

Article

Aerial drone surveys reveal the efficacy of a protected area network for marine megafauna and the value of sea turtles as umbrella species

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Supplementary materials

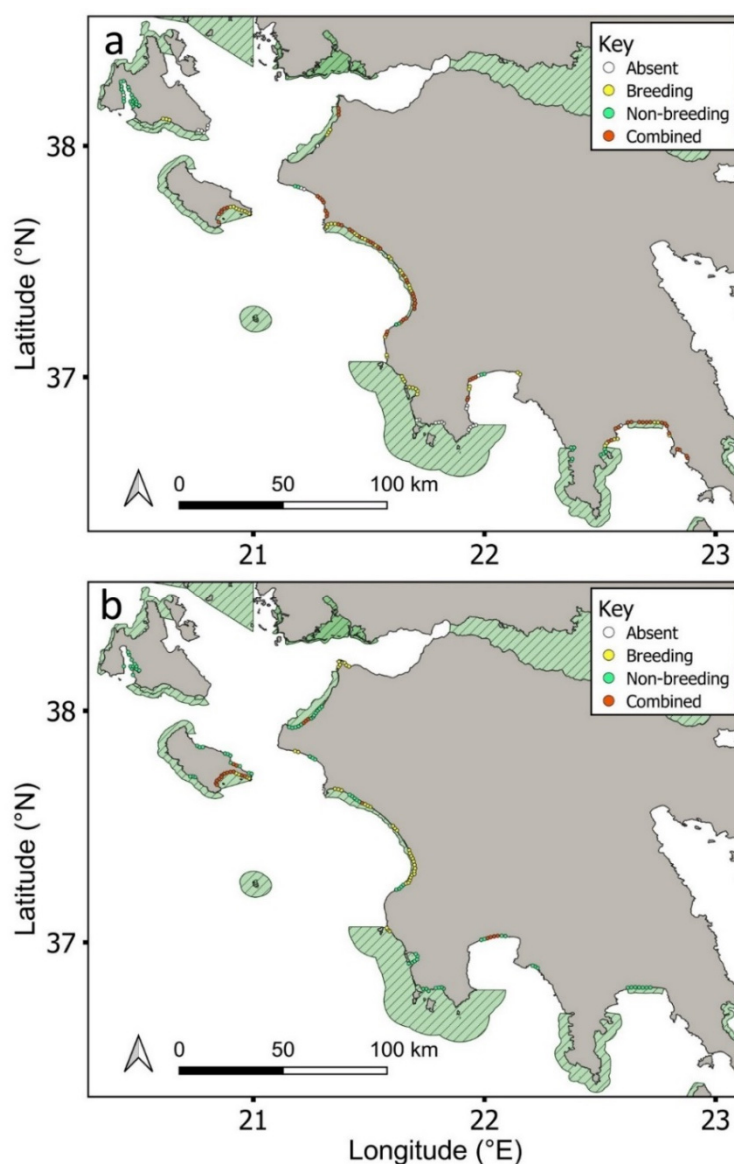


Figure S1. Study region showing the detection of loggerhead sea turtles during the breeding season (green circles), non-breeding season (blue circles), and both seasons combined (red circles) based on (a) aerial drone surveys and (b) tracking datasets.

