MAPS OF SPECIES DENSITY MODELLING - MODELLING RESULTS

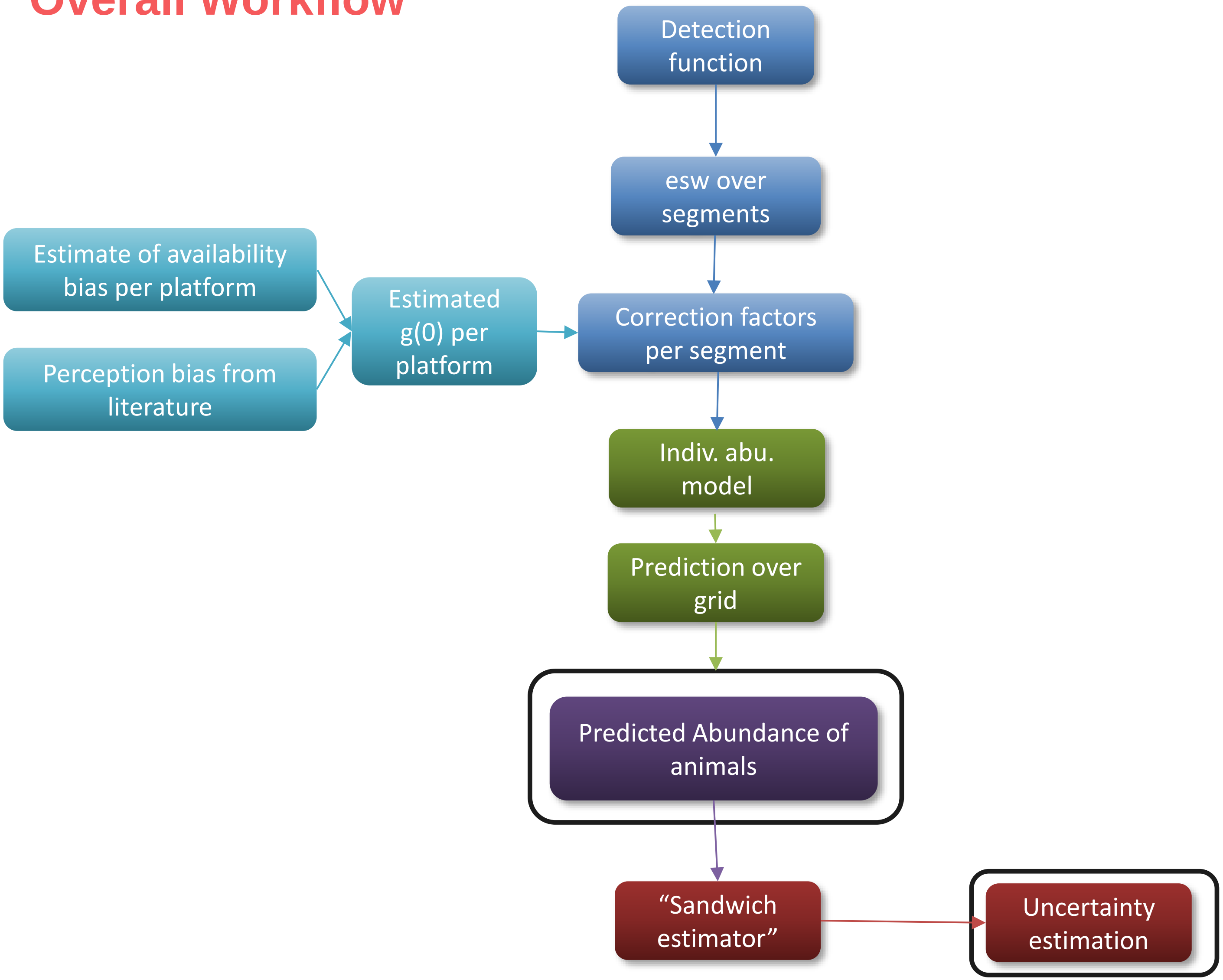
Issue: Species Density Modelling

Background

Slides presented by Ana Cañadas during the 16th ACCOBAMS Scientific Committee meeting, Agenda item 3.2.1. "Mediterranean modelling results", for increasing knowledge about the state of cetaceans in the ACCOBAMS area.

Overall Workflow

Overall Workflow



Detection functions

Covariates detection functions

Factor covariates

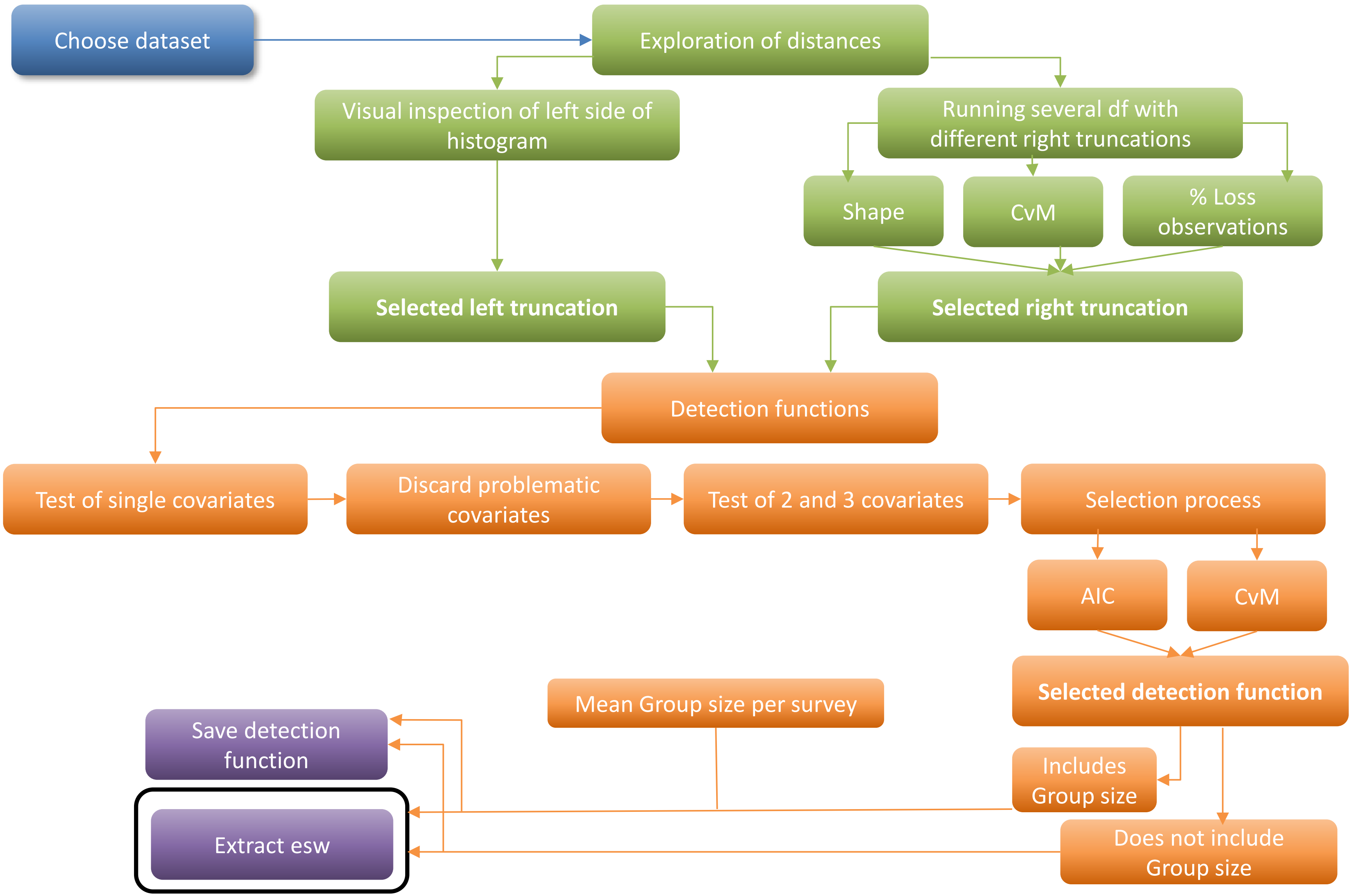
Name	Value
BeaufortCode	0_1, 2_3
Beaufort.fac	0, 1, 2, 3 (>3 discarded)
SubjectiveCode	Excellent, Good, Moderate (Poor discarded)
GlareCode	None, Slight, Moderate, Severe
CloudsCode2	0_3, 4_5, 6_8 (Eighths of sky covered)
TurbidityCode	Clear, Moderate, Turbid
VisibilityCode	2_5, 5_10 (km of visibility)
WeatherCode	Fair, Unknown
SkyGlint	0, 1
Name	Survey name
CommonName	Species name
Confidence	Definitive-Probably, Ambiguous
Region	BlackSea, Mediterranean
PlatformHeight.fac	Observation platform height (in m)
Group.plat	Platform group
Group.plat2	None, 3_5, 6_8, 10_11 (Second platform)

* Most covariates include also the value “Unknown”

Continuous covariates

Name	Value
Beaufort	0, 0.5, 1, 1.5, 2, 2.5, 3
Swell	0, 0.2, 0.5, 1, 1.5, 2 (m)
Clouds	0, 1 ,2 , 3, 4, 5, 6, 7, 8
Visibility	3, 5, 7 (kms)
Year	Year
Month	Month
detsize	Group size
Log.detsize	Logarithm of group size
PlatformHeight	Observation platform height (in m)
Speed	Mean speed of the platform (km/h)

Detection functions - Workflow



Spatial modeling

Covariates spatial models Black Sea

Dynamic covariates

Name	Value	Unit
Chl	Concentration of Chlorophyll in sea water	mg m-3
Current E vel	eastward ocean current velocity	m s-1
Current N vel	northward ocean current velocity	m s-1
Phytoplankton	Concentration of Phytoplankton Biomass in sea water	mmol m-3
Primary prod	Net primary production of biomass expressed as carbon per unit volume in sea water	mg m-3 day-1
Salinity	Salinity	Ppt (gr/Kg)
Sbt	Sea floor temperature	°C
Ssh	sea surface height	m
Sst	sea surface temperature-mean	°C
Sst sd	sea surface temperature-sd	°C

* Given the enormous spatial/temporal heterogeneity in the surveys used in these models, and after unsuccessfully trying to use the month/year covariates, it was decided to use climatologies for the dynamic covariates (i.e. the monthly means over the full range of years, eliminating the interannual heterogeneity). These models are labeled "Summer_clim" and "Winter_clim".

** Not relevant for the Mediterranean

Static covariates

Name	Value
Aspect	Orientation of the sea floor (0-359º)
Depth	Depth of the sea floor (m)
Dist25 **	Distance to the 25 m isobath
Dist50 **	Distance to the 50 m isobath
Dist100	Distance to the 100 m isobath
Dist250	Distance to the 250 m isobath
Dist500	Distance to the 500 m isobath
Dist1000	Distance to the 1000 m isobath
Dist2000	Distance to the 2000 m isobath
DistAbyss	Distance from the Abyss
DistSlope	Distance from the Slope
DistShelf	Distance from the Continental Shelf
DistLand	Distance from the coast
DistCan	Distance from canyons
DistEsc	Distance from escarpments
DistCanEsc	Distance from canyons and escarpments
SlopePct	Slope of the sea floor (%)
Lon	Longitude
Lat	Latitude

Covariates spatial models Mediterranean

Dynamic covariates

Name	Value	Unit
Chl	Concentration of Chlorophyll in sea water	mg m-3
Current E vel	eastward ocean current velocity	m s-1
Current N vel	northward ocean current velocity	m s-1
Phytoplankton	Concentration of Phytoplankton Biomass in sea water	mmol m-3
Primary prod	Net primary production of biomass expressed as carbon per unit volume in sea water	mg m-3 day-1
Salinity	Salinity	Ppt (gr/Kg)
Sbt	Sea floor temperature	°C
Ssh	sea surface height	m
Sst	sea surface temperature-mean	°C
Sst sd	sea surface temperature-sd	°C
Chl_front_dist**	Distance to nearest major front	km
Chl_fron_strength**	Frontal gradient magnitude	log Chl mg m-3 km-1
Sst_front_dist**	Distance to nearest major front	km
Sst_front_strength**	Frontal gradient magnitude	°C km-1
Mix_layer-thickness**	Ocean mixed layer thickness defined by density	m

* Given the enormous spatial/temporal heterogeneity in the surveys used in these models, and after unsuccessfully trying to use the month/year covariates, it was decided to use climatologies for the dynamic covariates (i.e. the monthly means over the full range of years, eliminating the interannual heterogeneity).

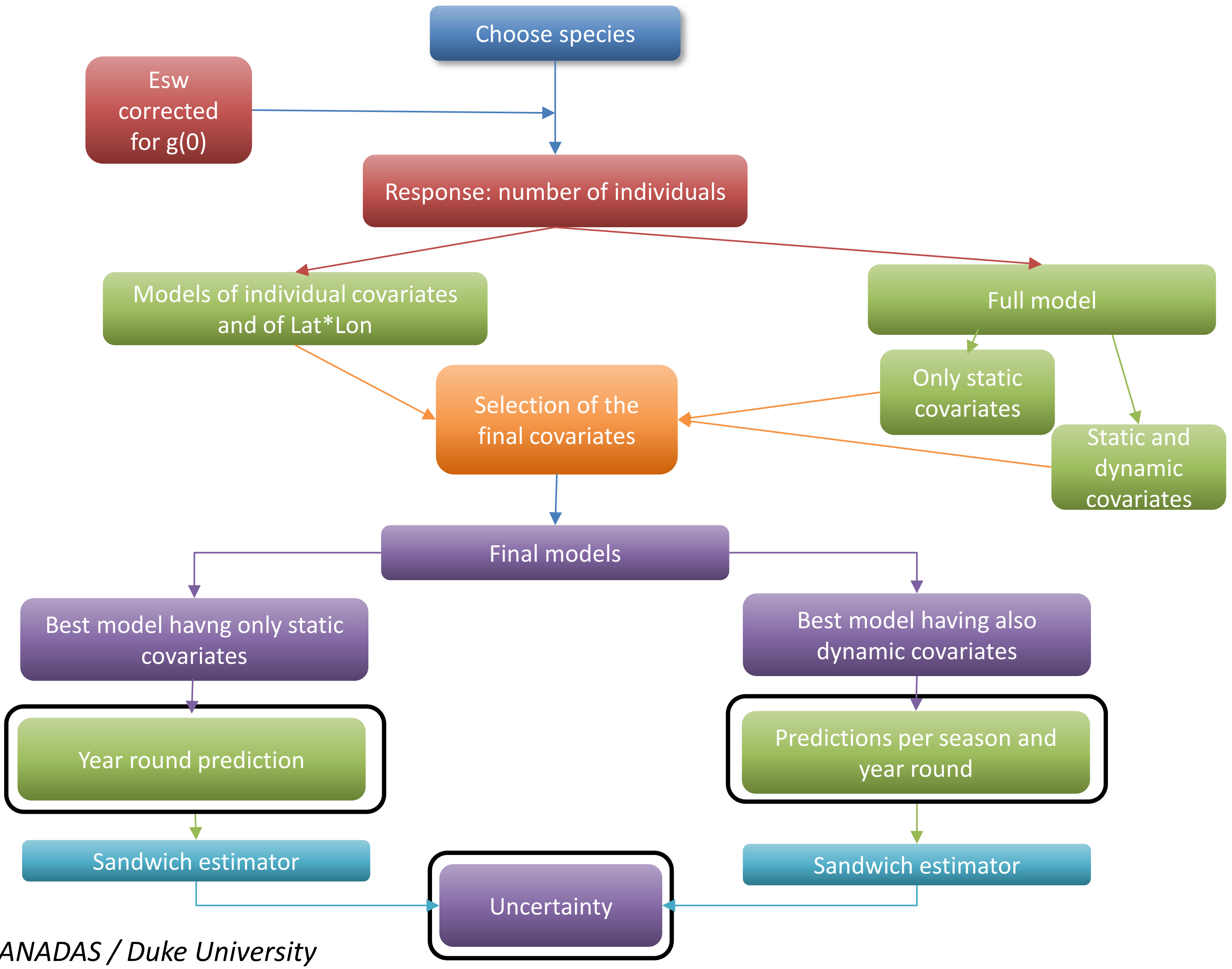
** Not available for the Black Sea

*** Not relevant for the Black Sea

Static covariates

Name	Value
Aspect	Orientation of the sea floor (0-359º)
Depth	Depth of the sea floor (m)
DistToAtl***	Distance to the Atlantic
WindFetch***	Distance from all coasts (360º)
Dist100	Distance to the 100 m isobath
Dist250	Distance to the 250 m isobath
Dist500	Distance to the 500 m isobath
Dist1000	Distance to the 1000 m isobath
Dist2000	Distance to the 2000 m isobath
Dist3000***	Distance to the 3000 m isobath
DistAbyss	Distance from the Abyss
DistSlope	Distance from the Slope
DistShelf	Distance from the Continental Shelf
DistLand	Distance from the nearest coast
DistCan	Distance from canyons
DistEsc	Distance from escarpments
DistCanEsc	Distance from canyons and escarpments
SlopePct	Slope of the sea floor (%)
Lon	Longitude
Lat	Latitude

Spatial modeling - Workflow



Winsorizing

Winsorizing

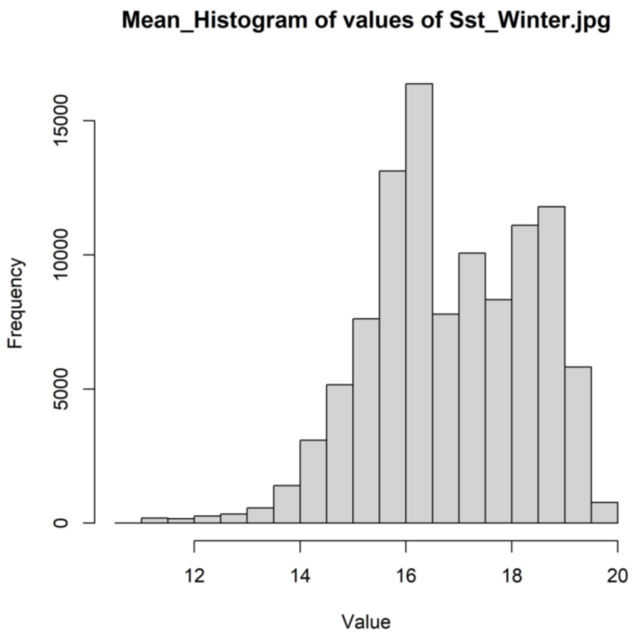
The problem of "edge effects" in a density surface model is a common issue, particularly when there is an extrapolation of the prediction. Extrapolation can occur when predictions are made beyond the sampled ranges of covariates, resulting in predictions for novel ranges of individual covariates or novel combinations of covariates. This often occurs when models are predicted beyond the geographic areas that were surveyed, but even when the prediction area is cropped to tightly fit surveyed areas, there can always be portions that have extreme values not sampled or poorly sampled, which, depending on the shape of the smooth function, may still create an edge effect. This problem has higher probability of occurring in very large study areas like the one considered here.

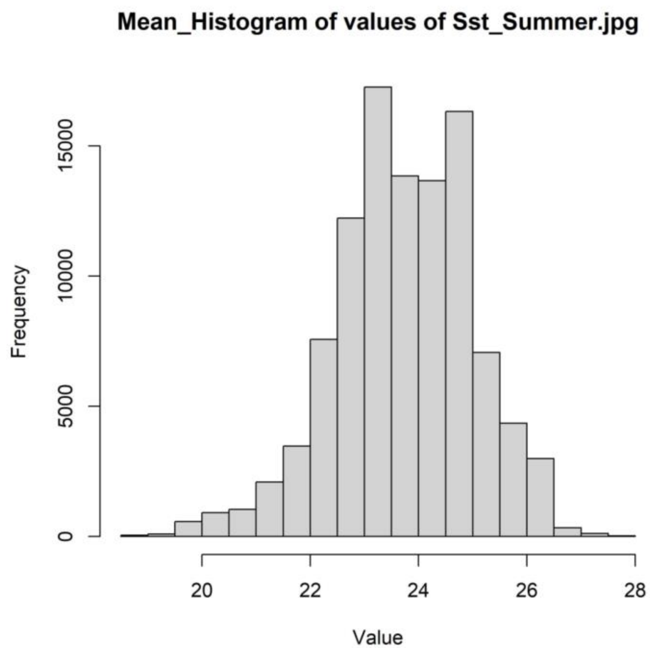
To minimize this problem, we used a method called "Winsorizing". Winsorizing is not equivalent to excluding data, but rather to censuring data, where the extreme values are replaced (instead of discarded) by certain percentiles or values. For model fitting, R can use the functions pmax() and pmin(), which return the "parallel maxima" or "parallel minima" of two or more input vectors. For example:

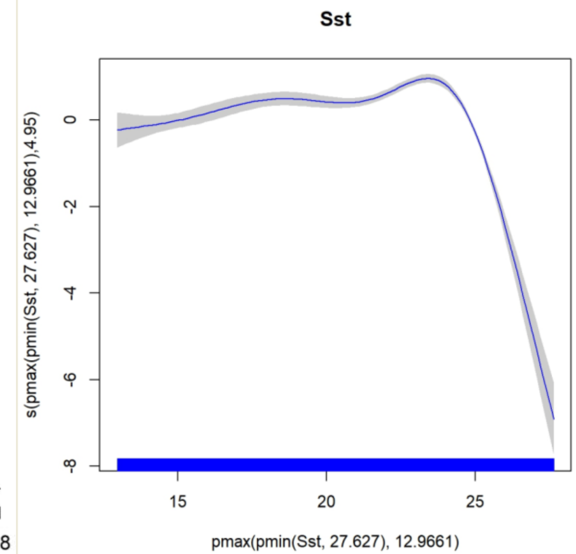
```
model<- gam(resp.var~s(pmax(pmin(X,20)),10))
```

means that the model will take whatever is larger, the value of X or 10, and whatever is smaller, the value of X or 20.

We applied this method to the covariates that tended to create these edge effect problems, using the either the 0.99 or the 0.999 percentile as value for pmax, and either the 0.1 or the 0.001 as value for pmin, depending on the range of values of the covariates.





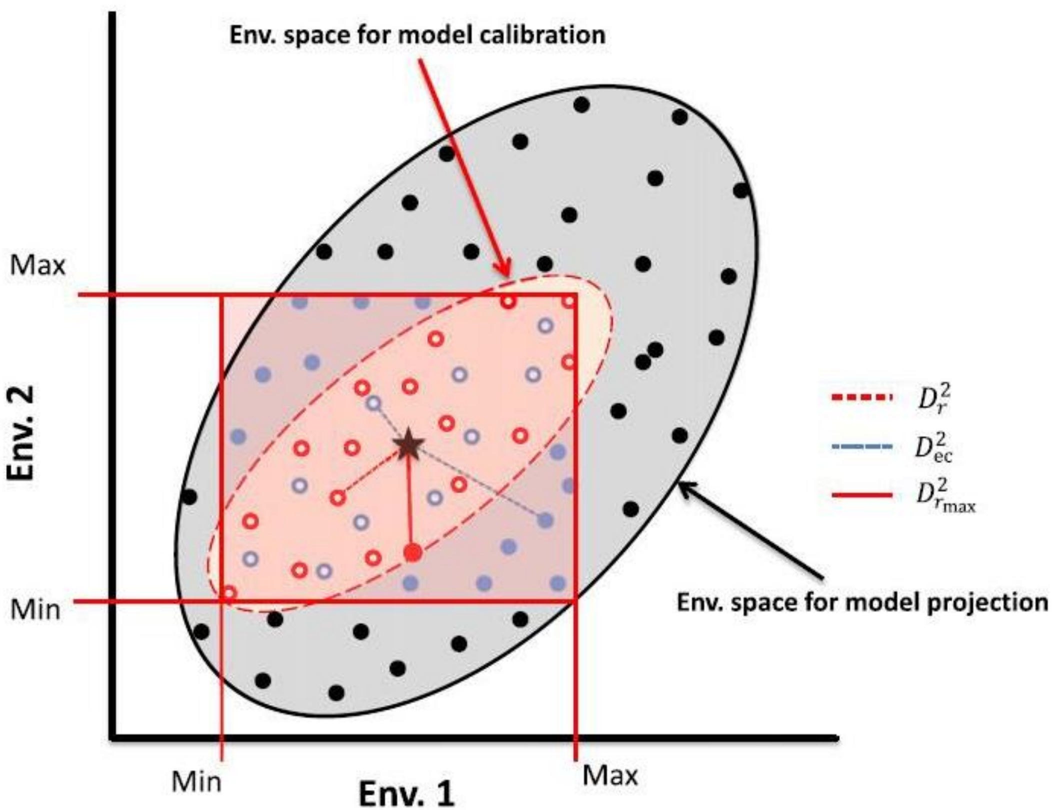


Characterizing extrapolations

Characterizing extrapolations

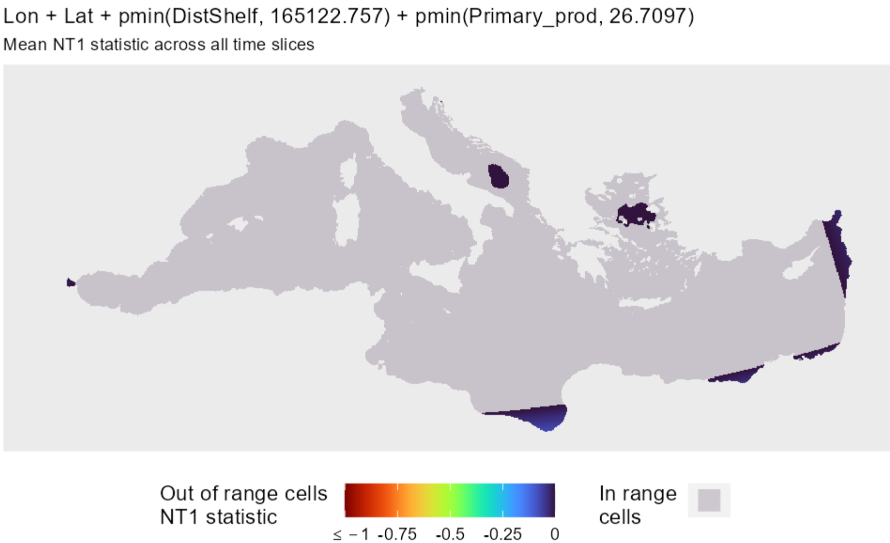
Extrapolation can occur when predictions are made beyond the boundaries of the study regions where the data used to fit DSMs were originally collected (e.g., Mannocci et al. 2015; Bouchet et al. 2020), resulting in model prediction for novel ranges of individual covariates (univariate or NT1 extrapolation) or novel combinations of covariates (multivariate or NT2 extrapolation) (Mesgaran et al. 2014).

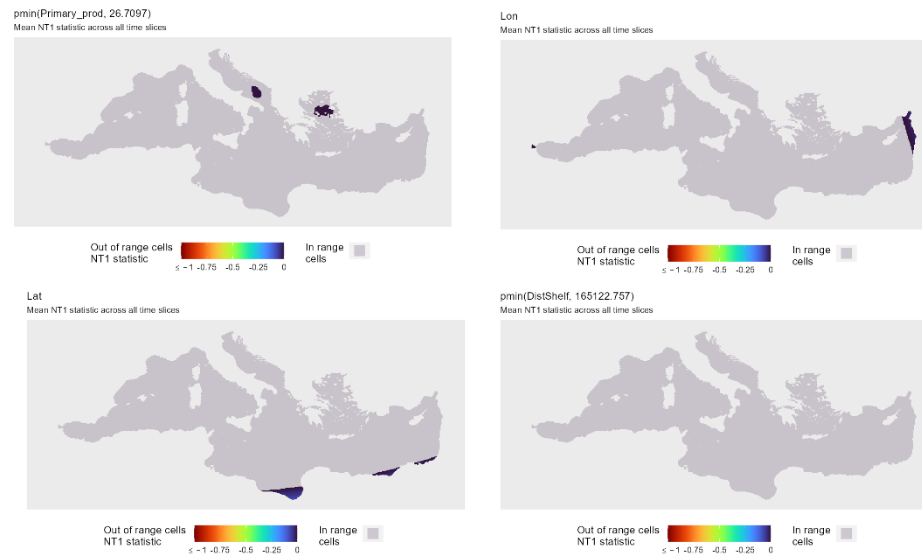
We calculated NT1 and NT2 for the final models of all species following Mesgaran et al. (2014). Following Bouchet et al. 2020, once NT1 and NT2 statistics were calculated for each final species model and rasters were produced, we plotted overlays of the two statistics to create an ExDet raster whereby all cells are assigned values based on the NT1 and NT2 results, where univariate extrapolation is indicated by values less than one, cells in range of covariates (e.g., no extrapolation) are indicated by values between zero and one, and cells with multivariate extrapolation are indicated by values greater than one.

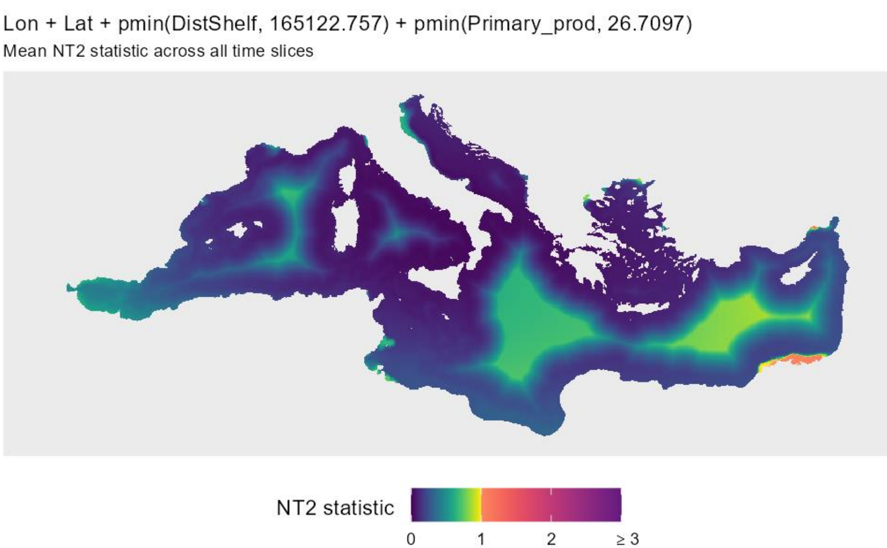


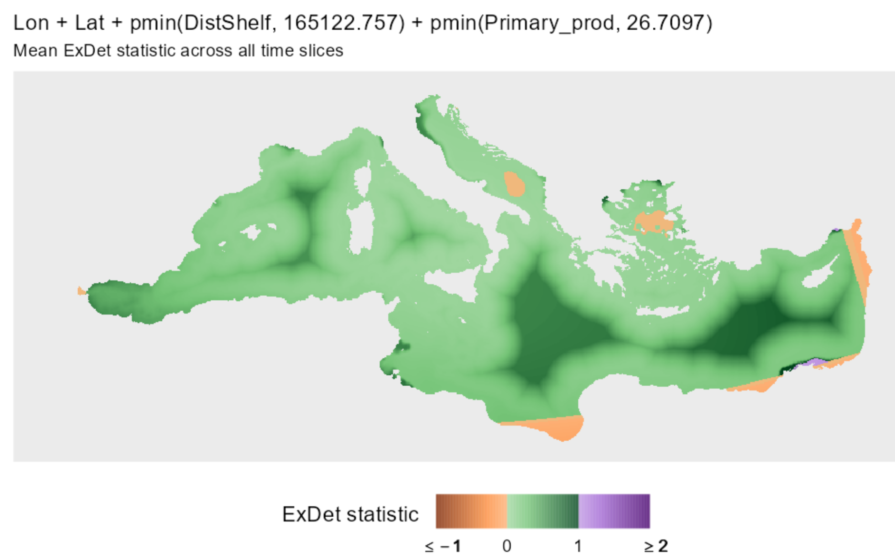
"Schematic presentation of the ExDet tool for the detection and quantification of extrapolation in correlative SDMs using two hypothetical environmental variables. Red open circles represent the distribution records that define the sampled environmental space (small pink oval) used for model calibration, and the red rectangle shows the univariate coverage of this space. Black and blue solid circles and blue open circles represent grids on which the model is going to be projected and thus define the projection environmental space (large grey oval). All grids from the projection domain that are outside the rectangle (black solid circles: Type 1 novelty; NT1) are trimmed, and the degree of their dissimilarity is calculated using the NT1 component of the tool. The remaining projection grids may represent covariate combinations not captured (blue solid circles: Type 2 novelty; NT2) or captured (blue open circles) in the sampled environments of calibration data. For each grid within the rectangle, the Mahalanobis distance (D2) is calculated with respect to the center of the environmental space of the calibration data (black solid asterisk). The maximum distance found in the calibration data (D2r max: red line with corresponding point shown as solid red circle) is then used to delineate the 'boundary' of data (dashed red ellipse). If the Mahalanobis distance of a point in the projection space (D2 ei) is larger than the D2r max, that point represents a novel environment (blue solid circle). For both analogous and novel points, a multivariate combination novelty index (NT2) is then calculated."

Characterizing extrapolations (example of Dde – noAlb)









Black Sea

Collaborators

Effort

Collaborator	Area Covered	Platform	Range of years	Effort (km)
ACCOBAMS	Russia, West & South Black Sea	Plane	2018-2019	8,439
Brema	Kerch Strait, Central & NW Black Sea	Ship	2003-2005	1,388
Green Balkans	Bulgaria	Ship	2015-2021	7,063
Ilia State University	Georgia	Ship	2014-2019	2,745
IO-BAS	Bulgaria	Ship	2015-2017	2,119
Istambul University	Turkey, Marmara Sea	Ship	2005-2019	959
MareNostrum	Romania	Plane,Ship	2013	7,358
Moscow State University	Azov Sea, Georgia, Russia & Ukraine	Plane,Ship	2001-2005	9,118
Sinop University	Sinop peninsula (Turkey)	Ship	2019-2020	745
TCR	Turkey	Ship	2005-2008	521
TUDAV	W Turkey	Ship	2019-2021	1,019
Zonguldak Bülent Ecevit University	Turkey	Ship	2019-2022	820
			TOTAL	**42,292**

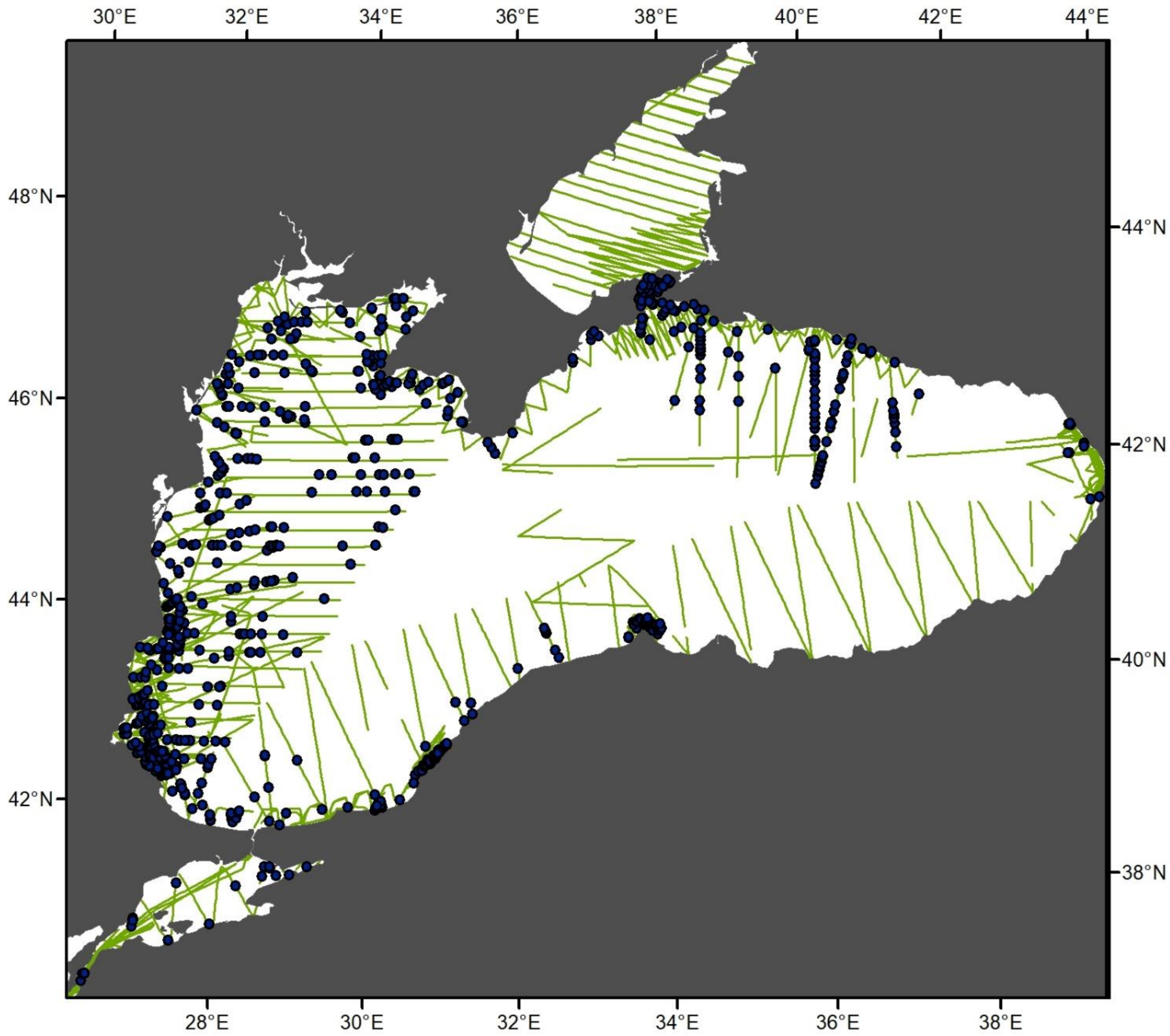
Collaborators

Sightings

Collaborator	Area Covered	Bottlenose dolphins	Common dolphins	Harbour porpoises
ACCOBAMS	Russia, West & South Black Sea	245	811	892
Brema	Kerch Strait, Central & NW Black Sea	43	50	39
Green Balkans	Bulgaria	245	252	773
Ilia State University	Georgia	10	790	1241
IO-BAS	Bulgaria	70	18	163
Istambul University	Turkey, Marmara Sea	18	8	14
MareNostrum	Romania	275	592	481
Moscow State University	Azov Sea, Georgia, Russia & Ukraine	142	78	196
Sinop University	Sinop peninsula (Turkey)	37	30	141
TCR	Turkey	15	0	0
TUDAV	W Turkey	39	39	50
Zonguldak Bülent Ecevit University	Turkey	86	63	132
	TOTAL	**1225**	**2731**	**4122**

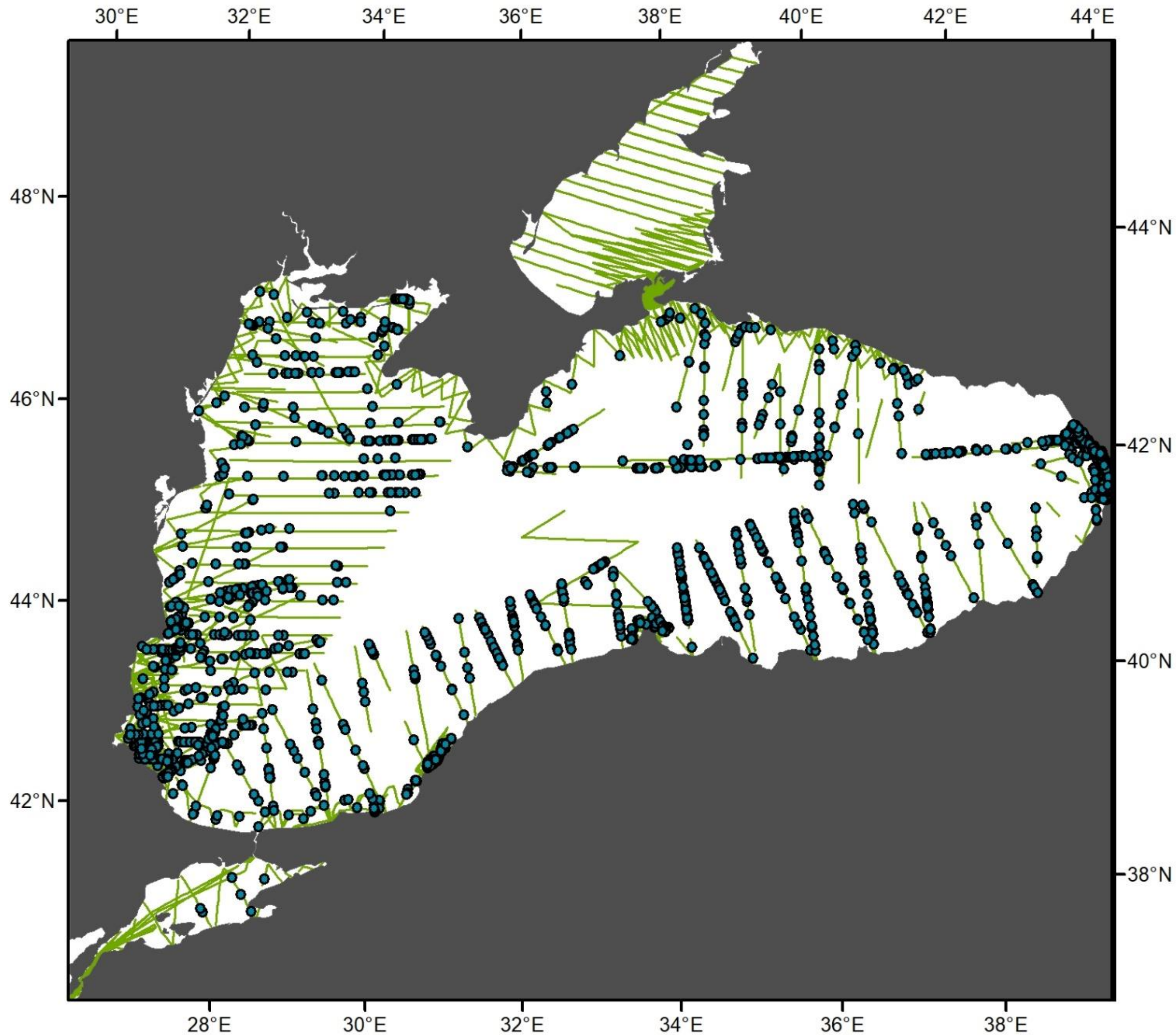
Observations

Bottlenose dolphins



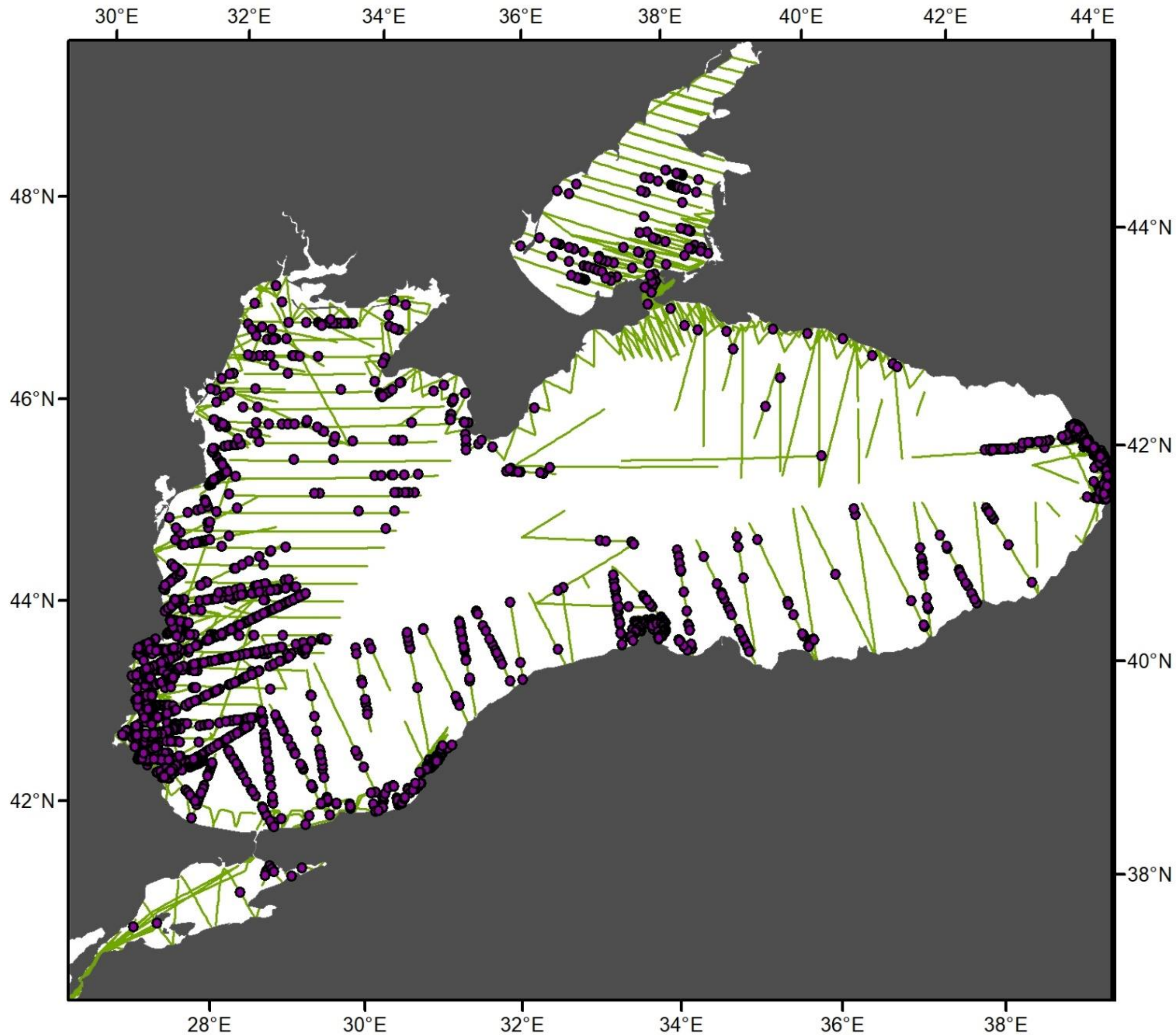
Observations

Common dolphins



Observations

Harbour porpoises



Seasonality

Issues that arose during the review meeting

- Two seasons were created, same as for the Mediterranean: Summer (May to October) and Winter (November to April)
- Not enough data to model winter on its own (except southern coastal strip)
- Collaborators agree that:
    - Total density in Summer and Winter should be the same for the three species
    - For next round:
        - Seasonality should be different, maybe work with 4 seasons
        - Need discussion on how far back to go, due to climate change and evidences from strandings

Comparison with CENOBS

- Our estimates for harbour porpoise and common dolphins match very well with those from CENOBS when CENOBS is corrected by the correction factor for planes 183-B. For bottlenose dolphins we get a higher abundance, possibly related to the aerial feature of CENOBS.

