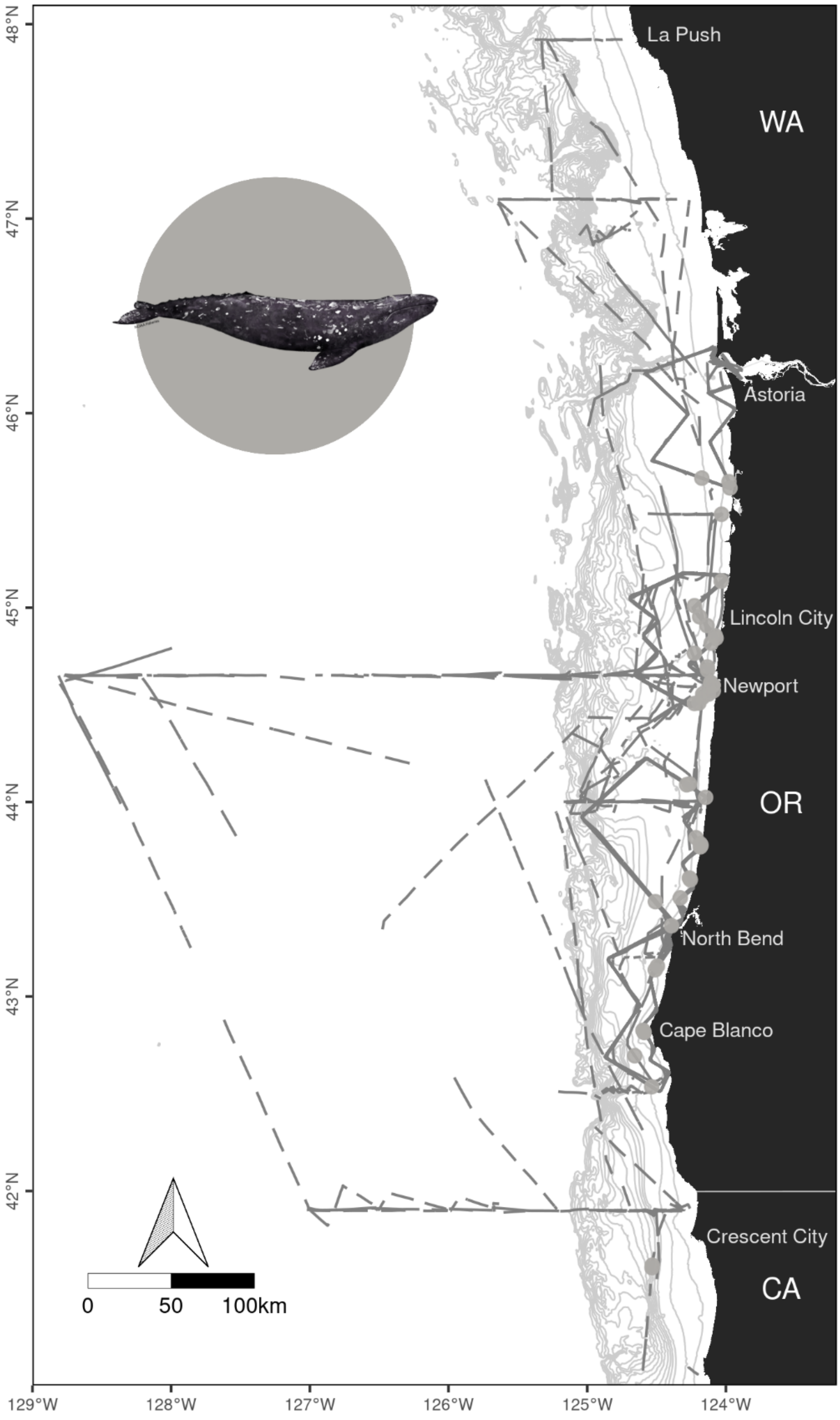

Figure S1: Map of shipboard and helicopter survey effort and observations of gray whales from 2016 to 2021 in Oregon waters (OR), USA. Dark grey lines represent surveyed transect lines in Oregon (OR), California (CA) and Washington (WA) states. Land is shown in black and isobaths from 50 to 1500 m are shown in light grey. Maps are limited to 41°N but shipboard effort extends down to 37°N. Credit for whale illustration: NOAA Fisheries.

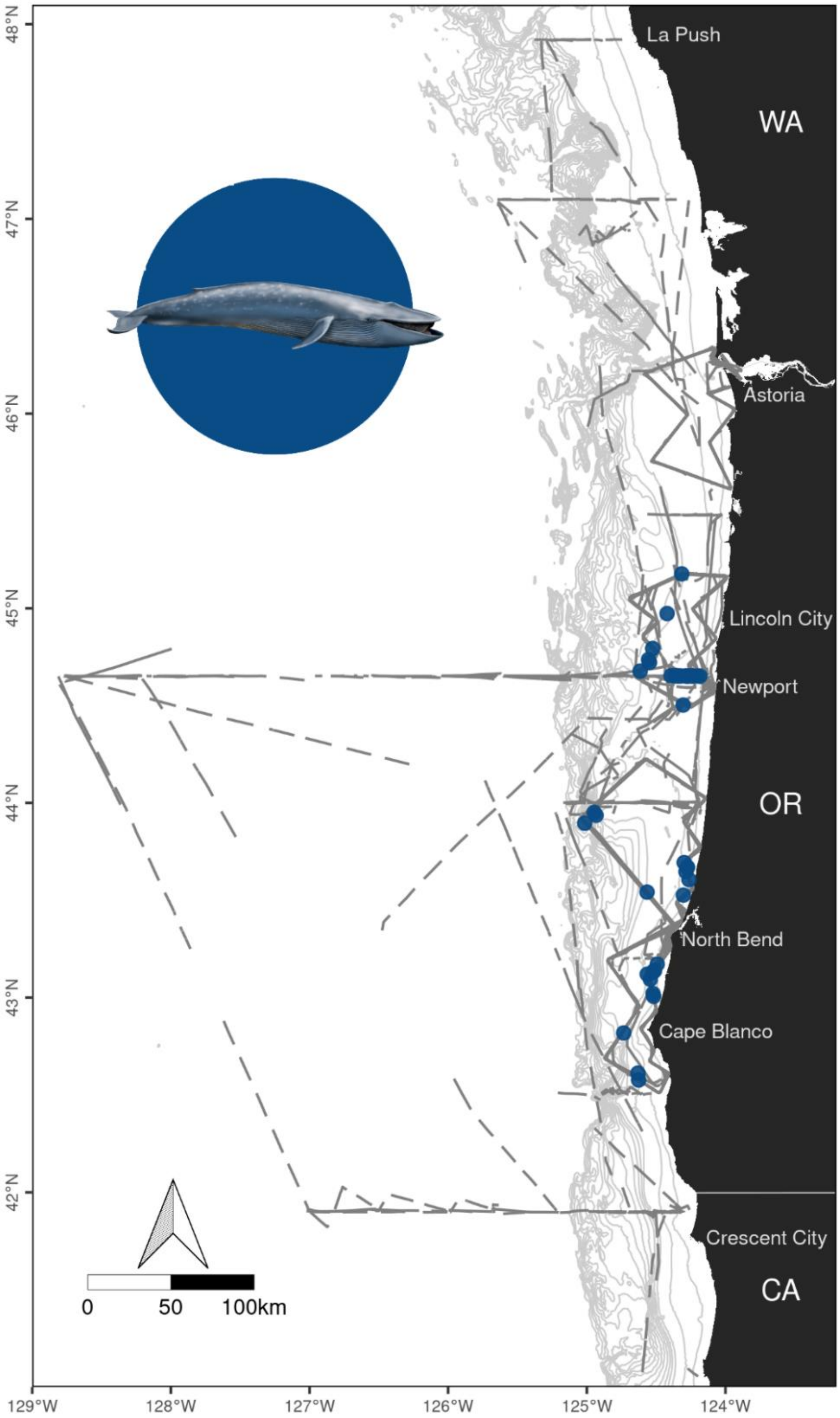

Figure S2: Map of shipboard and helicopter survey effort and observations of blue whales from 2016 to 2021 in Oregon waters (OR), USA. Dark grey lines represent surveyed transect lines in Oregon (OR), California (CA) and Washington (WA) states. Land is shown in black and isobaths from 50 to 1500 m are shown in light grey. Maps are limited to 41°N but shipboard effort extends down to 37°N.