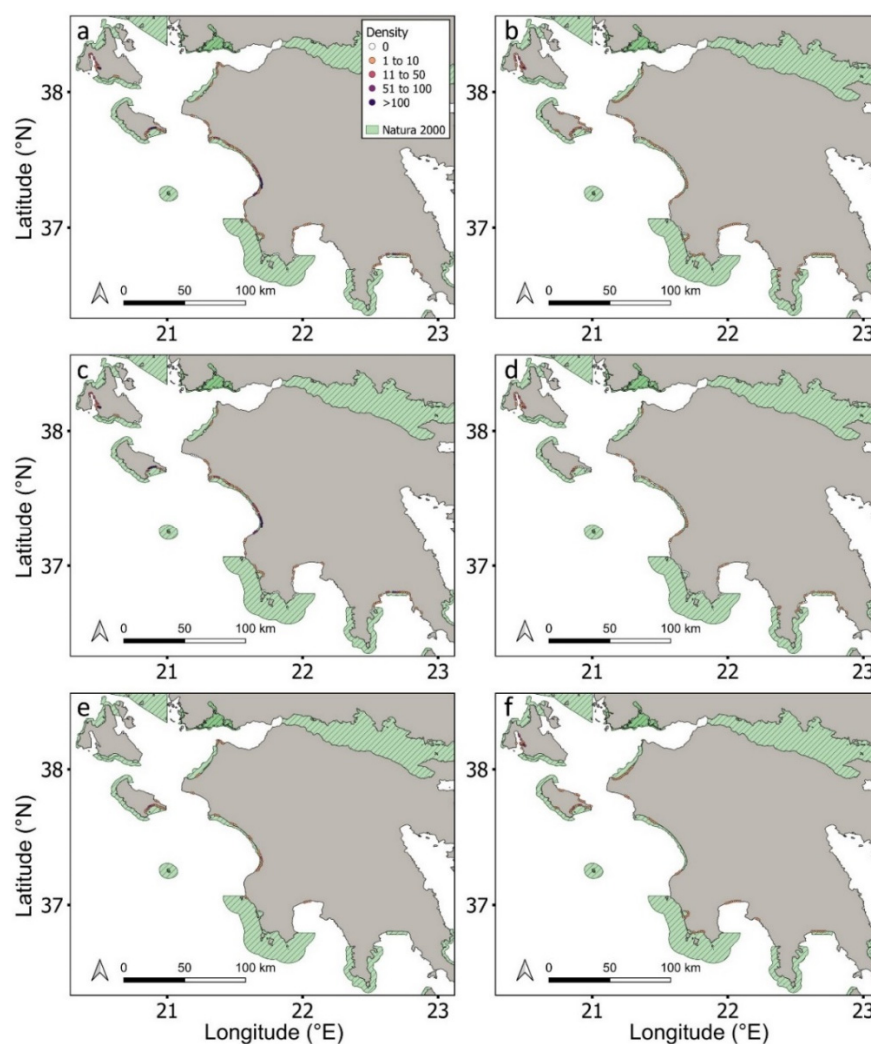


Figure S2. Map of the study region showing turtle density groupings (1-10, 11-50, 51-100, >100 turtles/km) for the breeding and non-breeding periods from (a,b) aerial drone surveys and literature sources combined, (c,d) Aerial drone surveys only, and (e,f) literature sources only. Natura 2000 protected areas: dashed green polygons. Circles represent 2 km sections (cells) along coastline. Key (Density; top right in panel a) is the same across all panels.

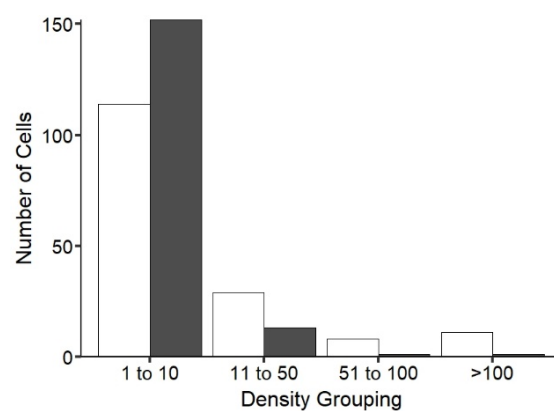


Figure S3. Distribution of density groupings (1-10, 11-50, 51-100, >100 turtles/km) across sites for the breeding (light grey; $n_{1-10} = 115$, $n_{11-50} = 28$, $n_{51-100} = 8$, $n_{>100} = 11$) and non-breeding (black; $n_{1-10} = 152$, $n_{11-50} = 13$, $n_{51-100} = 1$, $n_{>100} = 1$) periods from aerial drone surveys and literature sources combined.

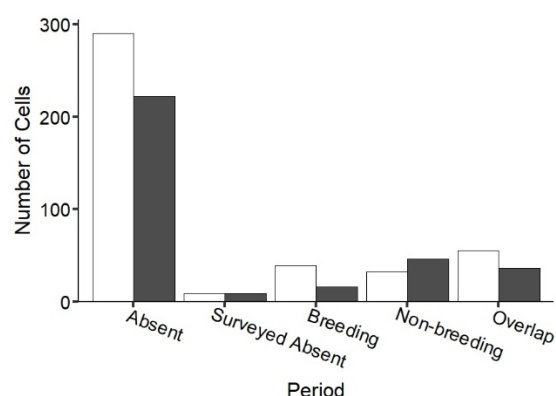


Figure S4. Distribution of cells inside (light grey) and outside (black) MPAs. Cell counts were higher for sites in MPAs ($\chi^2 = 9.08$, $df = 3$, $P < 0.05$) for sites where turtles were detected in breeding, non-breeding, or overlapping periods. Detections are from aerial drone surveys and literature sources combined. Of cells containing no turtles, 12 were surveyed by aerial drones and 518 were not, with no significant difference being found in analyses excluding these cells; thus data presented here include all cells (with non-surveyed cells excluded: $\chi^2 = 9.24$, $df = 3$, $P < 0.05$).