- Collaborators agree that they consider the uncorrected CENOBS estimates as correct, and therefore ours too.

- General perception of the collaborators is overestimation after correction.
    - There has no previous corrected estimates for the Black Sea
    - Need for correction factor specific for the Black Sea.

Bottlenose dolphin

Black Sea - Bottlenose dolphin

Estimated abundance and uncertainty

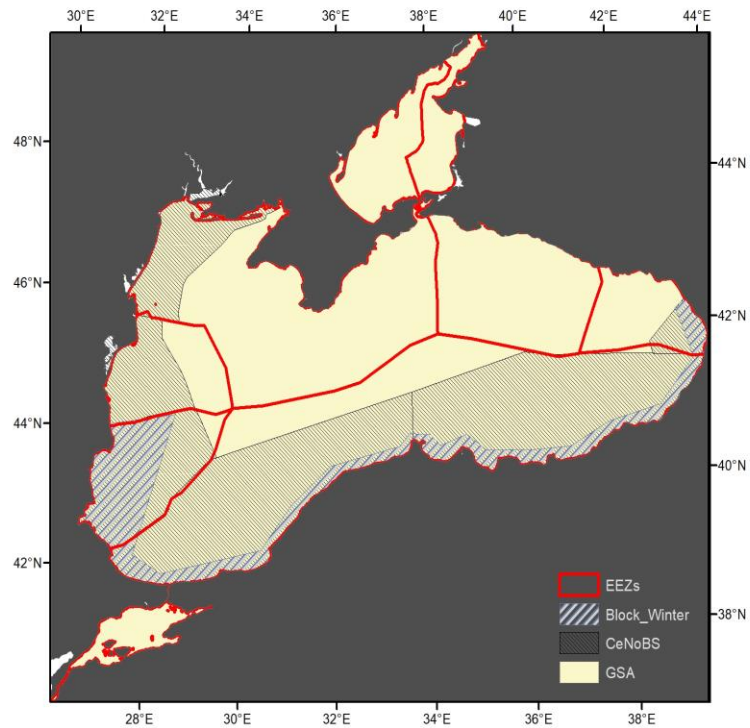
Number of observations: 964

Number of individuals: 2923

Covariates: Depth + Salinity + Sst + Lon,Lat

Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Summer	76,712	0.199132	0.1817	60,403	116,221
Winter	90,789	0.234378	0.5104	43,947	221,293
AllYear	83,750	0.216755	0.4152	46,174	180,137

Block.name	density	pred_model	cv	L95ci_abundance	U95ci_abundance
BS_coastal_winter	0.275100	14,462	0.4312	7,688	31,346
EEZ_BS_Bulgaria	0.203376	7,061	0.4756	3,395	15,605
EEZ_BS_Georgia	0.161233	3,689	0.4162	1,901	7,435
EEZ_BS_Romania	0.438705	12,969	0.4760	6,073	27,937
EEZ_BS_Russia	0.141015	7,195	0.4333	3,677	15,076
EEZ_BS_Turkey	0.129186	22,291	0.5002	10,407	51,033
EEZ_BS_Ukraine	0.272735	29,952	0.4506	14,734	63,327
GSAs_BlackSea	0.197459	82,819	0.4219	42,322	168,194
MSFD_Romania	0.436367	12,899	0.4769	6,041	27,857
StudyArea_CENOBS	0.199974	**44,028**	0.3998	**23,325**	**87,178**



CENOBS: 22,720*

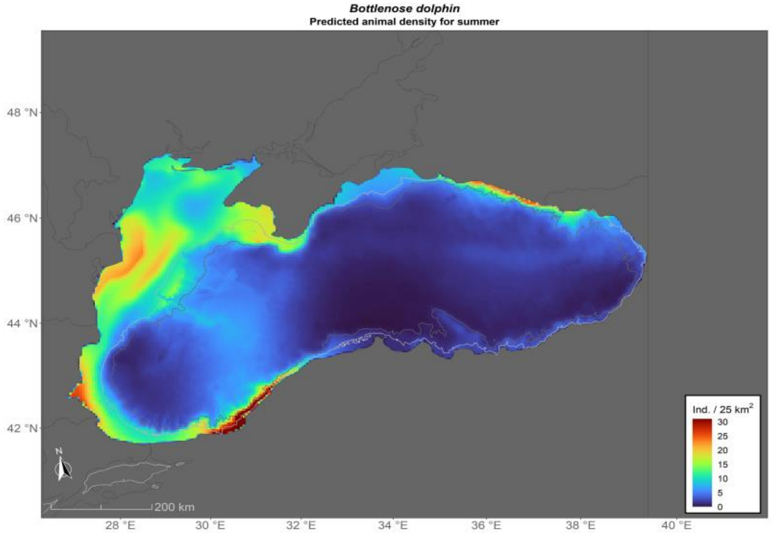
Corr. factor: 0.755

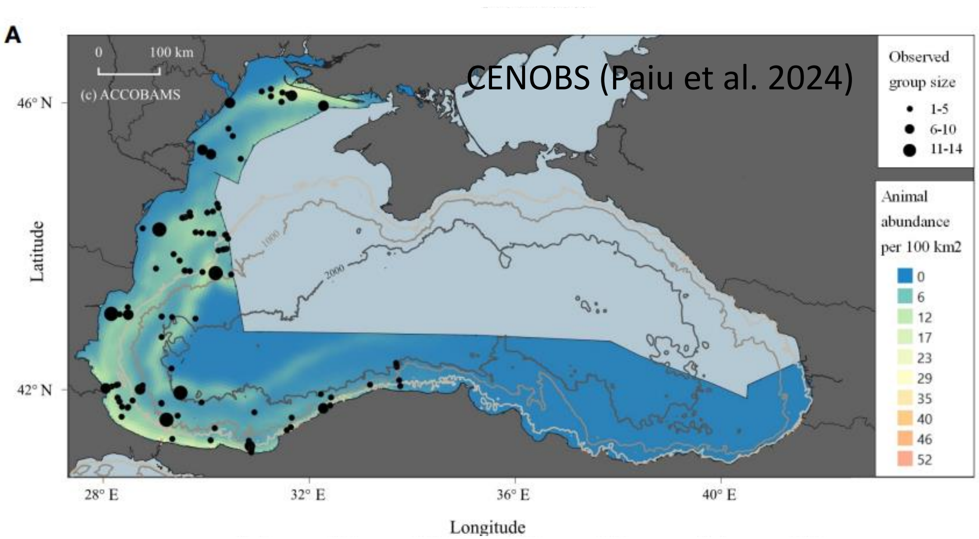
CENOBS corrected: **30,093**

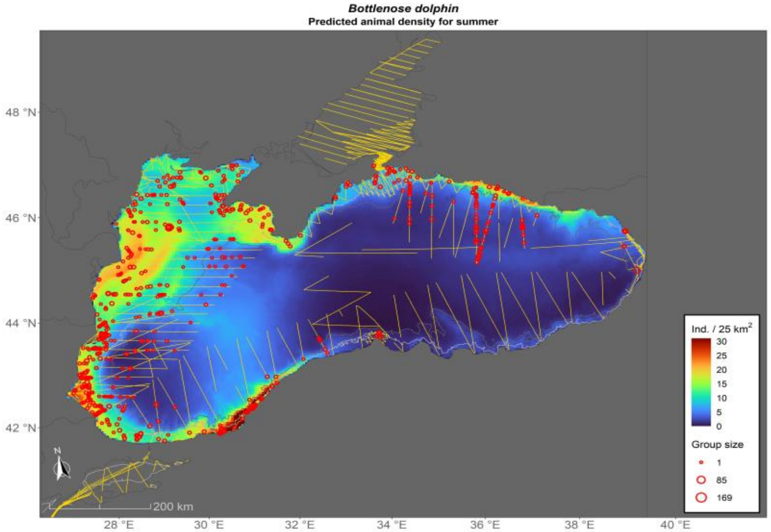
*Hardly includes any coastal waters

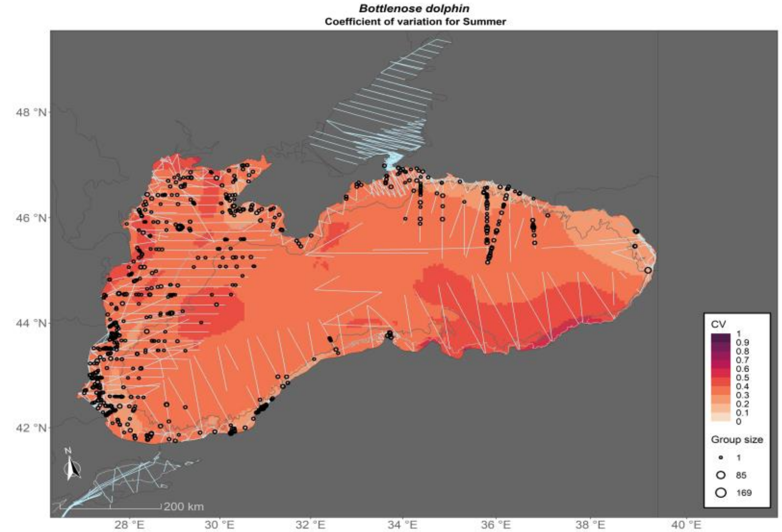
Black Sea - Bottlenose dolphin

Plots of predicted density and CV for for Summer



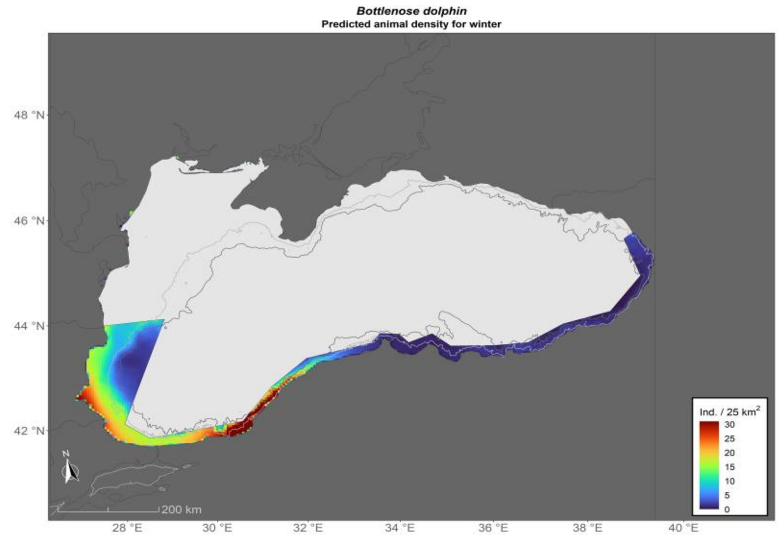


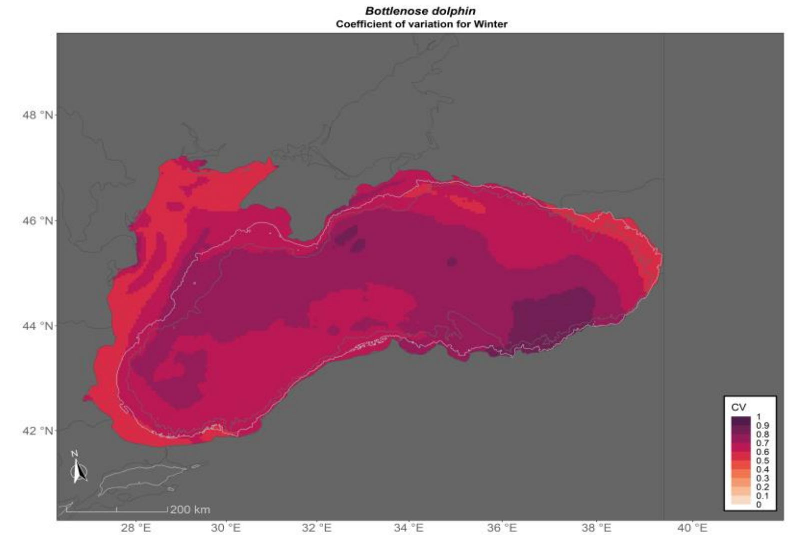


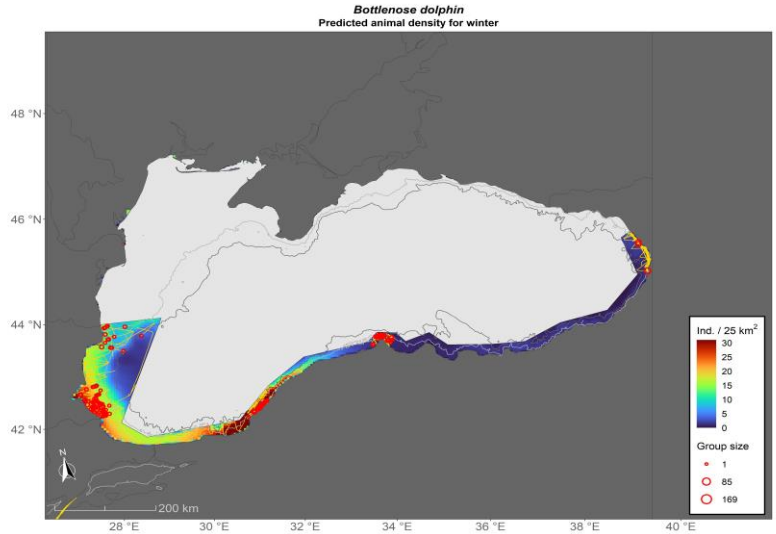


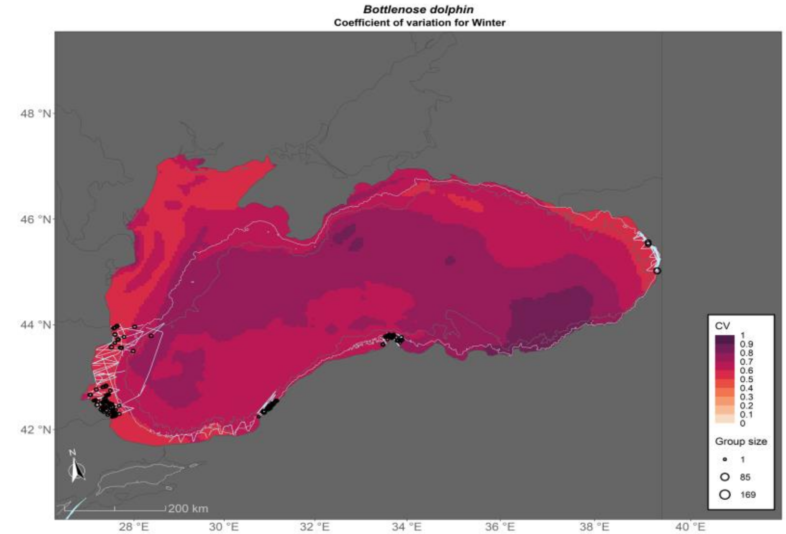
Black Sea - Bottlenose dolphin

Plots of predicted density and CV for Winter









Azov - Bottlenose dolphin

Estimated abundance and uncertainty

Number of observations: 436

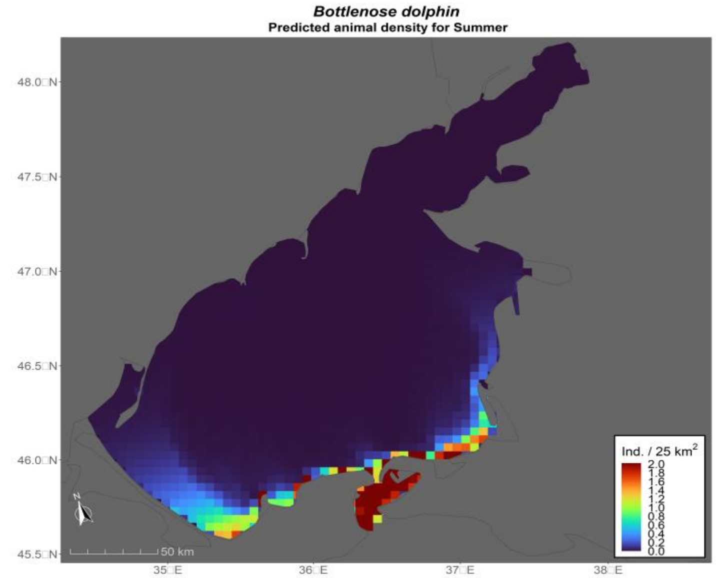
Number of individuals: 1073

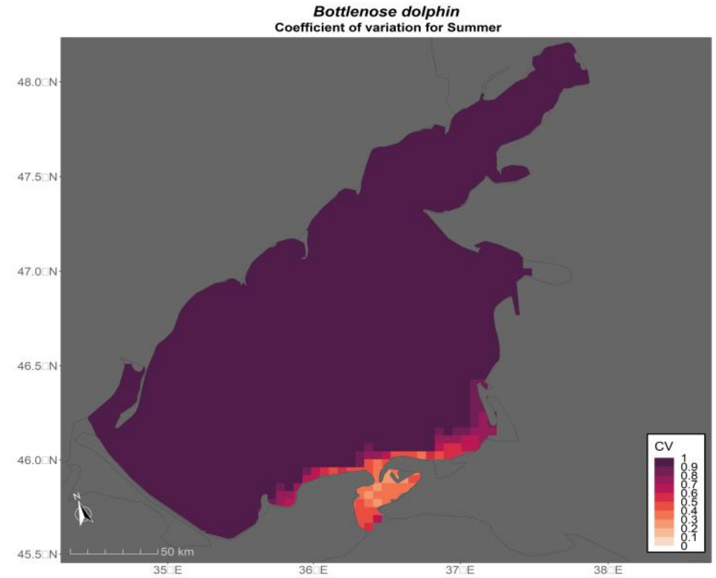
Covariates: Depth + Lon,Lat

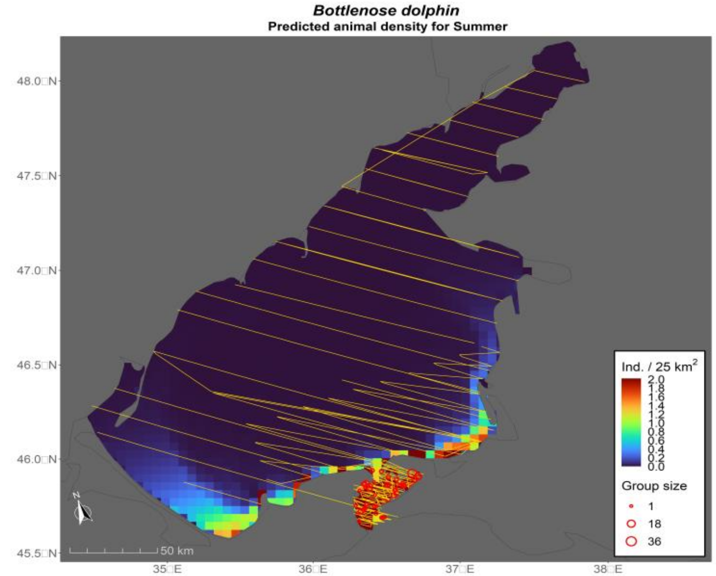
Block.name	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Azov	217	0.005731	0.3204	437	1,300

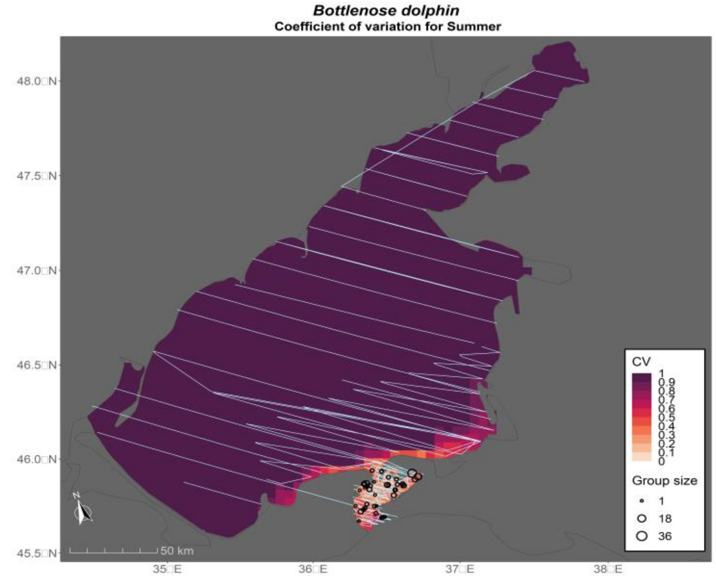
Azov - Bottlenose dolphin

Plots of predicted density and CV









Common dolphin

Black Sea - Common dolphin

Estimated abundance and uncertainty

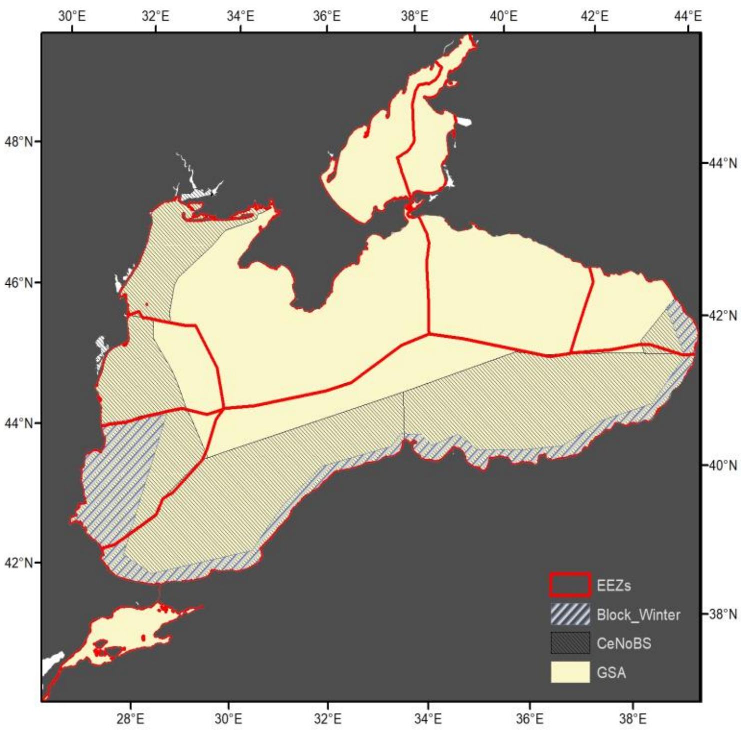
Number of observations: 2326

Number of individuals: 8437

Covariates: Ssh + Sst + Sst_sd + Lon,Lat

Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Summer	276,344	0.685833	0.2400	189,296	439,901
Winter	245,408	0.609380	0.2322	170,288	386,059
AllYear	260,876	0.647606	0.2439	177,648	417,946

Block.name	density	pred_model	cv	L95ci_abundance	U95ci_abundance
BS_coastal_winter	0.706125	37,121	0.2554	25,191	61,443
EEZ_BS_Bulgaria	0.412253	14,313	0.2836	8,814	23,454
EEZ_BS_Georgia	1.107736	25,345	0.2787	15,912	41,711
EEZ_BS_Romania	0.383939	11,350	0.3206	6,590	19,603
EEZ_BS_Russia	0.619936	31,631	0.2722	19,893	51,116
EEZ_BS_Turkey	0.753787	130,066	0.2509	85,001	204,427
EEZ_BS_Ukraine	0.432713	47,521	0.2878	29,290	78,944
GSAs_BlackSea	0.619278	259,740	0.2450	170,676	402,937
MSFD_Romania	0.384878	11,377	0.3204	6,611	19,652
StudyArea_CENOBS	0.648352	**142,747**	0.2526	**92,358**	**223,306**



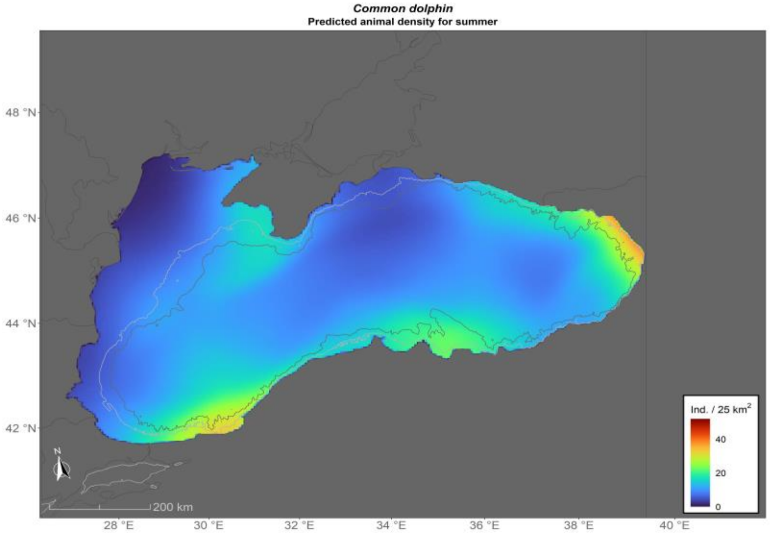
CENOBS: 108,283

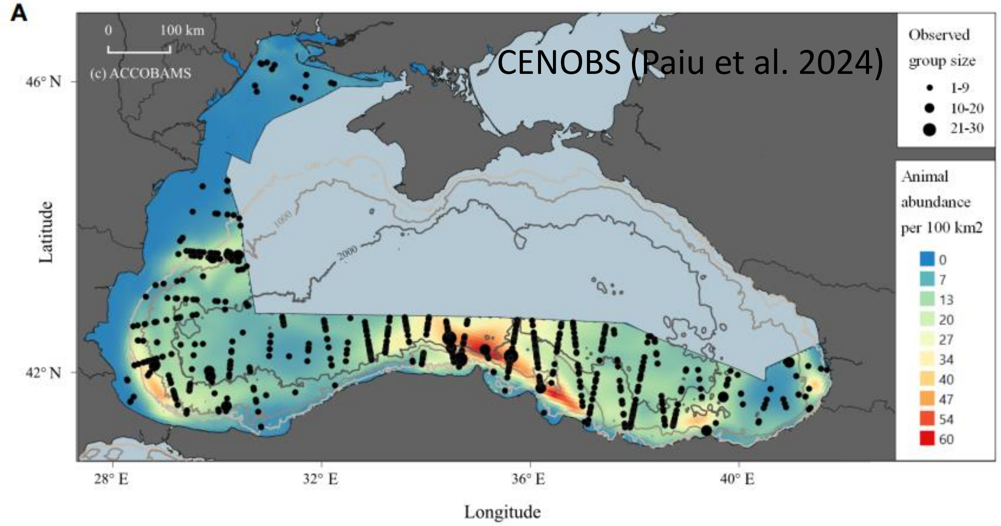
Corr. factor: 0.725

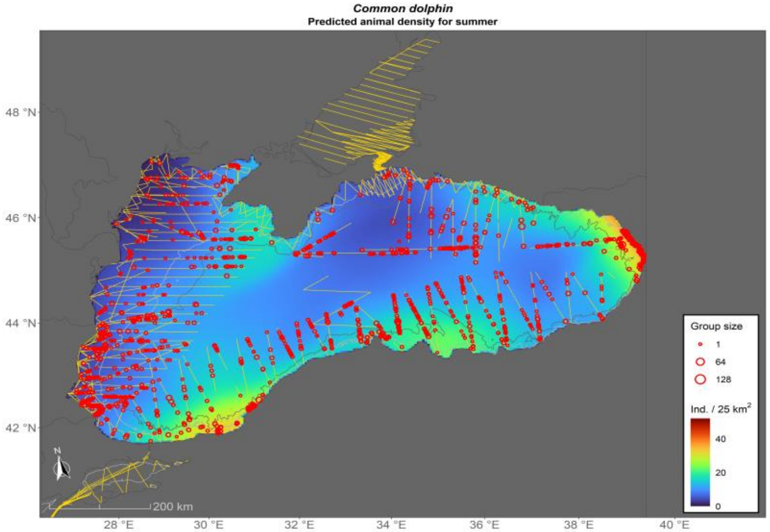
CENOBS corrected: **149,356**

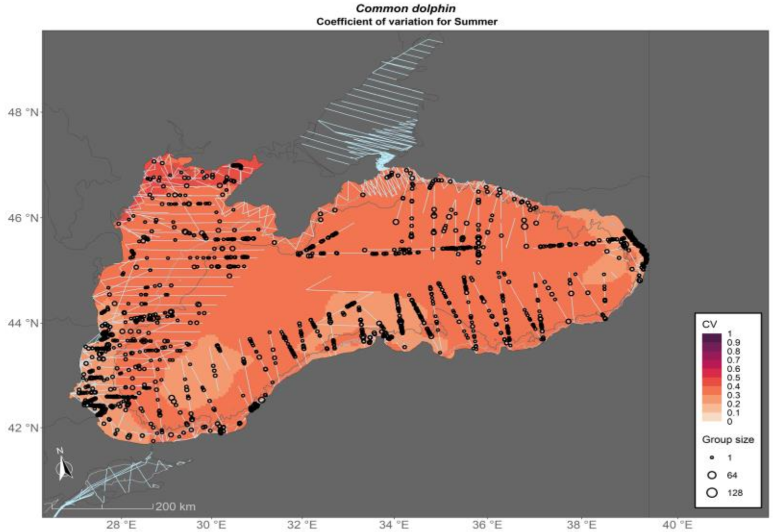
Black Sea - Common dolphin

Plots of predicted density and CV for for Summer



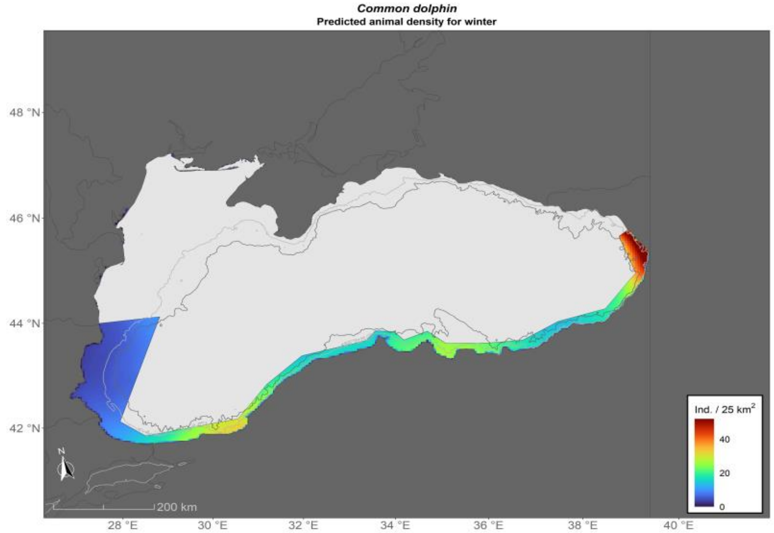


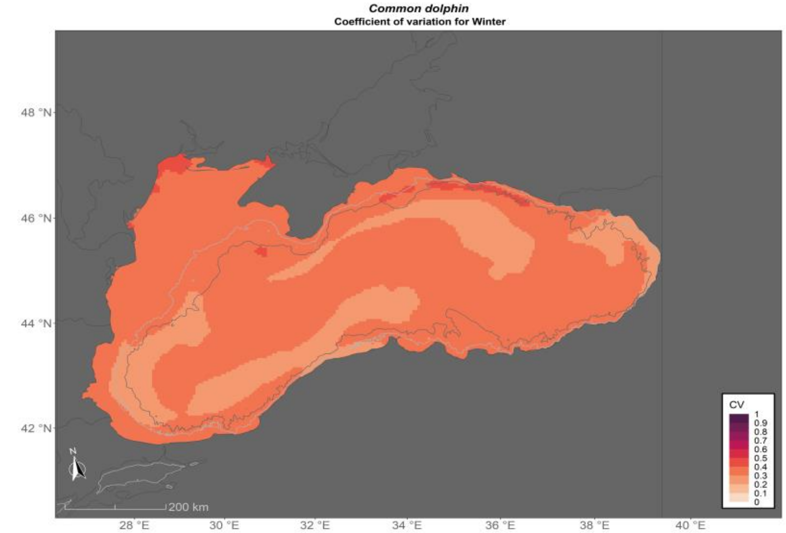


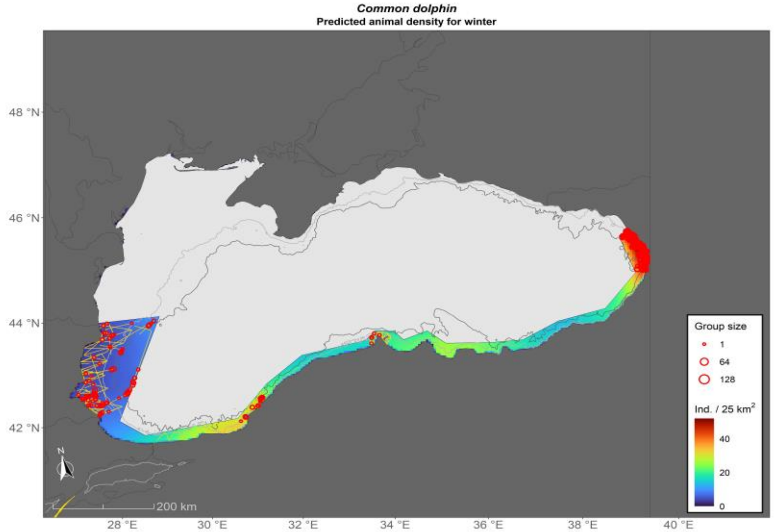


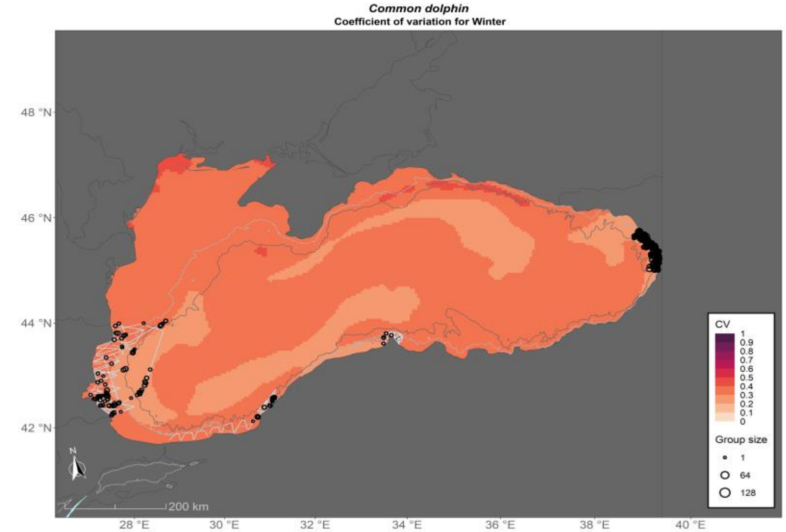
Black Sea - Common dolphin

Plots of predicted density and CV for Winter









Harbour porpoise

Black Sea – Harbour porpoise

Estimated abundance and uncertainty

Number of observations: 2074

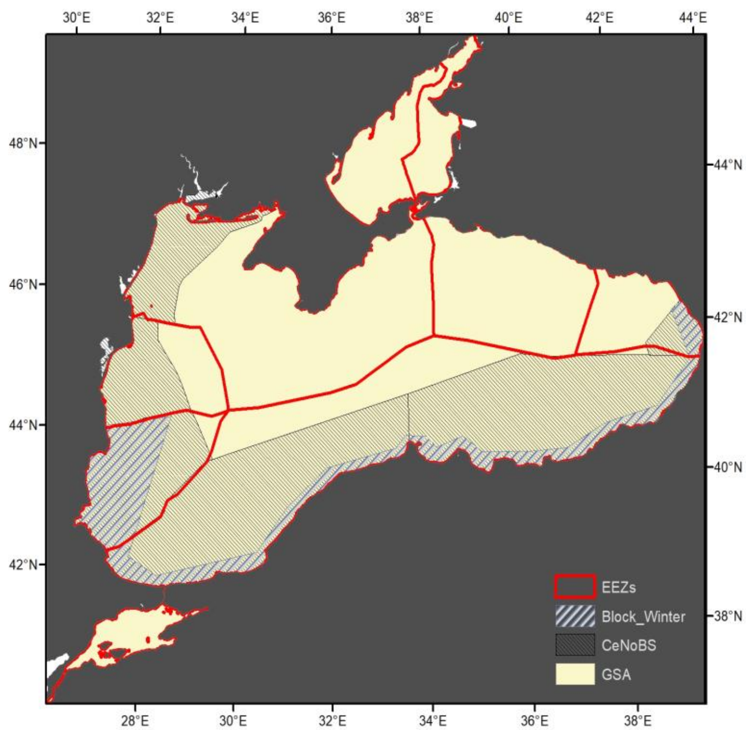
Number of individuals: 3542

Covariates summer: Chl + Ssh + Sst + Sst_sd + Lon,Lat

Covariates winter: Depth + Sst_sd

Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Summer	392,406	0.980151	0.3466	230,152	738,976
Winter	351,859	0.919042	0.4338	190,830	783,579

Block.name	density	pred_model	cv	L95ci_abundance	U95ci_abundance
BS_coastal_winter	2.012155	105,779	0.3702	59,811	205,576
EEZ_BS_Bulgaria	1.963622	68,175	0.3030	40,964	115,608
EEZ_BS_Georgia	1.206731	27,610	0.2757	17,431	45,276
EEZ_BS_Romania	1.217475	35,991	0.2947	21,782	59,950
EEZ_BS_Russia	0.114341	5,834	0.3731	3,157	10,943
EEZ_BS_Turkey	1.174425	202,647	0.4198	103,812	410,181
EEZ_BS_Ukraine	0.466040	51,181	0.3164	30,071	88,337
GSAs_BlackSea	0.932360	391,054	0.3486	220,360	711,662
MSFD_Romania	1.208221	35,715	0.2951	21,618	59,573
StudyArea_CENOBS	1.335174	**293,964**	0.3607	**162,920**	**544,908**



