Supplementary Information

3D Diel Utilization Distribution: a novel perspective to understand marine turtle-fishery interaction

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Contents

Supplementary Methods

Supplementary Method S1

GFW Fishing event API Data Extraction and Vessel Characterization

Discrete apparent fishing events were extracted within the study area across a 13-year period (2012–2024) using the Global Fishing Watch (GFW) Fishing Events API via the `gfwr` R package. To optimize API request stability and prevent server timeouts given the extensive spatial and temporal scale, queries were executed systematically at a weekly temporal resolution. Each extracted fishing event provided spatial centroids, start and end timestamps, and a unique *vesselId*. Because the fishing events database lacks direct vessel characteristics, a secondary query was compiled using the `get_vessel_info()` function to retrieve historical registry data for each unique identifier. To ensure dynamic data matching, vessel registries were filtered using a time-window approach, assigning the specific gear type active during the year of the recorded fishing event. The multi-year dataset was then strictly filtered to retain only tracking data associated with industrial `"TRAWLERS"` and `"DRIFTING_LONGLINES"`.

Diel classification, Rasterization, and Spatial Resampling

For each validated fishing event, apparent fishing effort (hours) was computed as the exact duration between the start and end timestamps. Diel status ("day" or "night") was determined by evaluating the solar elevation angle at 5-minute intervals throughout the duration of each operation using the `solarpos()` function from `suntools` R package (1). Intervals where the sun was above the horizon (solar elevation > 0°) were classified as day, and events were categorized based on the absolute majority (>50%) of their operating duration. Classified events were then converted into spatial features and rasterized annually using the `terra` R package at an initial high resolution of 0.01° x 0.01° (≈ 1 km^2), computing the cumulative fishing hours per pixel. To match the scale of subsequent ecological analyses, annual rasters were projected to an equal-area coordinate reference system (EPSG:3035) and bilinearly resampled to a 10 x 10 km grid resolution. Finally, multi-year mean apparent fishing effort maps were derived by averaging the grid layers across the 2012–2024 timeseries for each gear type and diel period.

Supplementary Tables

Supplementary Table S1. Biometrics of and tracking information of loggerhead sea turtle tagged in this study.

OrganismID	CCL	Sex	Age Class	Deployment Date	Max dive depth (m)	Total dives recorded	Days tracked	Tag model
34319	50	unknown	juvenile	05/08/2015	106.5	1174	80	SPLASH10-344D
34321	83	♀	adult	21/06/2017	203	1050	82	SPLASH10-344D
34322	66.5	unknown	juvenile	16/07/2017	118.5	1304	111	SPLASH10-344D
34326+	52	unknown	juvenile	03/07/2017	146.5	893	153	SPLASH10-344D
34327+	58	♂	juvenile	26/08/2017	91.5	1677	215	SPLASH10-344D
138120	57	♀	juvenile	15/02/2018	102	74	13	SPLASH10-296F
151933	46	unknown	juvenile	09/07/2016	140.5	1883	188	SPLASH10-F-344A
151934*	73	unknown	juvenile	26/07/2016	253	1479	155	SPLASH10-F-344A
151935	65	unknown	juvenile	21/06/2016	238	4210	272	SPLASH10-296F
151936	60	unknown	juvenile	26/06/2016	130.5	2818	247	SPLASH10-296F
176001	75	unknown	juvenile	01/08/2018	124.5	2053	88	SPLASH10-344D
176002	63	unknown	juvenile	30/07/2018	253	2242	247	SPLASH10-344D
176003	62	unknown	juvenile	01/06/2019	160.5	2220	223	SPLASH10-344D
176004	52	unknown	juvenile	30/07/2018	113	1832	212	SPLASH10-344D
176005+	70	♂	juvenile	10/05/2019	174.5	1012	51	SPLASH10-344D
181761	61	unknown	juvenile	28/09/2019	102	122	14	SPLASH10-344D
181762	56	unknown	juvenile	11/07/2019	178	2377	219	SPLASH10-344D
200043+	66	♀	juvenile	09/07/2020	313.5	4151	239	SPLASH10-344D
200044	55	unknown	juvenile	06/06/2021	76	1277	68	SPLASH10-344D
200045+*	77	♀	adult	31/07/2020	208	1498	93	SPLASH10-344D
200046+	58	♀	juvenile	08/06/2022	68	416	26	SPLASH10-344D
222014	71	♀	adult	04/09/2021	153	1536	142	SPLASH10-344D
222015	55	unknown	juvenile	18/08/2021	253	2724	197	SPLASH10-344D
222016	57	♀	juvenile	28/09/2021	112	1381	203	SPLASH10-344D
222017	55.5	♀	juvenile	05/09/2021	134	529	62	SPLASH10-344D
235395	65	unknown	juvenile	08/05/2023	163.5	1506	70	SPLASH10-344D
235396	60	unknown	juvenile	08/05/2023	208	4473	214	SPLASH10-344D
235397	68.6	♂	juvenile	31/07/2023	242.5	2586	129	SPLASH10-344D