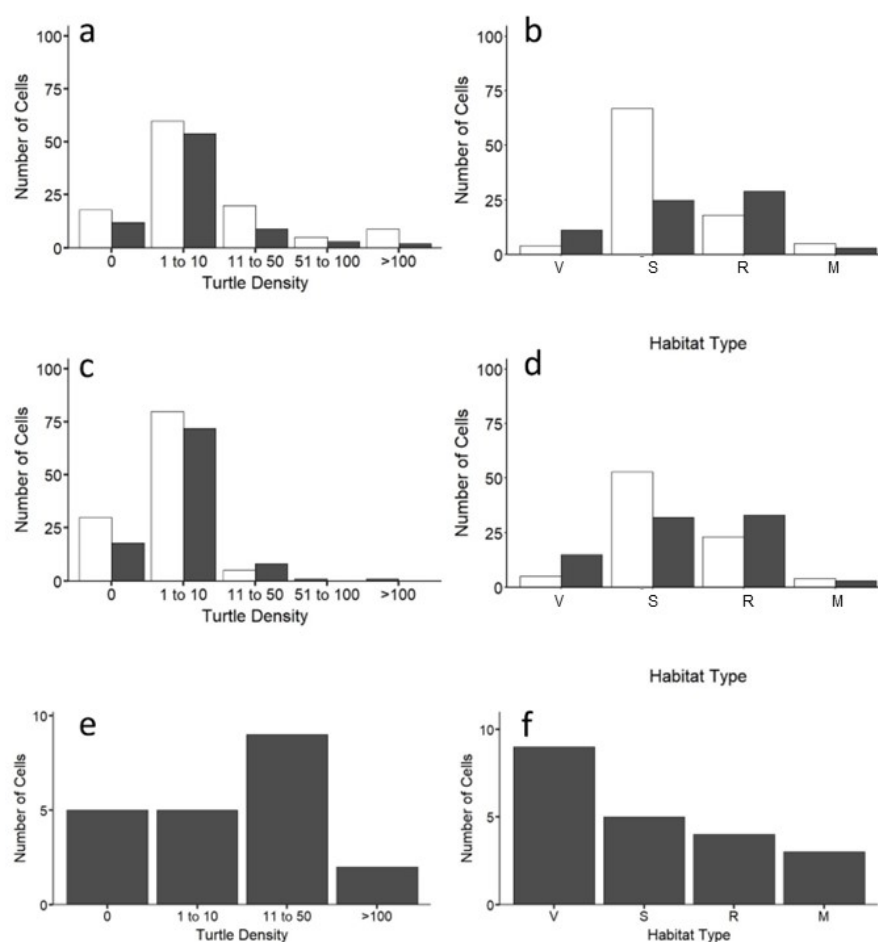


Figure S5. Barplots showing the number of cells that fall inside (light grey) and outside (black) of protected areas across densities during (a) breeding season, and (c) nonbreeding season. Barplots showing the number of cells of each habitat type (V = vegetated; S = submerged sandbanks; R = rocky outcrops and reefs; M = mud/silt) where turtles were detected during (b) breeding season, and (d) nonbreeding season. (e,f) Barplots showing (e) cells across densities and (f) cells of different habitat types among foraging turtles in the Gulf of Argostoli. All Argostoli cells were lacking protection. Natura 2000 protected areas: dashed green polygons. Circles represent 2 km sections along coastline.