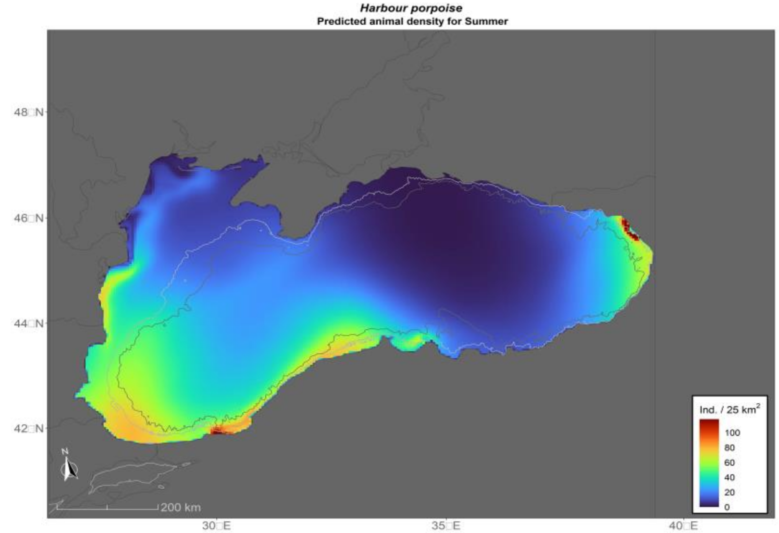
CENOBS: 93,808

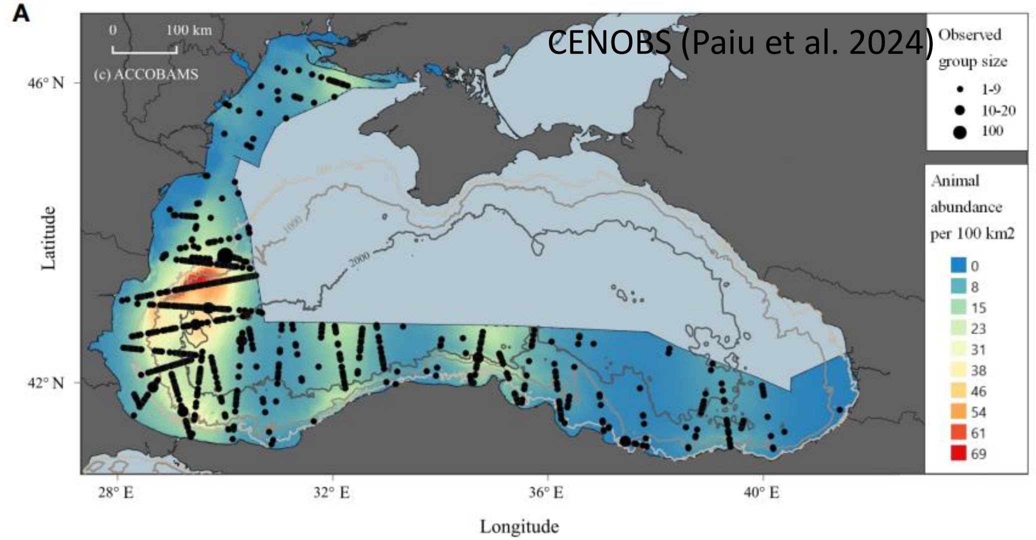
Corr. factor: 0.315

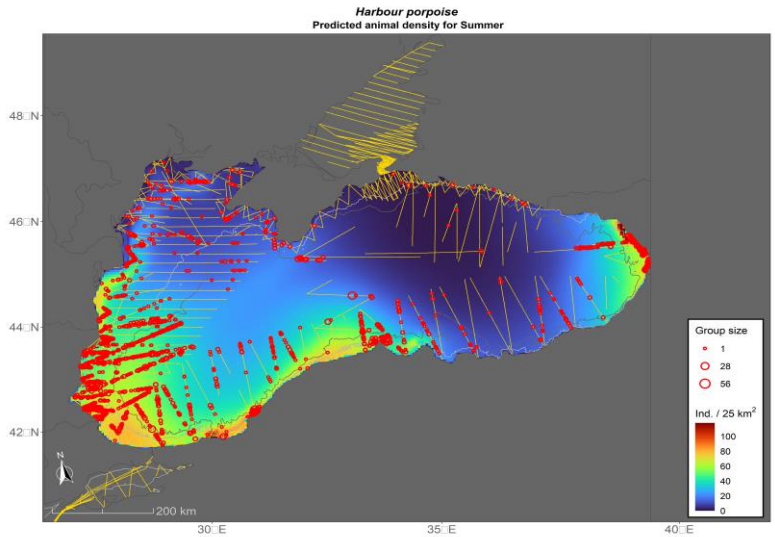
CENOBS corrected: **297,803**

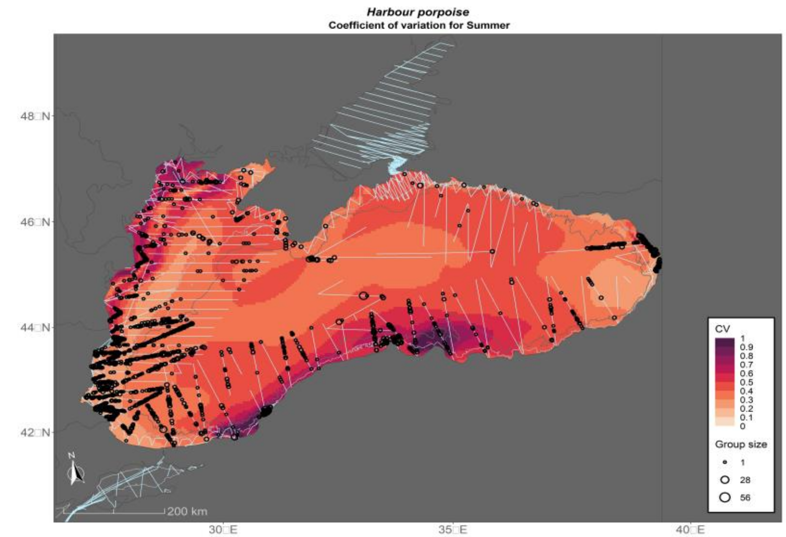
Black Sea – Harbour porpoise

Plots of predicted density and CV for for Summer









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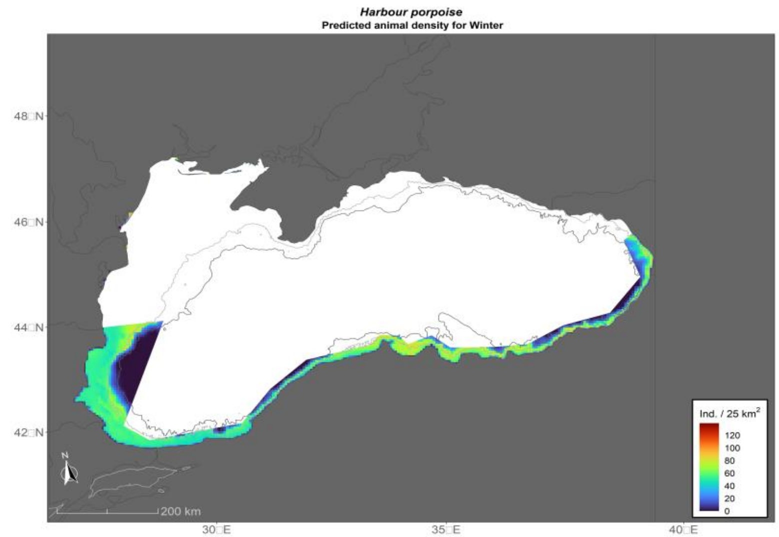
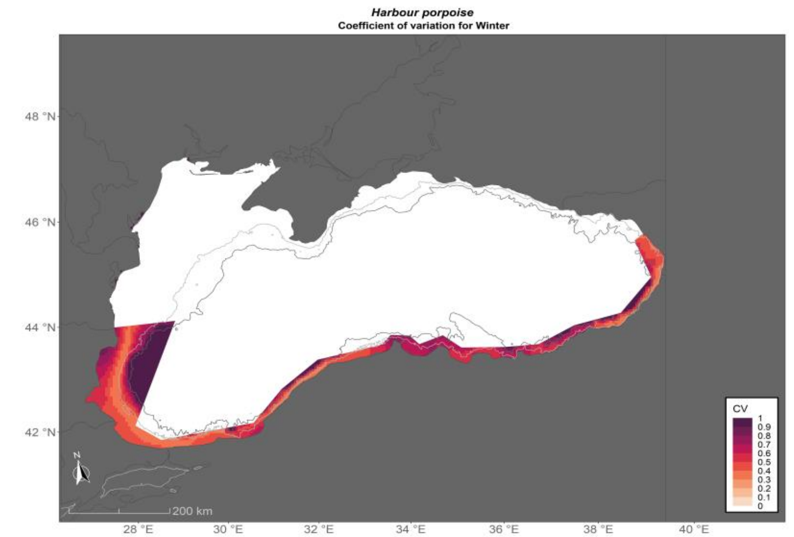
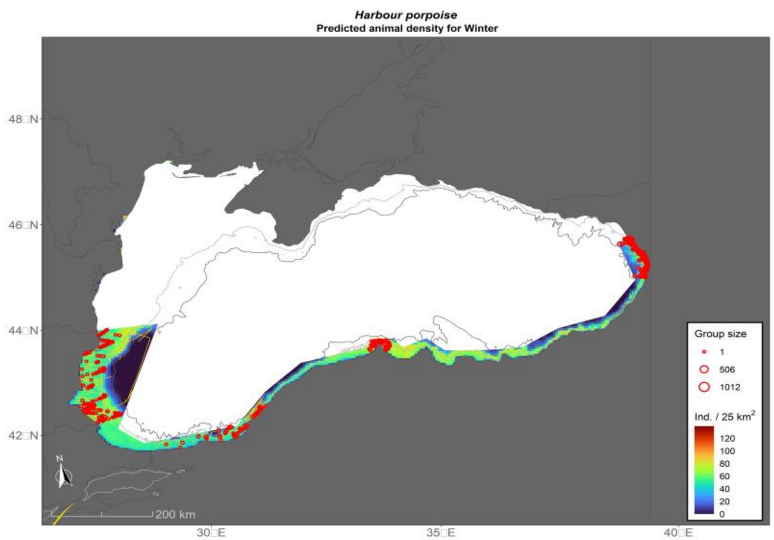
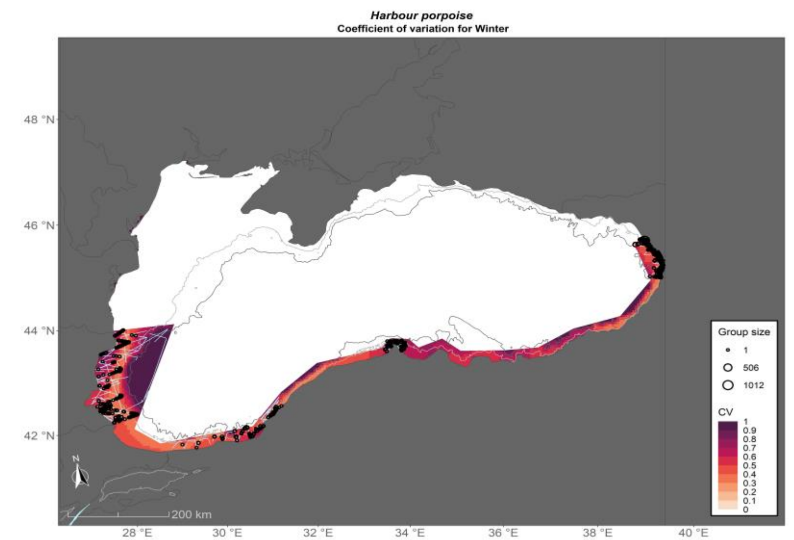
Black Sea – Harbour porpoise

Plots of predicted density and CV for Winter









Azov – Harbour porpoise

Estimated abundance and uncertainty

Number of observations: 900

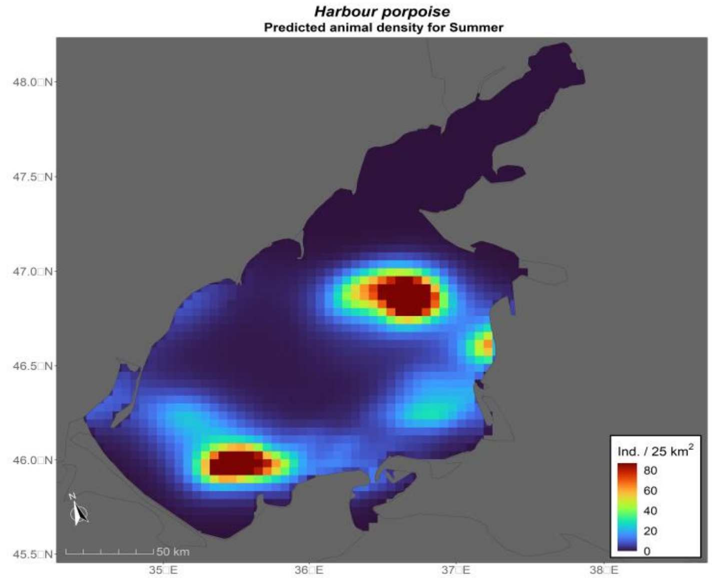
Number of individuals: 1450

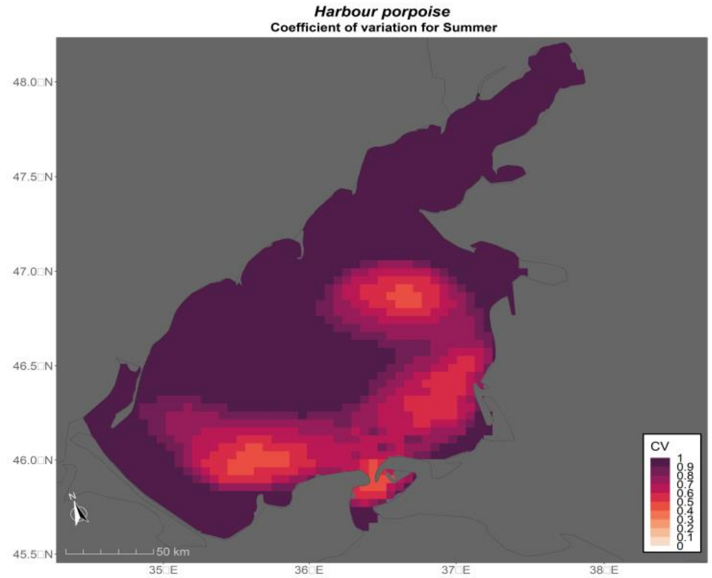
Covariates: Lon,Lat

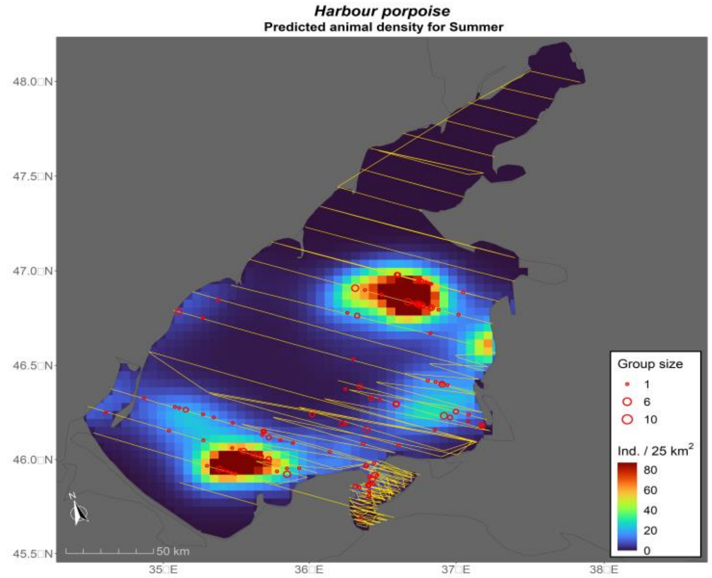
Block.name	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Azov	16,742	0.442123	0.1385	13,551	22,532

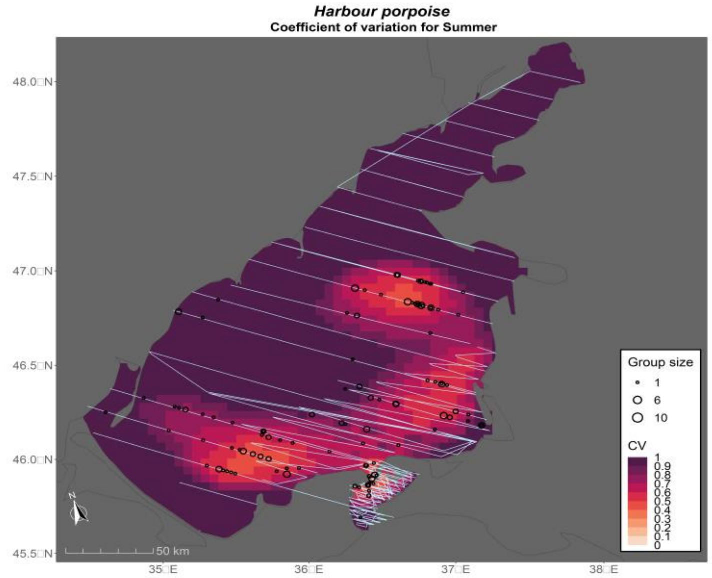
Azov – Harbour porpoise

Plots of predicted density and CV









Mediterranean Sea

Collaborators

Effort

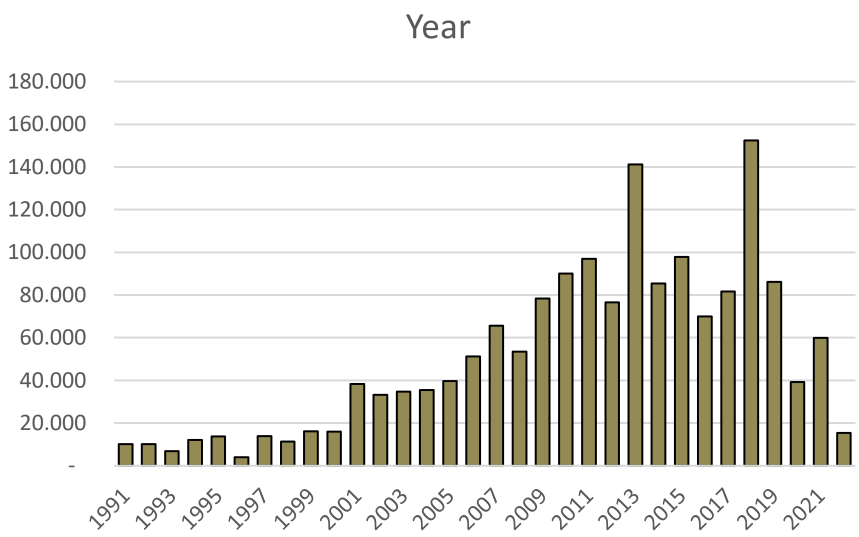
Collaborator	Area Covered	Platform	Range of years	Effort (km)
Accademia del Leviatano	Western Med	Ship	2012-2018	73,540
ACCOBAMS	All Mediterranean	Plane	2018-2019	73,151
Acquario di Genova	Gulf of Genova (Italy)	Ship	2001-2021	76,808
Alnilam	Alboran Sea	Ship	2011	472
AlnitakAlnilam	Alboran Sea & SE Spain	Ship	1992-2010	74,980
ANSE	SE Spain	Ship	2003-2009	9,246
Archipelago	Greece	Ship	2017-2021	14,482
Association BREACH	Gulf of Lyon	Ship	2013-2016	3,723
Association Nereide	Strait of Gibraltar	Ship	2018	1,239
BDRI	Sardinia	Ship	2004-2013	12,638
BWI	Adriatic Sea	Plane,Ship	2004-2022	173,771
Capo Carbonara Marine Protected Area	Western Med	Ship	2013-2019	14,552
Caterina Fortuna	Italy	Ship	2004-2007	1,708
CE.TU.S	Thyrrenian Sea	Ship	2003-2019	24,773
CIMA Research Foundations	Ligurian Sea	Ship	2008-2020	84,339
CIRCE	Strait of Gibraltar	Ship	2001-2014	27,715
CNRS	Western Med	Ship	2006-2007	7,324
EcoOcean	Gulf of Lyon	Ship	1998-2015	33,025

Collaborators (cont.)

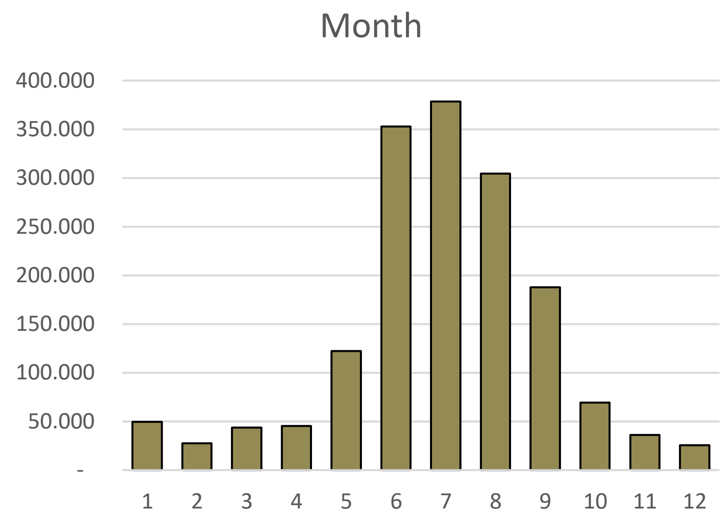
Effort

Collaborator	Area Covered	Platform	Range of years	Effort (km)
Gaia Research Institute & University of Torino	Eastern Med	Ship	2014-2016	15,772
IAMC	Italy	Ship	2011-2017	1,448
Ibrahem Benamer	Lybia, Tunisia	Ship	2014-2016	2,377
ICCAT	All Mediterranean	Plane	2011-2021	163,603
IMMRAC	Israel	Ship	1999-2020	45,312
ISPRA	Italy	Plane	2002-2020	11,350
Istambul University	Turkey	Ship	2005-2015	1,232
Ketos	Thyrrenian Sea	Ship	2013-2015	7,405
MCR	All Mediterranean	Ship	1994-2017	32,661
MERIS	Italy	Ship	2016-2018	1,455
MIRACETI	France	Ship	2004-2018	44,173
Morigenos	Slovenia	Ship	2008-2017	21,865
NURC	All Mediterranean	Ship	1999-2011	19,135
Oceanomare	Thyrrenian Sea	Ship	2001-2020	70,462
Pelagis	Gulf of Lyon	Plane	2011-2012	31,272
Pelagos	Greece	Ship	1999-2021	30,828
Stazione Zoologica di Napoli	Thyrrenian Sea	Ship	2019-2021	1,952
SUBMON	NE Spain	Ship	2009-2021	5,899
TCR	Turkey	Ship	2005-2008	6,277
Tethys	Central Med, Ionian Sea	Plane, Ship	1990-2021	324,693
Tursiops	Balearic Islands	Ship	2003-2019	30,102
University of Valencia	East Spain	Plane	2000-2021	40,481
Università di Palermo	Thyrrenian Sea	Ship	2016-2019	16,626
University of Barcelona	Western Med	Ship	2018-2020	7,585
University of Pisa	Thyrrenian Sea	Ship	2020-2022	1,598
			TOTAL	**1,643,048**

Collaborators



Total survey effort (km) per year available in the Mediterranean



Total survey effort (km) per month available in the Mediterranean

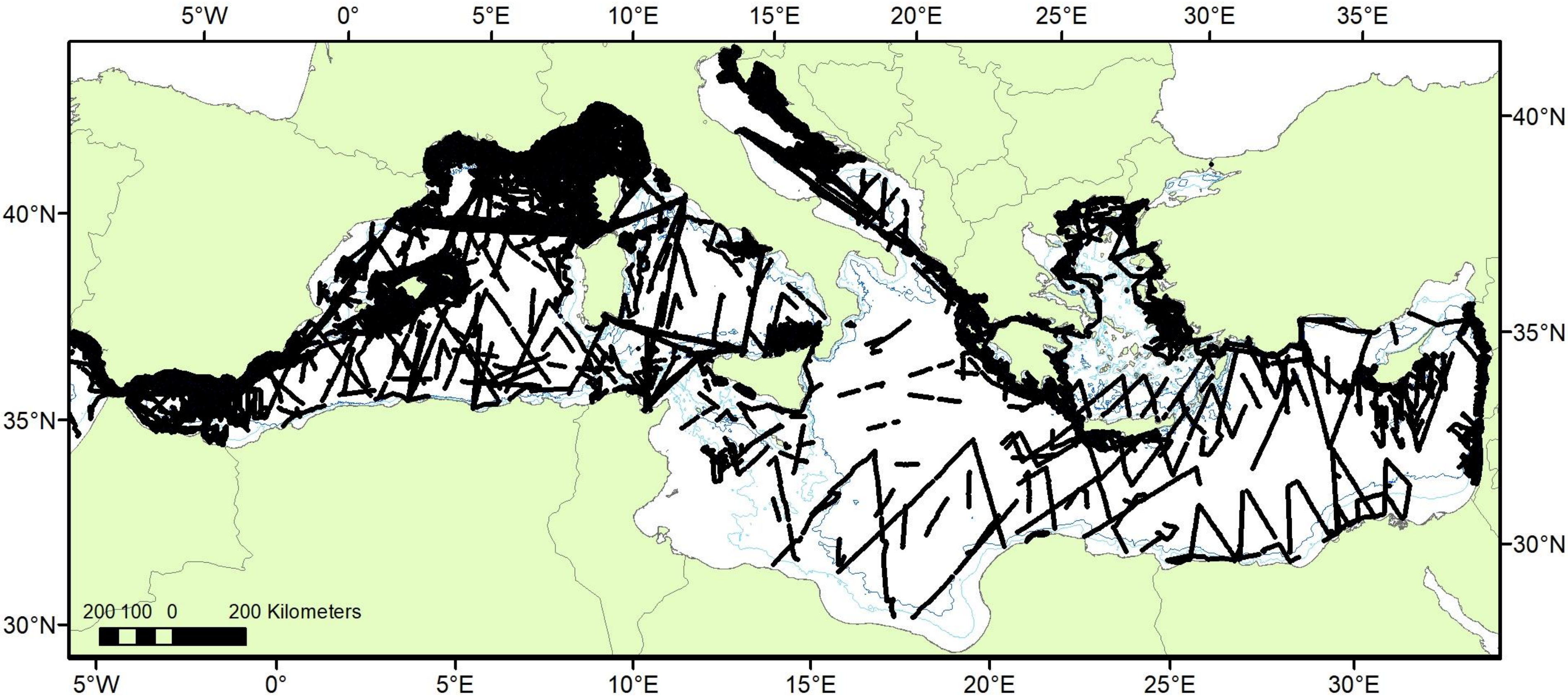
Collaborators

Sightings

CommonName	Adriatic	Aegean	Alboran	Ionian	Levantine	WMed_noAlb	Gibraltar	Total
Bottlenose beaked whale			4					**4**
Bottlenose dolphin	3277	228	525	1590	389	3681	446	**10136**
Common dolphin	6	220	1328	507	68	233	434	**2796**
Cuviers beaked whale	4	19	121	52	41	430		**667**
False killer whale			1		1	1		**3**
Fin whale	2		54	5	2	3586	64	**3713**
Harbour porpoise		17					6	**23**
Humpback whale						1		**1**
Hybrid Striped-Common dolphin				19				**19**
Killer whale							103	**103**
Long-finned pilot whale			637	8		181	453	**1279**
Minke whale			2	1		1		**4**
Monk seal		4			1			**5**
Rissos dolphin	18	23	185	41	14	509	1	**791**
Rough toothed dolphin				4	1	4		**9**
Sperm whale		12	32	110	108	1355	477	**2094**
Striped and common dolphin				1				**1**
Striped dolphin	263	170	1861	599	159	13235	482	**16769**
Striped or common dolphin		7	26	8	4	241	3	**289**
Unidentified Balaenoptera						8		**8**
Unidentified beaked whale		2	29	3		33		**67**
Unidentified cetacean			2	22	1	41		**66**
Unidentified dolphin	10	85	486	97	33	764	17	**1492**
Unidentified large cetacean				1		58		**59**
Unidentified large dolphin	2					4		**6**
Unidentified large whale						2		**2**
Unidentified medium cetacean	2	2		2		37	2	**45**
Unidentified odontocete						41		**41**
Unidentified small cetacean	2			3		13		**18**
Unidentified small dolphin	50	8		33	17	317	29	**454**
Unidentified small whale				2				**2**
Unidentified whale			5	5	2	9		**21**
Total	**3636**	**797**	**5298**	**3113**	**841**	**24785**	**2517**	**40987**