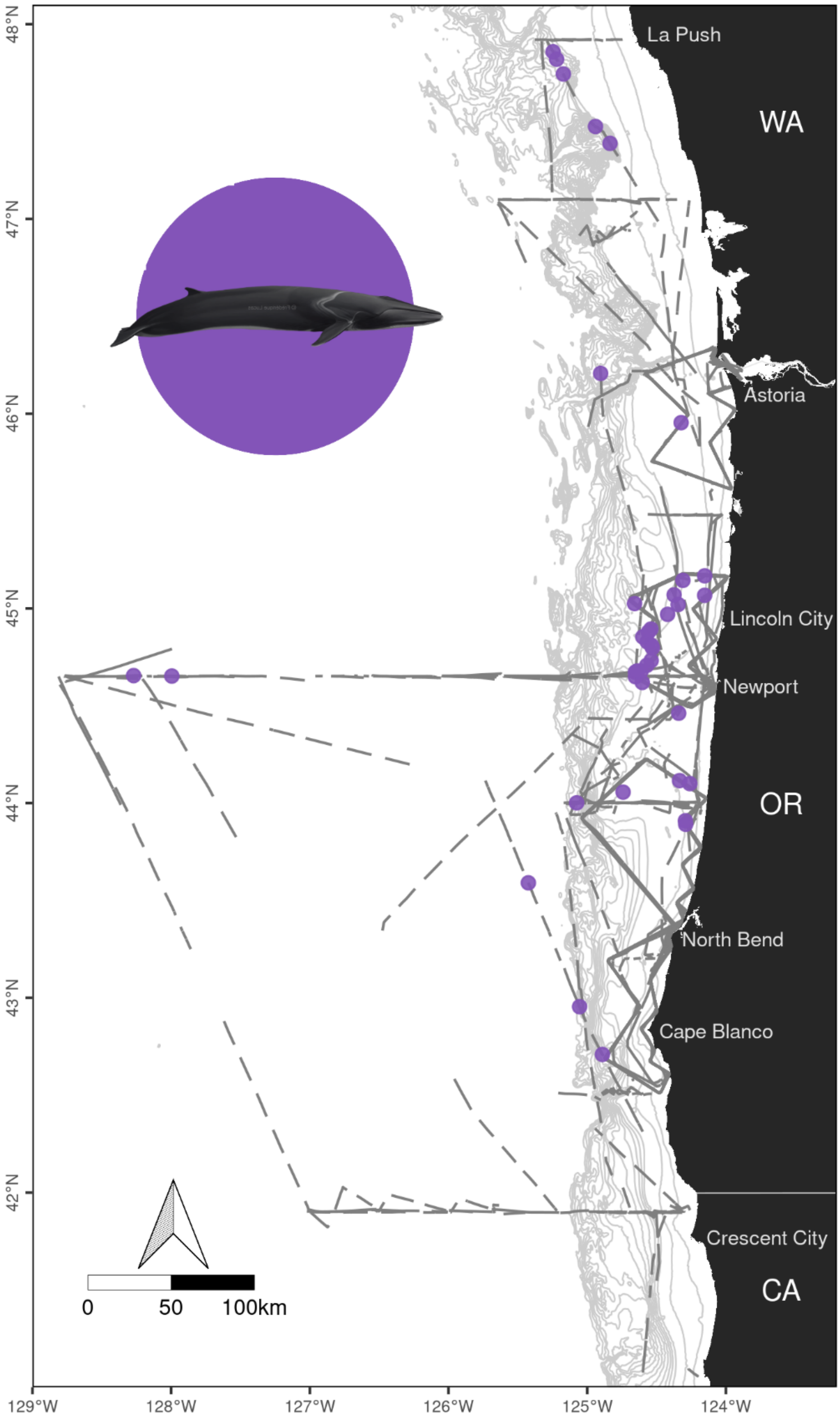

Figure S3: Map of shipboard and helicopter survey effort and observations of fin whales from 2016 to 2021 in Oregon waters (OR), USA. Dark grey lines represent surveyed transect lines in Oregon (OR), California (CA) and Washington (WA) states. Land is shown in black and isobaths from 50 to 1500 m are shown in light grey. Maps are limited to 41°N but shipboard effort extends down to 37°N. Credit for whale illustration: Frédérique Lucas.

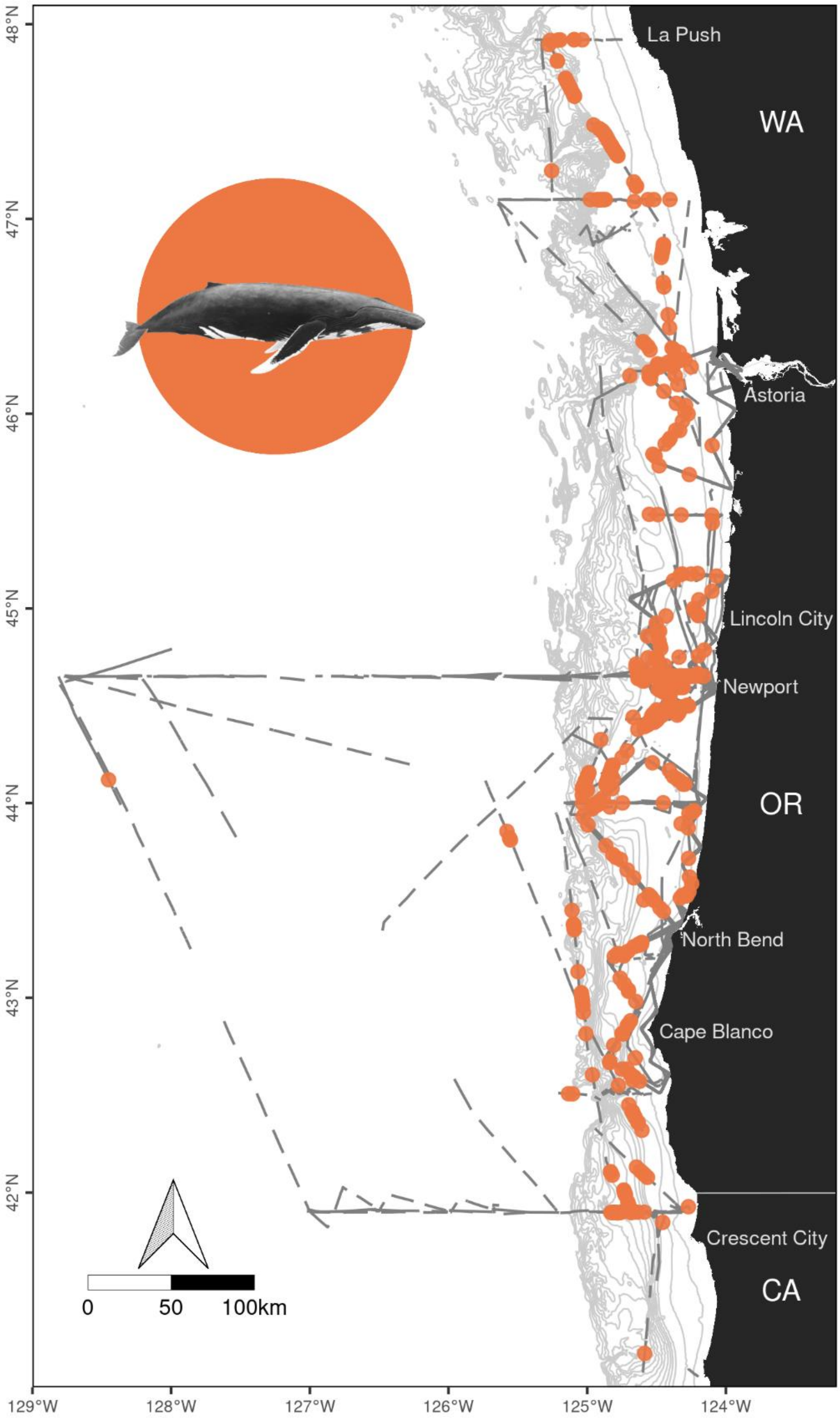

Figure S4: Map of shipboard and helicopter survey effort and observations of humpback whales from 2016 to 2021 in Oregon waters (OR), USA. Dark grey lines represent surveyed transect lines in Oregon (OR), California (CA) and Washington (WA) states. Land is shown in black and isobaths from 50 to 1500 m are shown in light grey. Maps are limited to 41°N but shipboard effort extends down to 37°N.