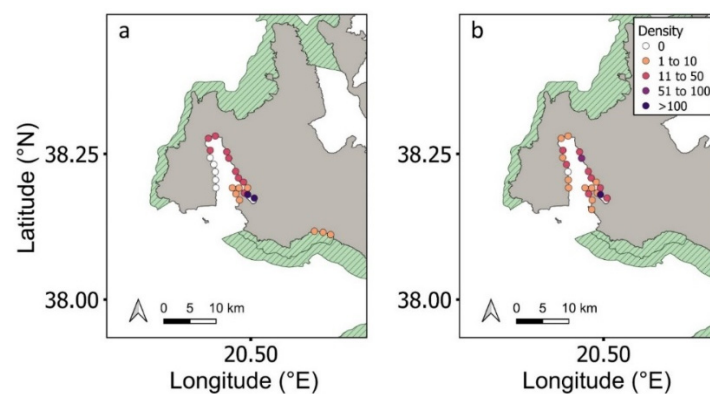


Figure S6. Argostoli Gulf (Kefalonia) showing turtle density groupings (1-10, 11-50, 51-100, >100 turtles/km) during (a) summer, and (b) autumn. Turtles in the gulf are foraging year-round

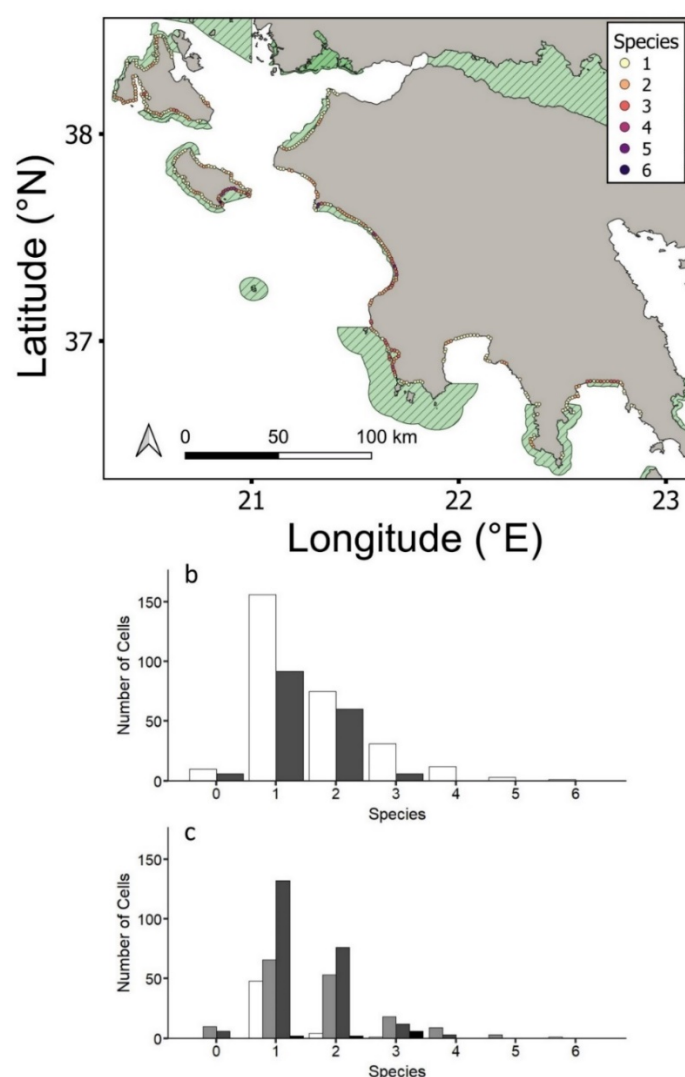


Figure S7. (a) Distribution of cells with one or more species detected across the study region. For distribution of individual groups see Supplementary Figures S6 and S7. (b-c) Number of cells (2 km sections) containing (b) cells containing zero to six species, that fall inside (light grey) and outside (black) protected areas. (c) Habitat type (white = vegetated, light grey = submerged sandbanks, dark grey = rocky outcrops and reefs, black = mud/silt) of cells containing multiple species. Species were more likely to fall within MPAs ($\chi^2 = 18.2$, $df = 2$, $P < 0.001$).