Tracks

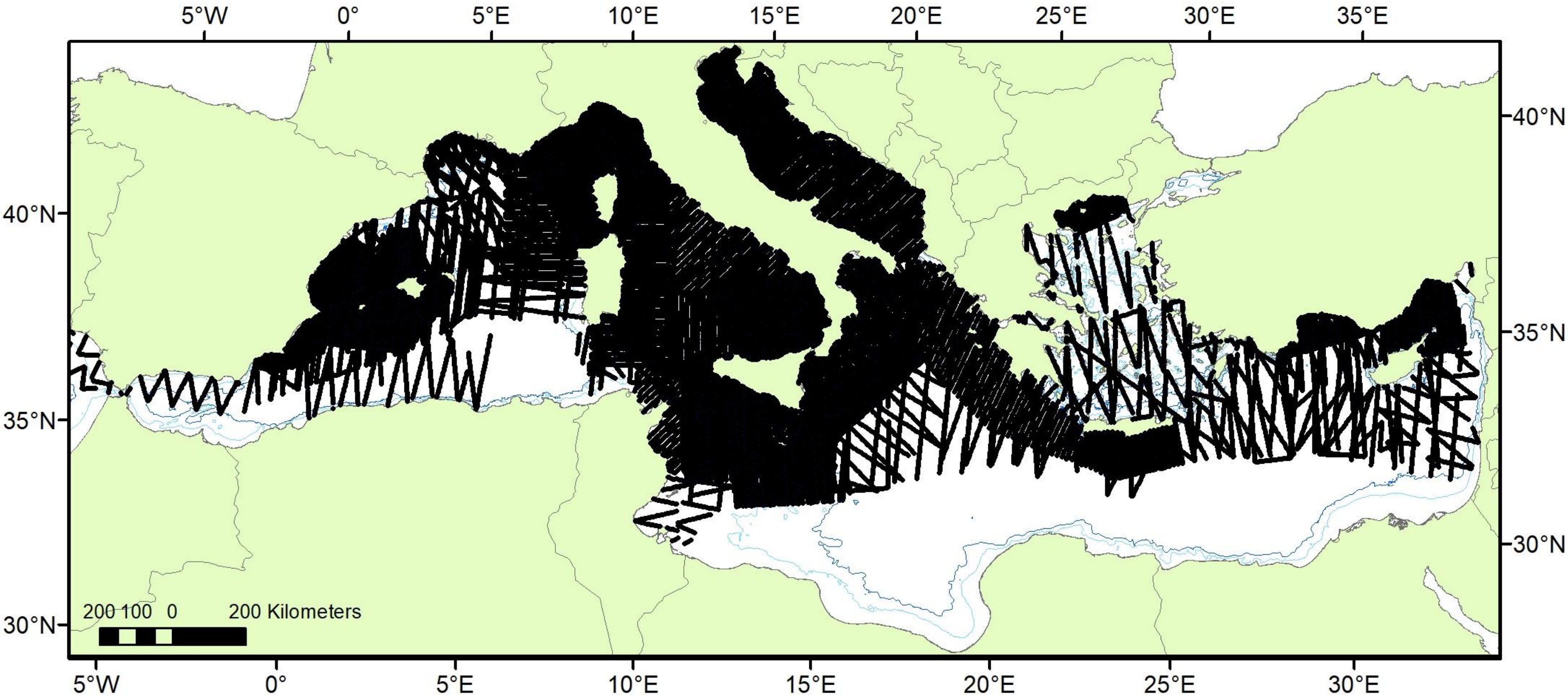
Ships



Ship-board surveys

Tracks

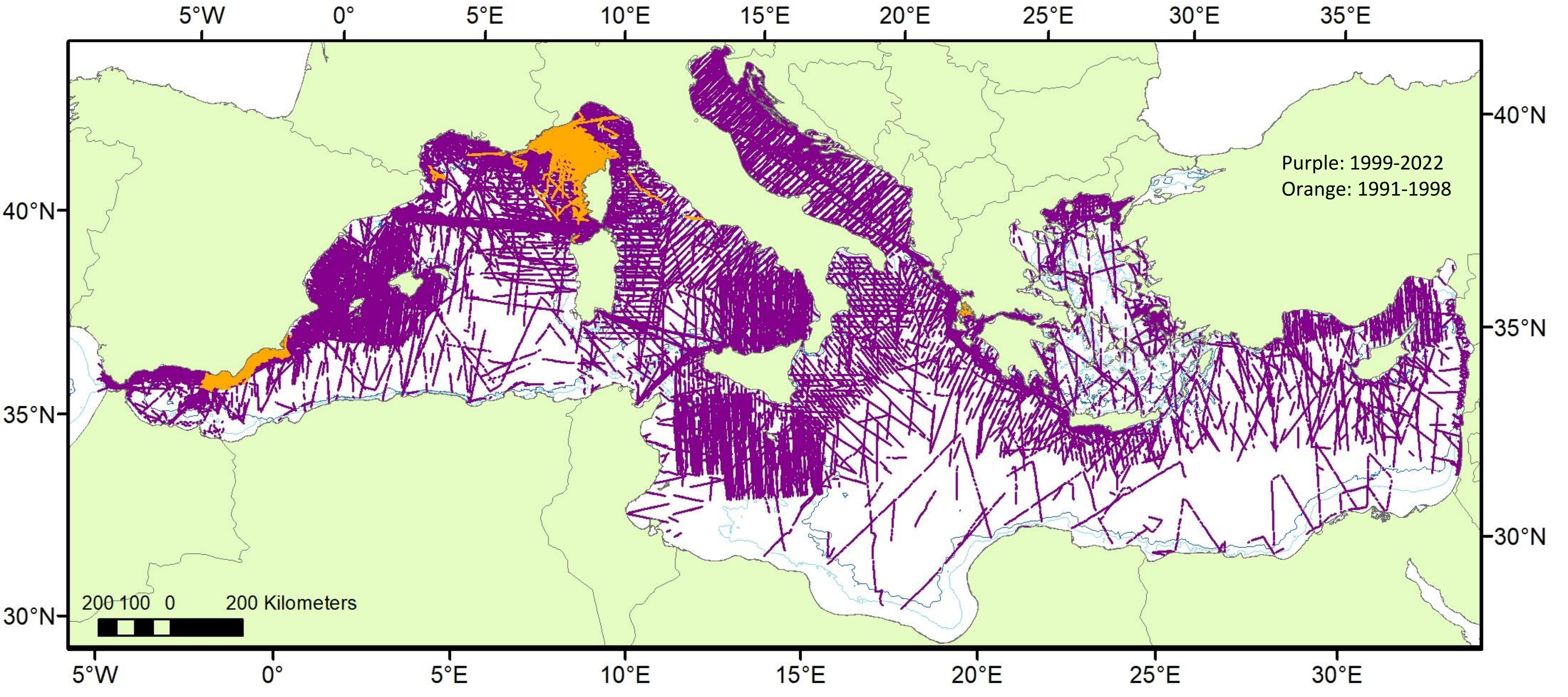
Planes



Aerial surveys

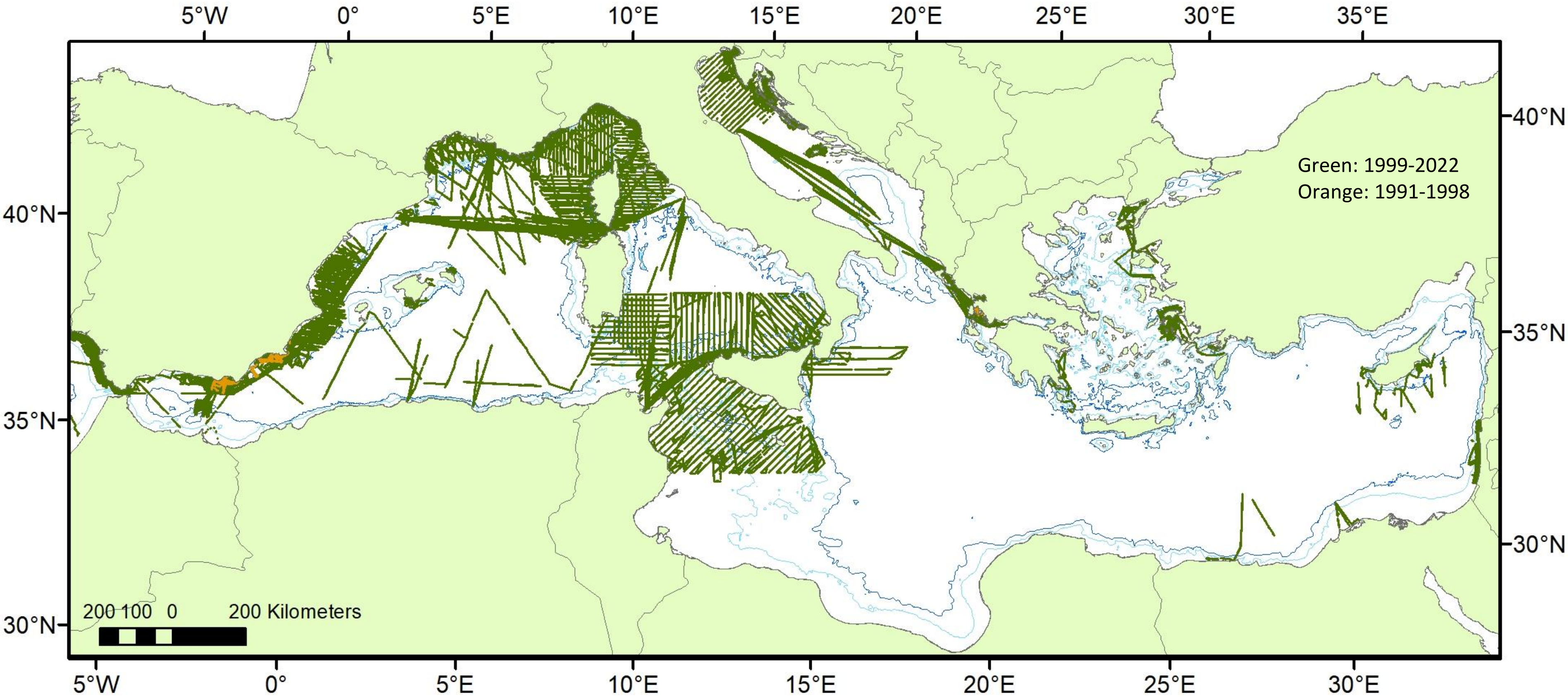
Tracks

Summer

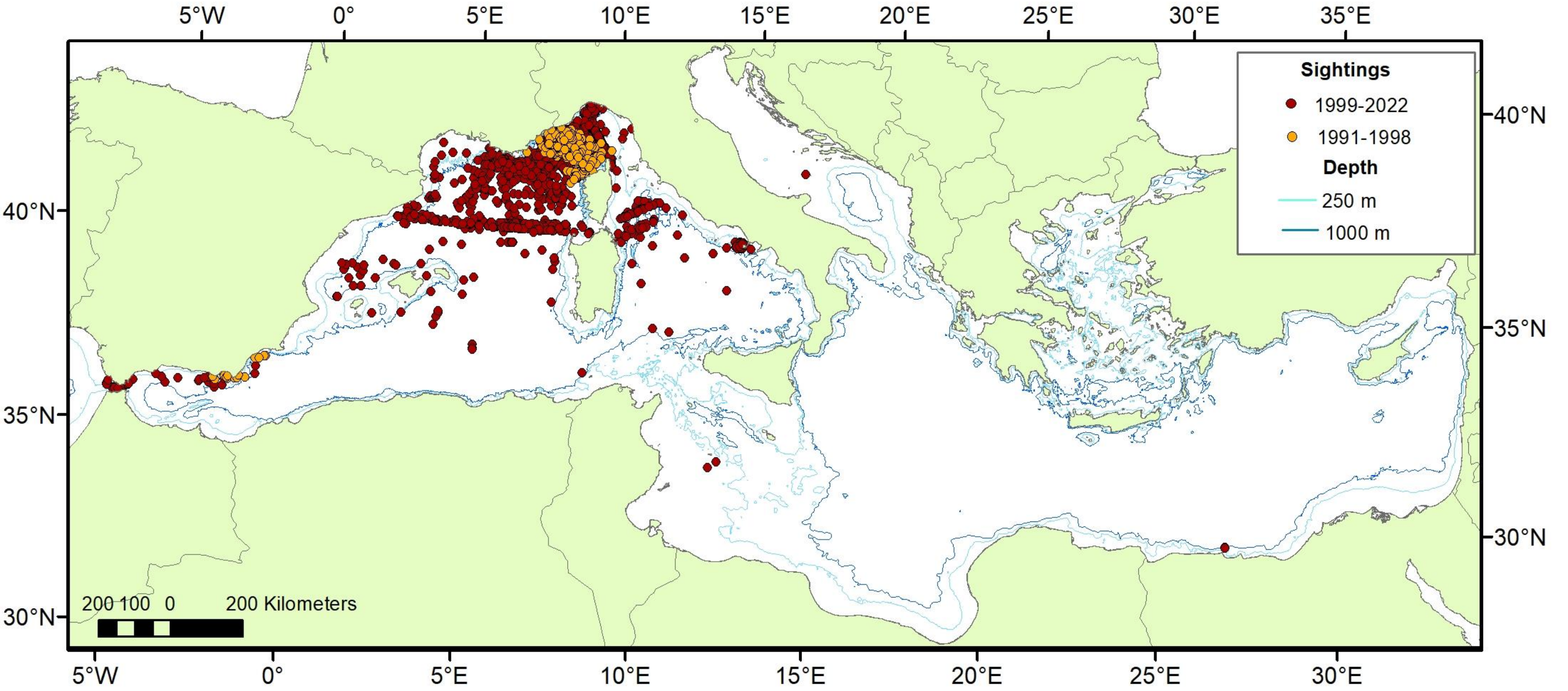


Tracks

Winter

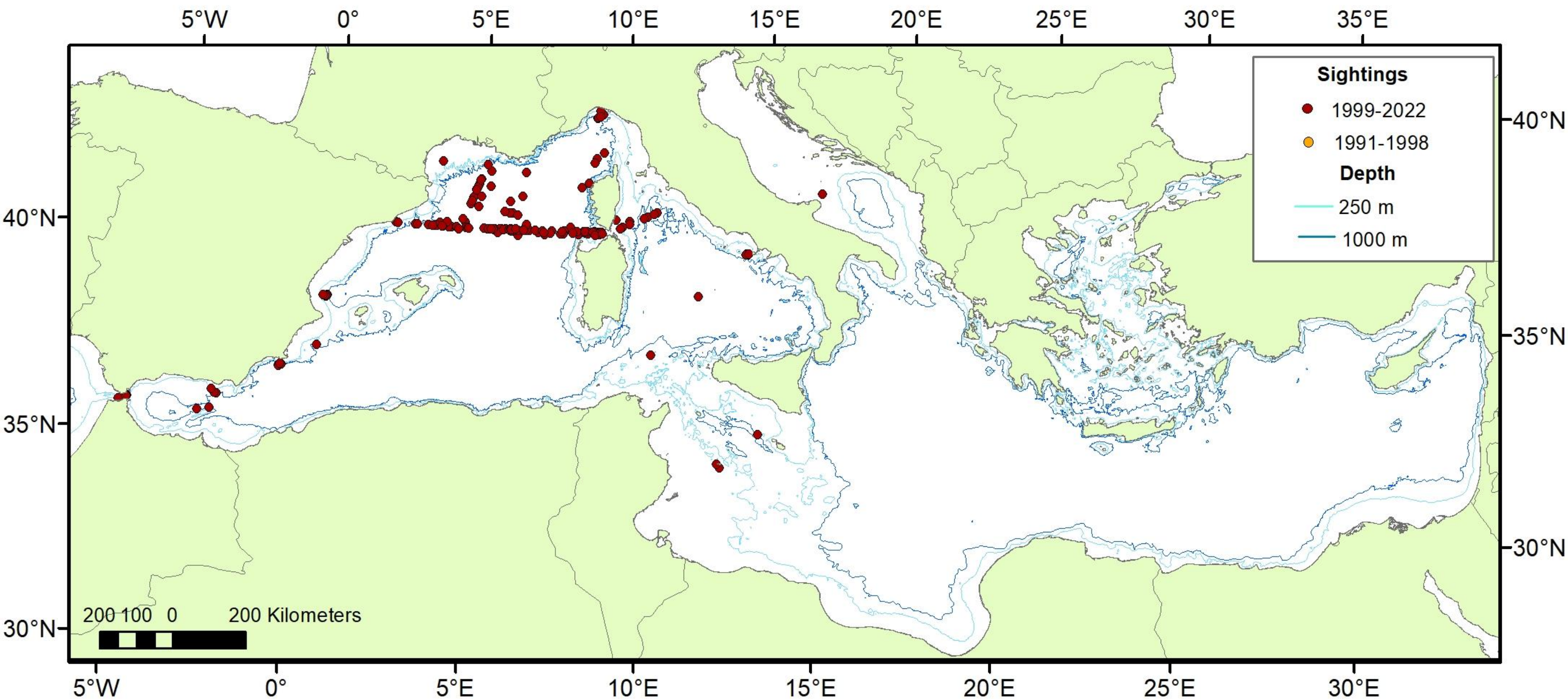


Observations



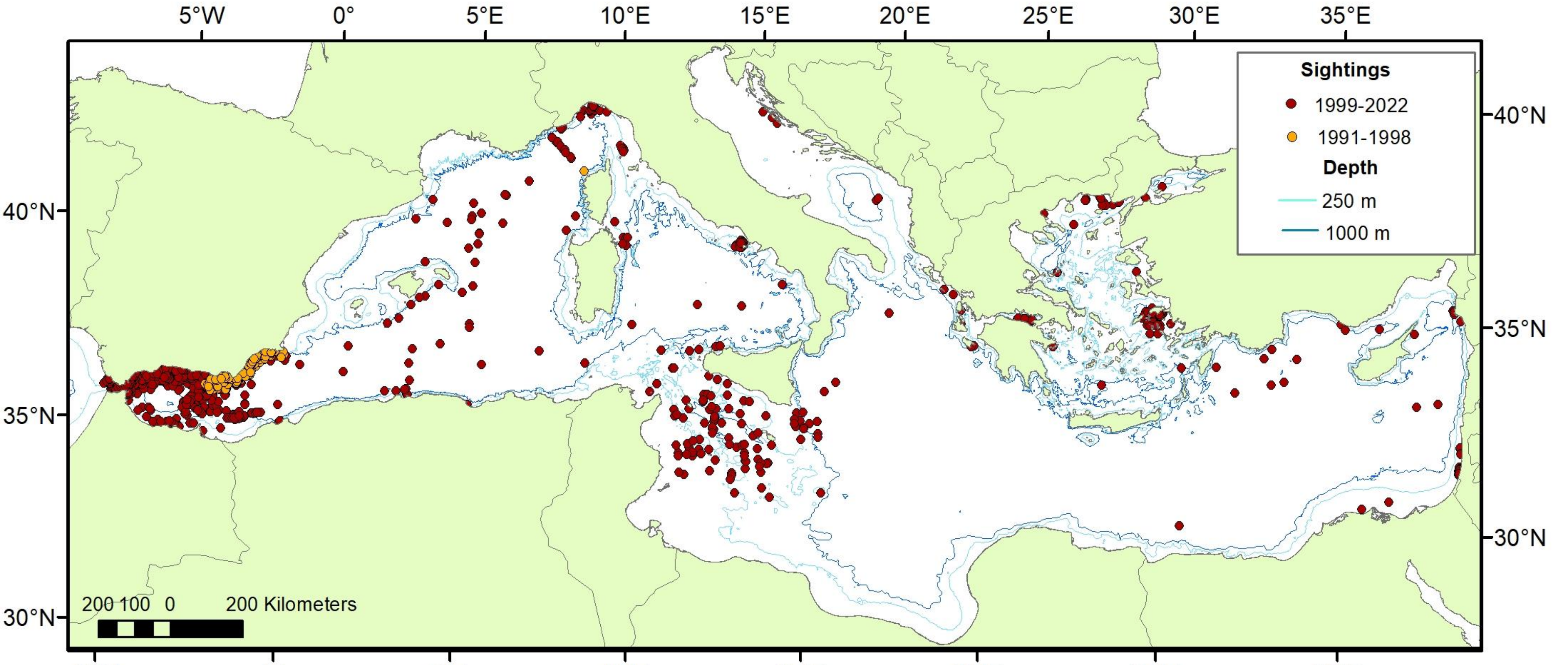
Sightings of Fin whale
Summer

Observations



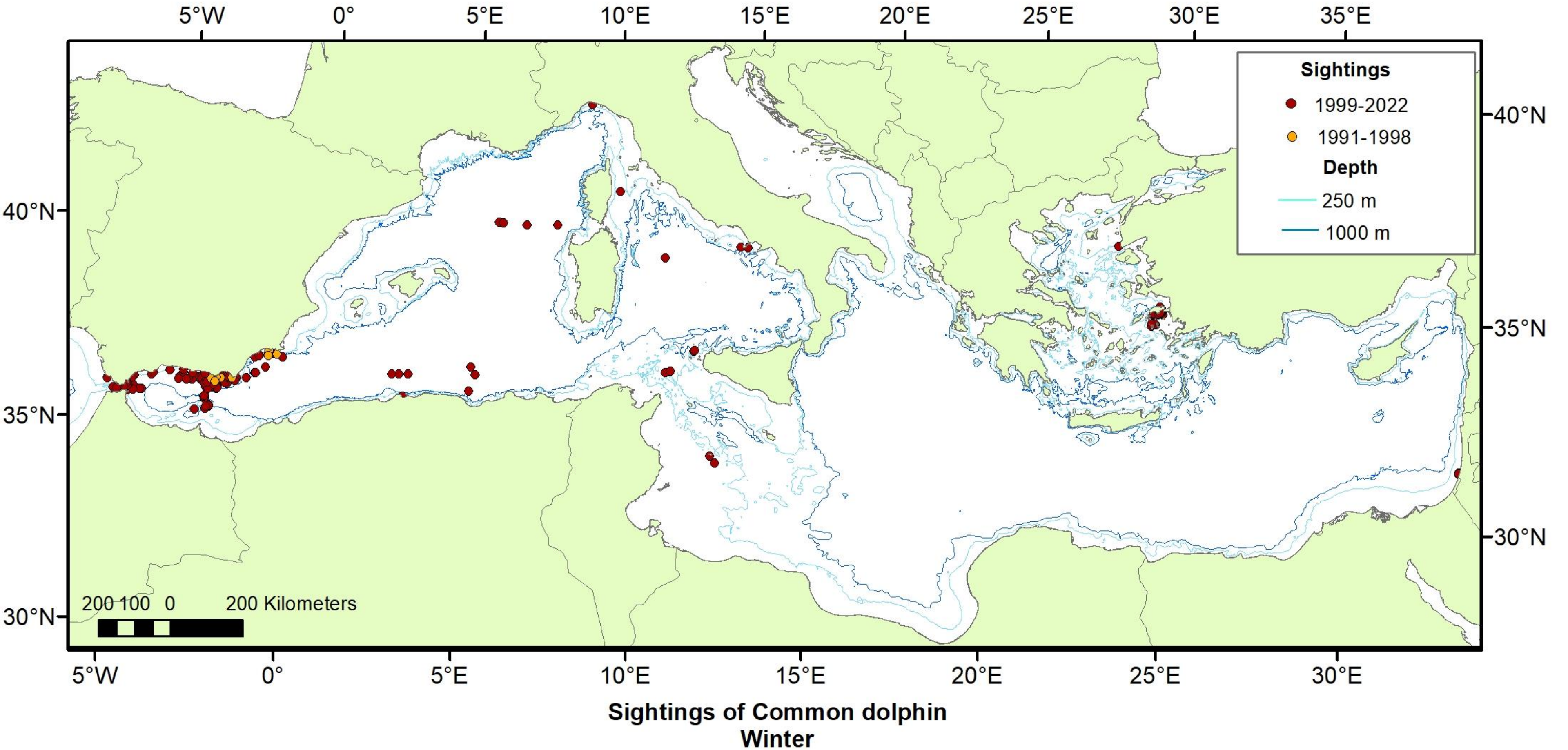
Sightings of Fin whale
Winter

Observations

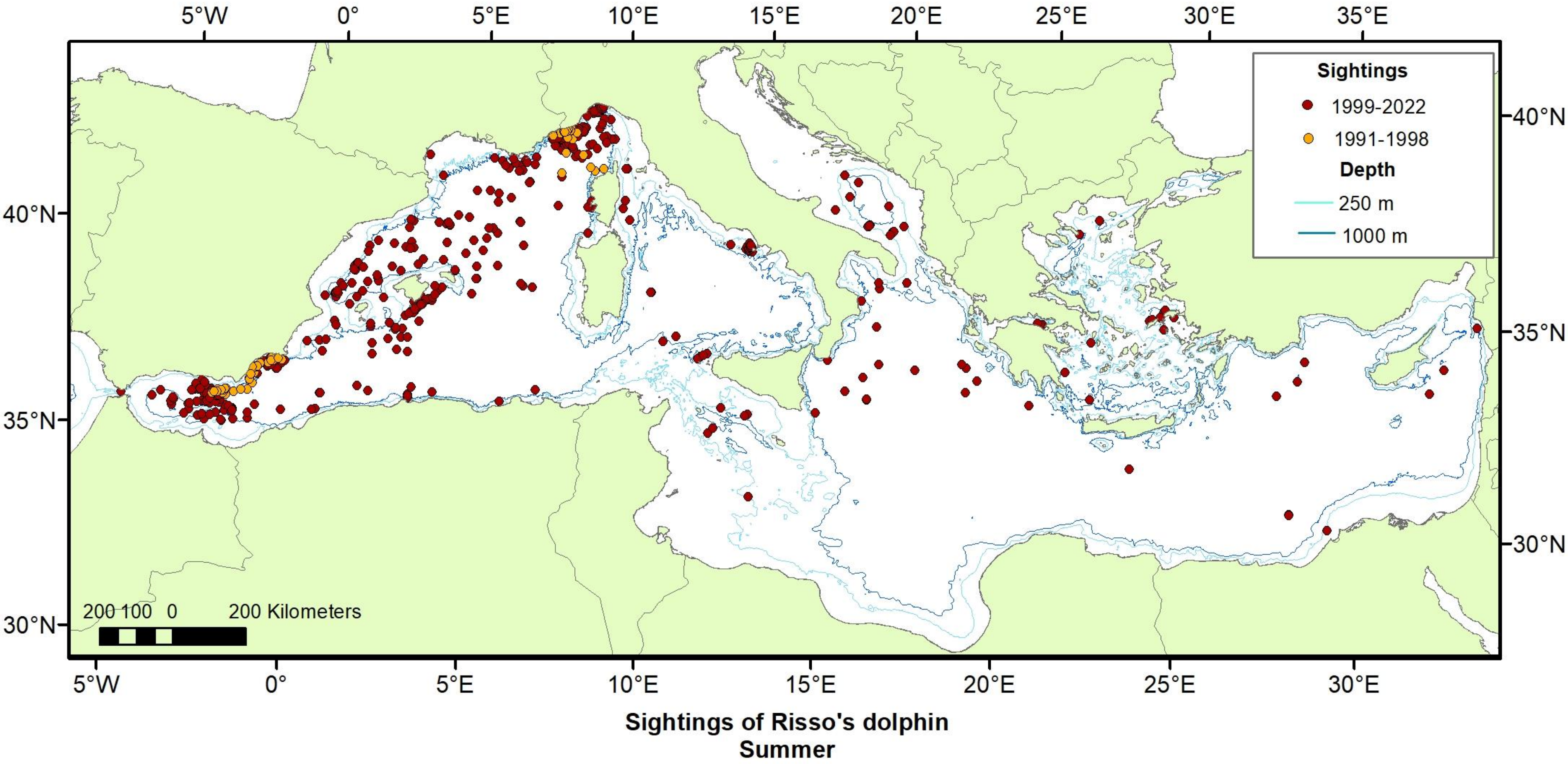


Sightings of Common dolphin
Summer

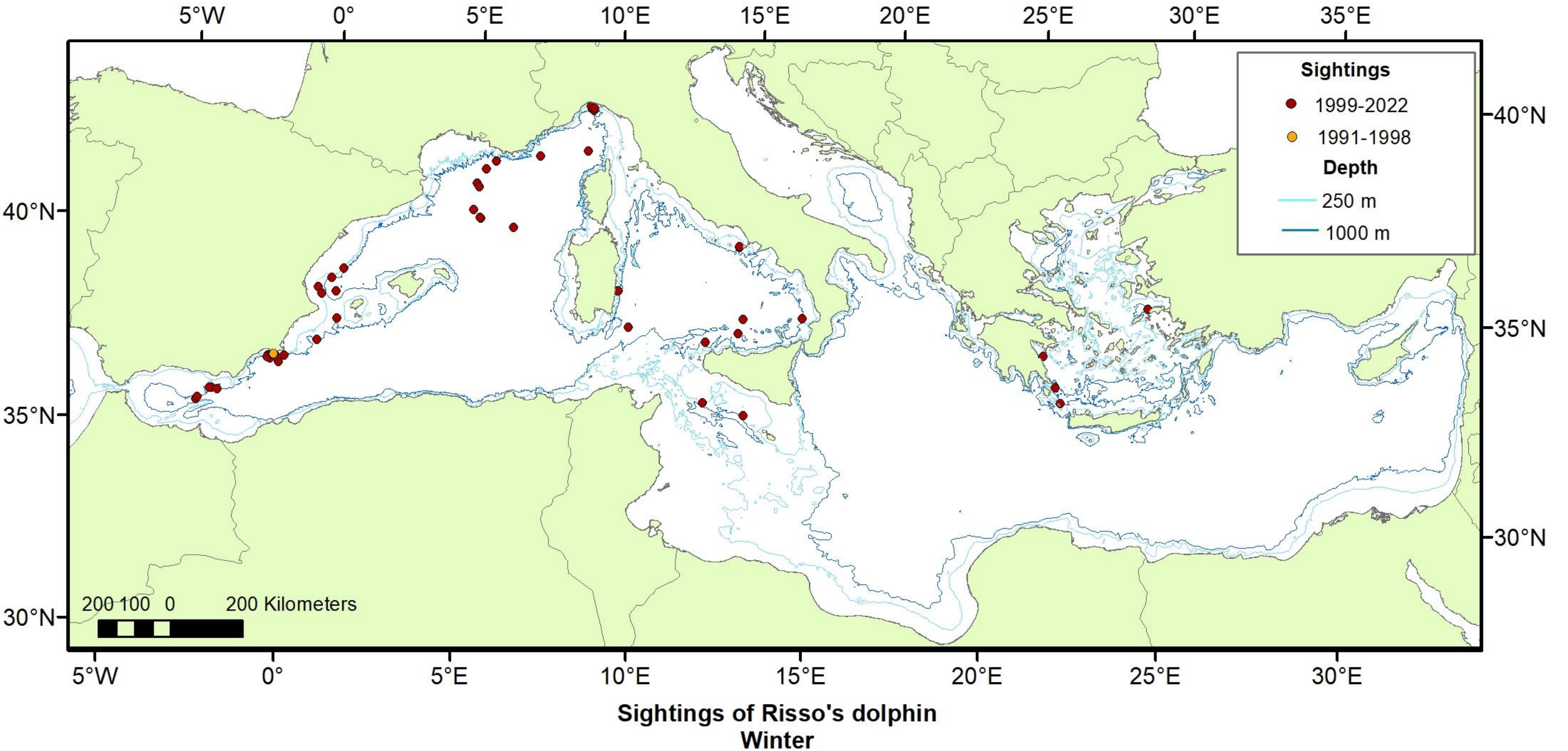
Observations



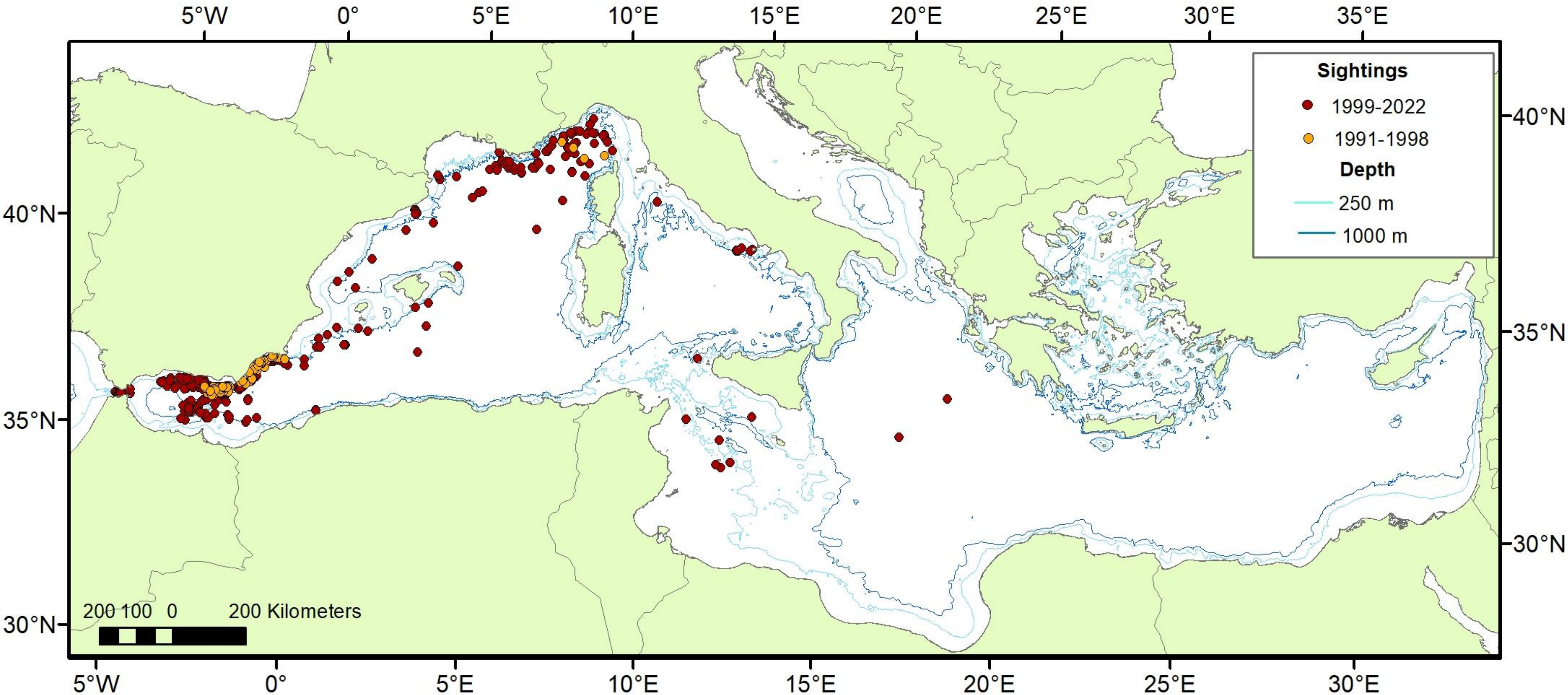
Observations



Observations

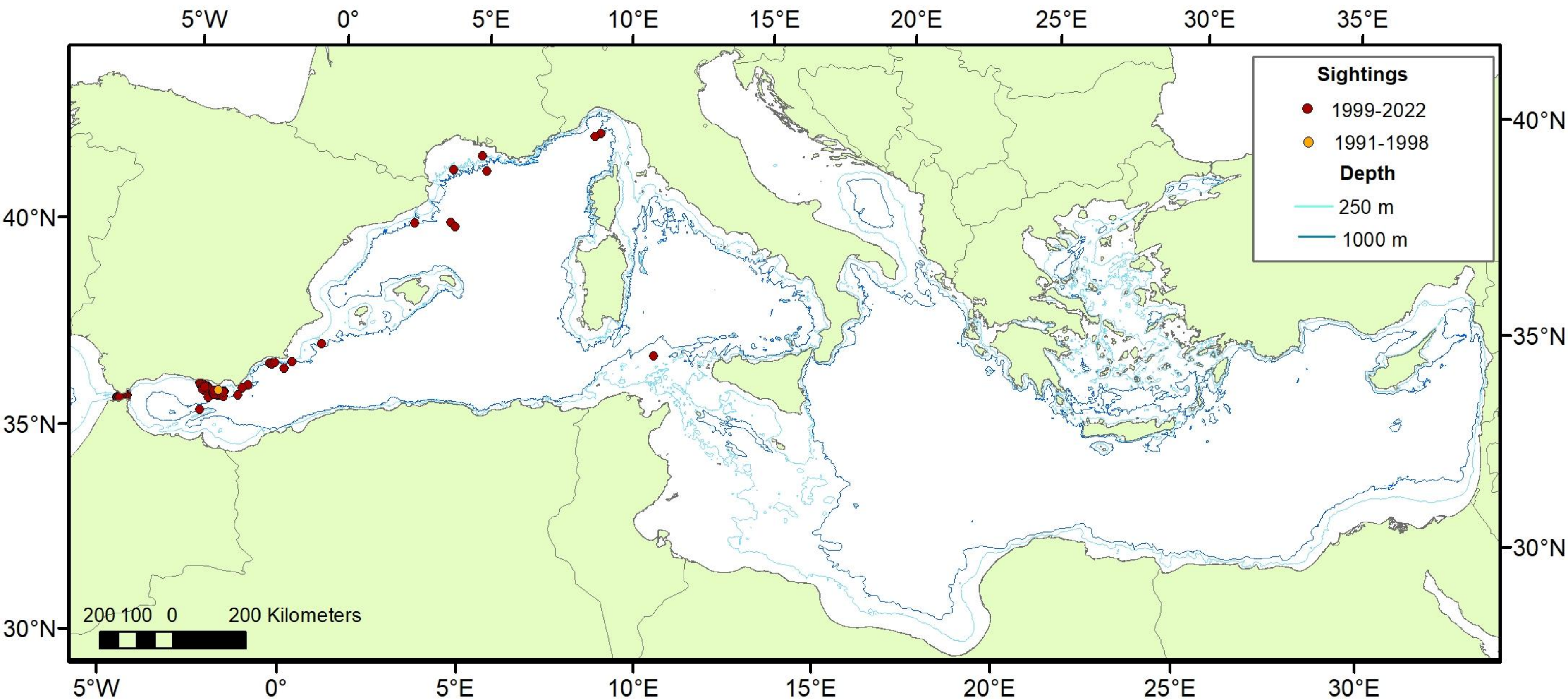


Observations



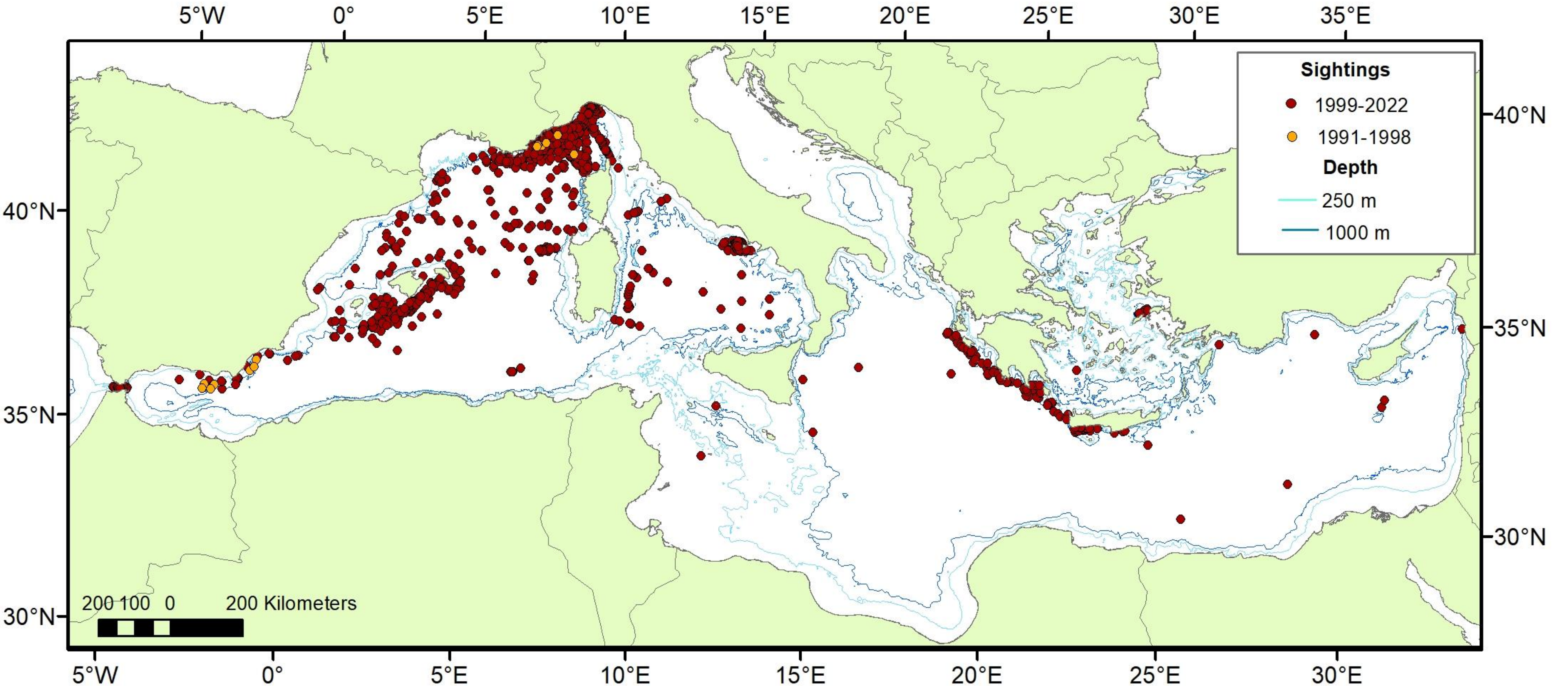
Sightings of Long-finned pilot whale
Summer

Observations



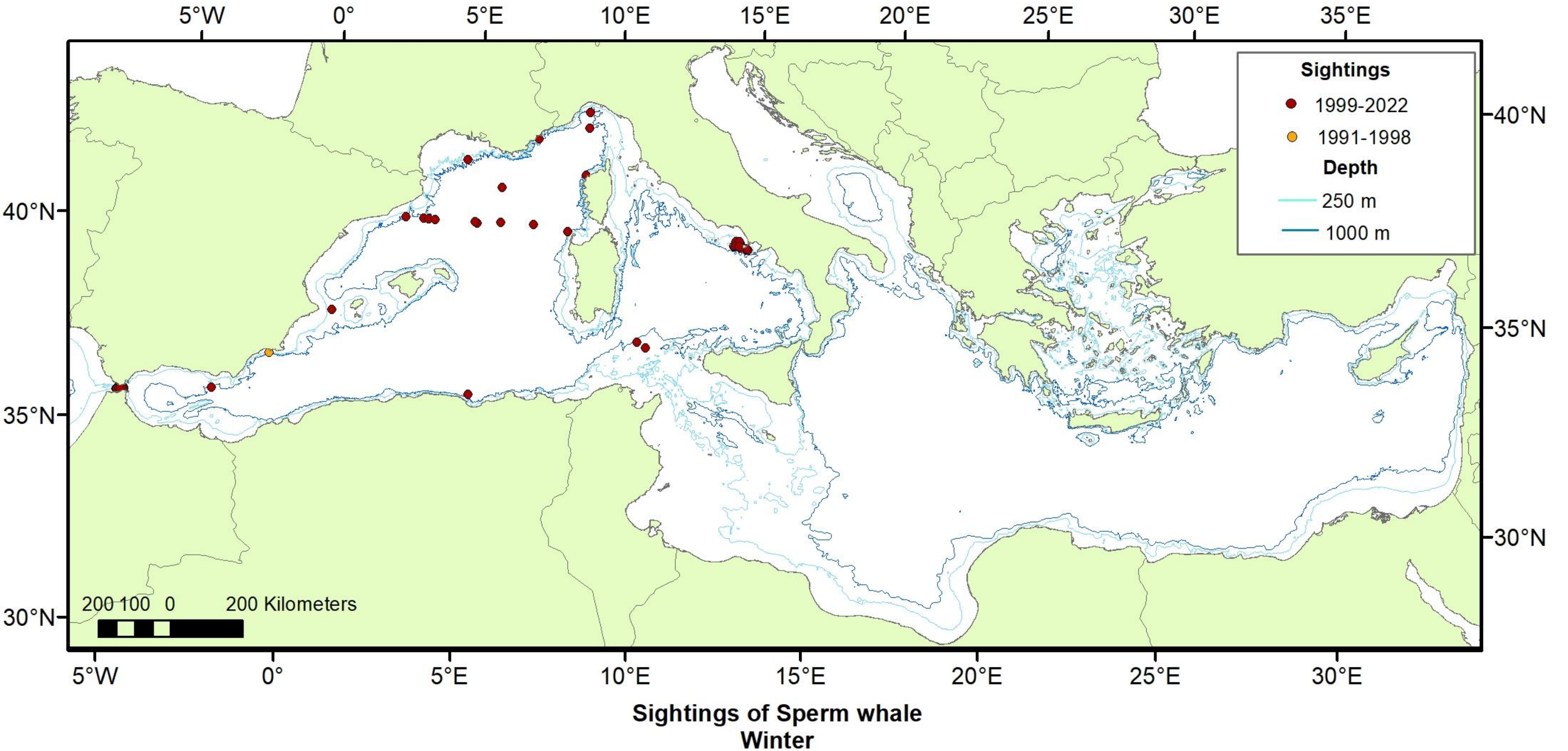
Sightings of Long-finned pilot whale
Winter