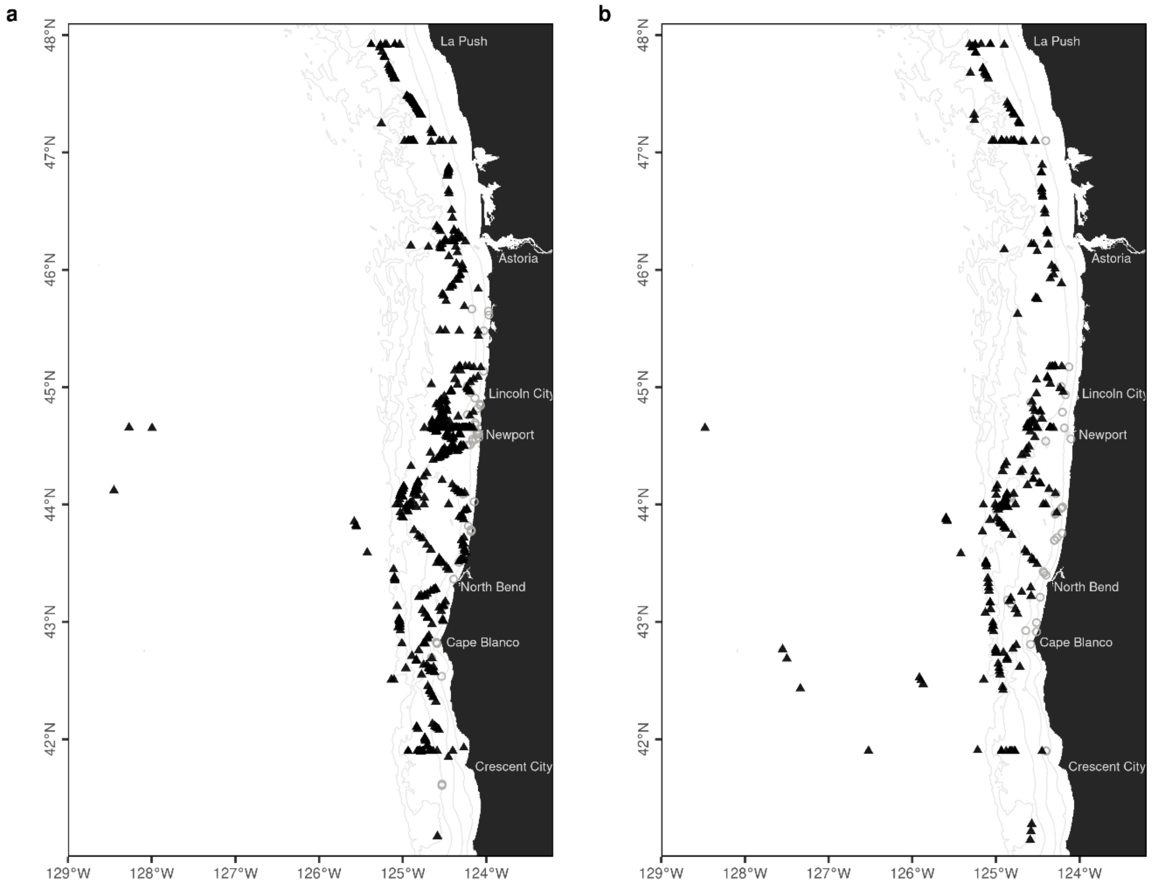

Figure S5: Maps of baleen whale groups identified in the field to the species level (a) and unidentified baleen whale classified into rorquals and gray whales with the random forest classifier (b). Rorqual whale and gray whale groups are respectively represented with black triangles and grey circles. Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines.

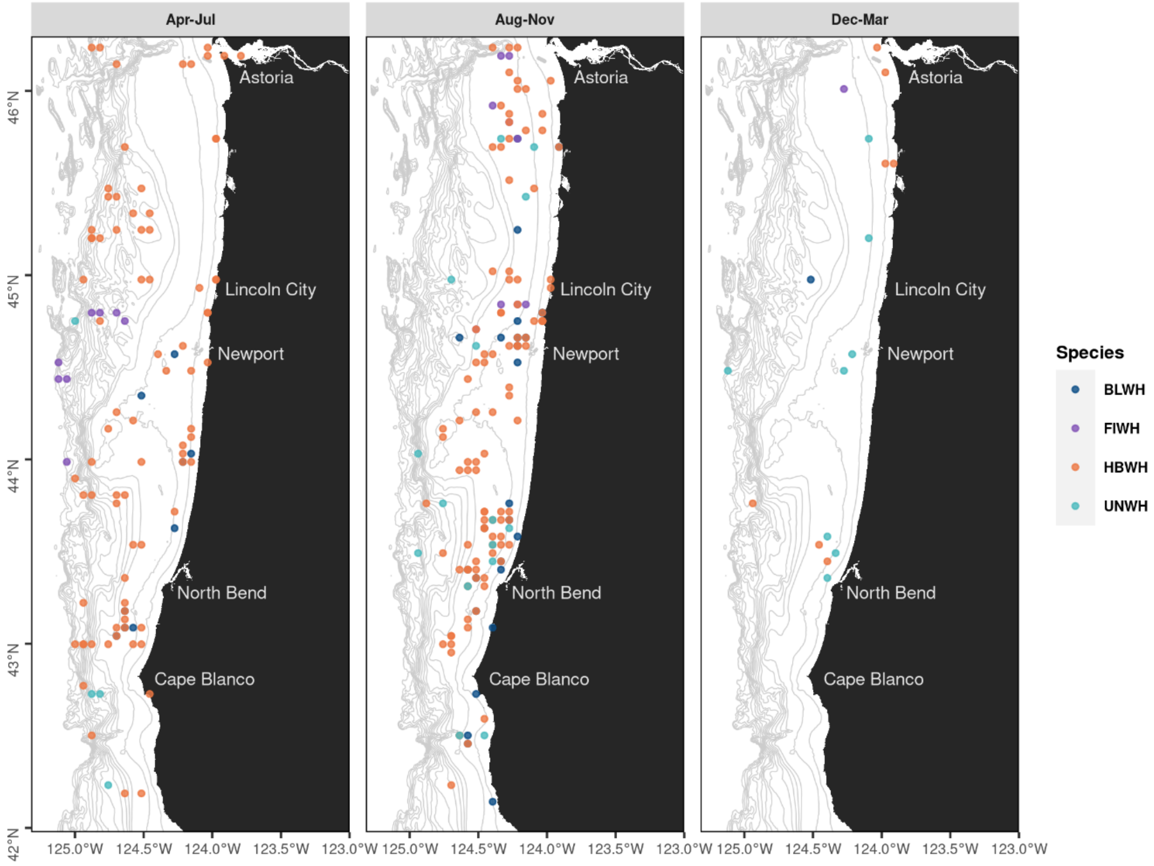

Figure S6: Independent rorqual sighting dataset aggregated over a 5-km resolution grid and used to validate rorqual density model predictions. Sightings were provided by different sources and cover the period 1989 to 2021 in Oregon waters (OR), USA. Dark grey lines represent surveyed transect lines in Oregon (OR). Land is shown in black and isobaths from 50 to 1500 m are shown in light grey. Sightings are colored by species: blue (BLWH), fin (FIWH), humpback (HBWH) and unidentified rorqual whales (UNWH).