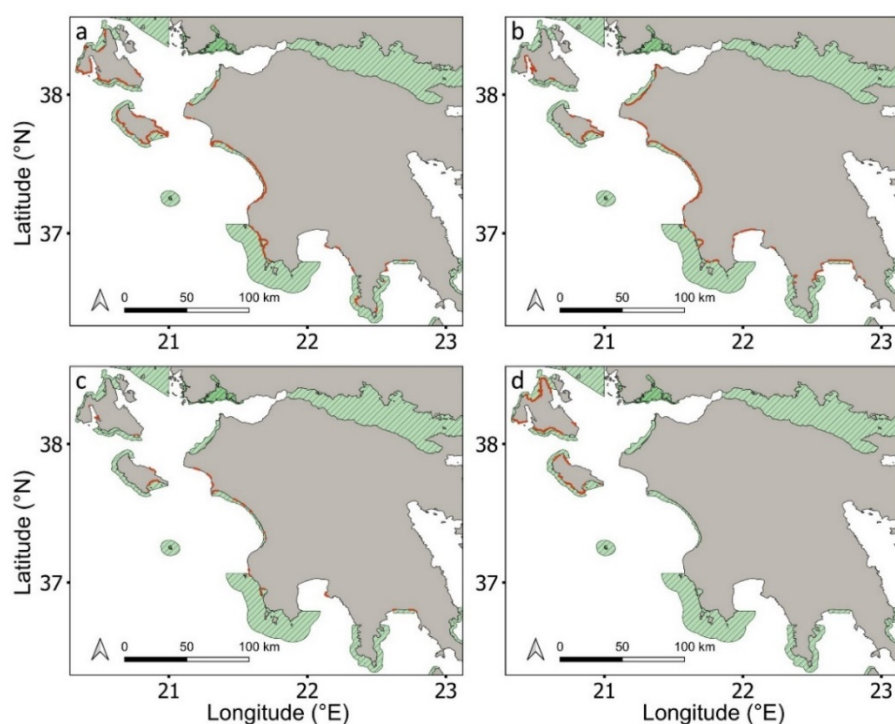


Figure S8. Study region showing detected presence from aerial drone surveys and literature sources combined for (a) cetaceans, (b) sea turtles (green and loggerheads combined), (c) elasmobranchs, and (d) pinnipeds. Natura 2000 protected areas: dashed green polygons. Circles represent 2 km sections along coastline.

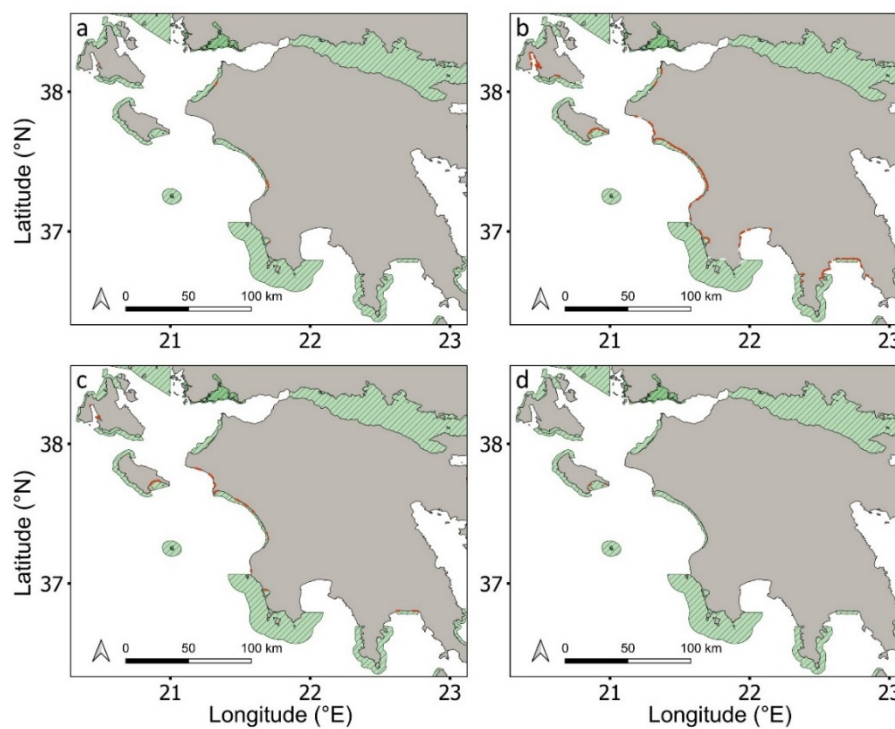


Figure S9. Study region showing detected presence from aerial drone surveys only for (a) cetaceans, (b) sea turtles (green and loggerheads combined), (c) elasmobranch, and (d) pinnipeds. Natura 2000 protected areas: dashed green polygons. Circles represent 2 km sections along coastline.