Observations

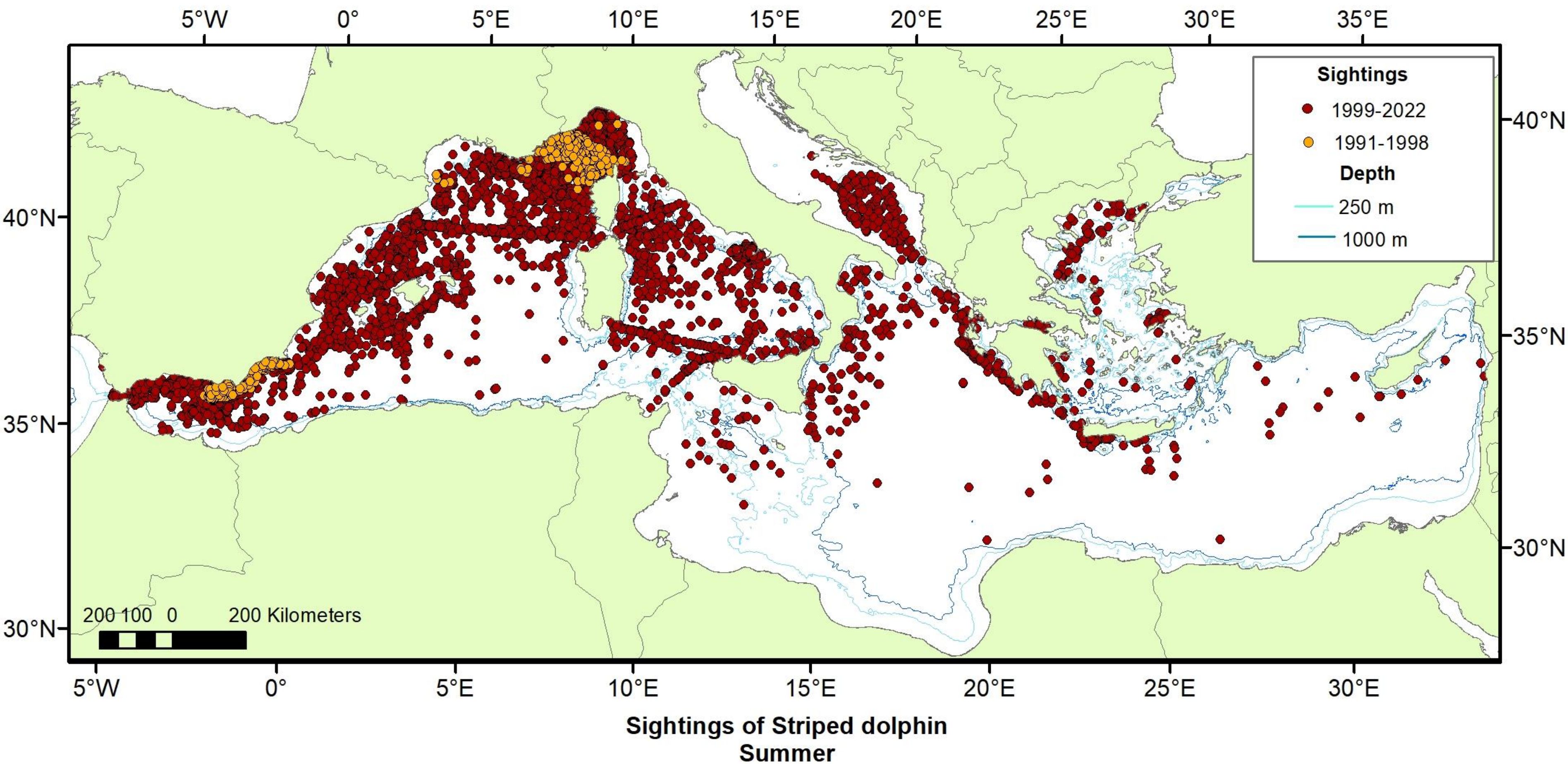


Sightings of Sperm whale
Summer

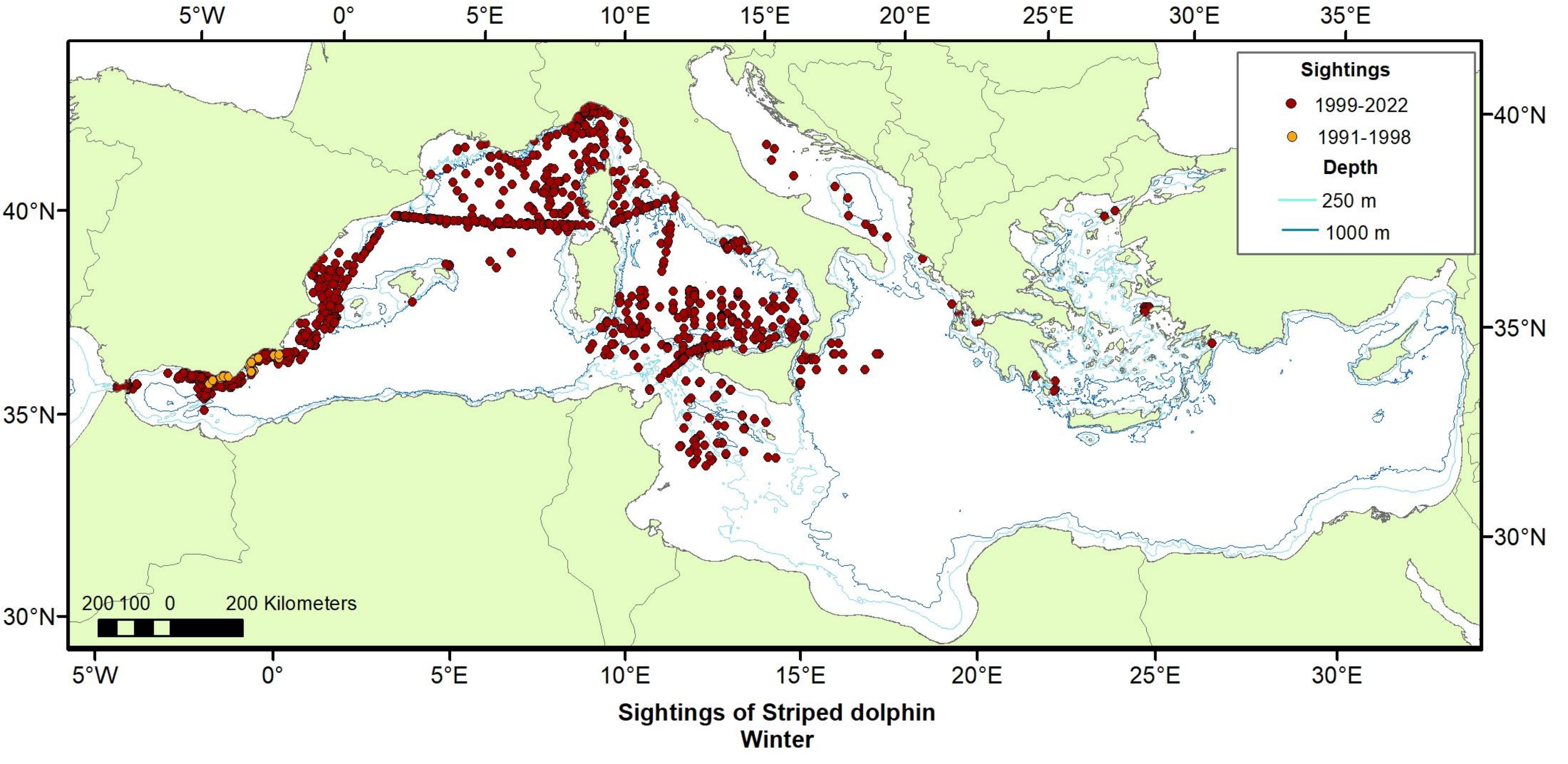
Observations



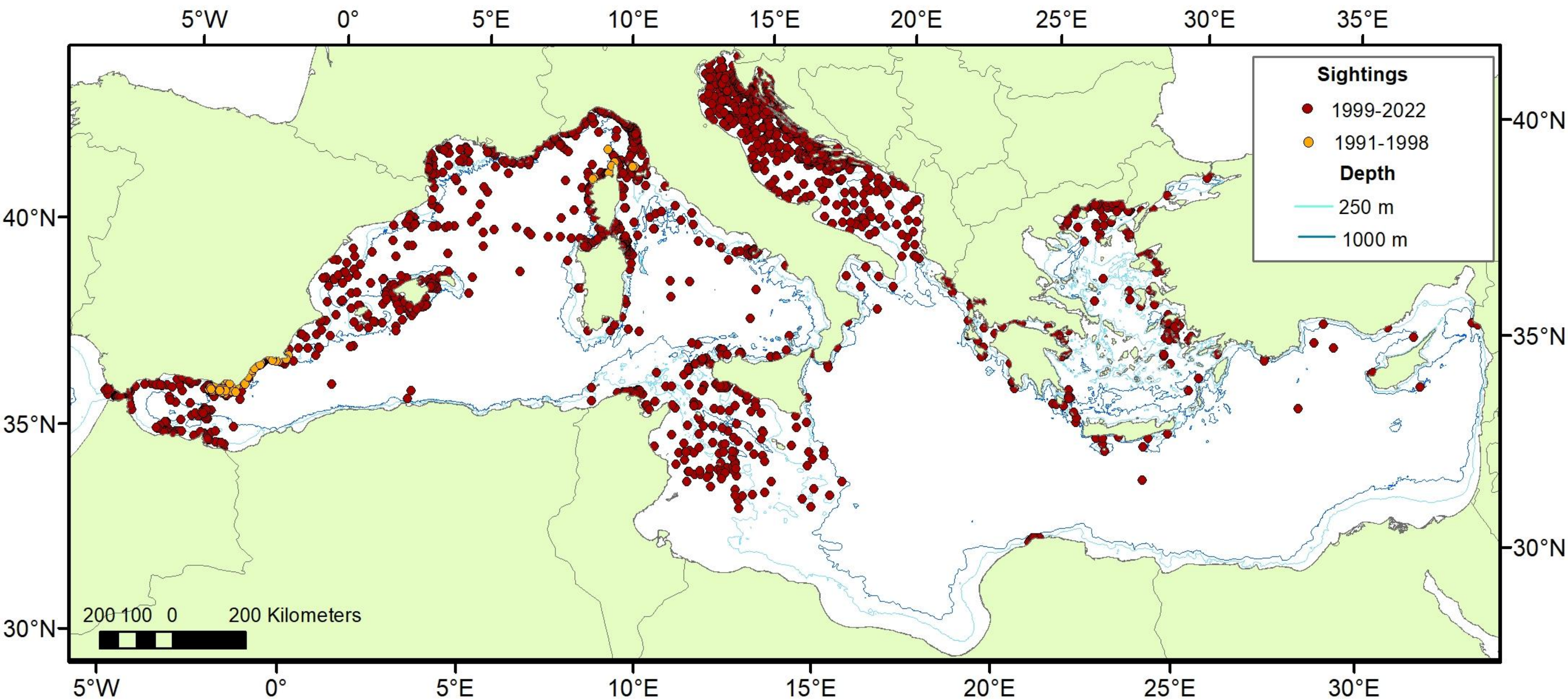
Observations



Observations

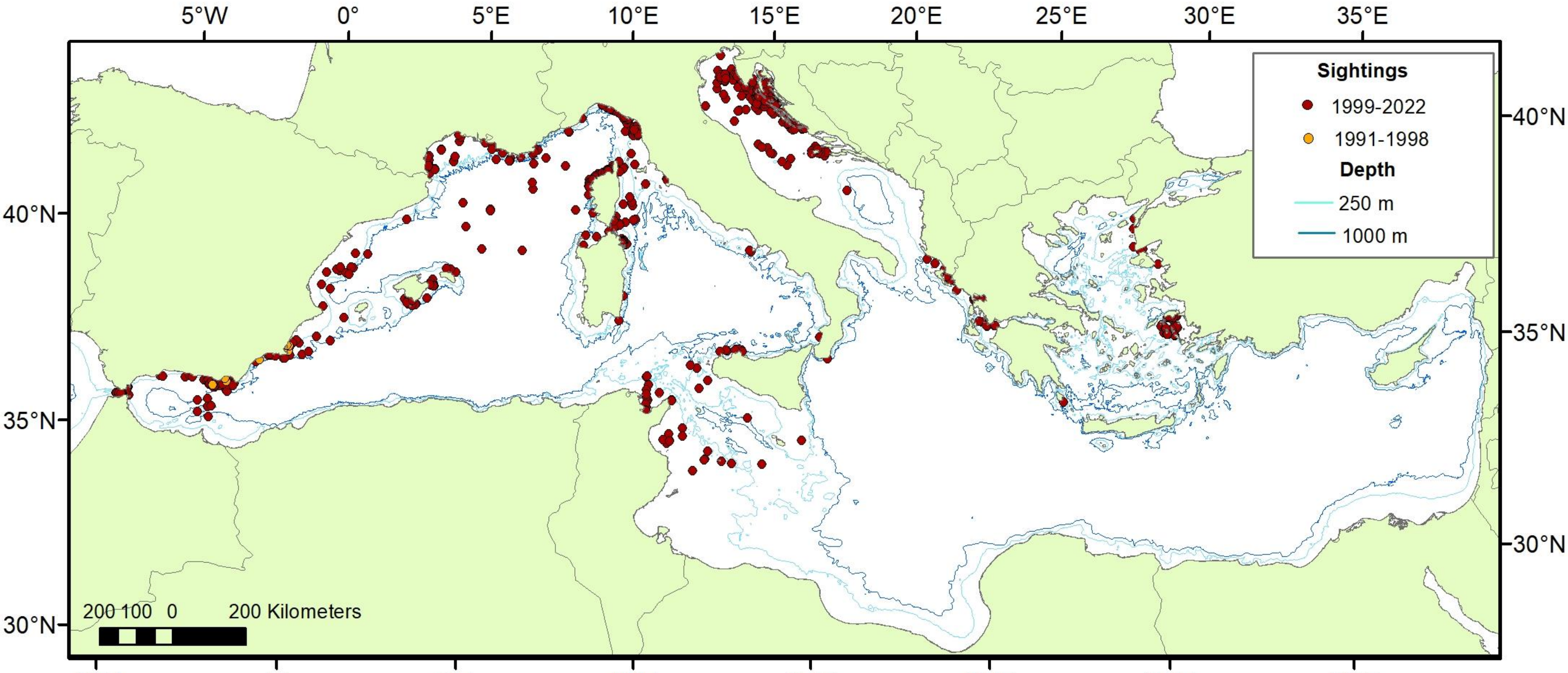


Observations



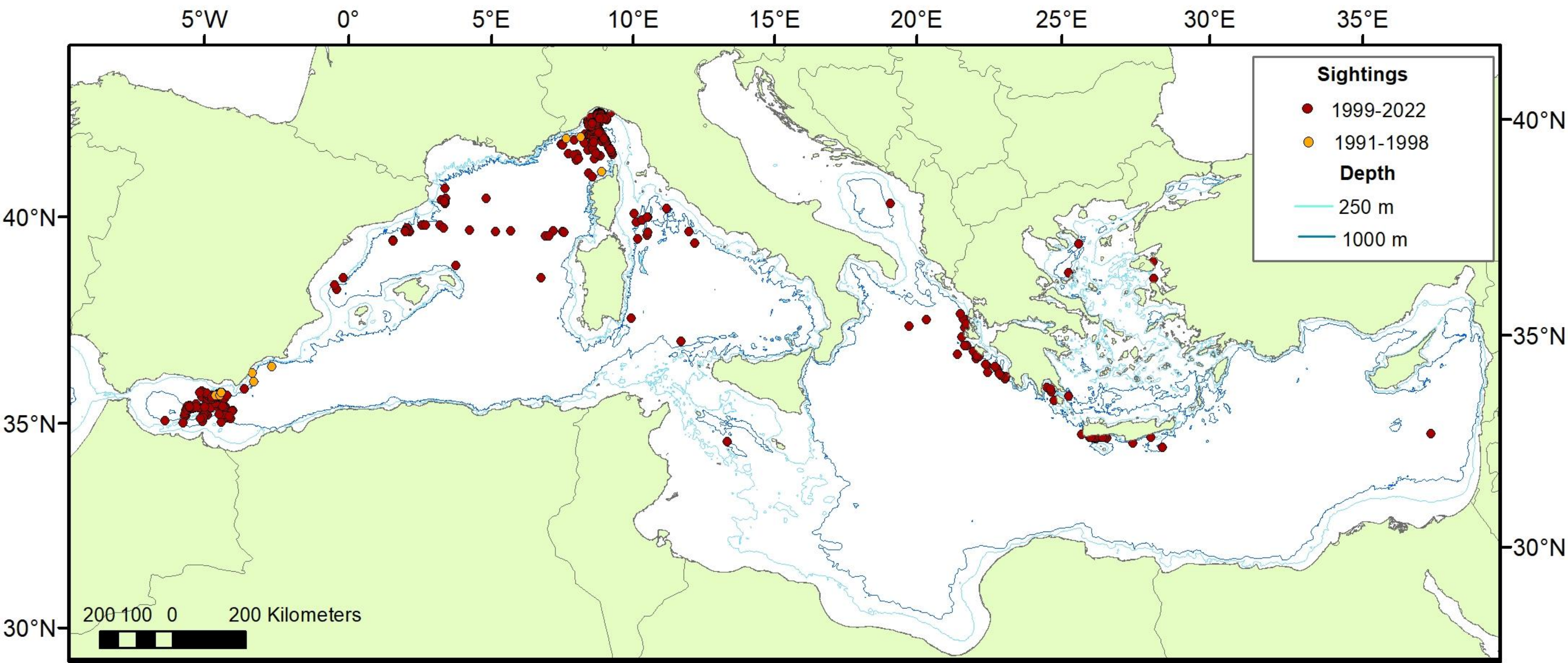
Sightings of Bottlenose dolphin
Summer

Observations



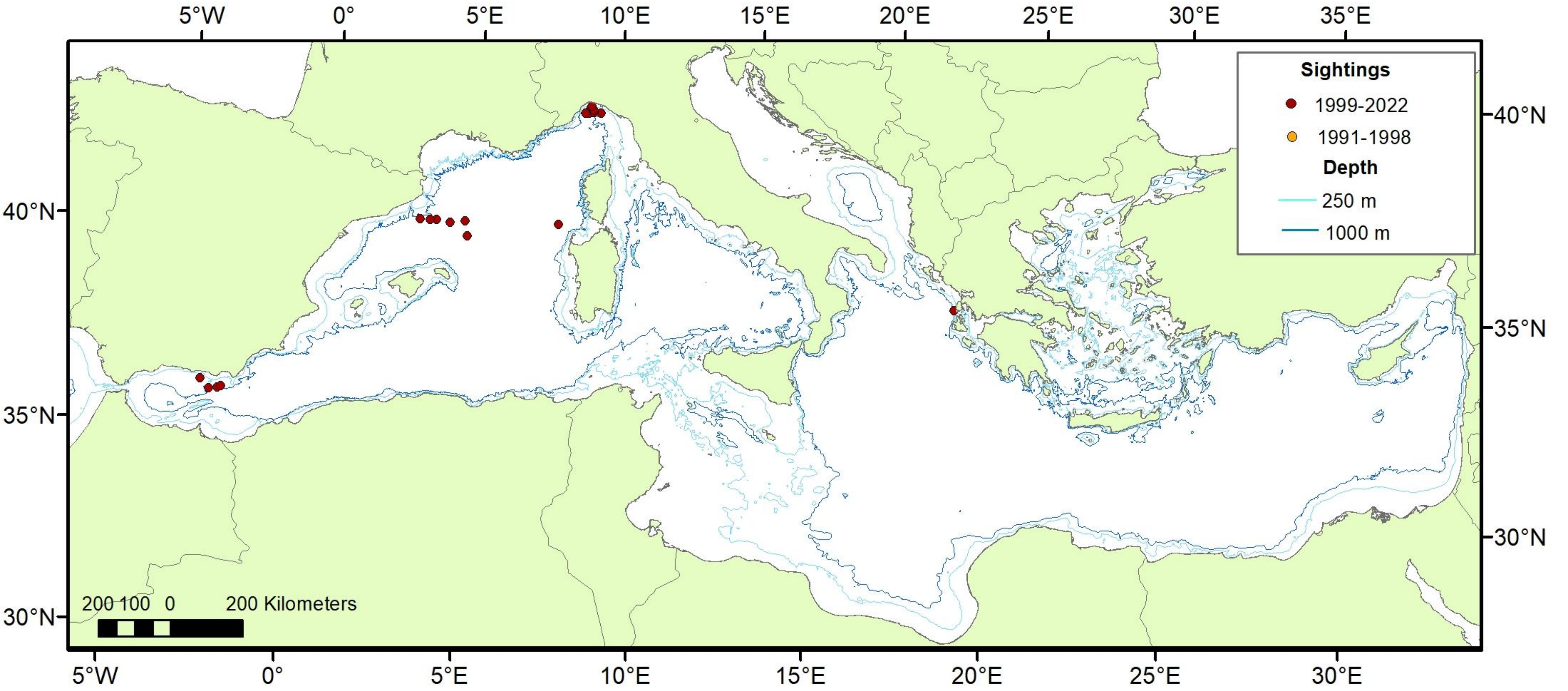
Sightings of Bottlenose dolphin
Winter

Observations



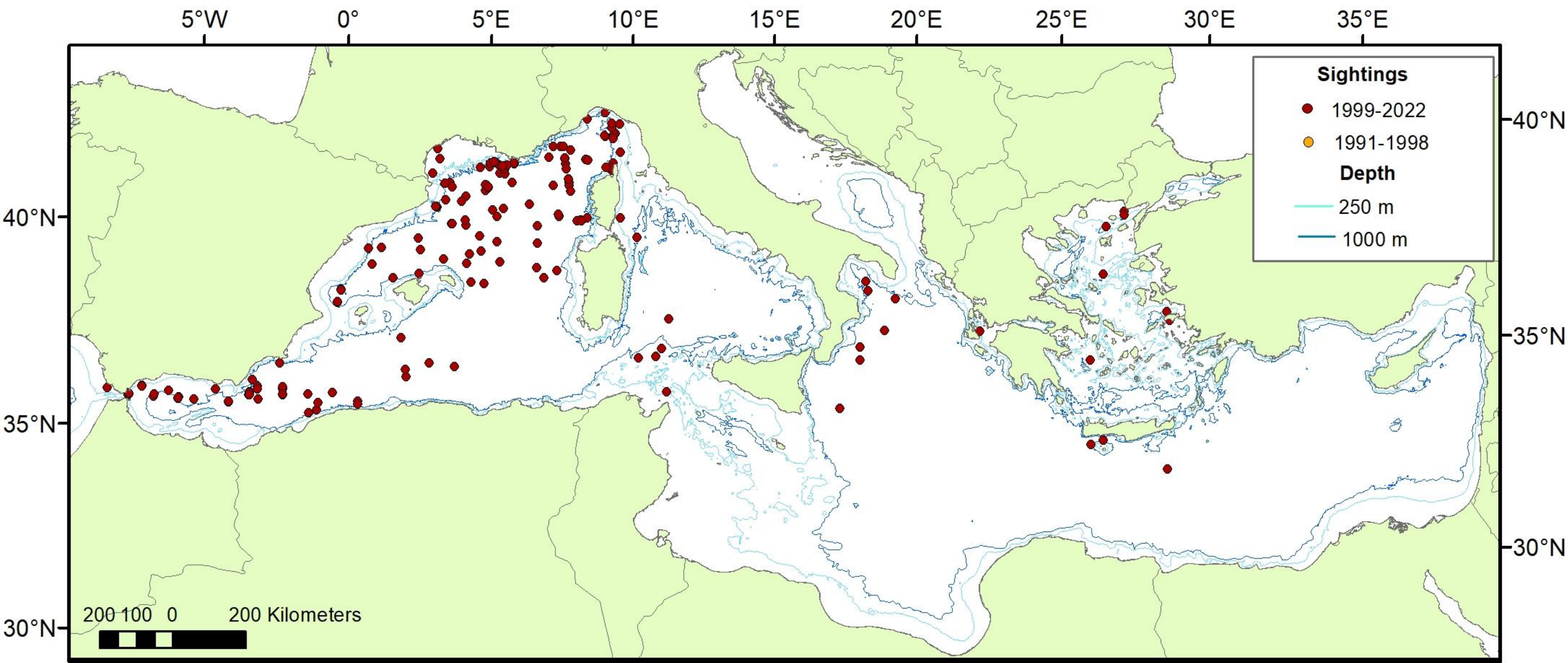
Sightings of Beaked whales
Summer

Observations



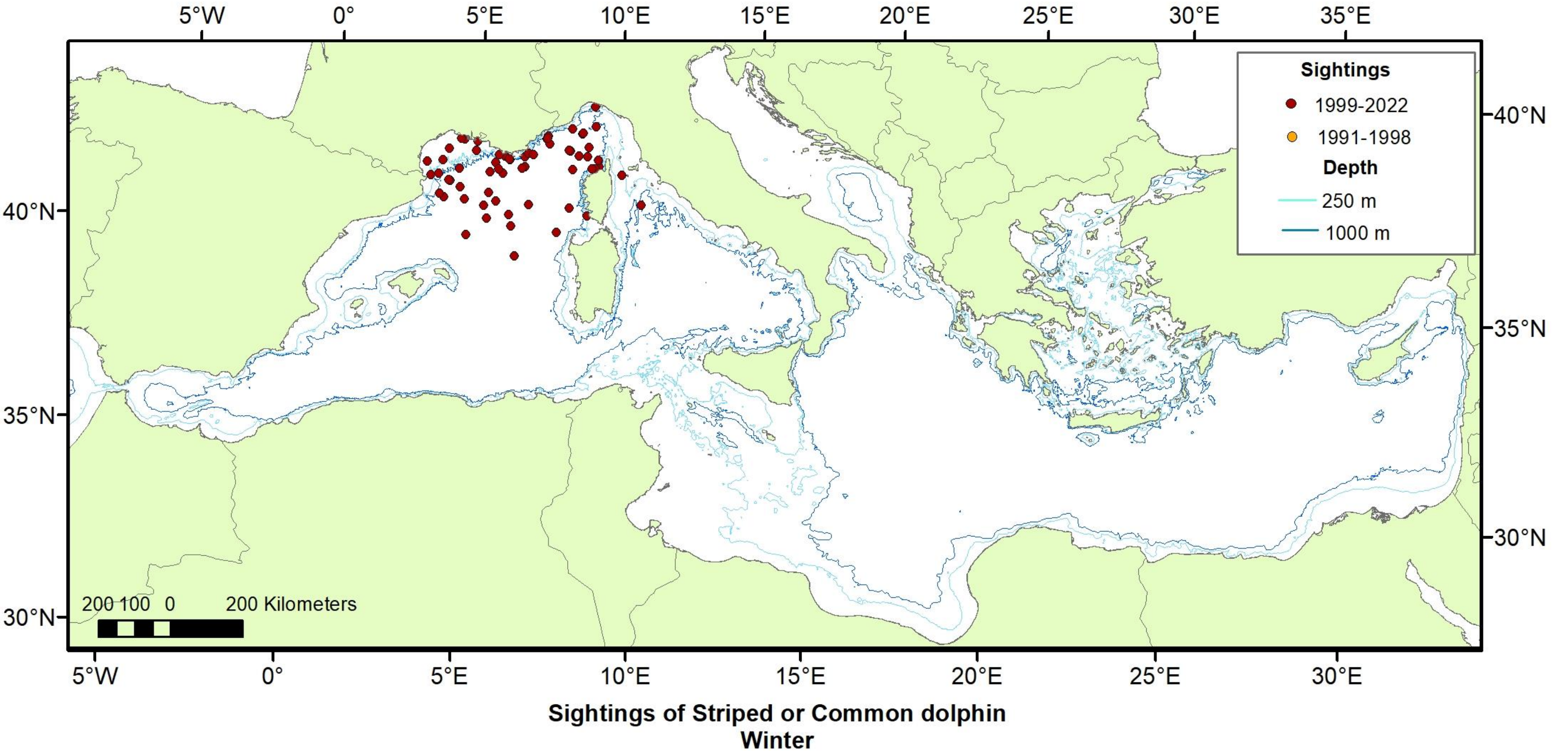
Sightings of Beaked whales
Winter

Observations

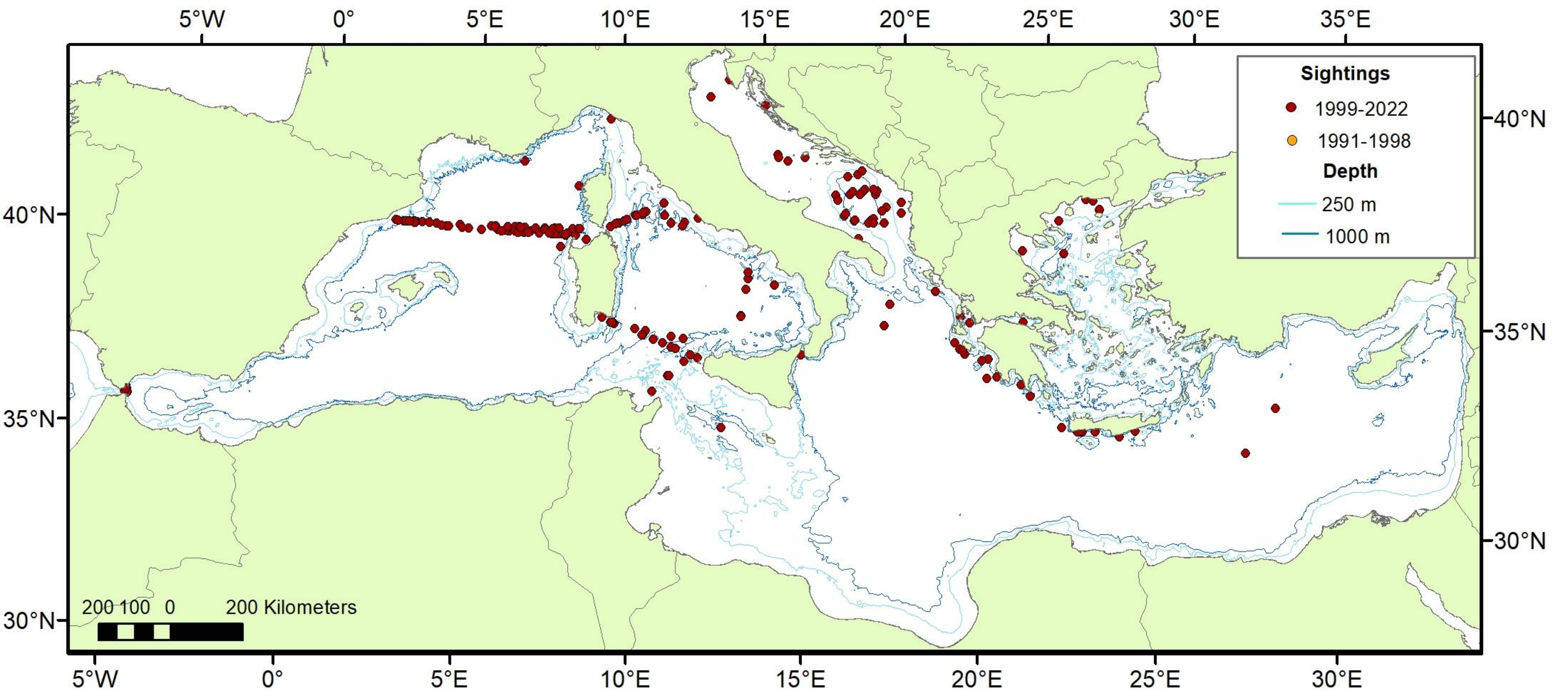


Sightings of Striped or Common dolphin
Summer

Observations

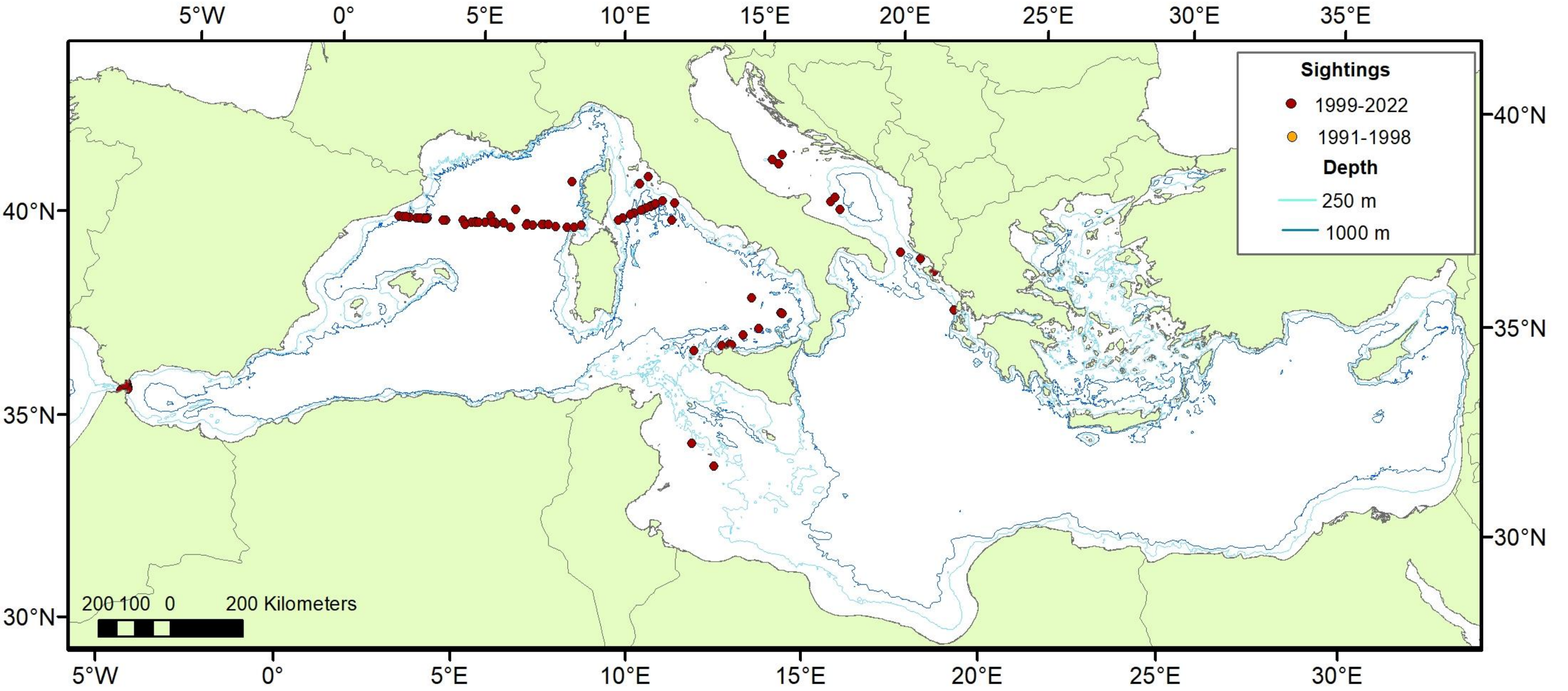


Observations



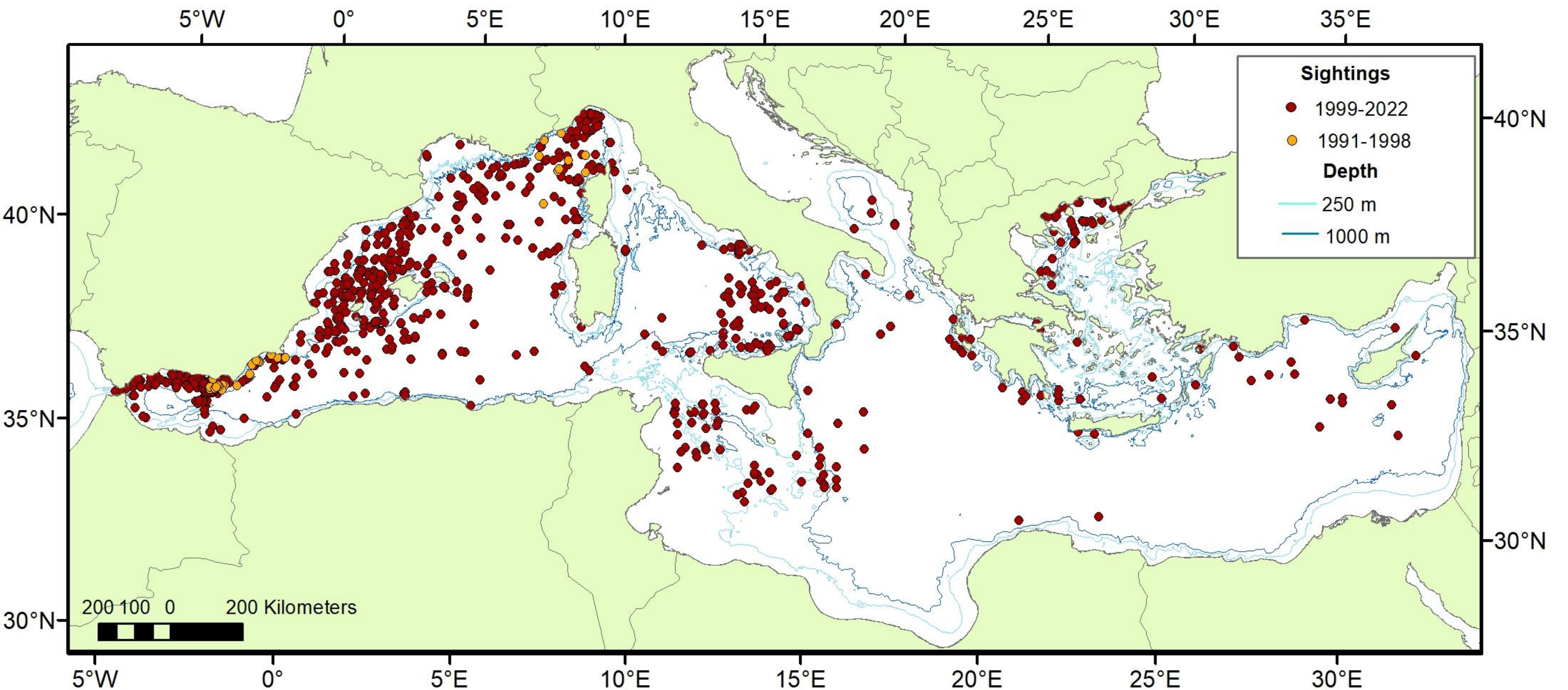
Sightings of Unidentified small dolphin
Summer

Observations



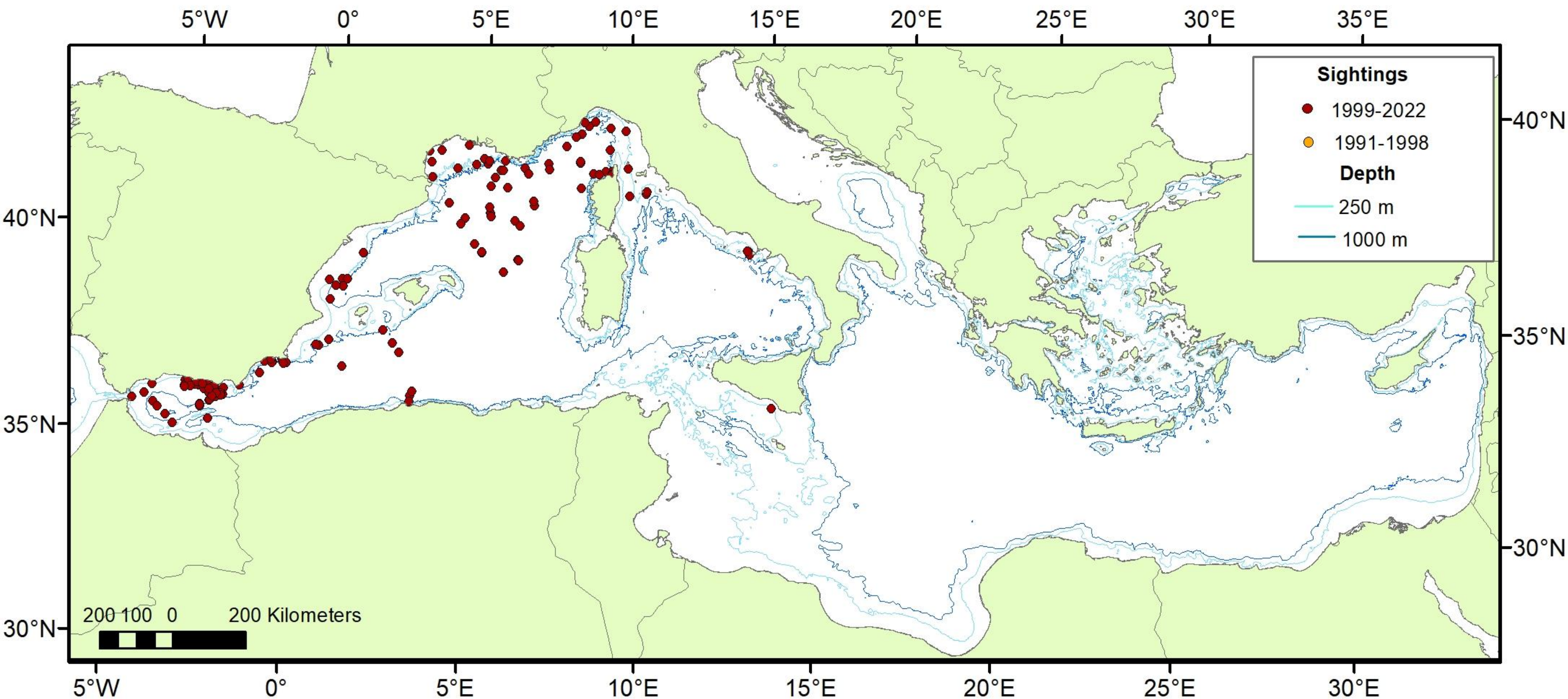
Sightings of Unidentified small dolphin
Winter

Observations



Sightings of Unidentified dolphin
Summer

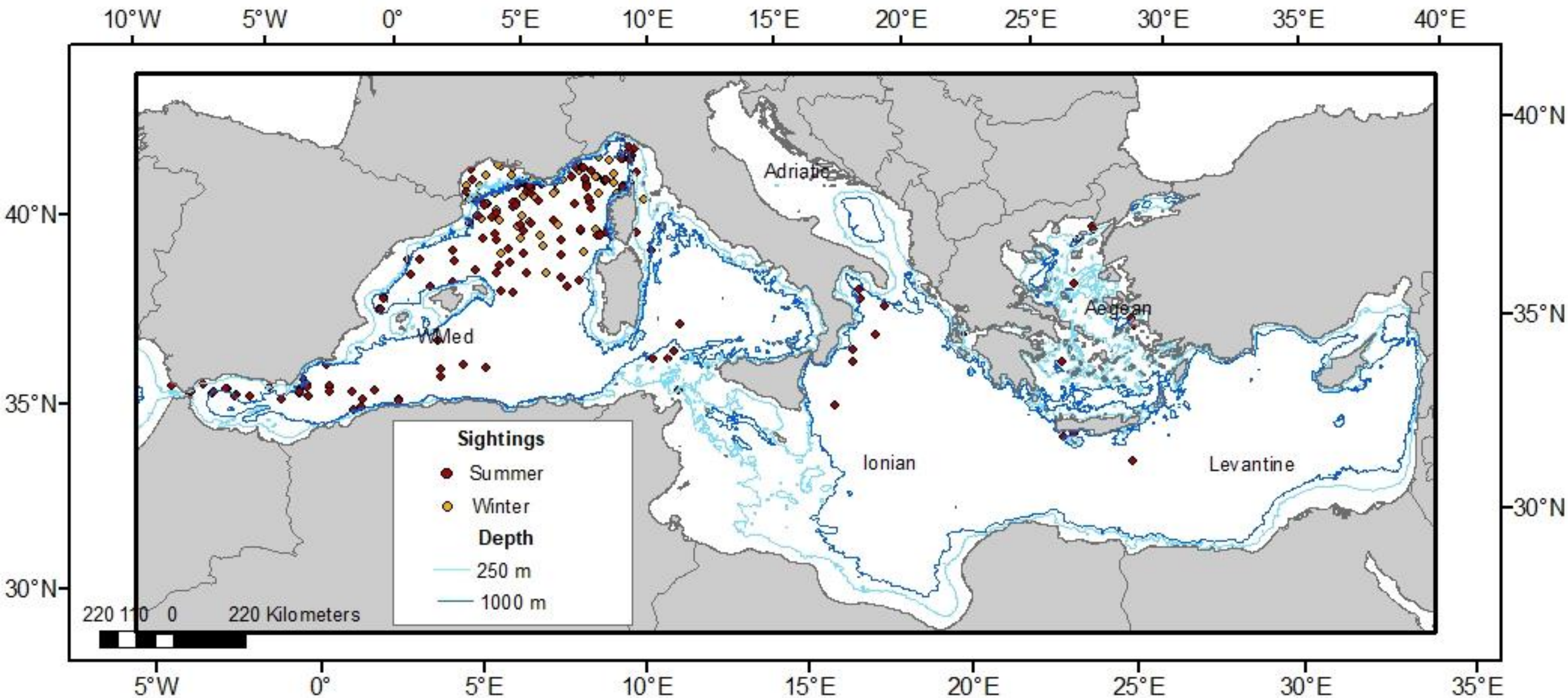
Observations



Sightings of Unidentified dolphin
Winter

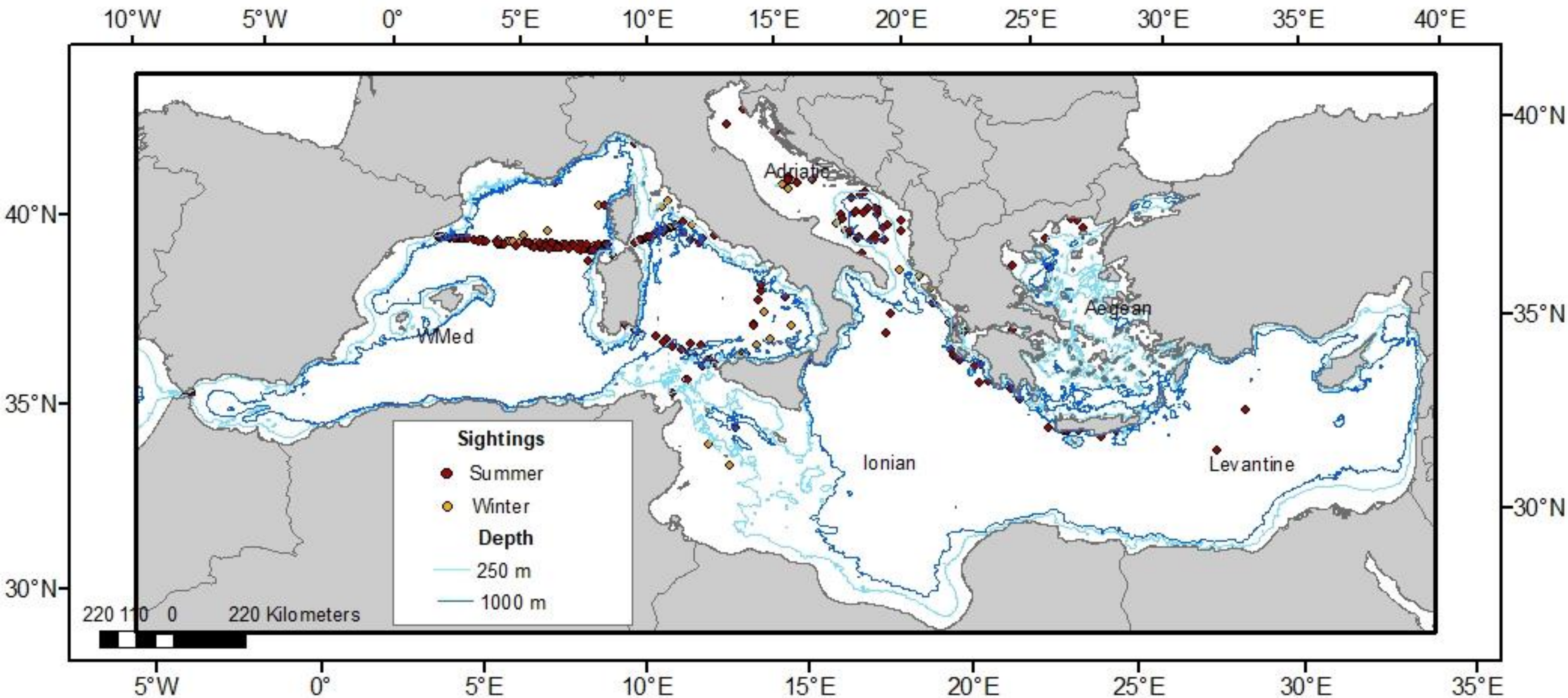
Dealing with ambiguous species identification

Observations of ambiguous species: Sco_or_Dde



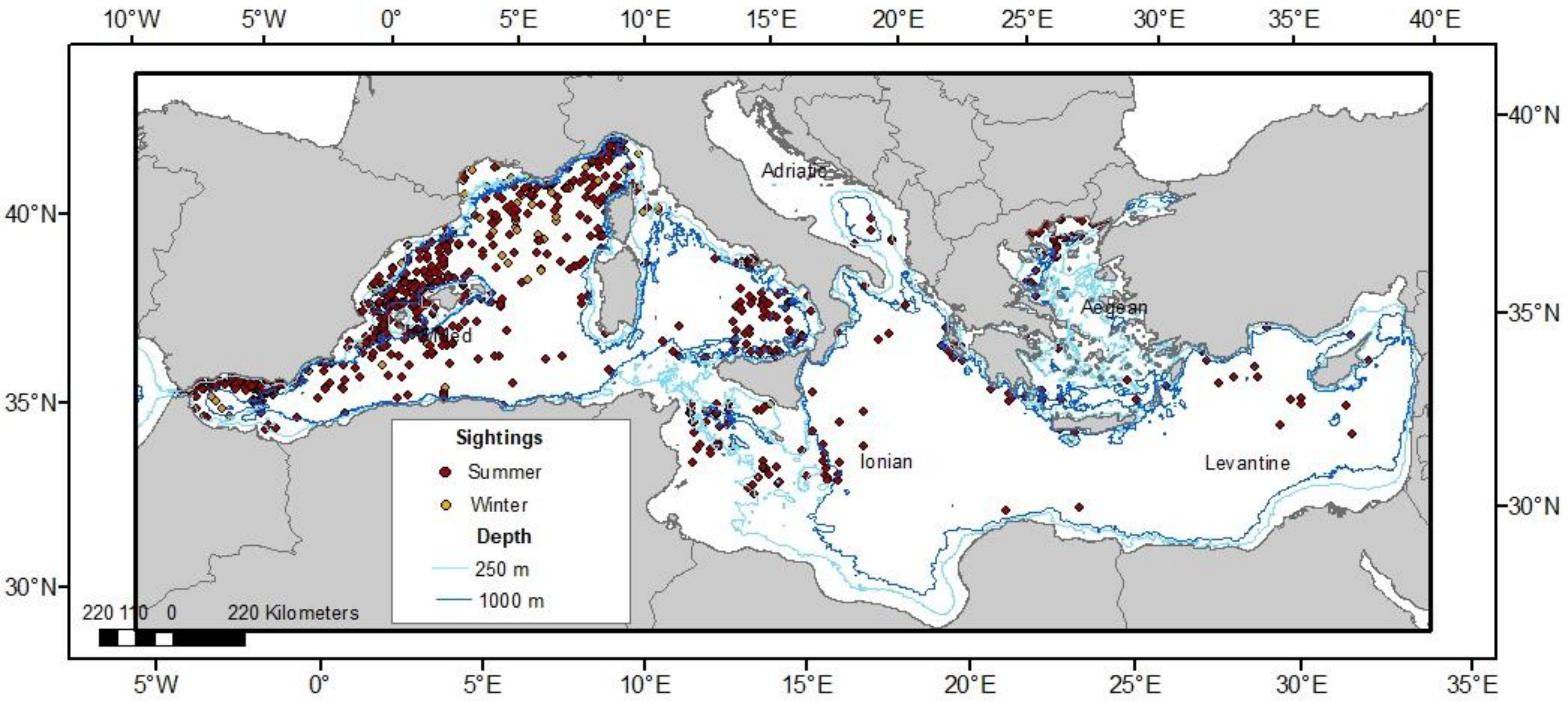
Striped or common dolphin

Observations of ambiguous species: Udo_small



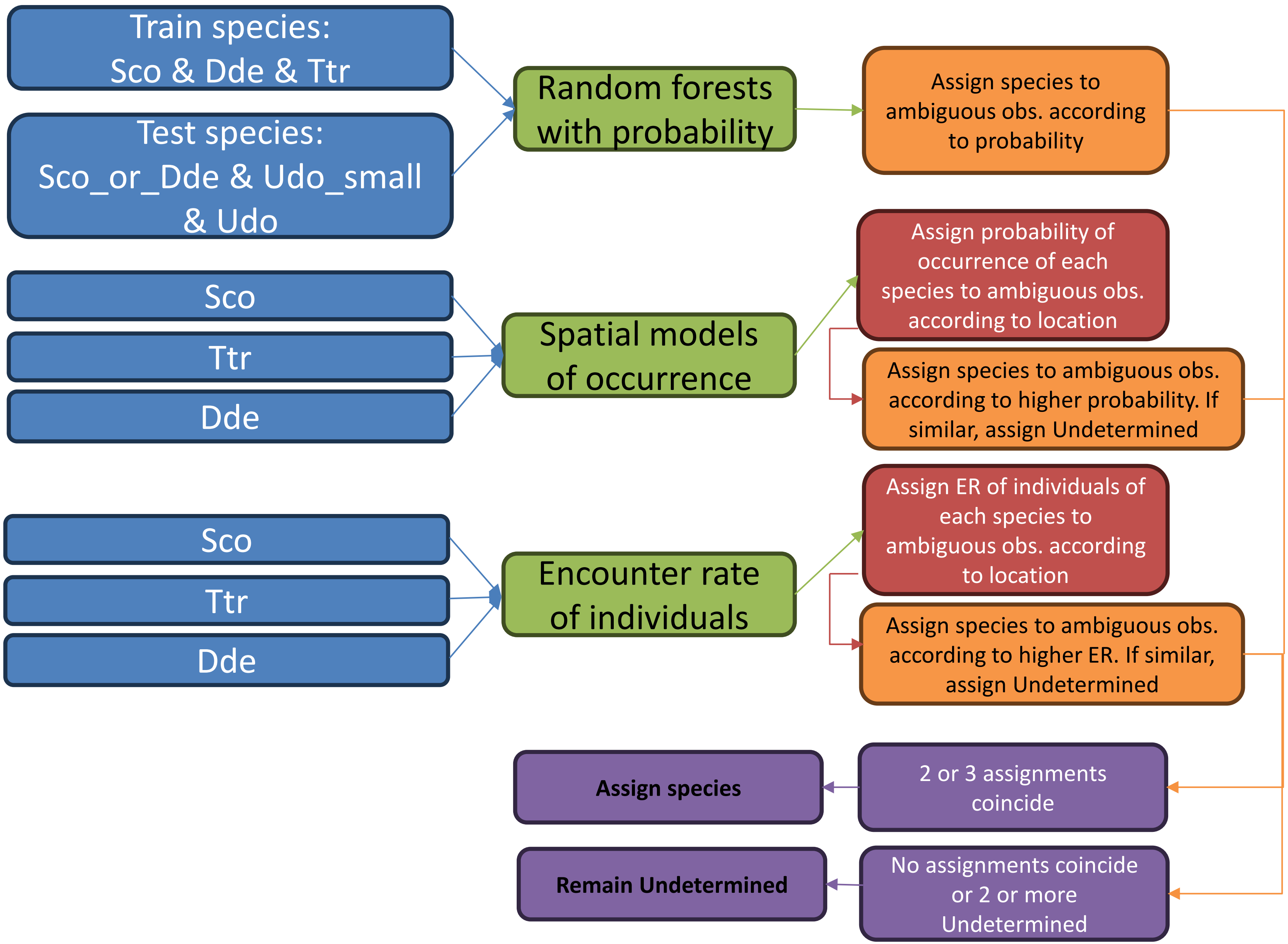
Unidentified small dolphin

Dealing with ambiguous species identification: Udo



Unidentified dolphin

Workflow



Train species:
Sco & Dde & Ttr
Test species:
Sco_or_Dde & Udo_small & Udo
Random forests with probability
Assign species to ambiguous obs. according to probability
Sco
Ttr
Dde
Spatial models of occurrence
Assign probability of occurrence of each species to ambiguous obs. according to location
Assign species to ambiguous obs. according to higher probability. If similar, assign Undetermined
Sco
Ttr
Dde
Encounter rate of individuals
Assign ER of individuals of each species to ambiguous obs. according to location
Assign species to ambiguous obs. according to higher ER. If similar, assign Undetermined
Assign species
2 or 3 assignments coincide
Remain Undetermined
No assignments coincide or 2 or more Undetermined

Random forests

Random forests are an ensemble learning method used for classification, regression, and other tasks. They create a forest of decision trees during training and output the mode of the classes (classification) or mean prediction (regression) of the individual trees. Each tree in the forest is built from a different bootstrap sample of the training data. This means each tree is trained on a random subset of the data. This helps in making the trees less correlated. Also, by averaging multiple deep decision trees, random forests reduce overfitting.

Covariates used in the Random Forests:
Depth, Sst, Lon, Lat, Salinity, DistLand, DistShelf, DistSlope, SlopePct, Primary_prod, Mix_layer_thickness, Ssh, Sst_front_strength, Block

Diagnostics of the Random Forests:

-Sensitivity (True Positive Rate): Sensitivity measures the ability of the model to correctly identify the positive class (e.g. Striped or common dolphin) among all actual positive instances.

-Specificity (True Negative Rate): Specificity measures the ability of the model to correctly identify the negative class (e.g. Unidentified small dolphin) among all actual negative instances.

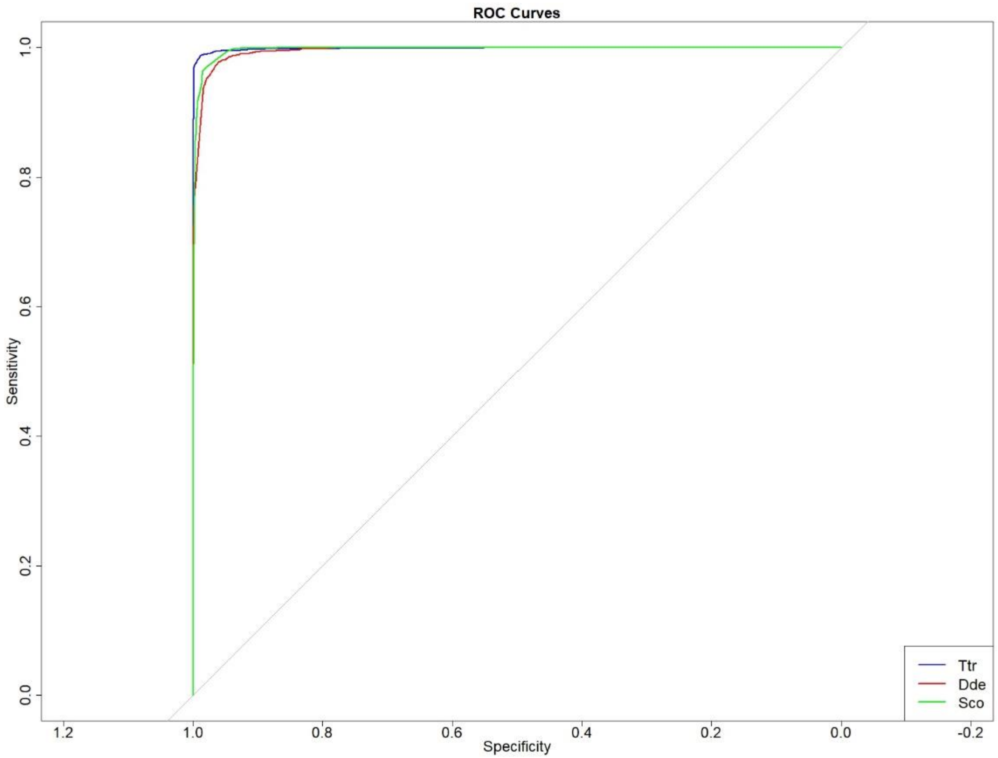
-Accuracy: Accuracy measures the overall correctness of the model's predictions.

- ROC curve: A ROC curve is a graphical representation of a classifier's performance. It plots the True Positive Rate (TPR, or sensitivity) against the False Positive Rate (FPR, or 1-specificity) at various threshold settings.

- AUC: The AUC is the area under the ROC curve. It provides an aggregate measure of the model's performance across all possible classification thresholds. An AUC of 0.5 suggests no discriminative power, equivalent to random guessing. An AUC closer to 1 indicates better model performance, with 1 being a perfect model.