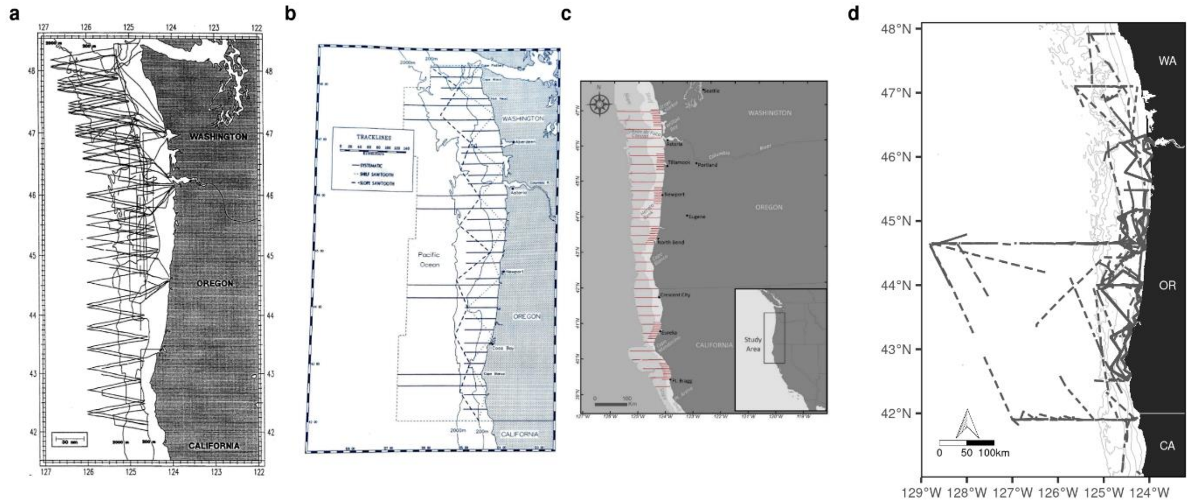

Figure S7: Systematic survey effort from three different sources included in the independent validation dataset (a, b, c, maps reproduced with permissions) and from the present study (d). a) DELPHIN survey (Green et al., 1992) and b) ORWA survey (Brueggeman, 1992) were conducted in 1989-1992. c) PaCSEA survey (Adams et al., 2014, 2016) was conducted in 2011-2012. d) present surveys were conducted in 2016-2021. Despite not having the exact same study design, each survey had a high spatial coverage across a similar region over the Oregon continental shelf and slope, including a similar temporal coverage (multiple survey days spread out throughout the year). Note that the surveys conducted over the 1989-1992 period (a, b) covered more offshore habitat than our recent 2016-2021 surveys. Maps reproduced with permissions.

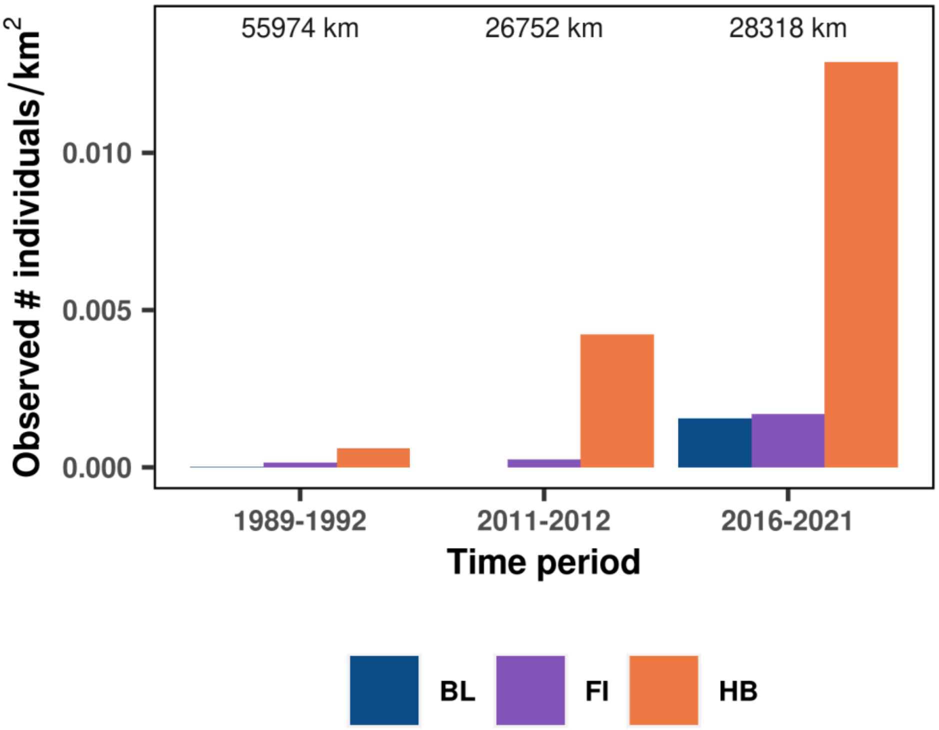

Figure S8: Comparison of the number of individual whales observed per km^2 of effort across systematic research surveys conducted in 1989-1992 (DELPHIN and ORWA marine mammal and seabird surveys), 2011-2012 (PaCSEA surveys) and 2016-2021 (present study). The numbers on top of each bar indicate kilometers surveyed in each period. For the purpose of this comparison, PaCSEA off-effort and off-strip sightings were filtered out. See Supplementary Table S1 and S2 for more details about systematic research survey data included in this comparison.

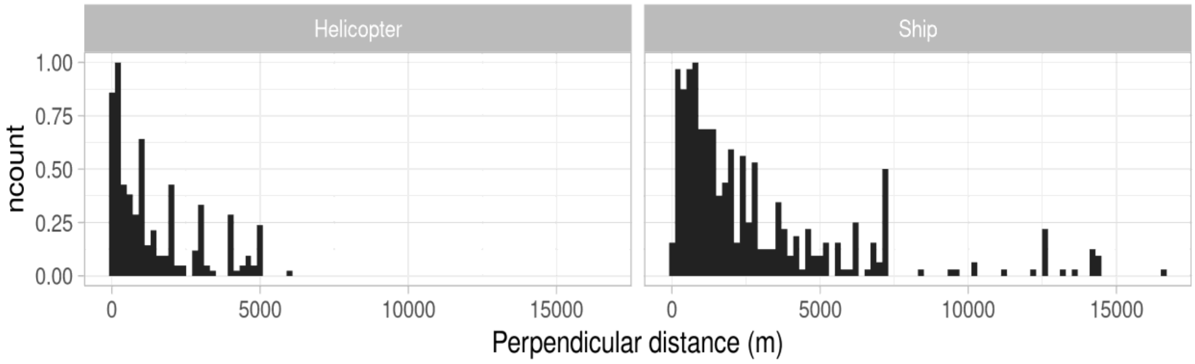

Figure S9: Distribution of perpendicular distance (in meters) measured upon rorqual whale detections during helicopter surveys (left) and shipboard surveys (right).

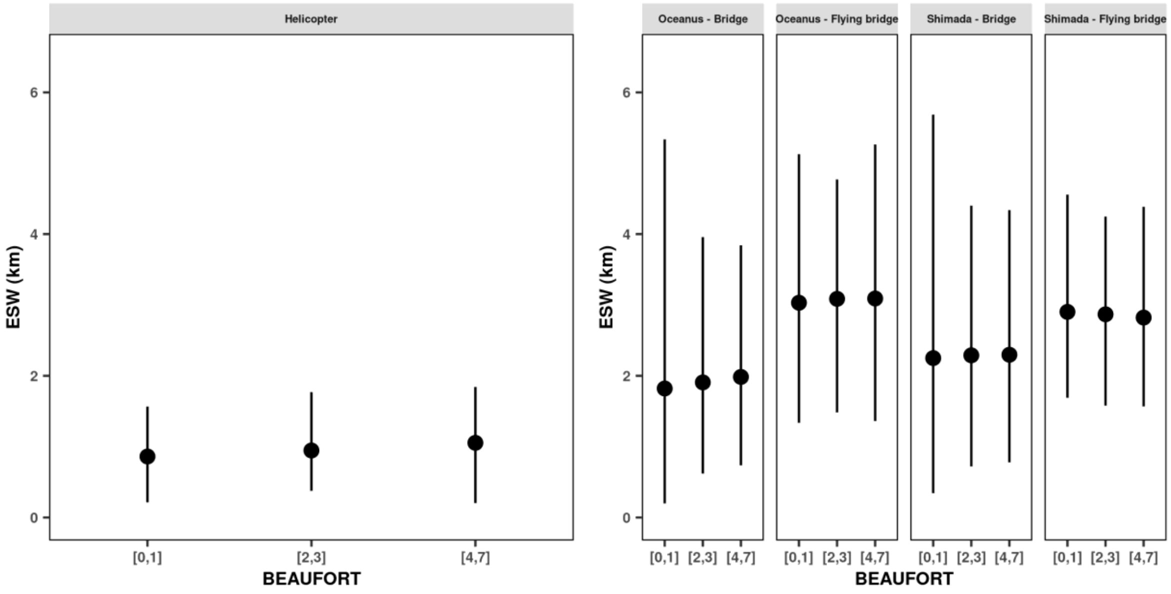

Figure S10: Rorqual effective strip width (ESW in km) estimated per platform (left: helicopter, right: shipboard), Beaufort sea state category and observation height. Points represent the median estimated ESW and line ranges represent the 95 % Bayesian credible intervals.