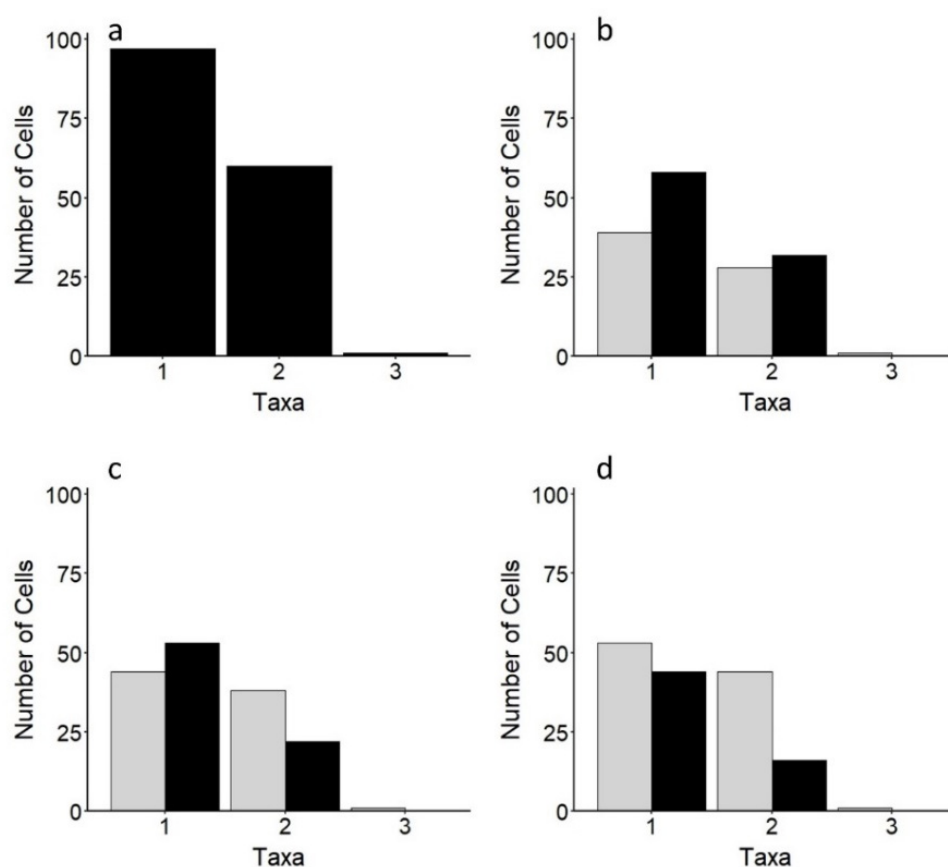


Figure S10. Total number of unprotected (black) cells containing one or more taxa (a) outside of PA status, and the number of additional cells that are protected (light grey) when extending PA coverage based on (b) all cells containing breeding turtles; (c) all cells containing non-breeding turtles; (d) cells containing records of either breeding or non-breeding turtles (combined).

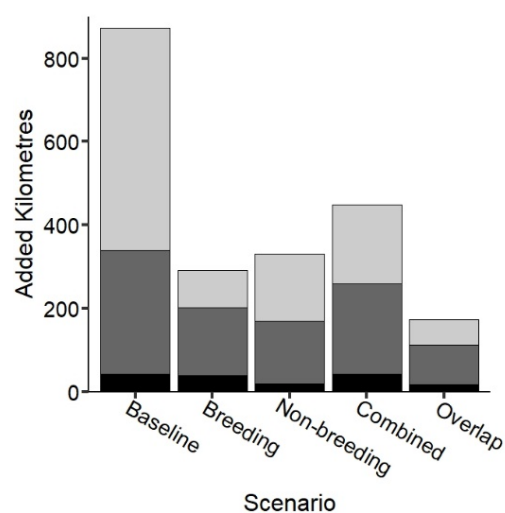


Figure S11. Number of kilometres of coastline inside or outside MPAs capturing taxa based on five scenarios: (1) all cells with one or more taxa (baseline); (2) all cells containing breeding turtles; (3) all cells containing non-breeding turtles; (4) all cells containing combined breeding and non-breeding turtles; (5) just overlapping cells containing breeding/non-breeding turtles (combined). Black: 3 taxa cells, dark grey: 2 taxa cells, light grey: 1 taxon cells.