Random forest results

Diagnostics:



Test	value
Accuracy	0.971
Sensitivity (Ttr)	0.974
Sensitivity (Dde)	0.766
Sensitivity (Sco)	0.995
Specificity (Ttr)	0.996
Specificity (Dde)	0.998
Specificity (Sco)	0.943
AUC	0.968

Results:

Percentage success for train species:

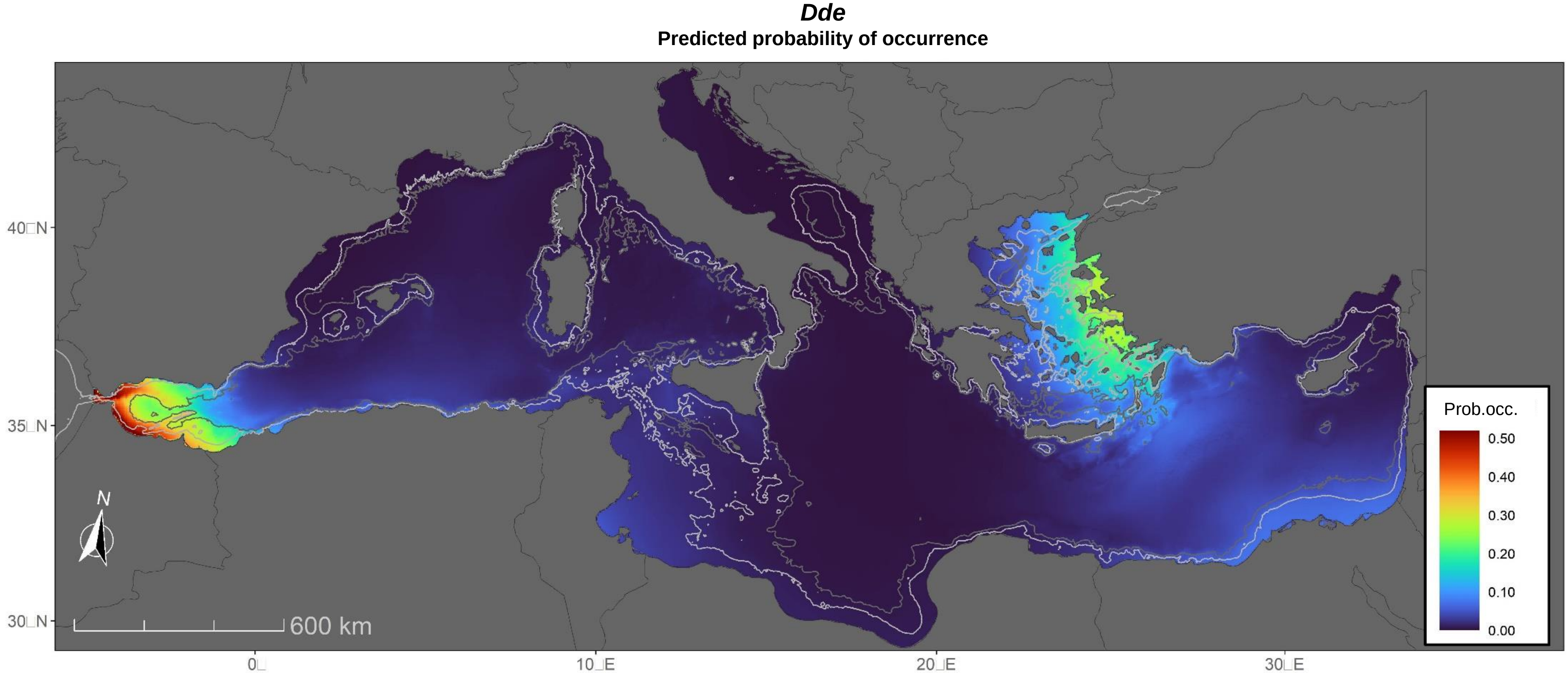
Prediction	Common dolphin	Striped dolphin	Bottlenose dolphin
Bottlenose dolphin	0.68	1.48	99.32
Common dolphin	96.31	2.67	0.43
Striped dolphin	3.01	95.85	0.25

Assignment of species:

Prediction	Common dolphin	Striped dolphin	Bottlenose dolphin	Total
Bottlenose dolphin	9	198	7891	**8098**
Common dolphin	1278	356	34	**1668**
Striped dolphin	40	12800	20	**12860**
Striped or common dolphin	5	224	55	**284**
Unidentified dolphin	77	824	115	**1016**
Unidentified small dolphin	15	236	27	**278**
Total	**1424**	**14638**	**8142**	**24204**

Models of occurrence

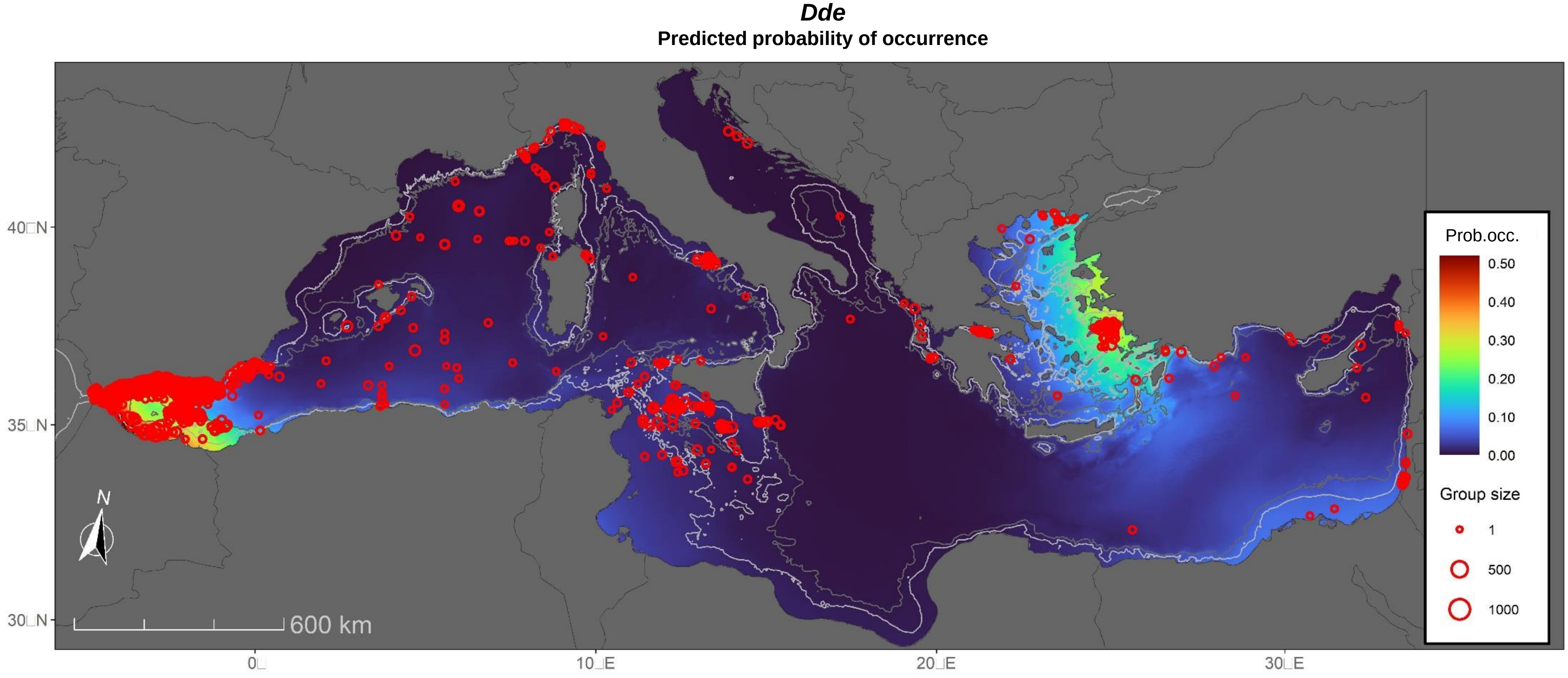
Common dolphin



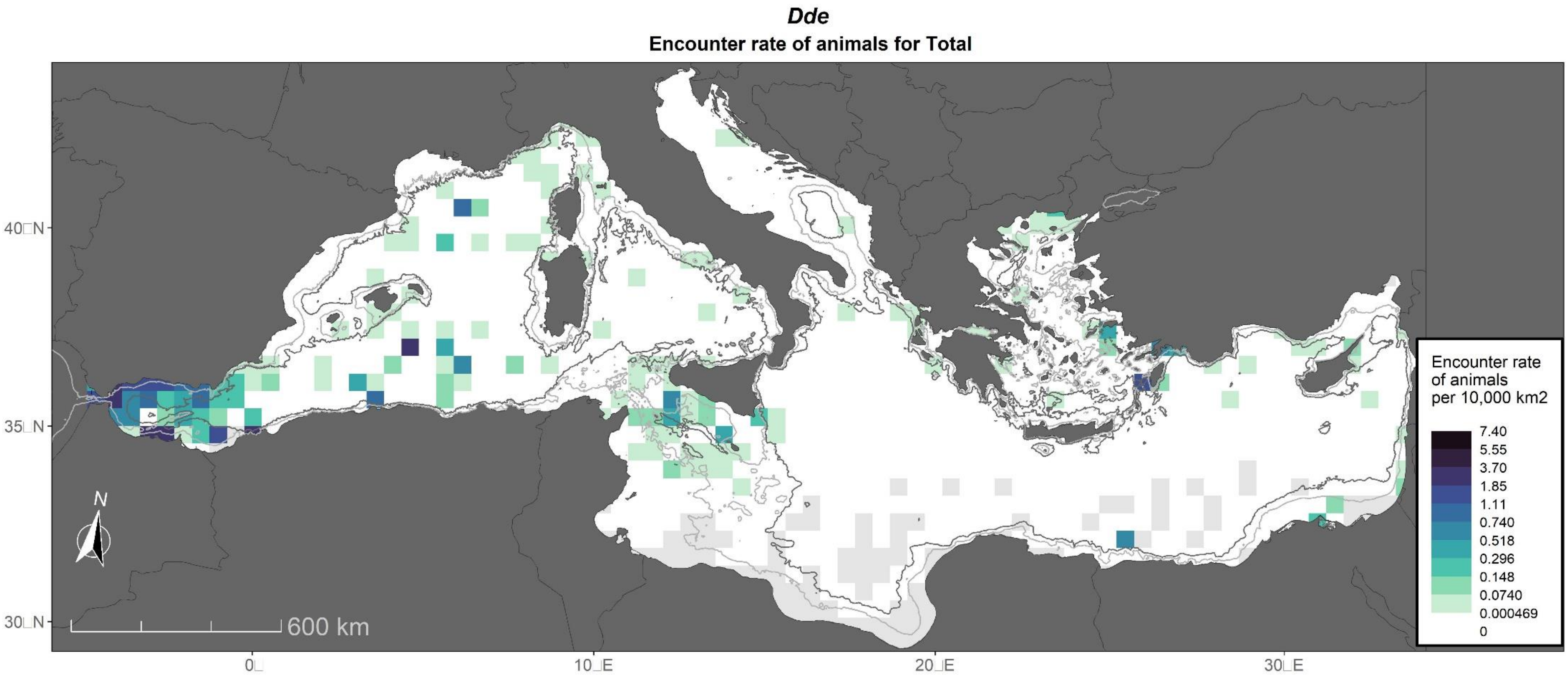
Covariates:
LonLat, Ssh, Sst, Depth

Models of occurrence

Common dolphin

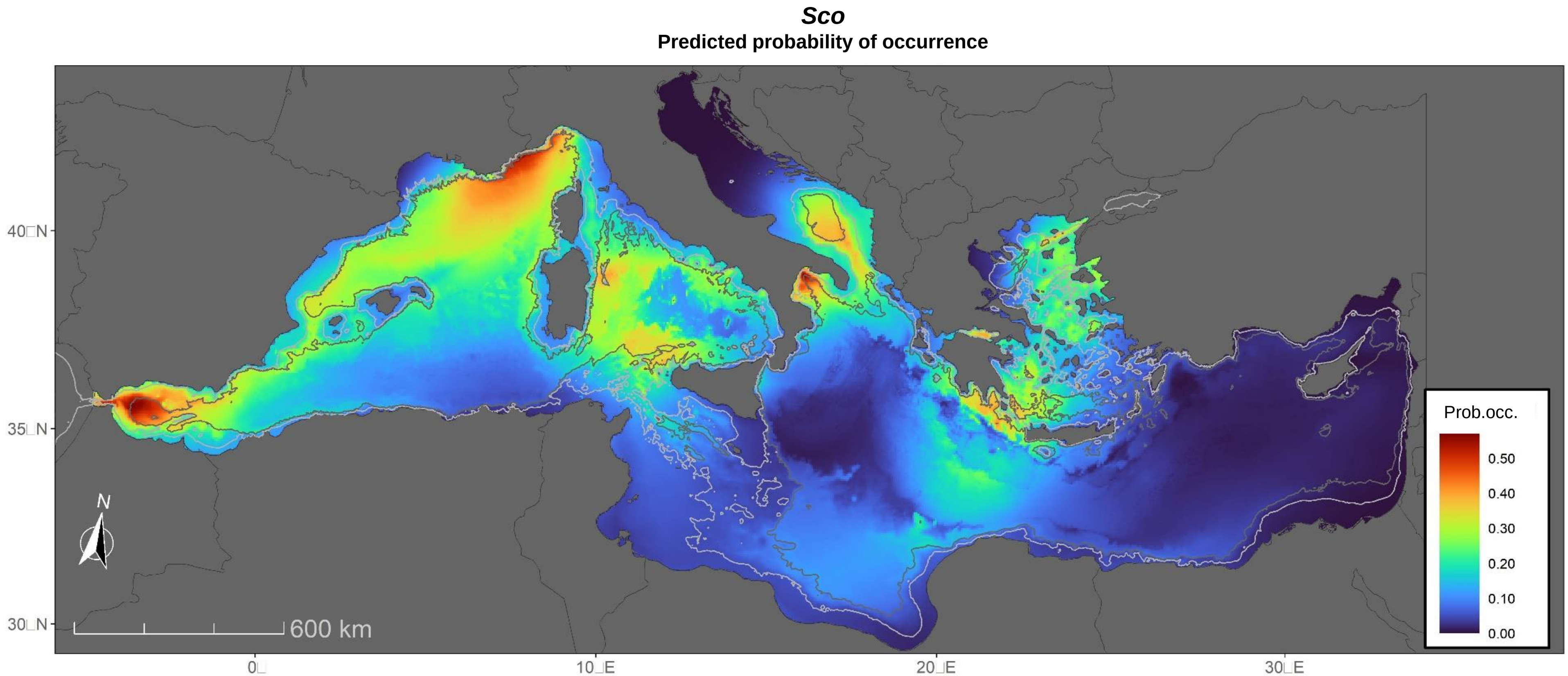


Encounter rate
Common dolphin



Models of occurrence

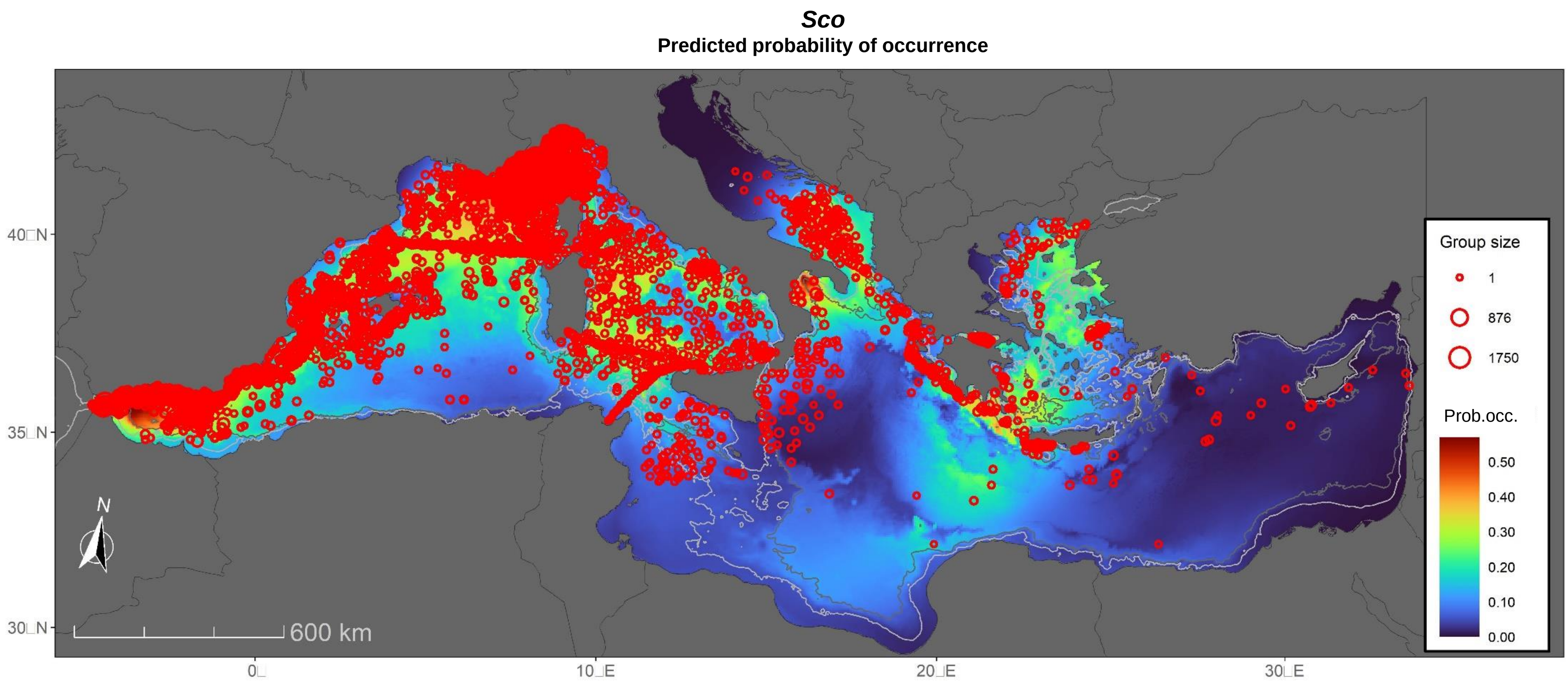
Striped dolphin



Covariates:
Ssh, Sst, Depth, Primary_prod

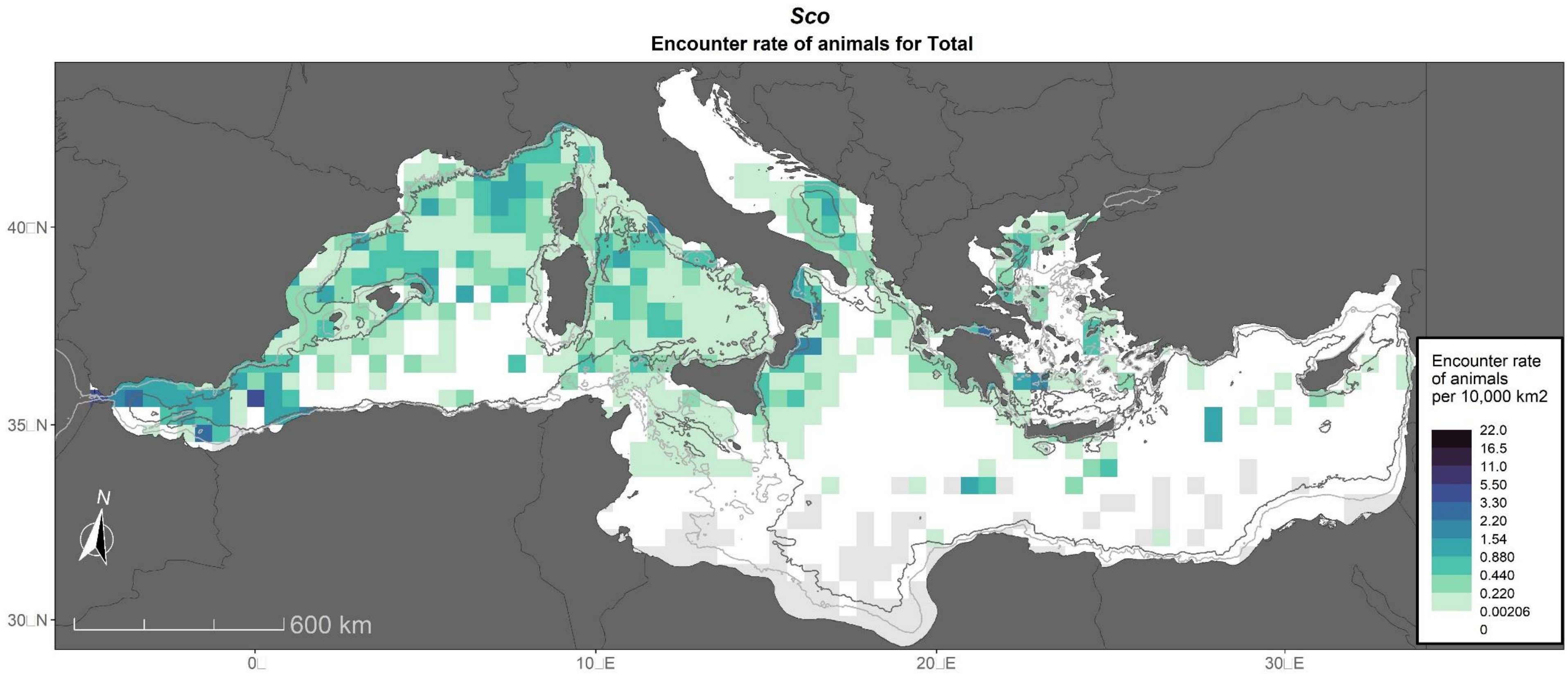
Models of occurrence

Striped dolphin



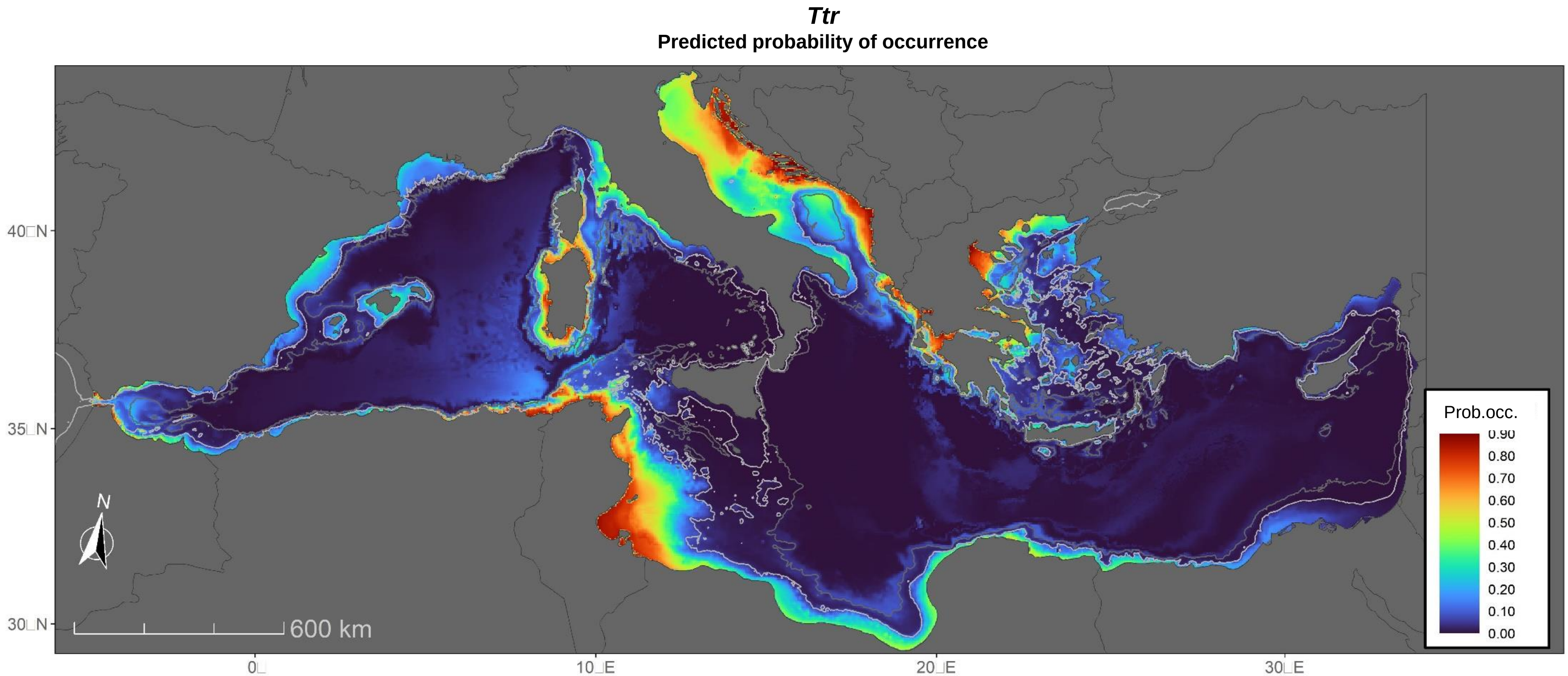
Encounter rate

Striped dolphin



Models of occurrence

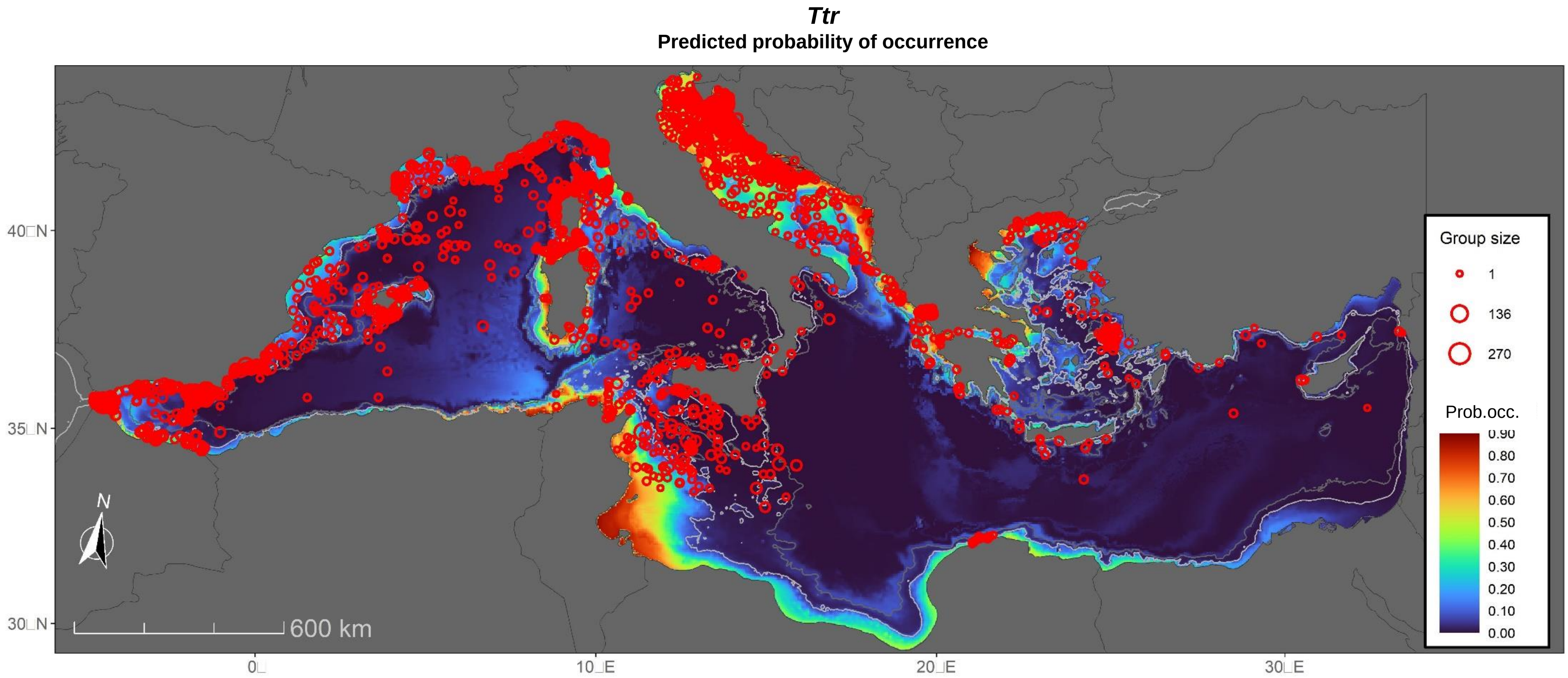
Bottlenose dolphin



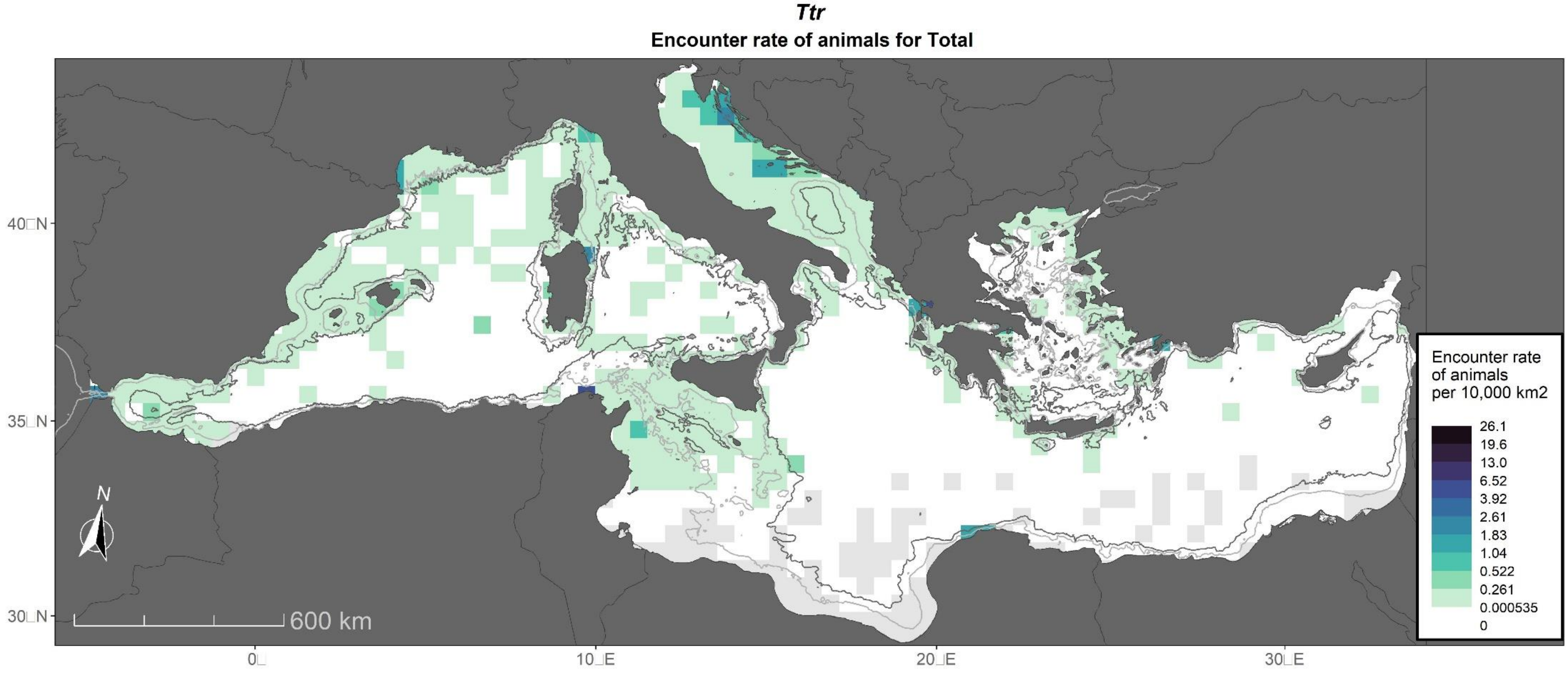
Covariates:
LonLat, Ssh, Sst, Depth, Sst_front_strength

Models of occurrence

Bottlenose dolphin



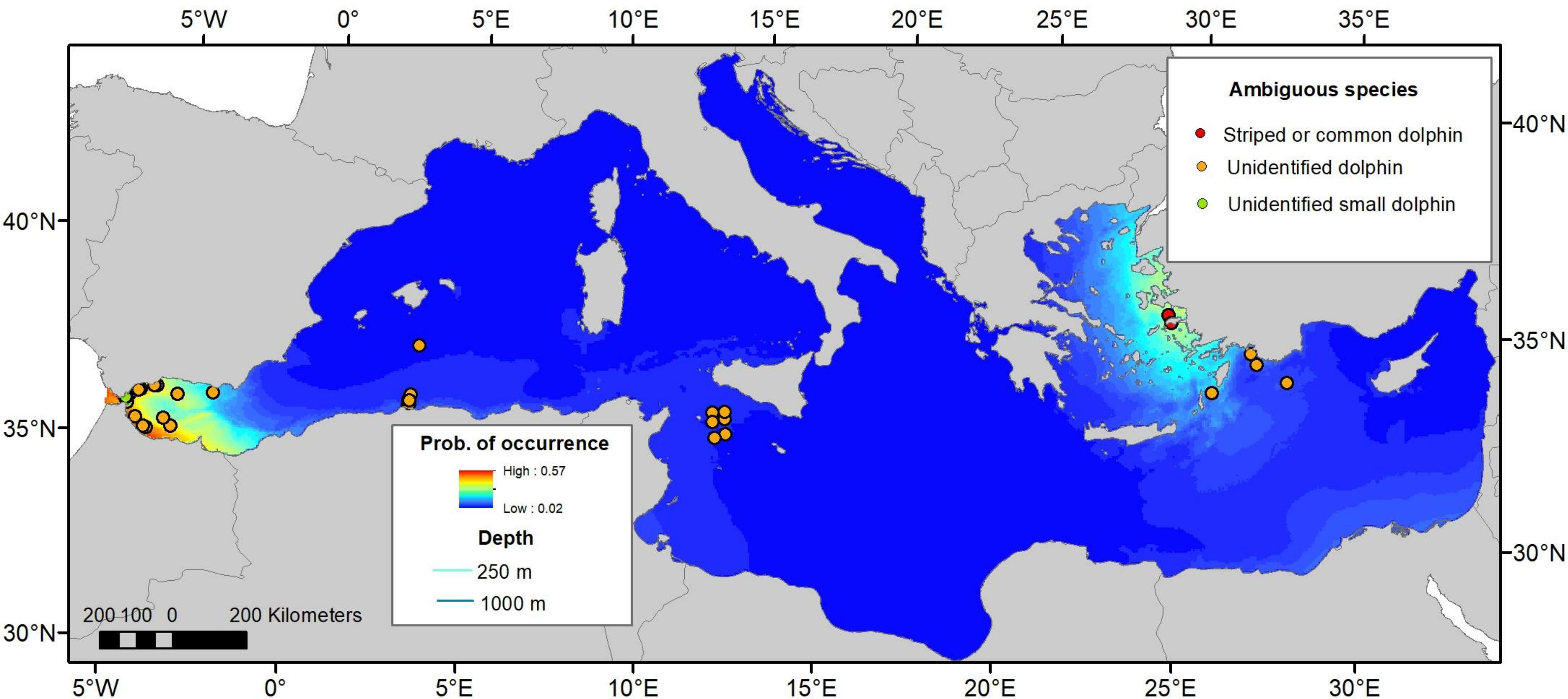
Encounter rate
Bottlenose dolphin



Final species assignment of ambiguous species

	Common dolphin	Striped dolphin	Bottlenose dolphin	Undetermined	Total
Striped or common dolphin	2	250	14	18	**284**
Unidentified dolphin	34	810	65	116	**1025**
Unidentified small dolphin	8	221	29	20	**278**
Total	**44**	**1281**	**108**	**154**	**1587**

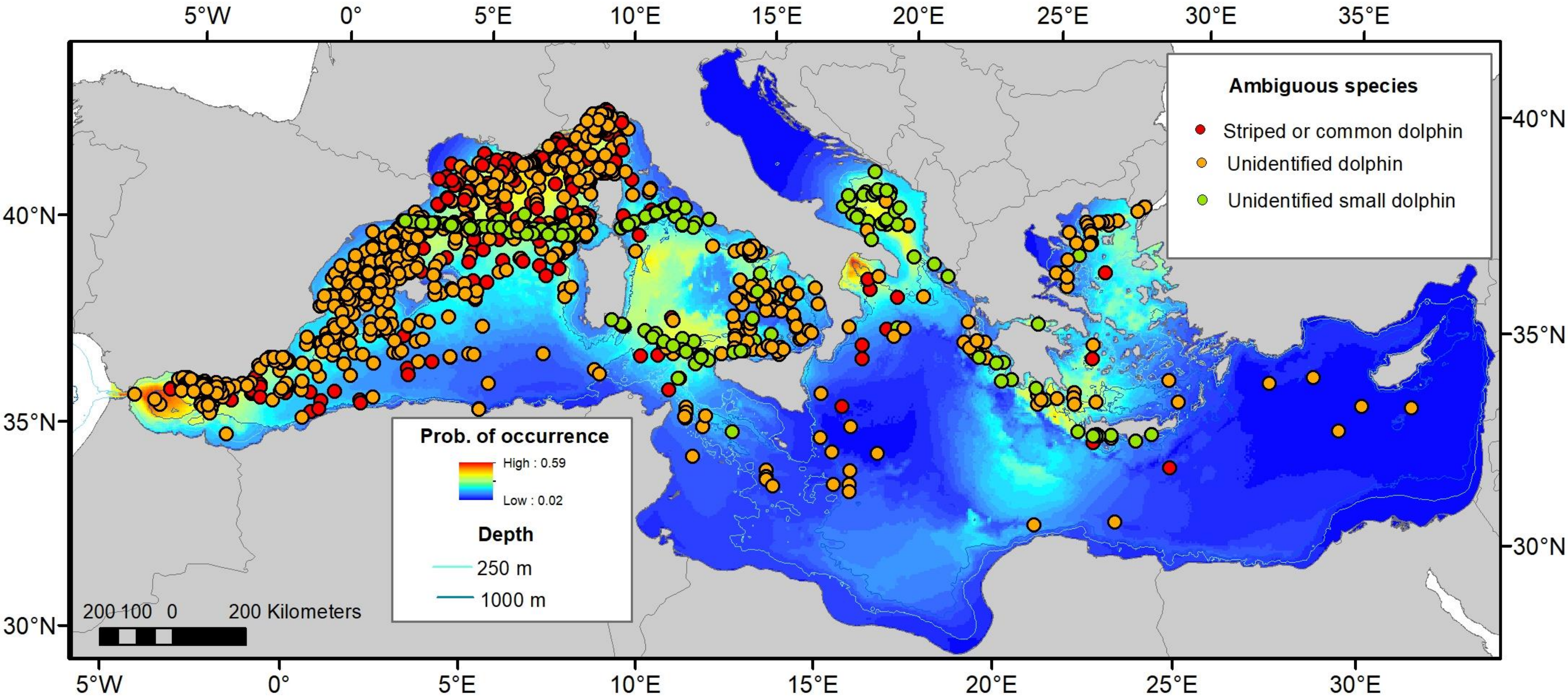
Final species assignment of ambiguous species



Probability of occurrence of common dolphin

Assignment of ambiguos species to common dolphins

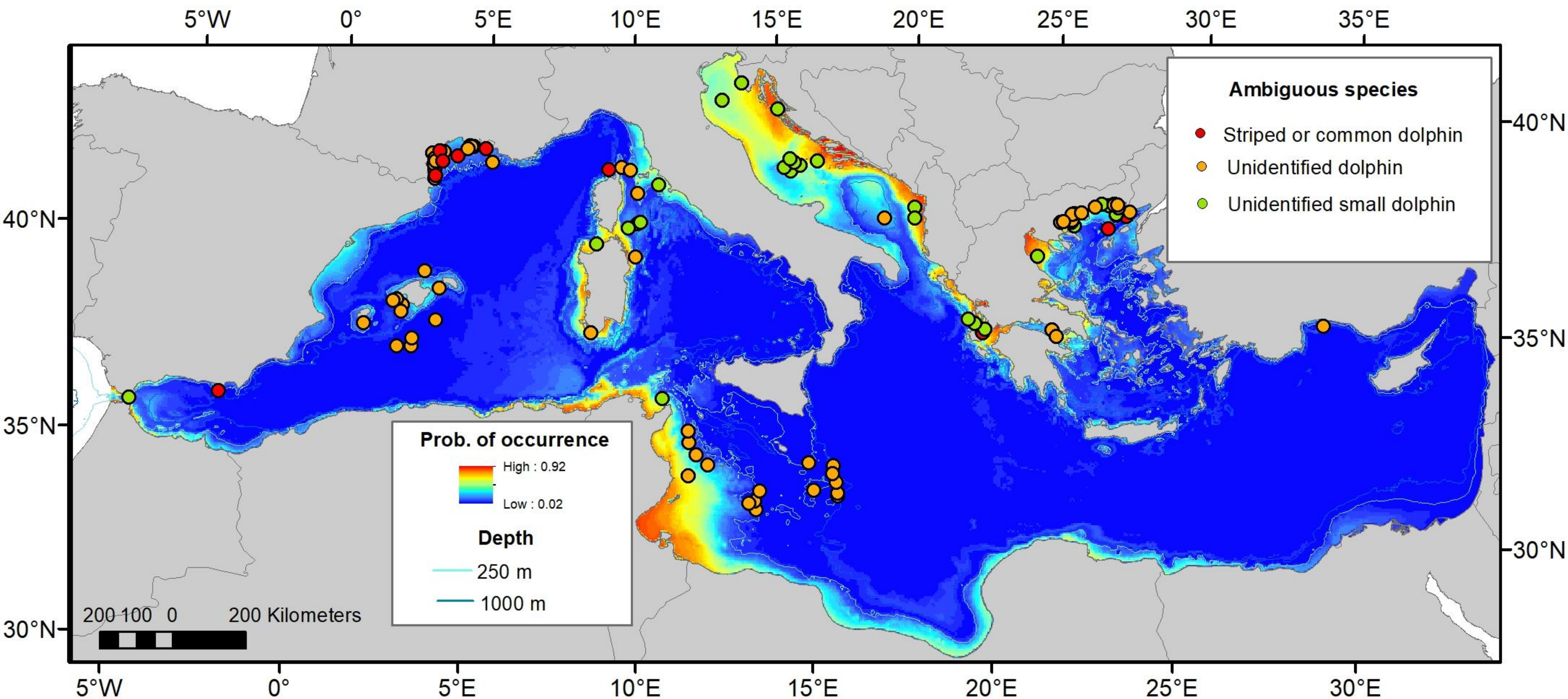
Final species assignment of ambiguous species



Probability of occurrence of striped dolphin

Assignment of ambiguos species to striped dolphins

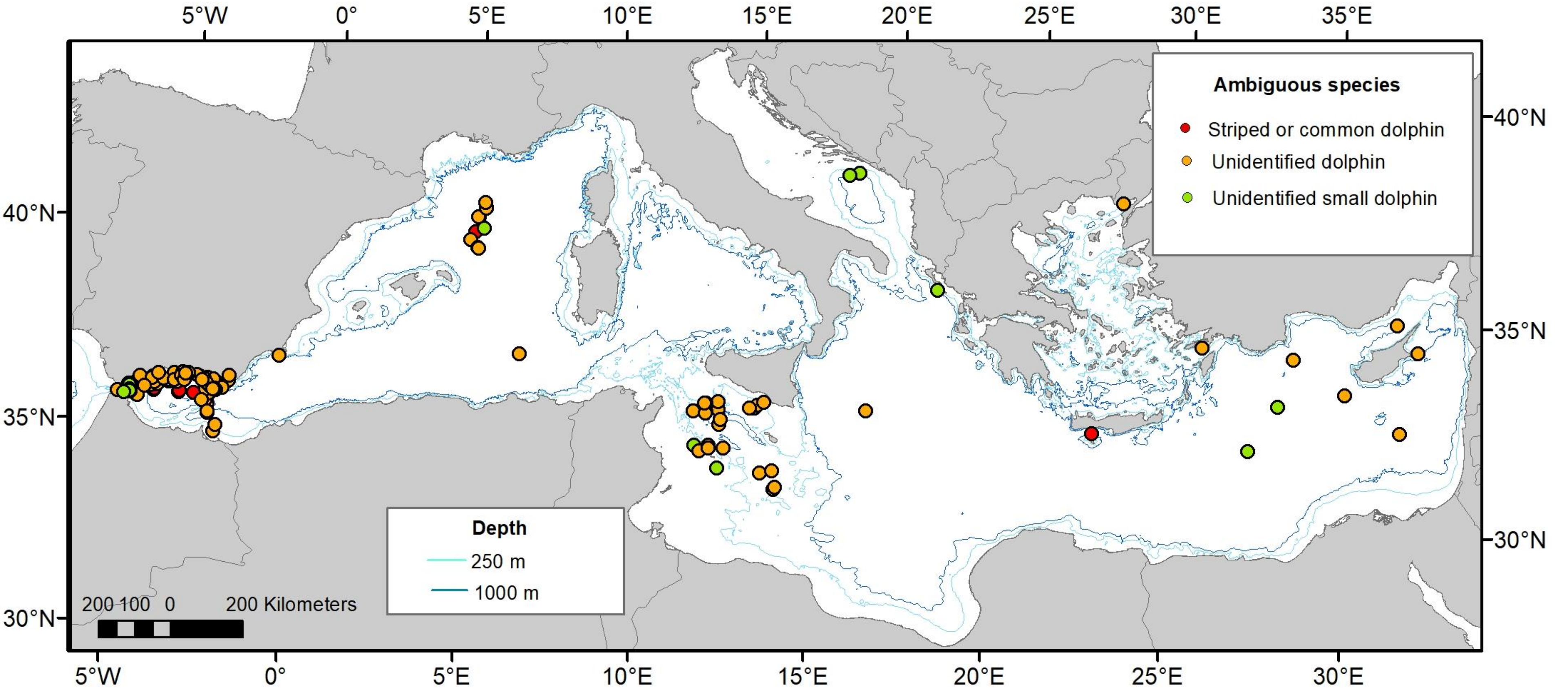
Final species assignment of ambiguous species



Probability of occurrence of bottlenose dolphin

Assignment of ambiguos species to bottlenose dolphins

Final species assignment of ambiguous species



Assignment of ambiguos species to "Undetermined"

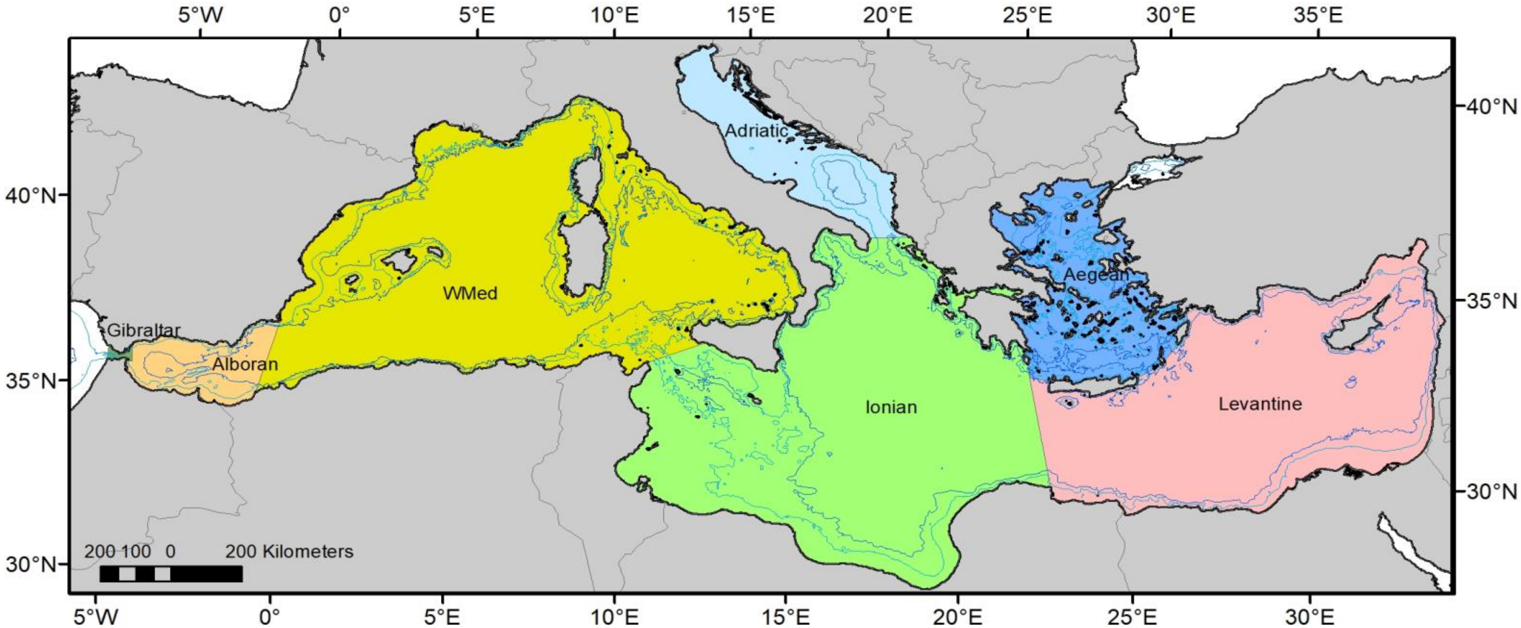
Mediterranean

Mediterranean - Bottlenose dolphin

Considerations

- Bottlenose dolphins were modeled for the whole year

- Several collaborators suggested that bottlenose dolphins needed to be modeled separately per block, given their different local adaptations to the habitat. So, this was done.



- **Adriatic:** a very large proportion of the available sightings in this block come from coastal photo-id surveys with no distances/bearings recorded. Applying an esw to these surveys, from similar platforms, and using them in the models, yielded a large overestimation. Therefore, those surveys were eliminated almost entirely, retaining only the last year for each of those surveys, to have at least some representation of the very coastal areas among the islands, not well covered by the aerial surveys. The resulting estimate was accepted by the local researchers, although it may still have a slight overestimation.