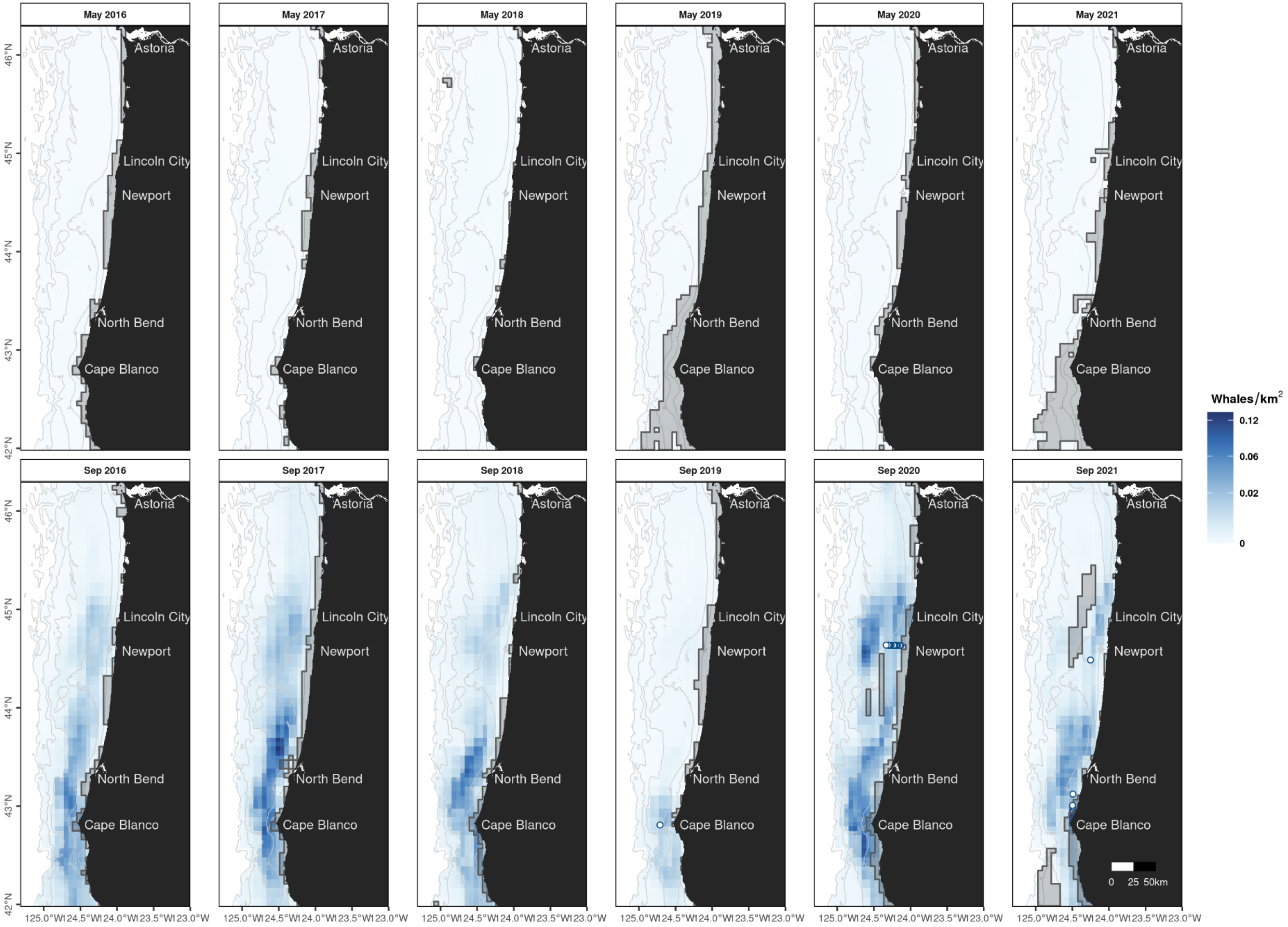

Figure S11: Predicted densities of blue whales in the months of May and September, 2016 to 2021. Densities are represented on a colored scale (square-root transformed gradient). Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Blue circles mark the position of observed blue whale groups during each month x year from shipboard and helicopter surveys used to train the models. Grey boxes overlayed on predictions delineate the areas of extrapolation where environmental conditions are non-analogous to the conditions in which the models were trained.

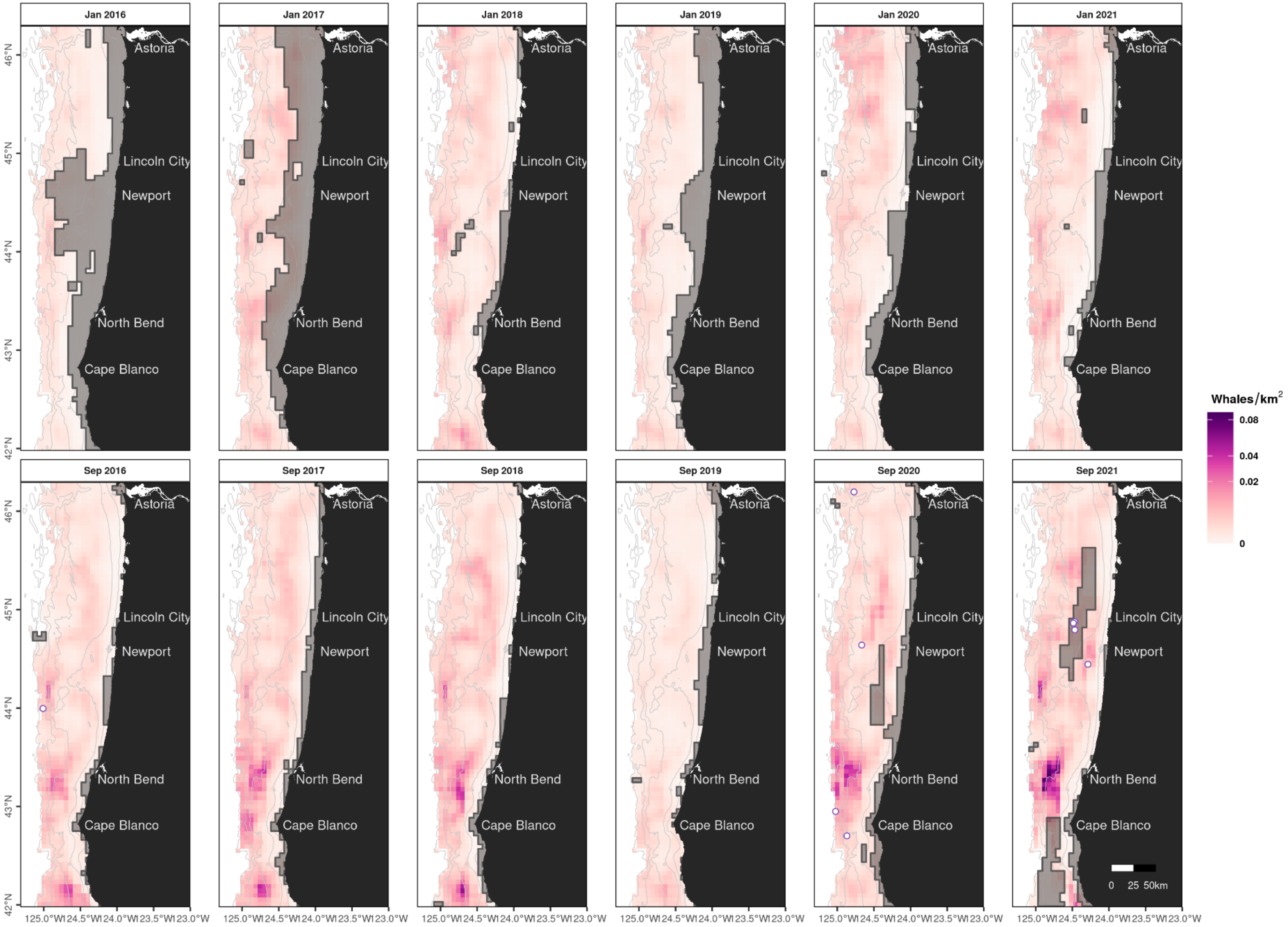

Figure S12: Predicted densities of fin whales in the months of January and September, 2016 to 2021. Densities are represented on a colored scale (square-root transformed gradient). Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Purple circles mark the position of observed fin whale groups during each month x year from shipboard and helicopter surveys used to train the models. Grey boxes overlayed on predictions delineate the areas of extrapolation where environmental conditions are non-analogous to the training conditions in which the models were trained.