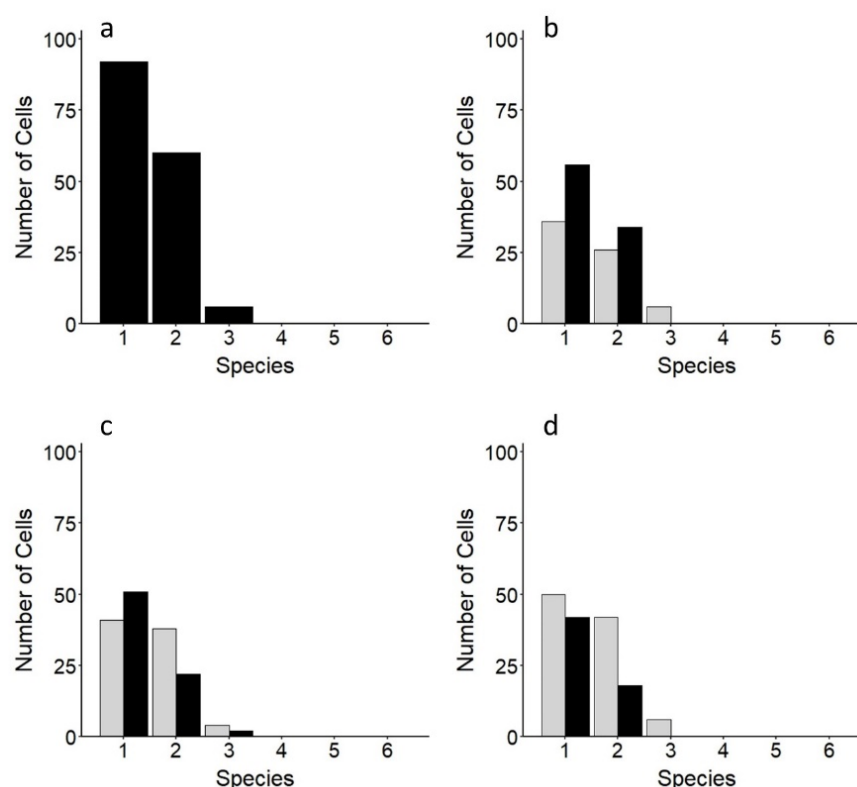


Figure S12. Total number of unprotected (black) cells containing one or more species (a) outside of PA status, and the number of additional cells that are protected (light grey) when extending PA coverage based on (b) all cells containing breeding turtles; (c) all cells containing non-breeding turtles; (d) cells containing records of either breeding or non-breeding turtles (combined).

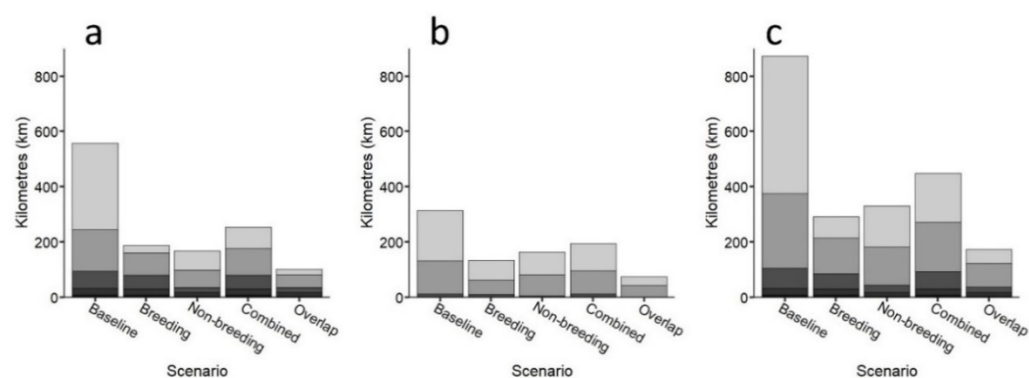


Figure S13. (a) Number of kilometres of coastline inside MPAs capturing species based on five scenarios: (1) all cells with one or more species (baseline); (2) all cells containing breeding turtles; (3) all cells containing non-breeding turtles; (4) all cells containing combined breeding and non-breeding turtles; (5) just overlapping cells containing breeding/non-breeding turtles (combined). Black: 6 species cells, light grey: 1 species cells, with intervals of 1 species between. (b) Number of additional kilometres required to extend protection effort outside MPAs based on the same four scenarios. (c) Number of additional kilometres required to extend protection effort regardless of MPA status based on the same four scenarios.

Table S1. Assimilated records of marine megafauna in the survey region from literature and online sources.