- **Strait of Gibraltar**: a very accurate abundance estimate exists for this block from photo-id work carried out over many years. Therefore, I scaled the estimate obtained with the model to the actual estimate from the local researcher. He agreed on the distribution pattern we obtained.

Mediterranean - Bottlenose dolphin

Estimated abundance and uncertainty

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Ionian	Full	17,690	0.023096	0.1170	14,117	21,783
Levantine	Full	20,719	0.036246	0.3917	10,465	38,234
Aegean	Full	5,278	0.027904	0.2925	3,046	8,327
WMed_noAlb	Full	30,270	0.038992	0.0350	31,388	35,919
Alb	Full	4,751	0.069146	0.2422	3,078	7,202
Gib_dist	Full	162	0.079140	0.1096	132	199
Adriatic	Full	15,312	0.115053	0.3157	8,446	24,760
Total	**Full**	**94,182**	**0.037570**	**0.1053**	**77,401**	**114,601**
Ionian	Sum	17,326	0.022621	0.1217	13,834	21,700
Levantine	Sum	14,349	0.025102	0.1835	10,314	19,963
Aegean	Sum	6,098	0.032239	0.2525	3,922	9,481
WMed_noAlb	Sum	30,270	0.038992	0.0348	29,526	33,764
Alb	Sum	5,274	0.076757	0.2245	3,546	7,844
Gib_dist	Sum	162	0.079140	0.1096	132	199
Adriatic	Sum	16,165	0.121463	0.2361	10,670	24,491
Total	**Sum**	**89,644**	**0.035759**	**0.0619**	**79,689**	**100,843**
Ionian	Win	18,054	0.023571	0.1096	14,725	22,136
Levantine	Win	27,088	0.047387	0.2385	17,812	41,196
Aegean	Win	4,458	0.023569	0.2197	3,021	6,580
WMed_noAlb	Win	30,270	0.038992	0.0348	29,526	33,764
Alb	Win	4,227	0.061519	0.1945	2,984	5,988
Gib_dist	Win	162	0.079140	0.1096	132	199
Adriatic	Win	14,459	0.108644	0.3902	7,581	27,578
Total	**Win**	**98,718**	**0.039379**	**0.0907**	**83,271**	**117,030**

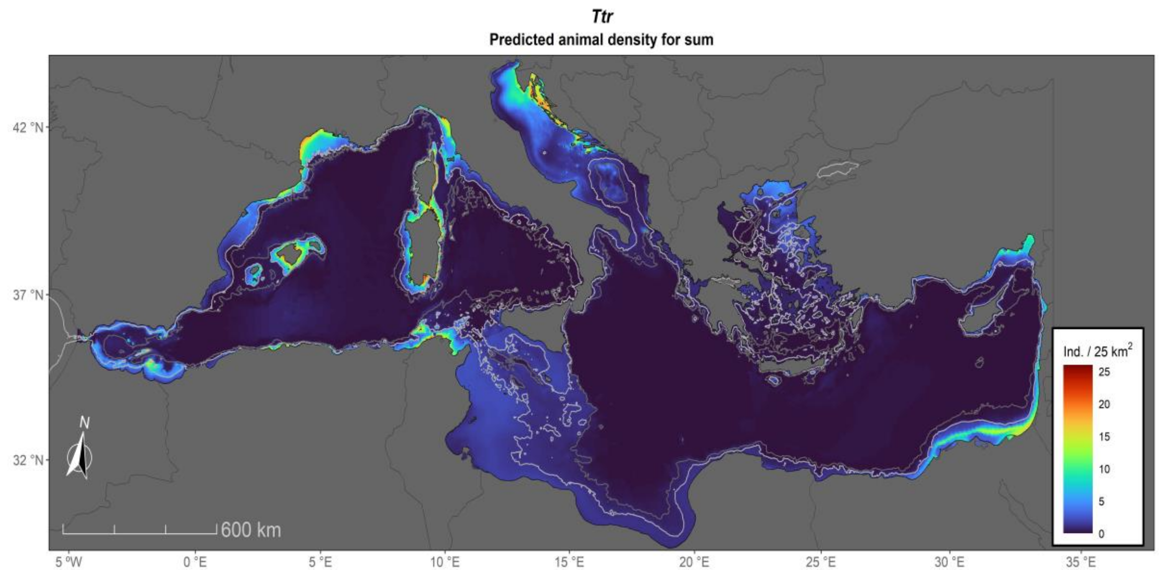
ACCOBAMS survey:

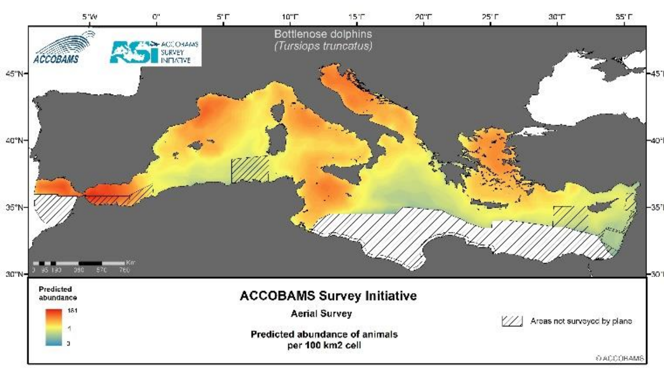
57,120 uncorrected
67,121 corrected (0.85)

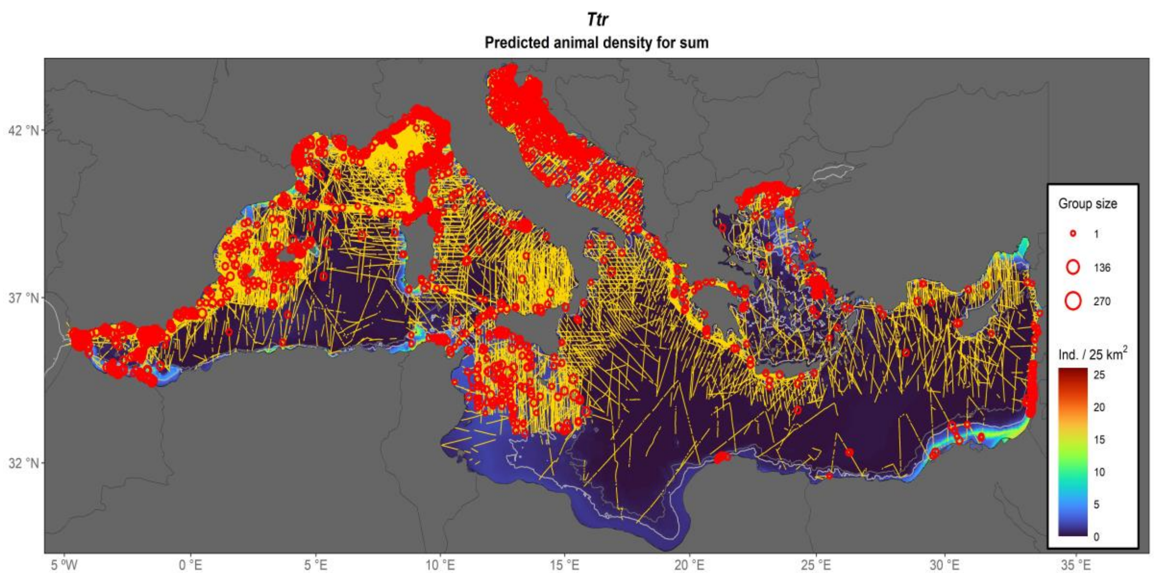
ACCOBAMS area from our analysis:
73,631 corrected

Mediterranean - Bottlenose Dolphin - Summer

Plots of predicted density and CV

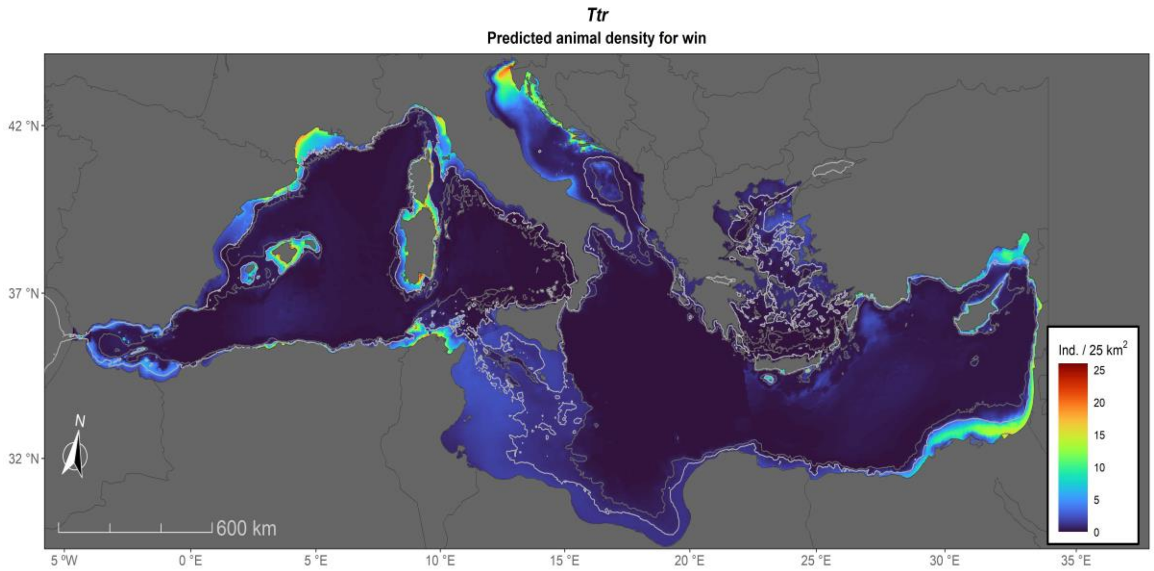


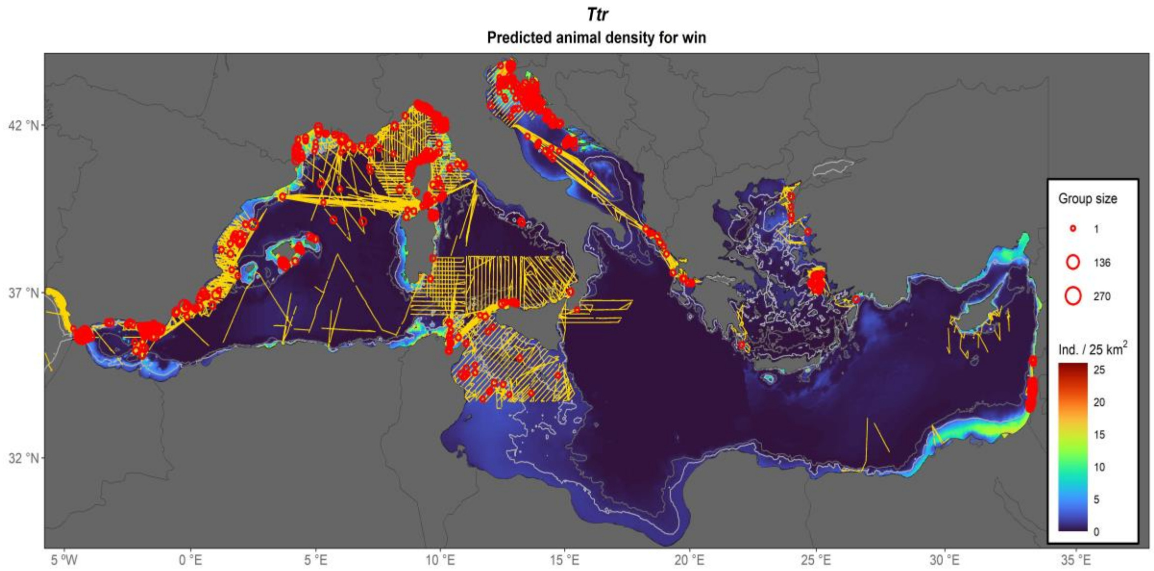




Mediterranean - Bottlenose dolphin - Winter

Plots of predicted density and CV





Mediterranean - Common dolphin

Considerations

- Models were better when modeling separately summer and winter.

- Several collaborators suggested that common dolphins in the Alboran Sea needed to be modeled separately from the rest. So, this was done, both for summer and winter.

Estimated abundance and uncertainty

Winter

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Alboran	Win	28,461	0.414219	0.3372	16,243	50,741
Gib_dist	Win	3,446	1.683439	0.1526	3,303	5,763
noAlb	Win	48,675	0.019981	0.6039	19,928	126,989
Total	**Win**	**80,582**	**0.032144**	**0.3838**	**42,632**	**152,315**

Summer

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Alboran	Sum	34,746	0.505691	0.1232	27,670	43,632
Gib_dist	Sum	3,446	1.683439	0.1526	3,303	5,763
noAlb	Sum	40,710	0.016711	0.1474	31,656	54,268
Total	**Sum**	**78,902**	**0.031474**	**0.0937**	**66,198**	**94,043**

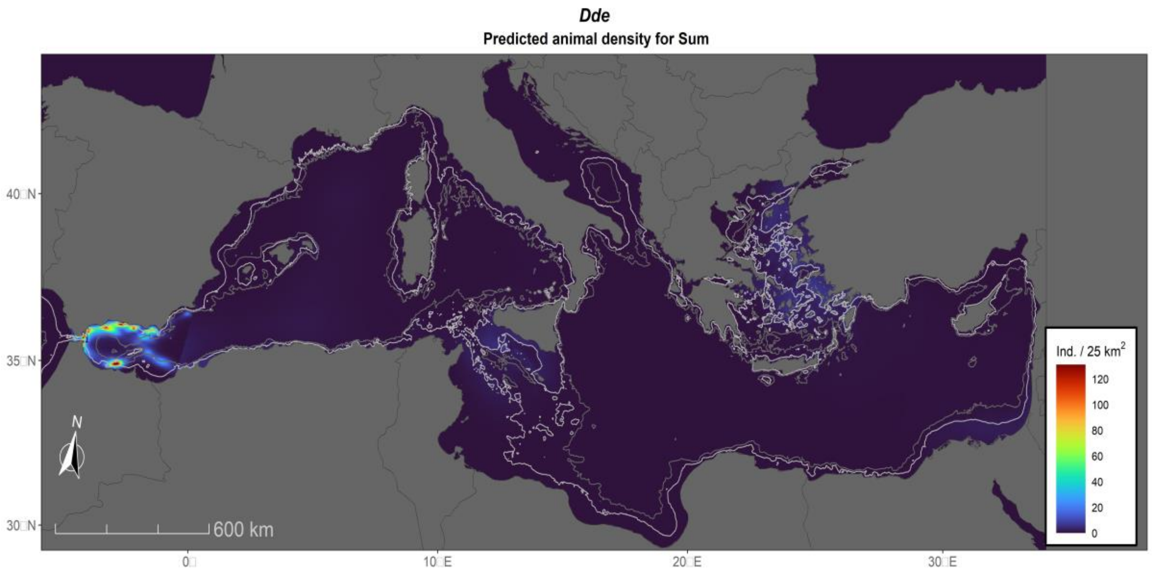
ACCOBAMS survey:

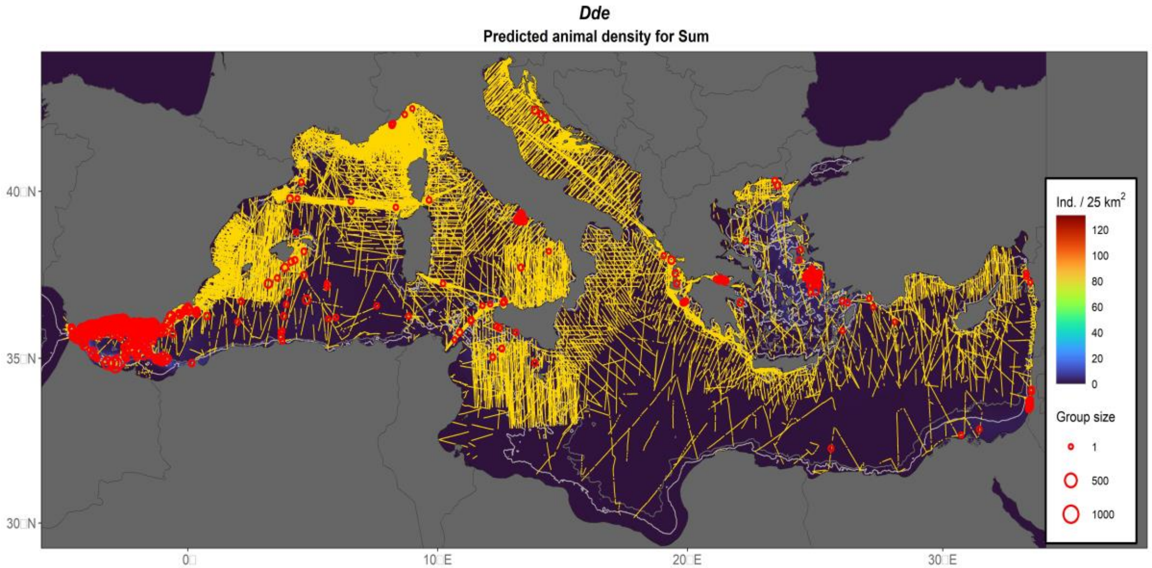
29,646 uncorrected
33,198 corrected (0.89)

ACCOBAMS area from our analysis:
75,142 corrected

Mediterranean - Common Dolphin - Summer

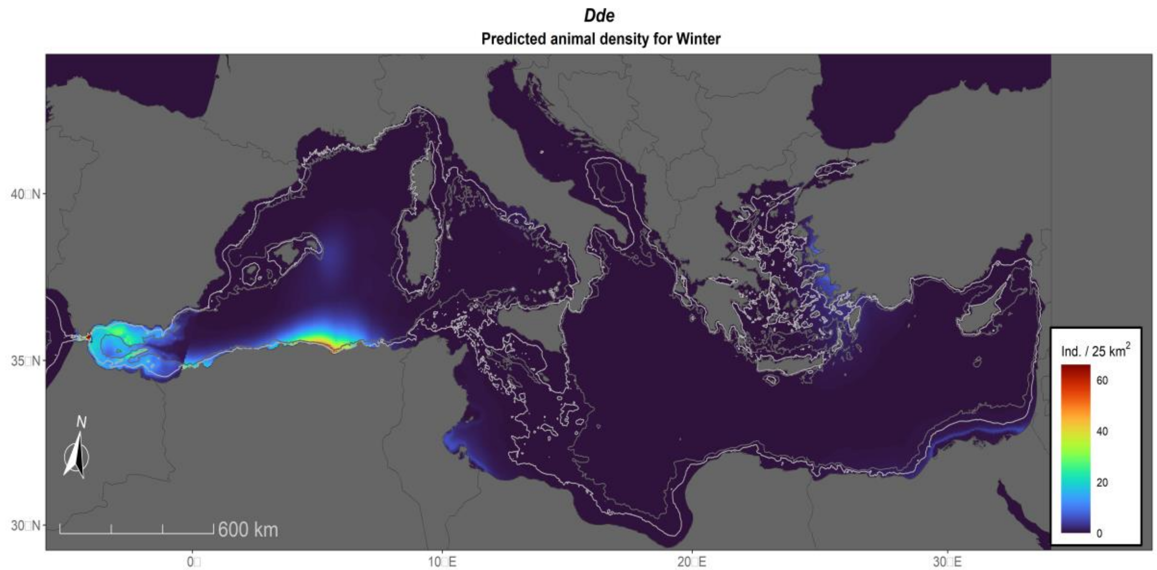
Plots of predicted density and CV

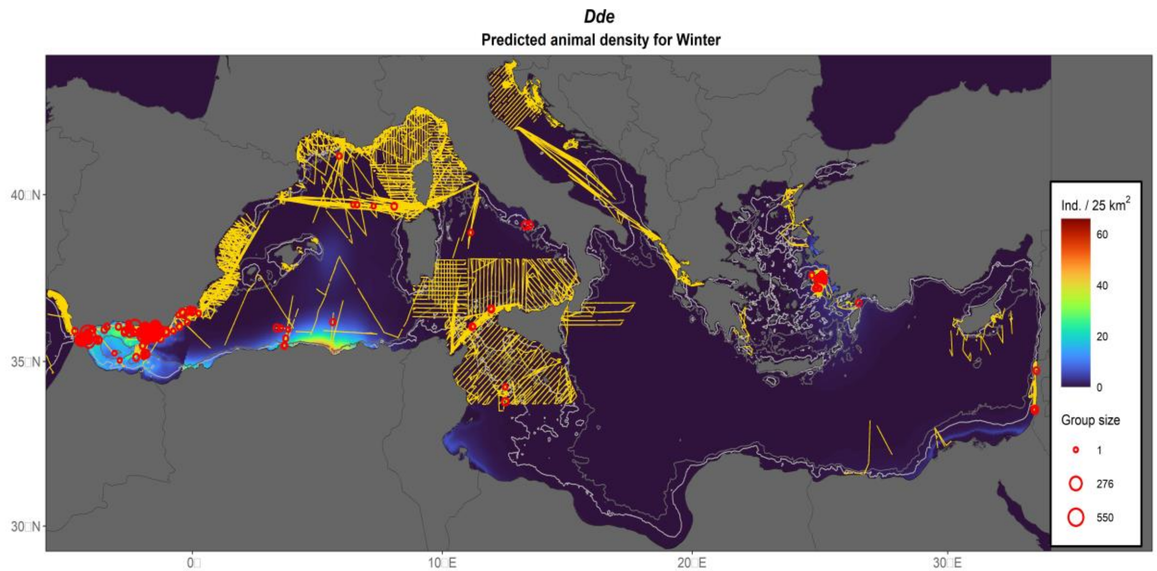




Mediterranean - Common Dolphin - Winter

Plots of predicted density and CV





Mediterranean - Striped dolphin

Considerations

- Models were better when modeling separately summer and winter.

- Only the Gibraltar Strait was modeled separately from the rest.

Estimated abundance and uncertainty

Winter

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Gib_dist	Win	3,863	1.887152	0.1082	3,536	5,290
noGib	Win	489,864	0.195568	0.1970	344,946	698,040
Total	**Win**	**493,727**	**0.196949**	**0.1955**	**347,928**	**700,622**

Summer

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Gib_dist	Sum	3,863	1.887152	0.1082	3,536	5,290
noGib	Sum	477,383	0.190585	0.1300	375,263	605,903
Total	**Sum**	**481,246**	**0.191971**	**0.1290**	**379,391**	**610,446**

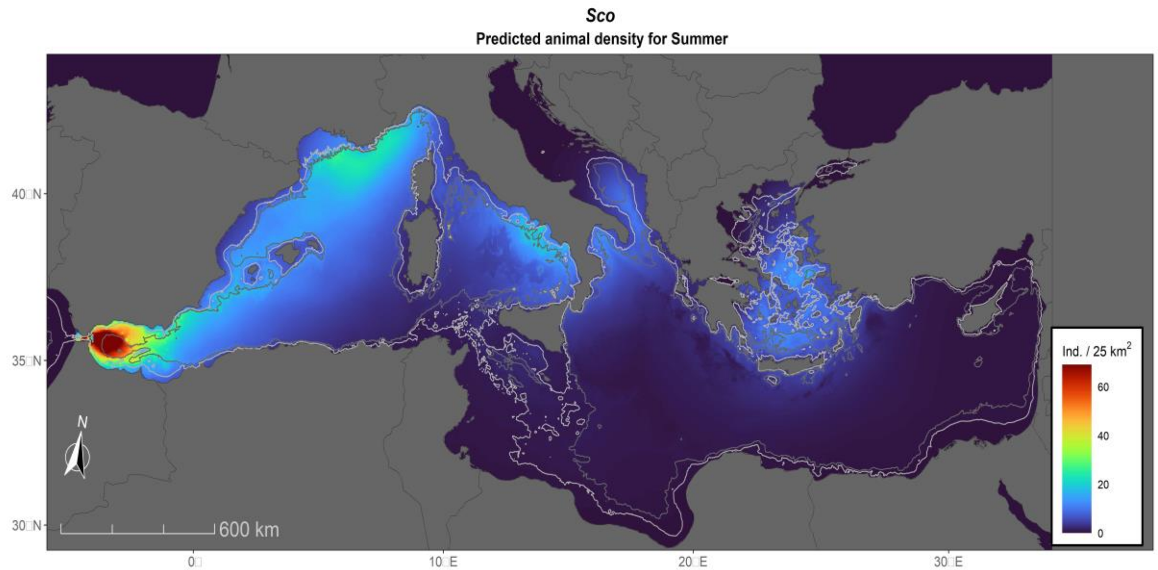
ACCOBAMS survey:

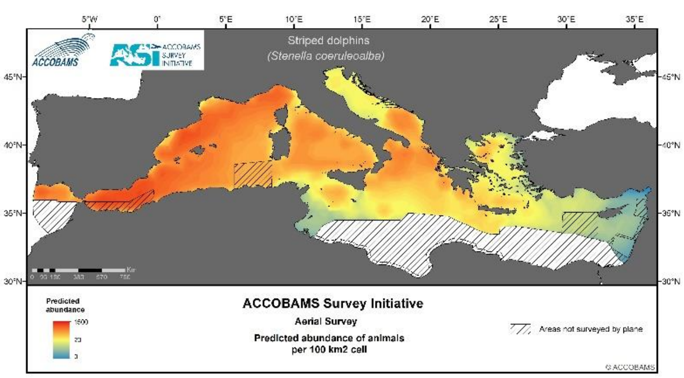
419,456 uncorrected
534,339 corrected (0.79)

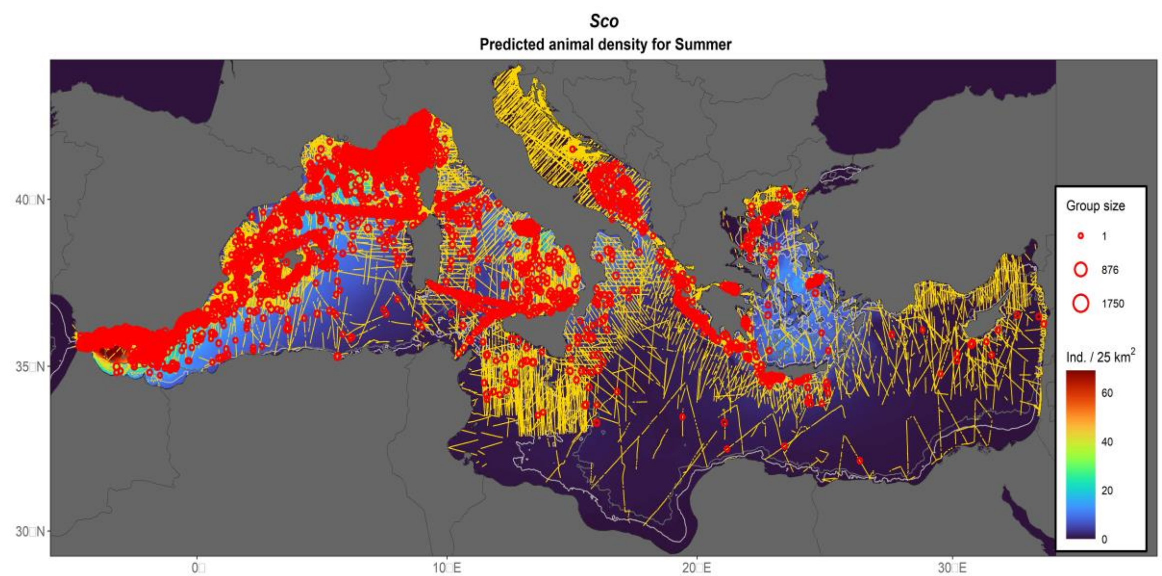
ACCOBAMS area from our analysis:
468,964 corrected

Mediterranean - Striped Dolphin - Summer

Plots of predicted density and CV

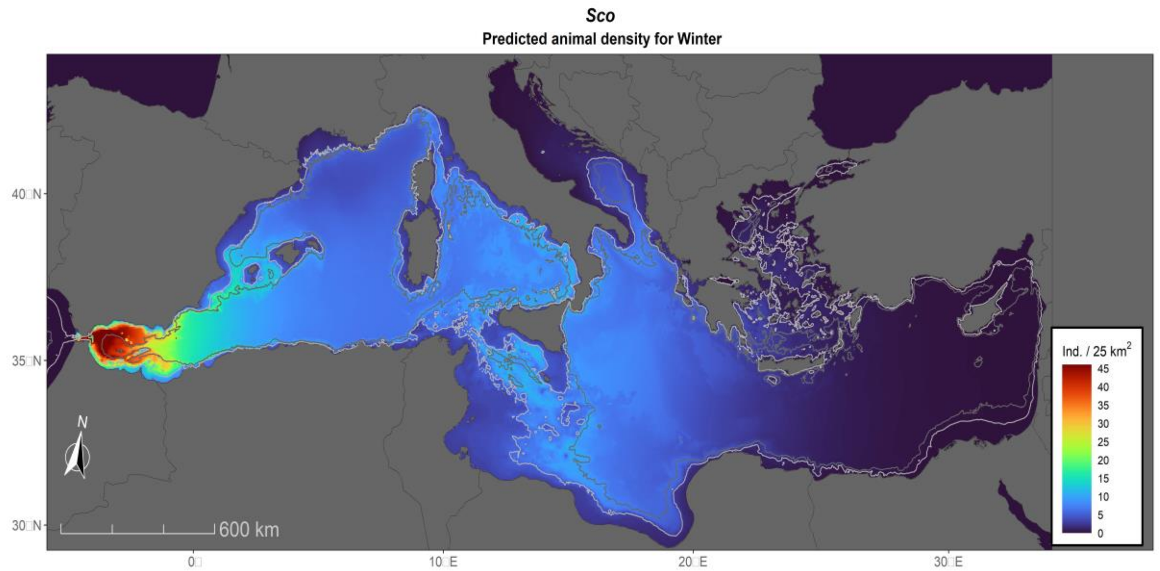


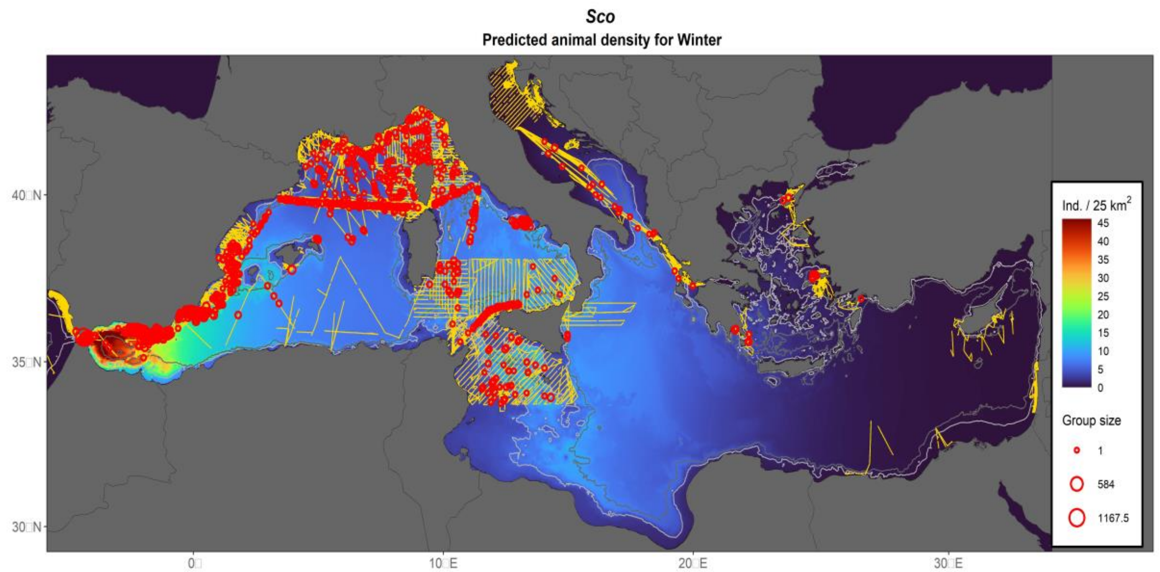




Mediterranean - Striped dolphin-Amb-all

Plots of predicted density and CV for Win





Mediterranean – Risso's dolphin

Considerations

- Models were better when modeling all year.
- The Gibraltar Strait was assumed to have zero density

Estimated abundance and uncertainty

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
noGib	Full	15,170	0.006056	0.1259	12,024	19,139
Total	**Full**	**15,170**	**0.006051**	**0.1259**	**12,024**	**19,139**
noGib	Sum	14,554	0.005810	0.1186	11,684	18,131
Total	**Sum**	**14,554**	**0.005806**	**0.1186**	**11,684**	**18,129**
noGib	Win	15,785	0.006302	0.1197	12,648	19,701
Total	**Win**	**15,785**	**0.006297**	**0.1197**	**12,648**	**19,701**

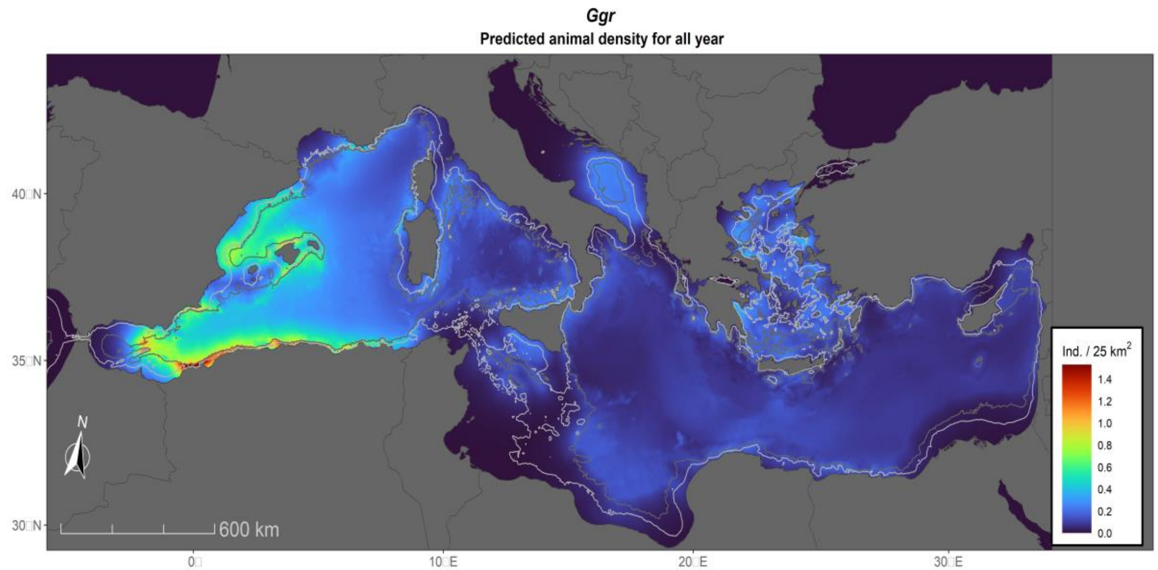
ACCOBAMS survey:

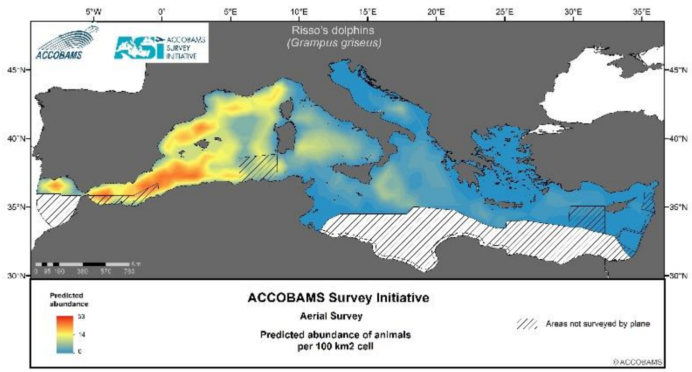
23,164 uncorrected
27,511 corrected (0.84)

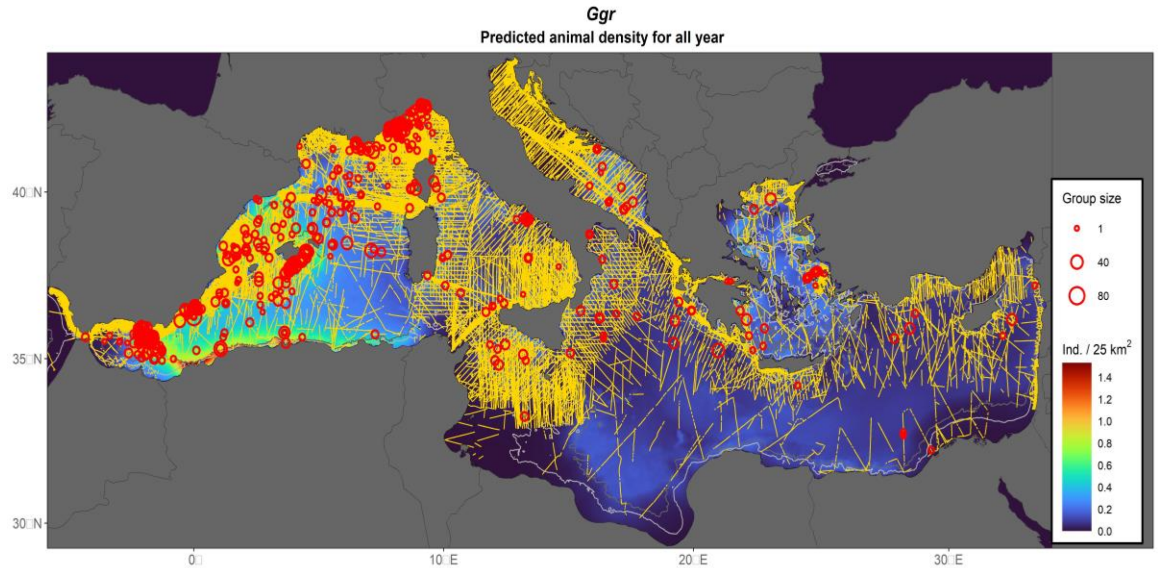
ACCOBAMS area from our analysis:
13,383 corrected

Mediterranean – Risso's Dolphin - Summer

Plots of predicted density and CV

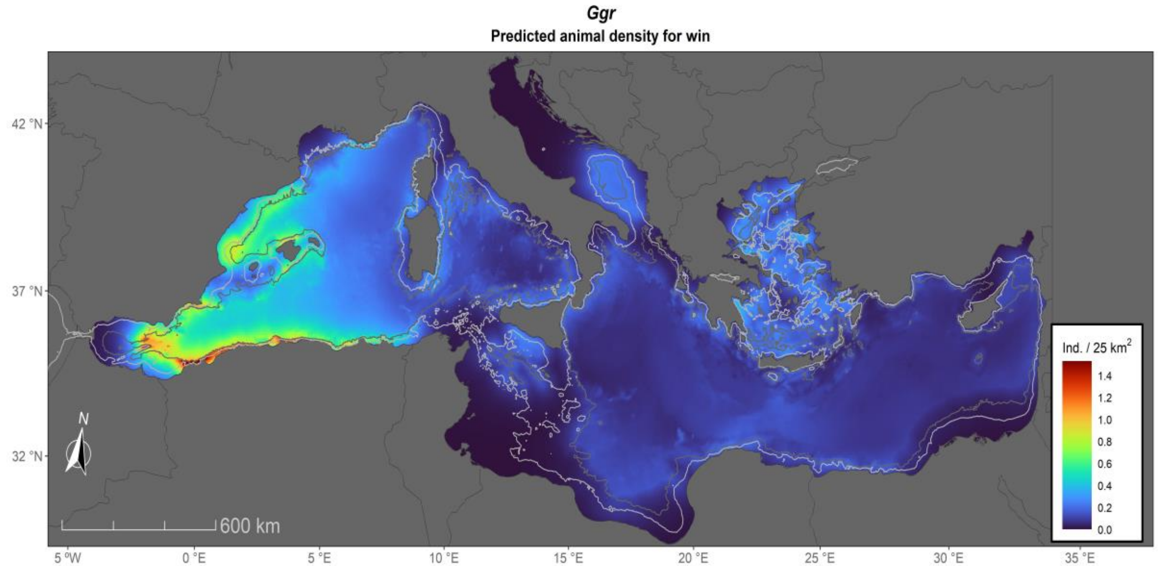


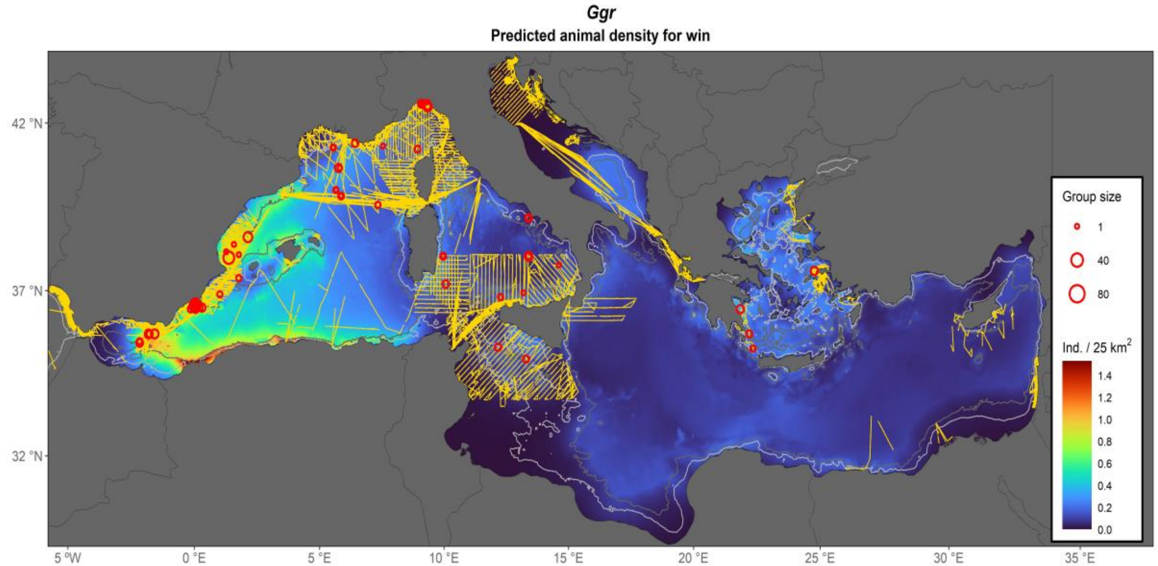




Mediterranean – Risso's Dolphin - Winter

Plots of predicted density and CV





Mediterranean – Long-finned pilot whale

Considerations

- Models were better when modeling all year. Better models were obtained when modeling since 1991.
- The Gibraltar Strait, the Alboran Sea and the rest of the Mediterranean were modeled separately.
- The Adriatic, the Aegean and the Levantine Seas, were assumed to have zero density
- **Strait of Gibraltar**: a very accurate abundance estimate exists for this block from photo-id work carried out over many years. Therefore, I scaled the estimate obtained with the model to the actual estimate from the local researcher. He agreed on the distribution pattern we obtained.