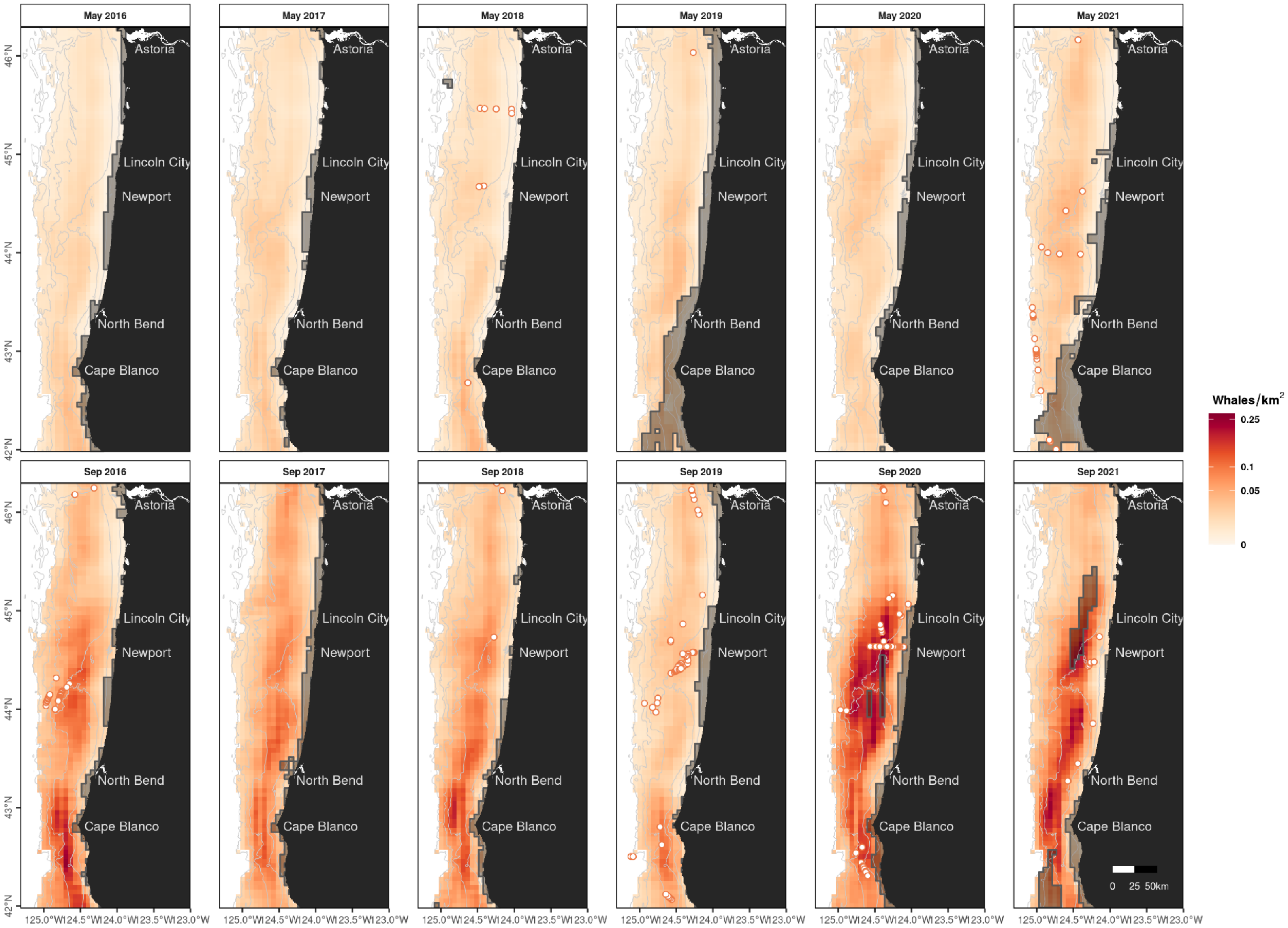

Figure S13: Predicted densities of humpback whales in the months of May and September, 2016 to 2021. Densities are represented on a colored scale (square-root transformed gradient). Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Orange circles mark the position of observed humpback whale groups during each month x year from shipboard and helicopter surveys used to train the models. Grey boxes overlayed on predictions delineate the areas of extrapolation where environmental conditions are non-analogous to the conditions in which the models were trained.

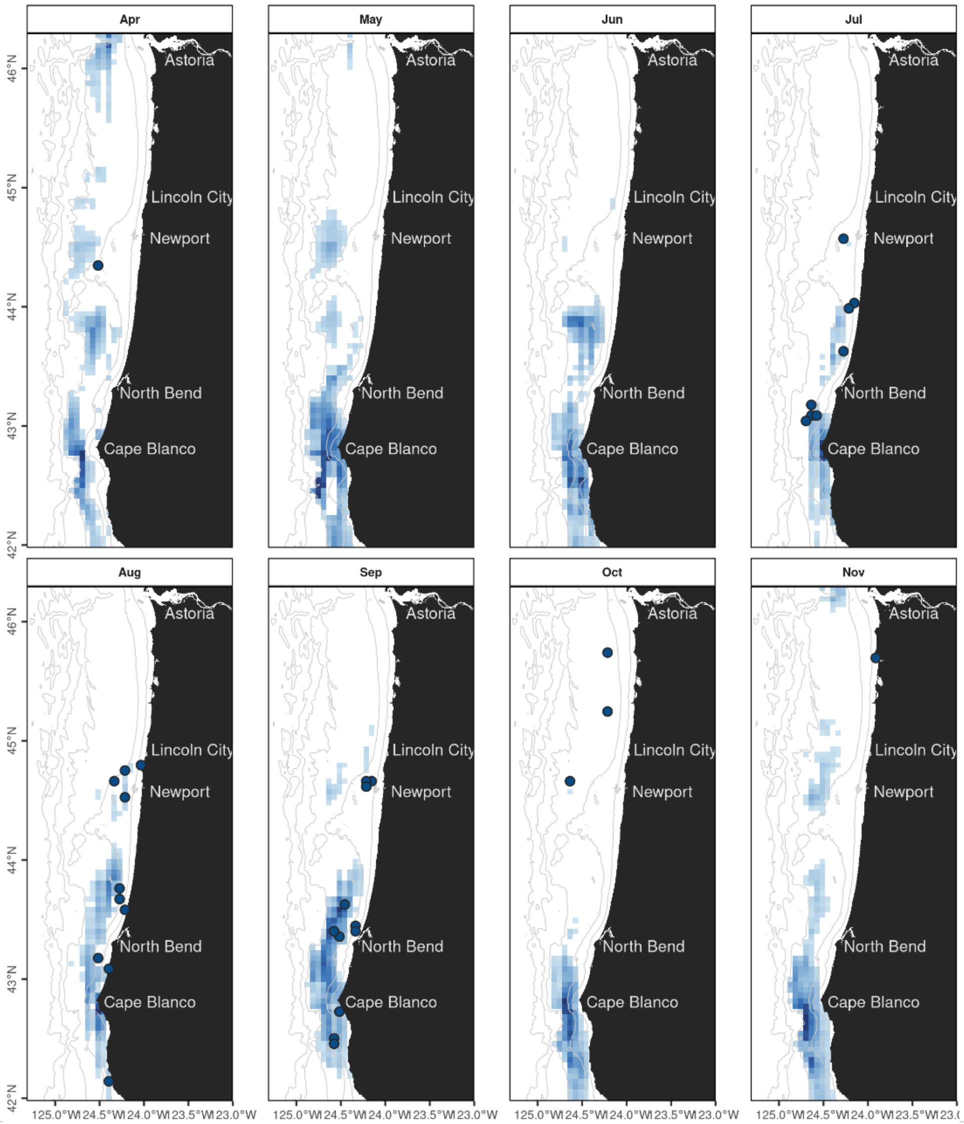

Figure S14: Monthly hotspots predicted over 2016-2021 for blue whales from April to November. The best 75 % of the summed and rescaled densities per month are represented on a blue colored scale. Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Colored circles mark the position of independent validation sightings of blue whales recorded during each month of 1989 to 2021.