Taxon	Species	Common Name	Monitoring Type	Source
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Sighting	[50]
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Tracking	[51]
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Tracking	[57]
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Tracking	[53]
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Tracking	[52]
Chelonia	<i>Caretta caretta</i>	Loggerhead turtle	Tracking	[54]
Cetacean	<i>Stenella coeruleoalba</i>	Striped dolphin	Sighting/Stranding	[44]
Cetacean	<i>Tursiops truncatus</i>	Bottlenose dolphin	Sighting/Stranding	[44]
Cetacean	<i>Delphinus delphis</i>	Short-beaked common dolphin	Sighting/Stranding	[44]
Cetacean	<i>Ziphius cavirostris</i>	Cuvier's beaked whale	Sighting/Stranding	[44]
Cetacean	<i>Physeter macrocephalus</i>	Sperm whale	Sighting/Stranding	[44]
Cetacean	<i>Balaenoptera physalus</i>	Fin whale	Sighting/Stranding	[44]
Pinniped	<i>Monachus monachus</i>	Mediterranean monk seal	Sighting	[55]
Cetacean	<i>Delphinus delphis</i>	Short-beaked common dolphin	Sighting	[56]
Cetacean	<i>Tursiops truncatus</i>	Bottlenose dolphin	Sighting	[56]
Elasmobranch	<i>Cetorhinus maximus</i>	Basking shark	Sighting	[58]
Elasmobranch	<i>Heptranchias perlo</i>	Sharpnose sevengill shark	Sighting	[59]
Elasmobranch	<i>Hexanchus griseus</i>	Bluntnose sixgill shark	Sighting	[60]
Pinniped	<i>Monachus monachus</i>	Mediterranean monk seal	Sighting	[61]
Elasmobranch	<i>Prionace glauca</i>	Blue shark	Sighting	[62]
Elasmobranch	<i>Raja clavata</i>	Thornback ray	Sighting	[63]
Elasmobranch	<i>Squalus blainville</i>	Longnose spurdog	Sighting	[64]
Cetacean	<i>Stenella coeruleoalba</i>	Striped dolphin	Sighting	[65]
Cetacean	<i>Tursiops truncatus</i>	Bottlenose dolphin	Sighting	[66]

Table S2. Chi-square Goodness of Fit Test statistics for different categories of cell classes, and the primary explanatory variable.

Cell Classes	Habitat Type	Statistic
Cells with 0 animals	Submerged Sandbanks	$\chi^2 = 10.2$, df = 3, P = 0.01685
Cells with 1 taxon	None associated	NA
Cells with 2 taxa	Vegetated	$\chi^2 = 25.5$, df = 3, P < 0.0001
Cells with 3 taxa	Vegetated	$\chi^2 = 34.1$, df = 3, P < 0.0001
Cetaceans	Rocky Outcrops and Reefs	$\chi^2 = 15.8$, df = 3, P < 0.0001
Chelonia	Submerged Sandbanks	$\chi^2 = 83.3$, df = 3, P < 0.0001
Elasmobranchs	Submerged Sandbanks	$\chi^2 = 71.3$, df = 3, P < 0.0001
Pinnipeds	Rocky Outcrops and Reefs	$\chi^2 = 17.3$, df = 3, P < 0.0001

Table S3. Chi-square Test statistics for the relationship between number of cells with multiple taxa encompassed under four scenarios: (1) breeding, (2) non-breeding, (3) combined breeding/non-breeding, and (4) overlap breeding/non-breeding, and whether these cells are inside MPAs, outside MPAs, or both.

Cell Taxa	Relationship to MPAs	Statistic
2 taxa and 3 taxa	Outside MPAs	$\chi^2 = 0.6$, df = 3, $P > 0.5$
2 taxa and 3 taxa	Inside MPAs	$\chi^2 = 0.7$, df = 3, $P > 0.5$
2 taxa and 3 taxa	Regardless of MPAs	$\chi^2 = 2.2$, df = 3, $P > 0.5$
1 taxon, 2 taxa, and 3 taxa	Outside MPAs	$\chi^2 = 1.1$, df = 6, $P > 0.5$
1 taxon, 2 taxa, and 3 taxa	Inside MPAs	$\chi^2 = 16.9$, df = 6, $P < 0.01$
1 taxon, 2 taxa, and 3 taxa	Regardless of MPAs	$\chi^2 = 13.3$, df = 6, $P < 0.05$