Estimated abundance and uncertainty

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
WMed-Ion-noAlb	Full	4,418	0.002865	0.2914	2,676	7,293
Alb	Full	3,106	0.045204	0.3751	1,663	5,797
Gib_dist	Full	285	0.139228	0.1569	214	379
Total	**Full**	**7,809**	**0.003115**	**0.2224**	**5,268**	**11,575**
WMed-Ion-noAlb	Sum	4,177	0.002708	0.3167	2,435	7,161
Alb	Sum	3,967	0.057735	0.2474	2,572	6,118
Gib_dist	Sum	285	0.139228	0.1569	214	379
Total	**Sum**	**8,429**	**0.003362**	**0.1955**	**5,940**	**11,961**
WMed-Ion-noAlb	Win	4,659	0.003021	0.2592	2,966	7,319
Alb	Win	2,245	0.032674	0.2302	1,496	3,370
Gib_dist	Win	285	0.139228	0.1569	214	379
Total	**Win**	**7,189**	**0.002868**	**0.1828**	**5,173**	**9,990**

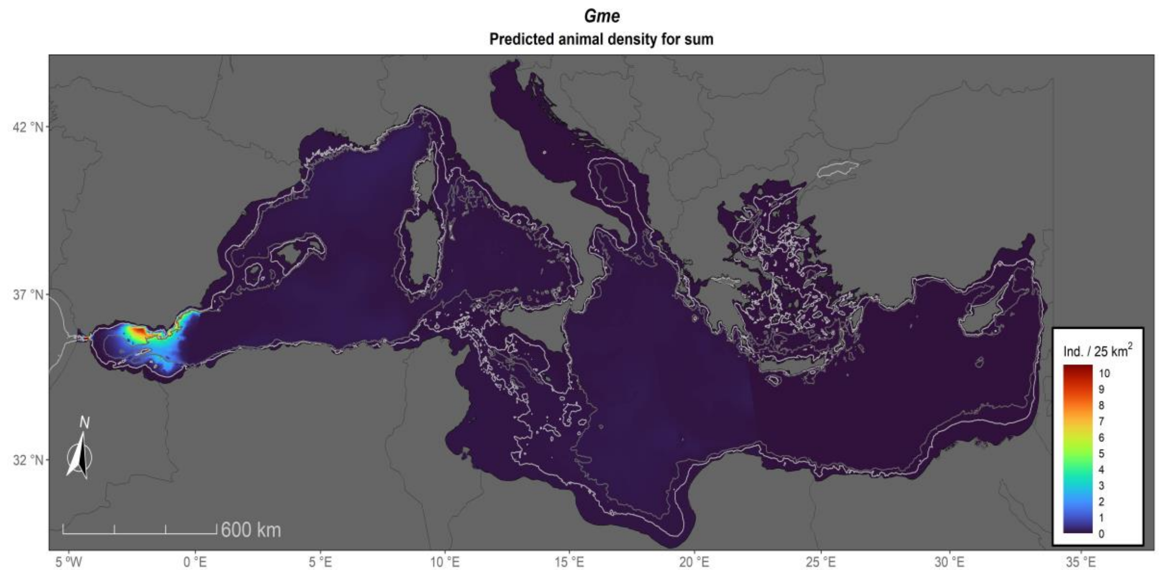
ACCOBAMS survey:

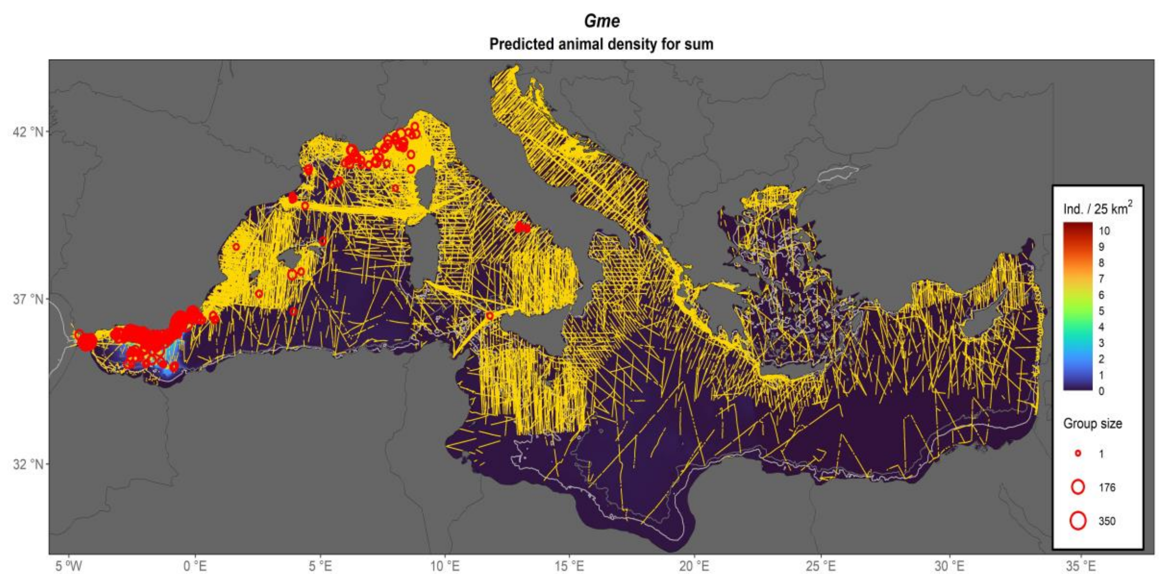
5,131 uncorrected
5,273 corrected (0.97)

ACCOBAMS area from our analysis:
6,965 corrected

Mediterranean – Long-finned pilot whale - Summer

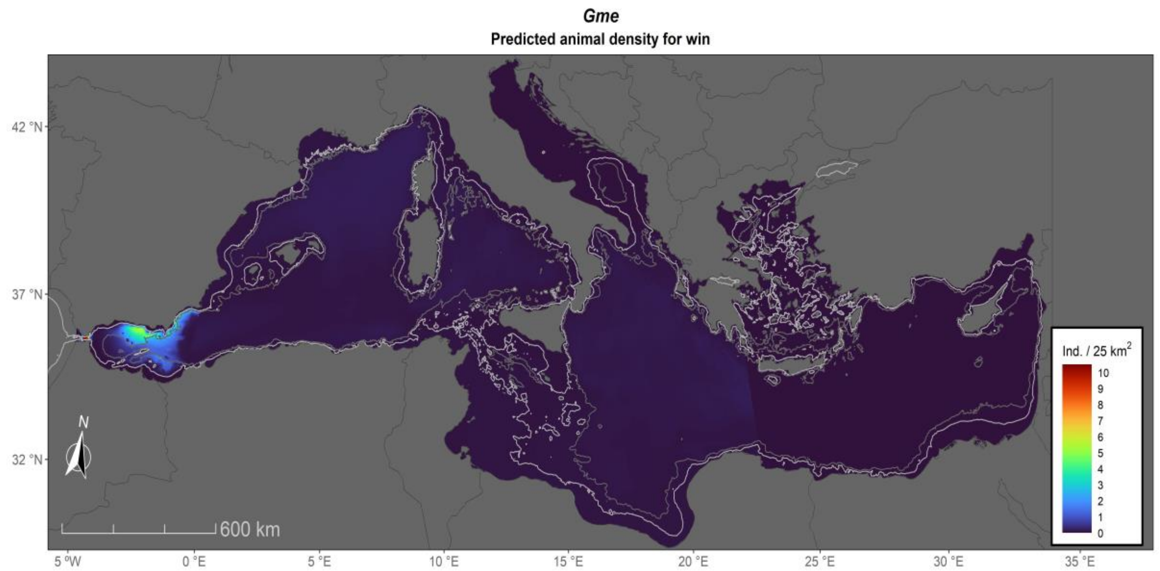
Plots of predicted density and CV

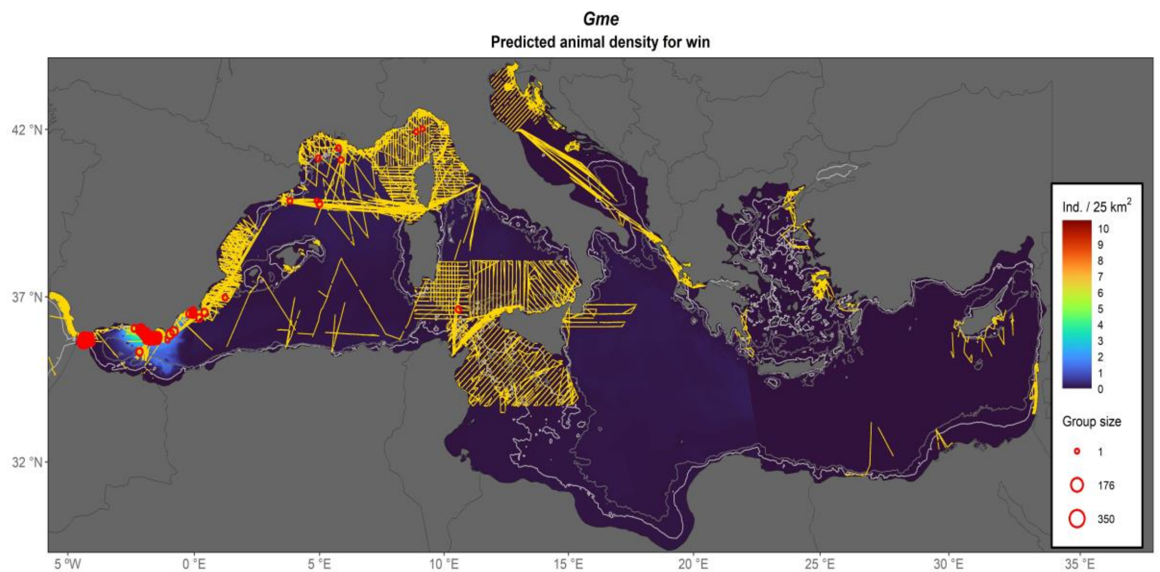




Mediterranean – Long-finned pilot whale - Winter

Plots of predicted density and CV





Mediterranean – Fin whales

Considerations

- Models were better when modeling all year.

- The Gibraltar Strait was modeled separately

Estimated abundance and uncertainty

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
Gib_dist	Full	10	0.004885	0.2072	8	16
noGib	Full	2,214	0.000884	0.1914	1,571	3,121
Total	**Full**	**2,224**	**0.000887**	**0.1905**	**1,580**	**3,130**
Gib_dist	Sum	10	0.004885	0.2072	8	16
noGib	Sum	1,989	0.000794	0.1596	1,489	2,660
Total	**Sum**	**1,999**	**0.000797**	**0.1588**	**1,497**	**2,669**
Gib_dist	Win	10	0.004885	0.2072	8	16
noGib	Win	2,438	0.000973	0.1631	1,813	3,278
Total	**Win**	**2,448**	**0.000977**	**0.1624**	**1,823**	**3,288**

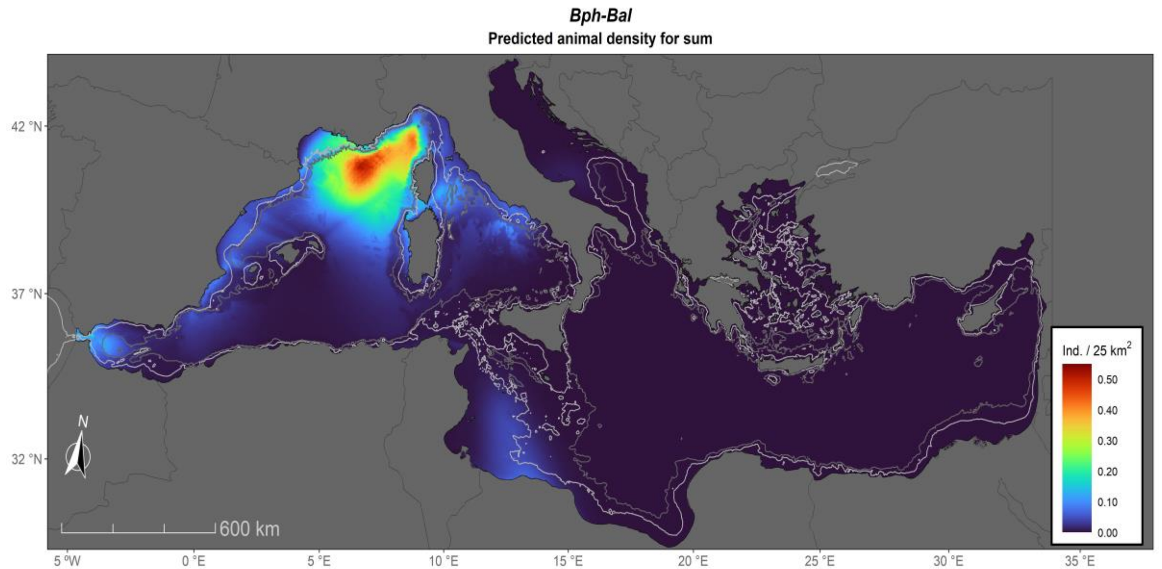
ACCOBAMS survey:

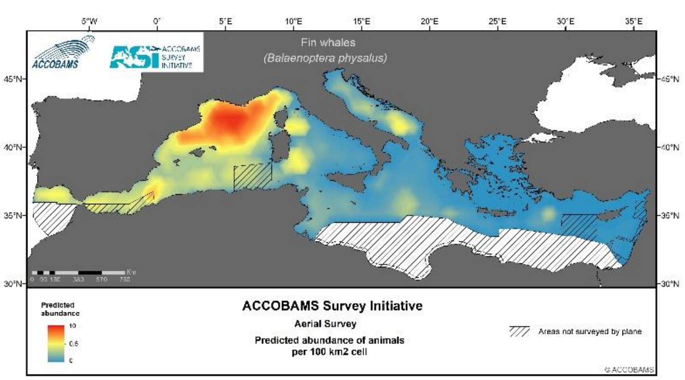
1,765 uncorrected
3,922 corrected (0.45)

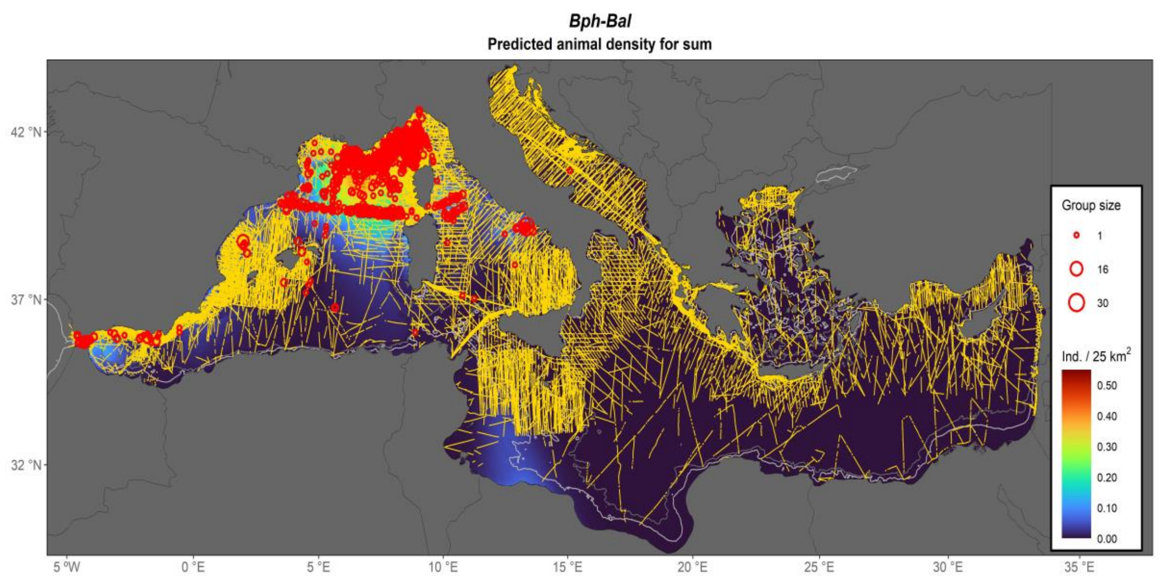
ACCOBAMS area from our analysis:
2112 corrected

Mediterranean – Fin whales - Summer

Plots of predicted density and CV

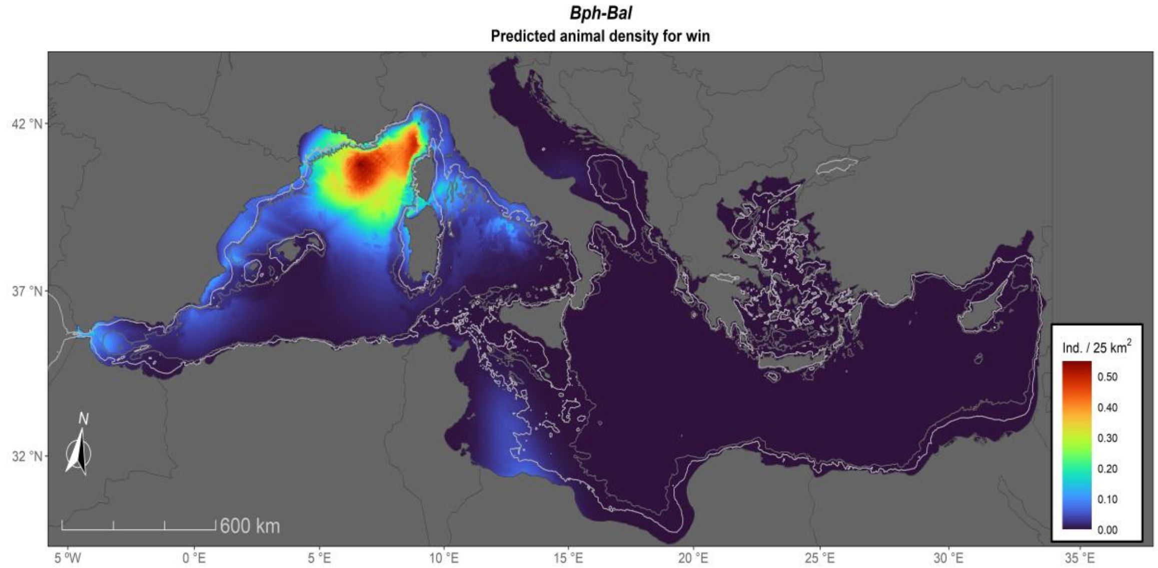


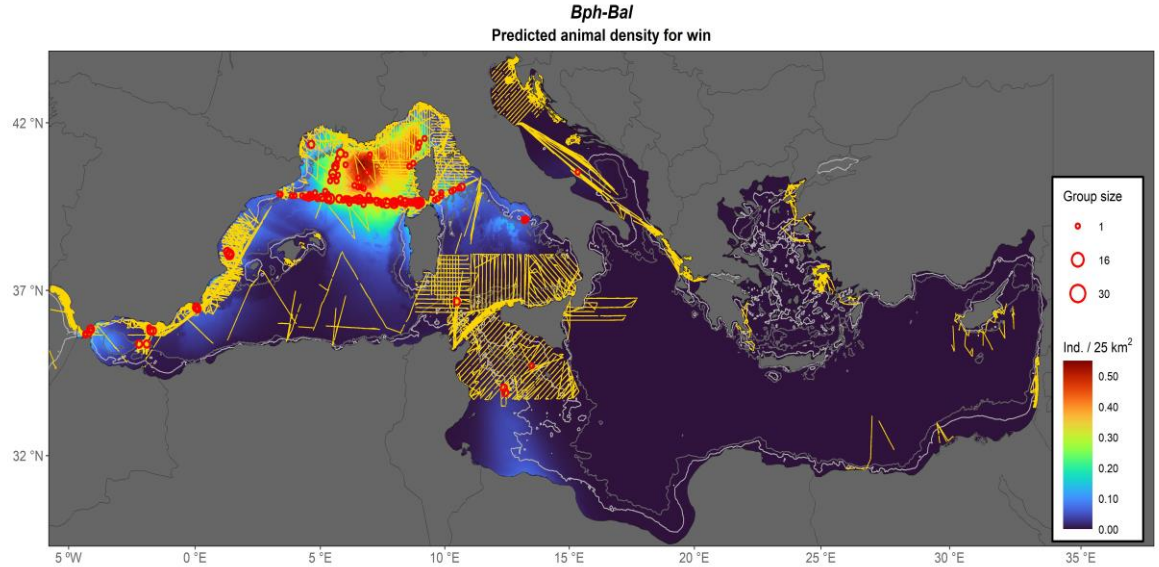




Mediterranean – Fin whales - Winter

Plots of predicted density and CV





Mediterranean - Sperm whale

Considerations

- Researchers from Pelagos (Greece) expressed their concern of a very large overestimation of sperm whales in the Eastern Mediterranean. After long discussions, we found out that the root problem was what we already discussed for the detection functions. Esw no valid for visual sightings.

- Once this was corrected, the abundance estimates came down much closer to what the researchers think is plausible. They think there is still some overestimation, but that is based on their knowledge mostly on the Hellenic Trench.

- No sightings were available for winter (very low effort too), but collaborators indicated that they do have acoustic detections and visual opportunistic detections too. They suggest that in winter there is the same density as in summer, so the summer density for EMed was applied for that region in winter too.

Estimated abundance and uncertainty

Winter

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
EMed	Sum	500	0.000328	0.2488	323	773
WMed	Win	2611	0.003082	0.3474	1513	4869
Gib_dist	Win	58	0.028334	0.1014	50	73
Total	**Win**	**3169**	**0.001264**	**0.2224**	**5268**	**11575**

Summer

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
EMed	Sum	500	0.000328	0.2488	323	773
WMed	Sum	4404	0.005199	0.1074	3734	5571
Gib_dist	Sum	58	0.028334	0.1014	50	73
Total	**Sum**	**4962**	**0.001979**	**0.2224**	**5268**	**11575**

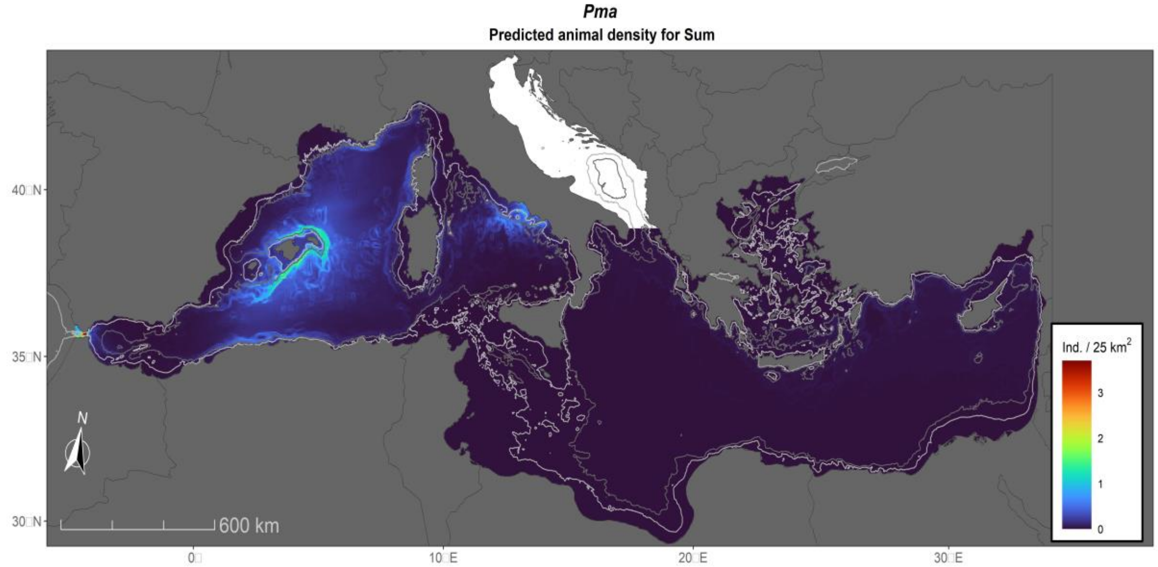
ACCOBAMS survey:

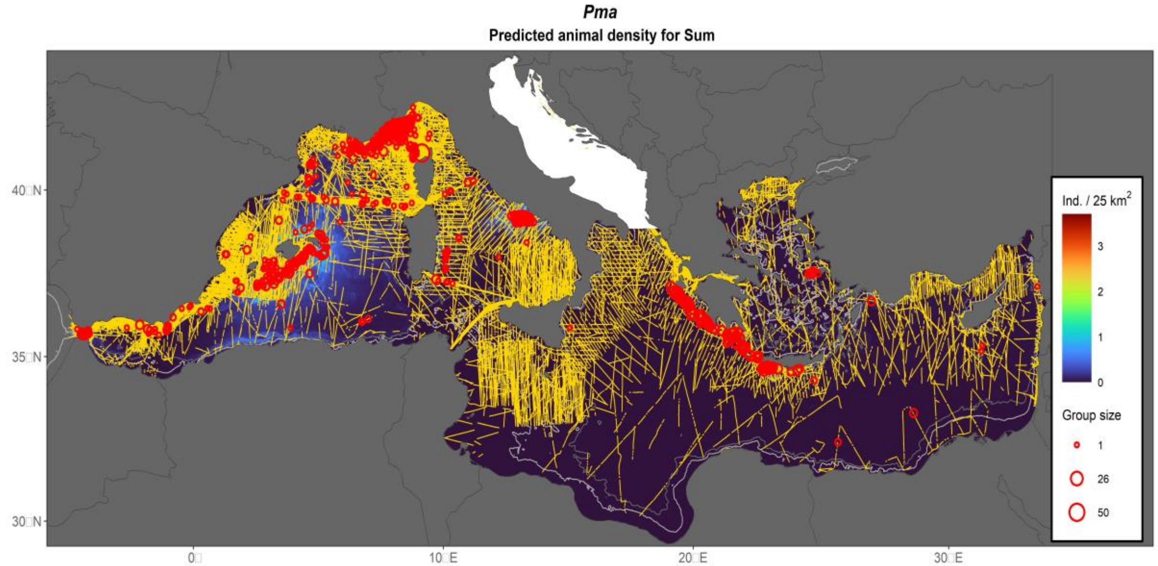
1,416 uncorrected
3,955 corrected (0.36)

ACCOBAMS area from our analysis:
4,799 corrected

Mediterranean – Sperm whales - Summer

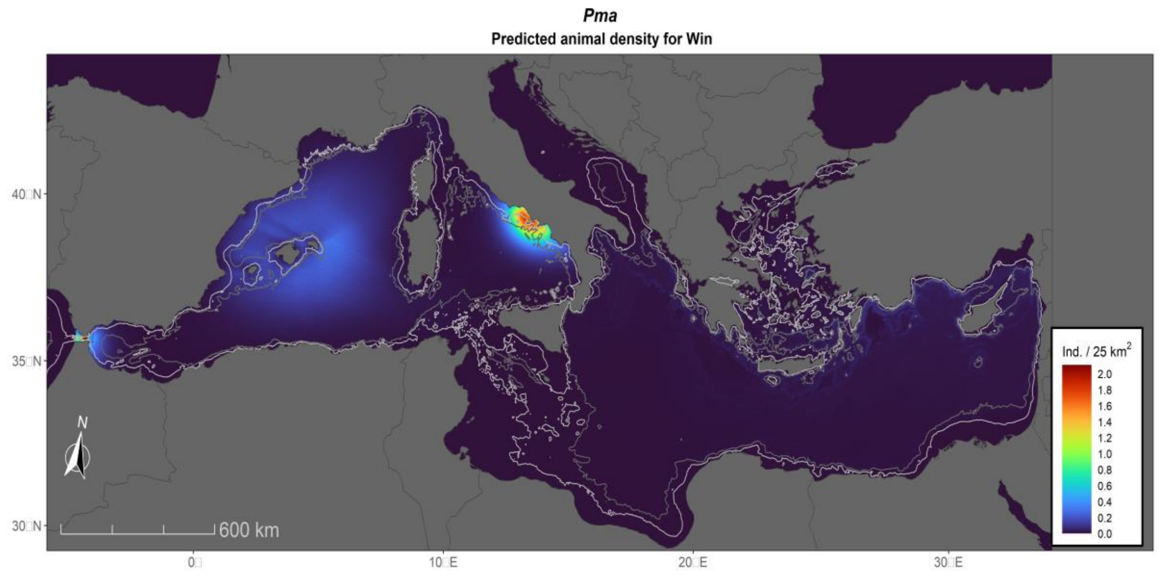
Plots of predicted density and CV

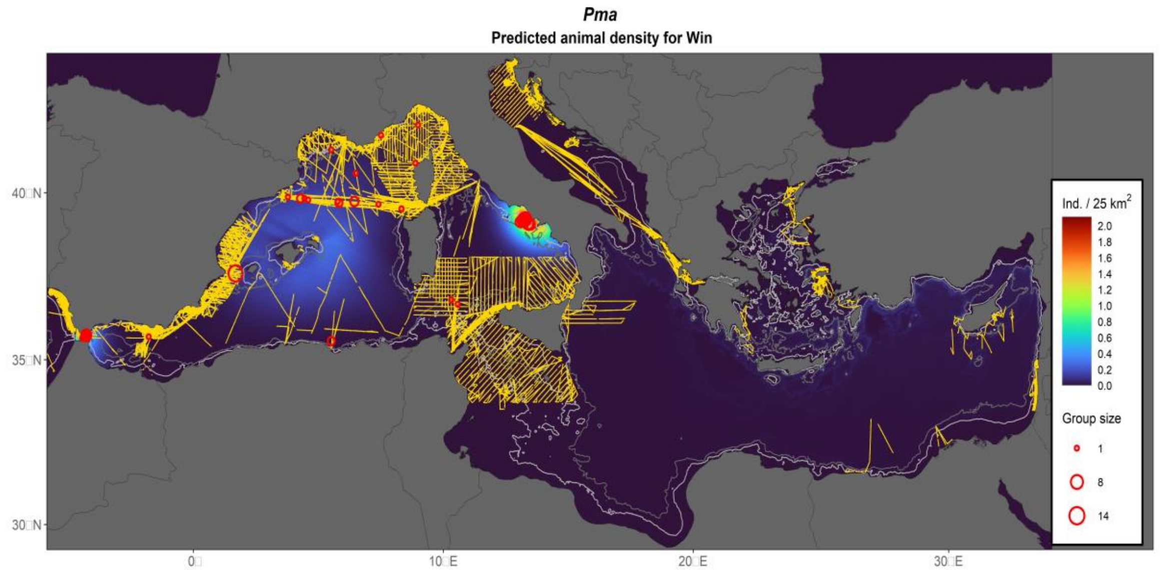




Mediterranean – Sperm whales - Winter

Plots of predicted density and CV





Mediterranean - Cuviers beaked whale

Considerations

- Models were better when modeling all year.

- Eastern and western Mediterranean were modeled separately

Estimated abundance and uncertainty

Block	Season	model.abundance	density	cv	L95ci_abundance	U95ci_abundance
WMed	Full	1,066	0.001258	0.2021	746	1,535
EMed	Full	3,175	0.001267	0.2697	2,390	6,093
Total	**Full**	**4,241**	**0.001692**	**0.2082**	**2,927**	**6,144**
WMed	Sum	1,100	0.001299	0.1986	774	1,575
EMed	Sum	3,175	0.001267	0.2697	2,390	6,093
Total	**Sum**	**4,275**	**0.001705**	**0.2067**	**2,958**	**6,178**
WMed	Win	1,033	0.001219	0.2011	723	1,484
EMed	Win	3,175	0.001267	0.2697	2,390	6,093
Total	**Win**	**4,208**	**0.001679**	**0.2094**	**2,899**	**6,108**

Cañadas et al. 2017:

5,799 corrected

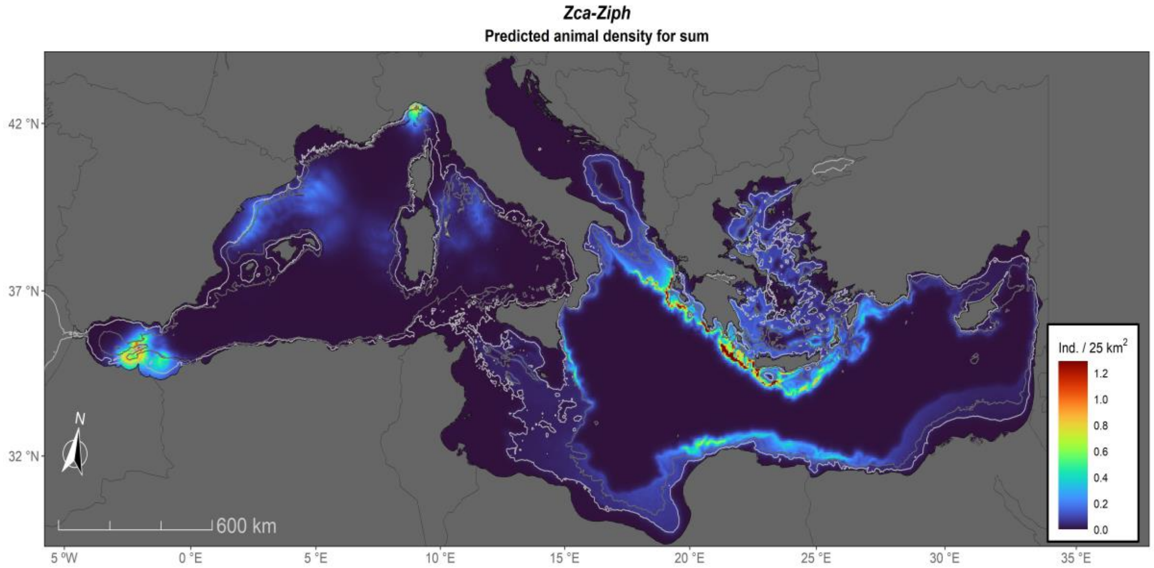
ACCOBAMS survey:

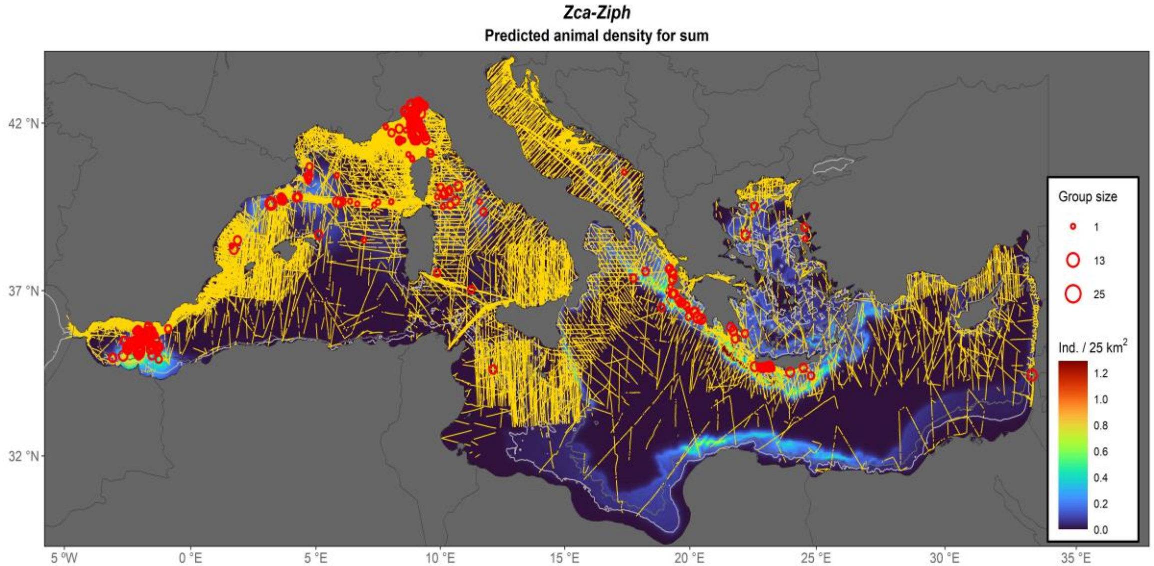
2,980 uncorrected
20,272 corrected (0.15)

ACCOBAMS area from our analysis:
3,644 corrected

Mediterranean – Cuviers beaked whale - Summer

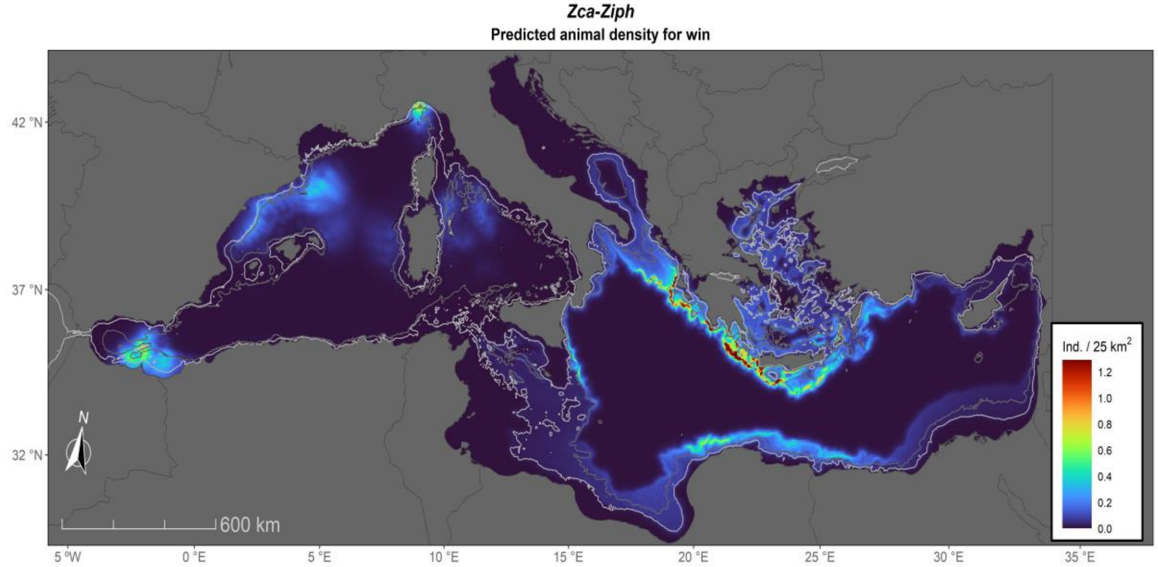
Plots of predicted density and CV

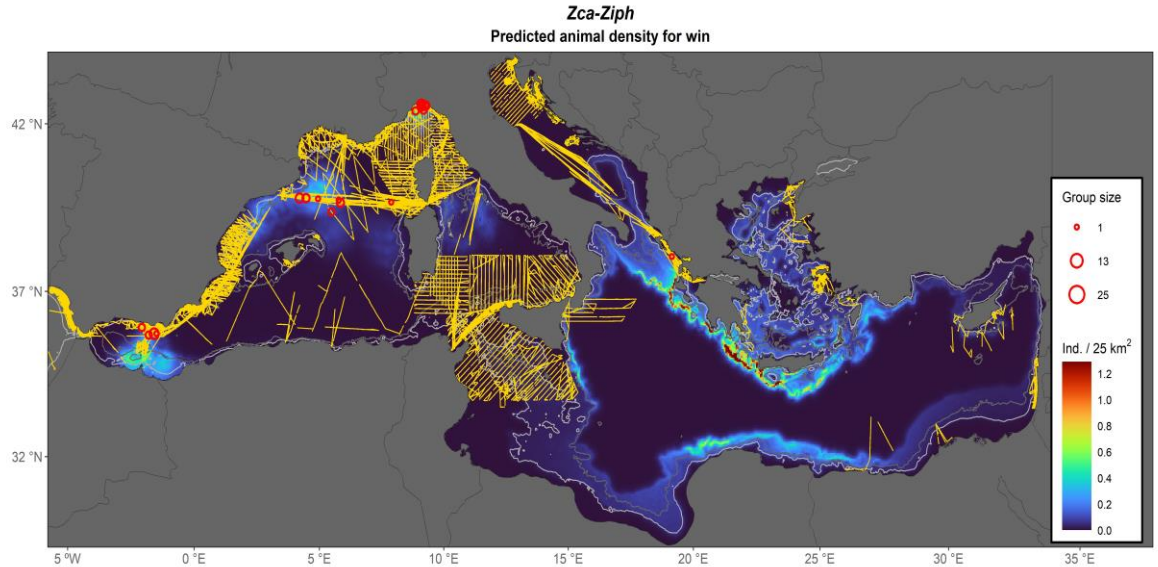




Mediterranean – Cuviers beaked whale - Winter

Plots of predicted density and CV





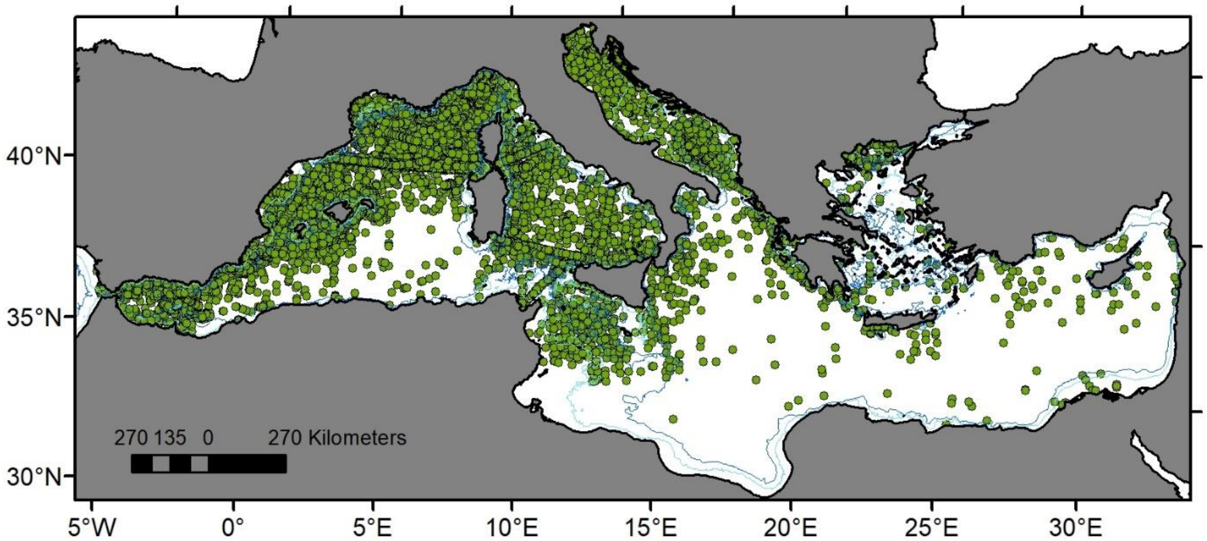
Mediterranean – General considerations

- Seasonality
  - Temporal-spatial heterogeneity
  - Monthly climatologies
- Sperm whales
  - Visual observations after acoustic tracking
  - Incorporation of acoustic surveys in the future
- Datasets without distances
  - Esw from similar platforms as proxy
  - Potential biases

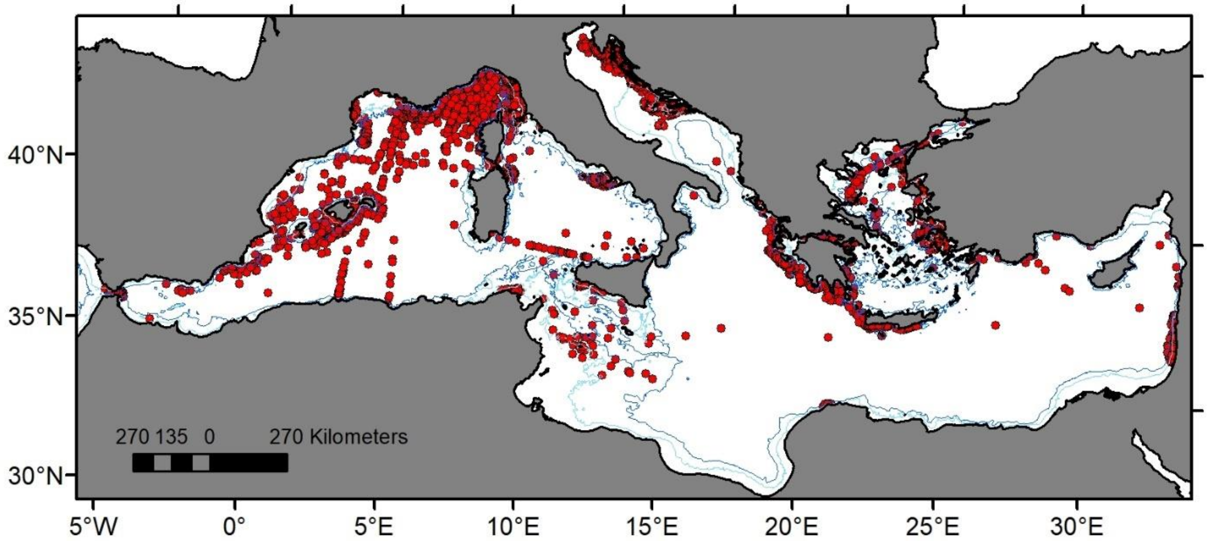
Species	No dist.	Dist	Total	% No dist	% Dist
Bottlenose dolphin	5624	2314	7938	70.8	29.2
Common dolphin	712	1845	2557	27.8	72.2
Cuviers beaked whale	277	372	649	42.7	57.3
False killer whale	1	2	3	33.3	66.7
Fin whale	972	2524	3496	27.8	72.2
Harbour porpoise		23	23	0.0	100.0
Killer whale	6	89	95	6.3	93.7
Long-finned pilot whale	90	1141	1231	7.3	92.7
Rissos dolphin	158	487	645	24.5	75.5
Sperm whale	832	800	1632	51.0	49.0
Striped dolphin	4979	10111	15090	33.0	67.0
Striped or common dolphin		289	289	0.0	100.0
Unidentified Balaenoptera		8	8	0.0	100.0
Unidentified beaked whale	6	35	41	14.6	85.4
Unidentified dolphin	143	1196	1339	10.7	89.3
Total	13800	21236	35036	39.4	60.6

Mediterranean – General considerations

- Datasets without distances



Observations with distances, all species together, in the Mediterranean



Observations without distances, all species together, in the Mediterranean

Mediterranean – Future work

- Acquire more data of modeled species starting from 2022 and update existing models.
- Explore the possibility of further splitting the study area into different regions, according to the characteristics of the species, to be modeled independently or hierarchically, e.g., with factor-smoother relationships that incorporate the region as a factor.
- Whenever enough data is available, further stratify the data for the detection functions. If possible, go down to the level of individual surveys when that is feasible.
- Explore how to better deal with the observations without distance data to reduce potential biases.
- Given sufficient data and information from collaborators, stratify sperm whales into lone adult males and social groups, given their very different detectability and habitat use.
- Consider incorporating acoustic survey data for beaked whales and sperm whales to improve models.
- Refine the issue of ambiguous sightings in depth, maybe by stratifying by regions too.
- Try to incorporate rough-toothed dolphins if more sightings become available.
- Review abundance trends for some species and interannual variations, given the large span of the data available.