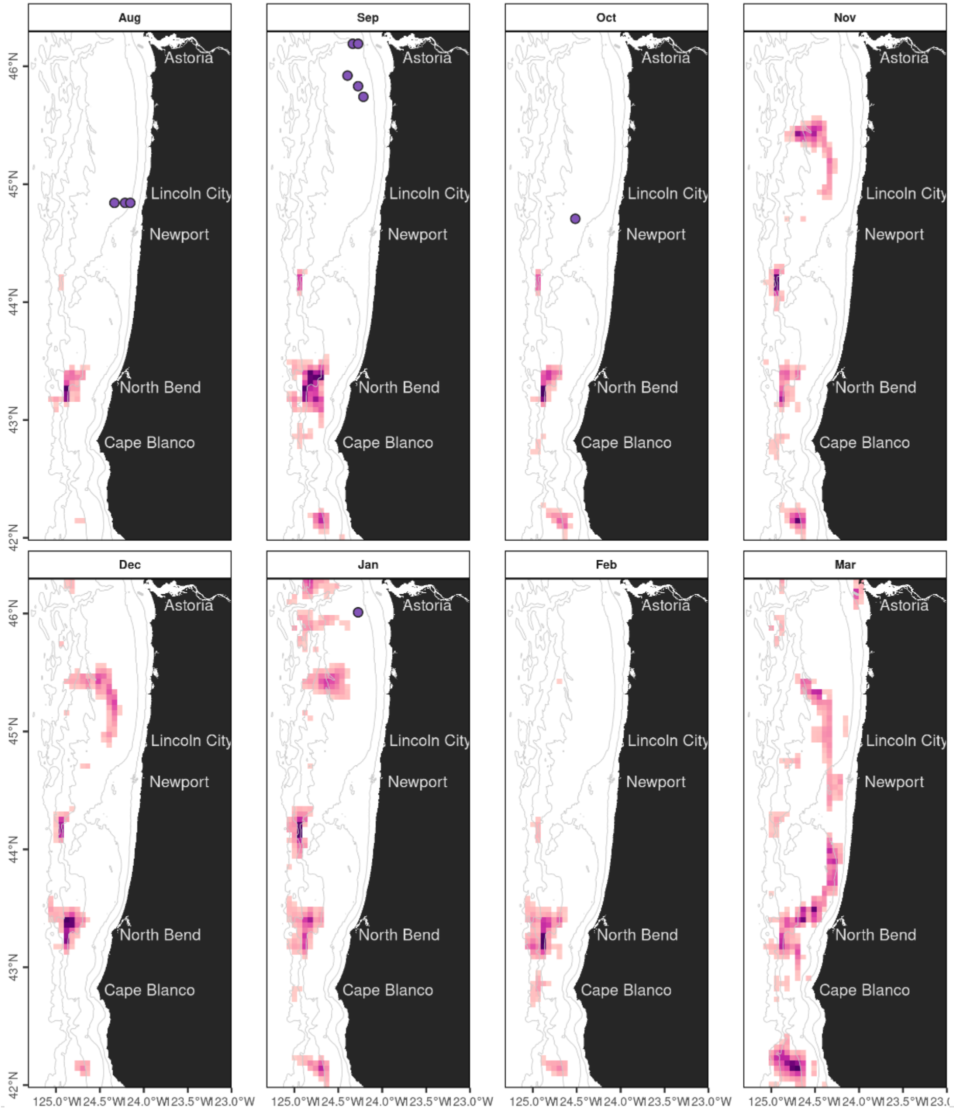

Figure S15: Monthly hotspots predicted over 2016-2021 for fin whales from April to November. The best 75 % of the summed and rescaled densities per month are represented on a purple colored scale. Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Colored circles mark the position of independent validation sightings of fin whales recorded during each month of 1989 to 2021.

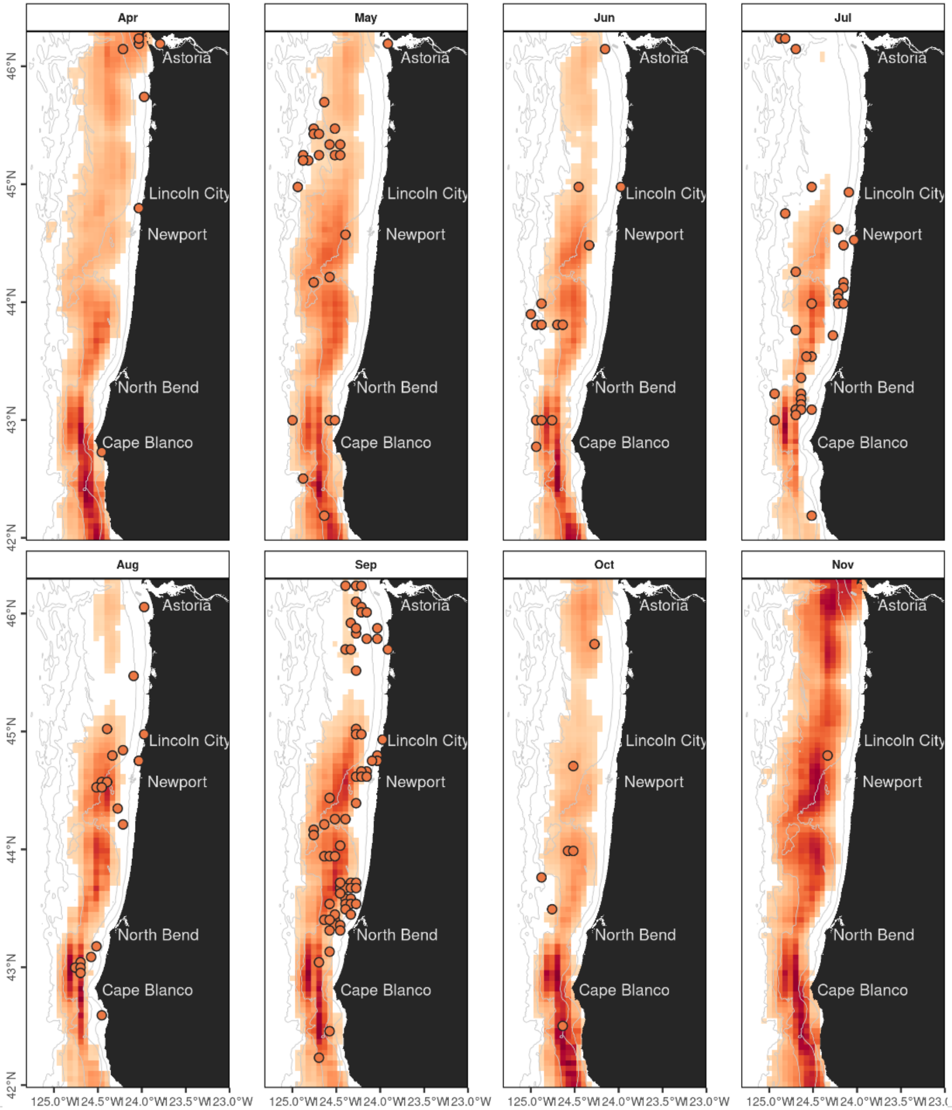

Figure S16: Monthly hotspots predicted over 2016-2021 for humpback whales from April to November. The best 75 % of the summed and rescaled densities per month are represented on an orange colored scale. Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Colored circles mark the position of independent validation sightings of humpback whales recorded during each month of 1989 to 2021.

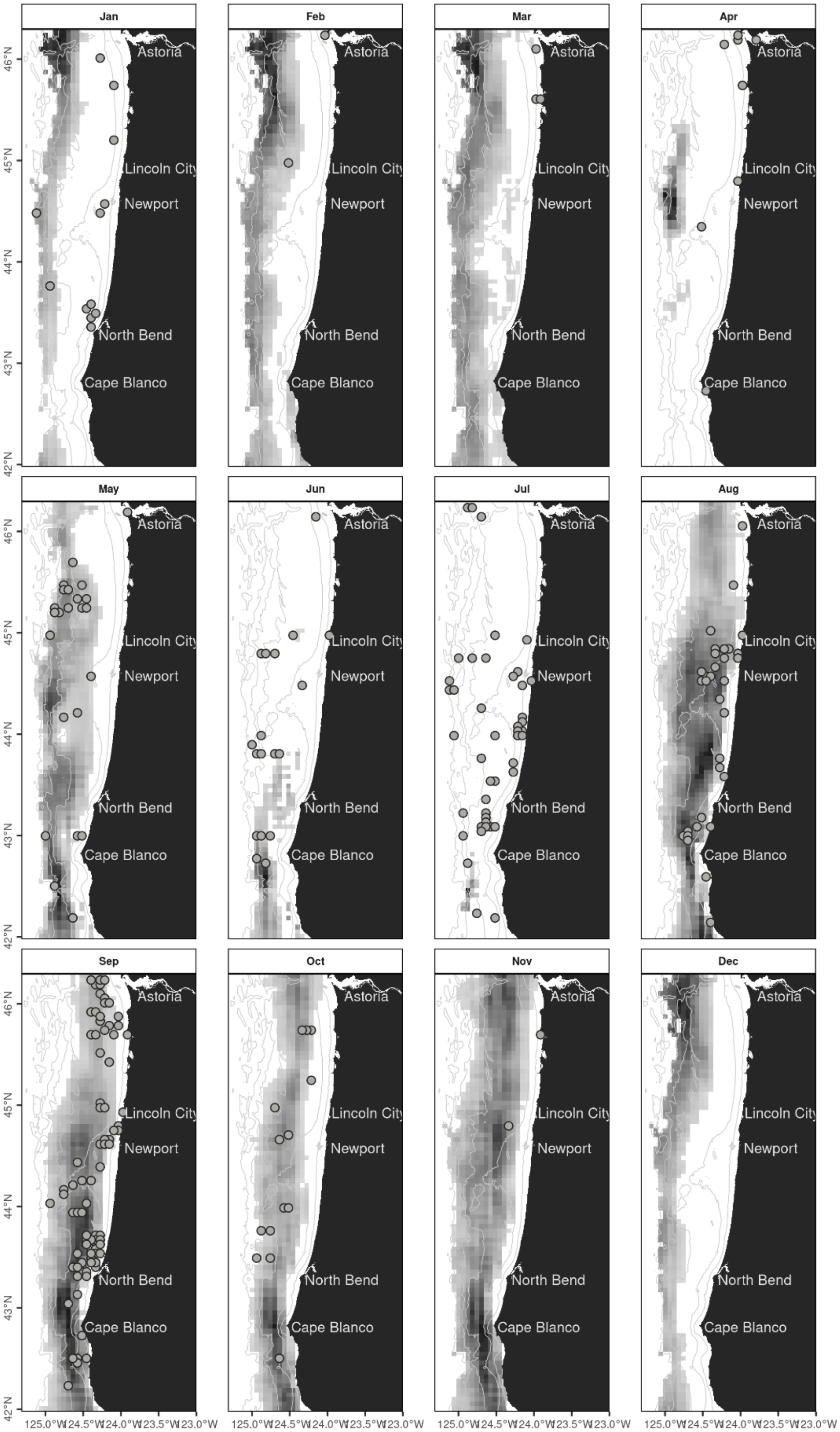

Figure S17: Monthly hotspots predicted over 2016-2021 for rorqual whales. The best 75 % of the summed and rescaled densities per month are represented on a grey colored scale. Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Colored circles mark the position of independent validation sightings of rorquals recorded during each month of 1989 to 2021.

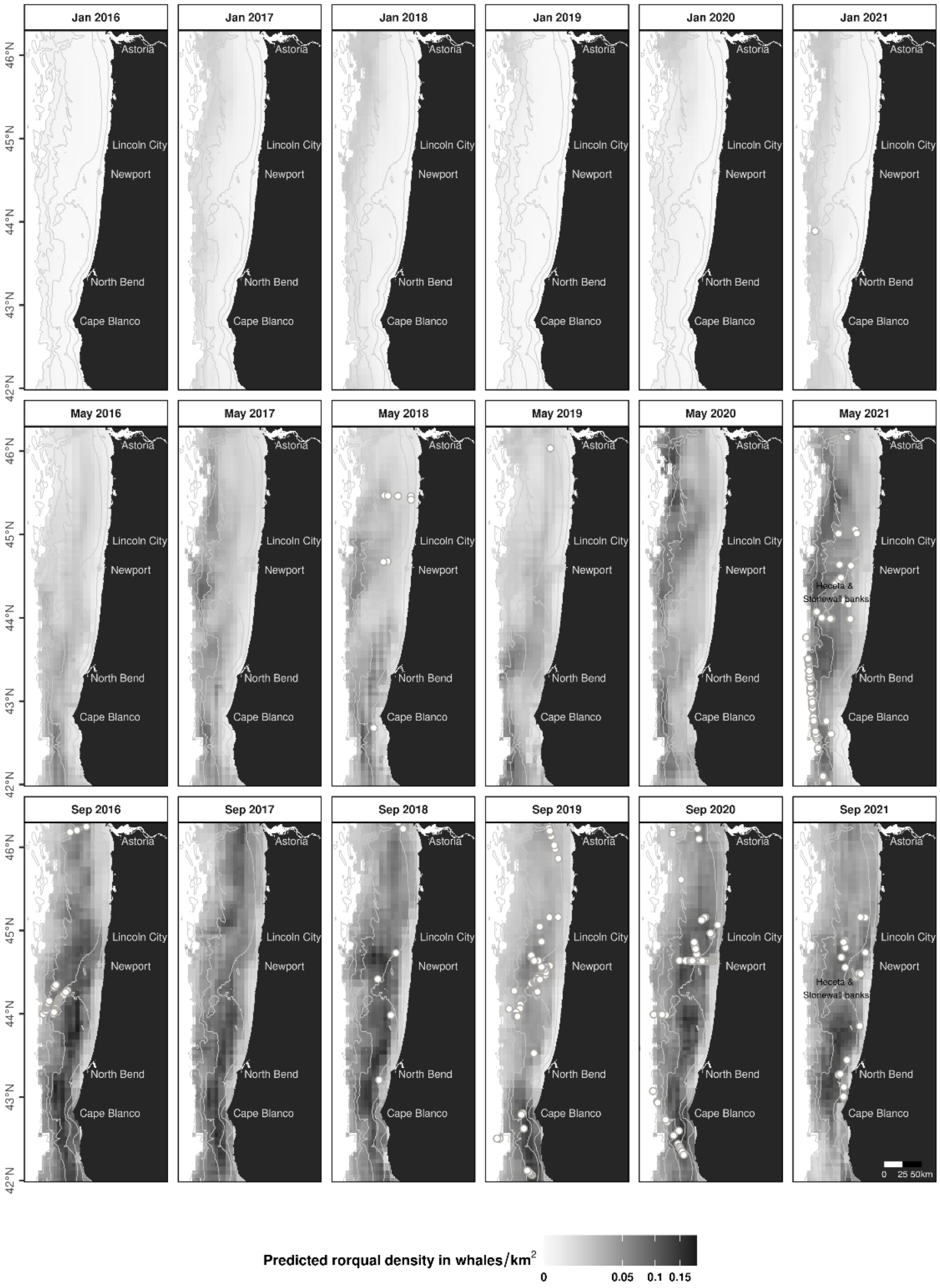

Figure S18: Color-blind-friendly replicate of Figure 6 showing the predicted seasonal densities of rorqual whales for the months of January, May and September, 2016 to 2021. Densities are represented on a gray scale (square-root transformed gradient). Land is shown in black. Isobaths (50, 100, 500, 1,000 and 1,500 m deep) are represented with grey lines. Grey circles mark the position of observed rorqual groups during each month x year from shipboard and helicopter surveys used to train the models. The absence of observations may be due to an absence of survey effort.