* For this *organismID*, only the tracking and dive records within the study area are included (as well as in the mains analysis), although its movement range extends beyond the study boundaries; additional information about movement range in Supplementary Information of Harvey-Carroll et al. (2025)

+ *organismID*, rehabilitated in rescue center (Palma Aquarim, Mallorca, Spain)

Supplementary Table S2. Comparison of generalized linear mixed models (GLMM) using a Gamma distribution with log link to select the optimal degrees of freedom (df) for the spline term in explaining mean dive depth. All models include the fixed effects of day/night and season, a natural spline function of time (num_day) with varying df, and a random intercept for individual ID (organismID). Model performance is assessed via AIC, BIC, log-likelihood, and spline term significance

meandep ~ daynight + season + splines::ns(num_day, df = j) + (1 | organismID)

Model (df spline)	AIC	BIC	logLik	Random variable	σ^2	Splines significance
df = 1	365554.7	365625.6	-182769.3	0.0506	0.273	p = 0.395
df = 2	365241.8	365321.6	-182611.9	0.0518	0.271	2/2 terms significative; p < 0.001
df = 5	364457.1	364563.5	-182216.5	0.0443	0.268	3/5 terms significative; p < 0.001
df = 8	364436.4	364569.3	-182203.2	0.0438	0.267	6/8 terms significative; p <0.001

Supplementary Table S3. Comparison of generalized linear mixed models (GLMM) using a Gamma distribution with log link to select the optimal degrees of freedom (df) for the spline term in explaining maximum dive depth. All models include the fixed effects of day/night and season, a natural spline function of time (num_day) with varying df, and a random intercept for individual ID (organismID). Model performance is assessed via AIC, BIC, log-likelihood, and spline term significance.

maxdep ~ daynight + season + splines::ns(num_day, df = j) + (1 | organismID),

Model (df spline)	AIC	BIC	logLik	Random variable	σ^2	Splines significance
df = 1	434415.6	434486.6	-217199.8	0.048	0.310	p = 0.715
df = 2	433719.5	433799.3	-216850.7	0.050	0.307	2/2 terms significative; p < 0.001
df = 5	432844.2	432950.6	-216410.1	0.042	0.302	5/5 terms significative; p < 0.001
df = 8	432814.4	432947.3	-216392.2	0.042	0.302	6/8 terms significative; p <0.001

Supplementary Table S4. Surface drifting longline gear types and its soak depths ranges (meters) used. LLALB, Longline Albacore [target species: Albacore (*Thunnus alalunga*) or little tunny]; LLAM, Longline American [target species: Swordfish (*Xiphias gldius*)]; LLHB, Longline Home-Base [target species: Swordfish (*Xiphias gladius*)], LLJAP, Longline Japanese [target species: Bluefin tuna (*Thunnus thynnus*)].

Drifting longline and soak depth range (m)	Reference
LLALB ≈ 20- 50 LLAM ≈ 50- 90 LLHB ≈ 40- 70 LLJAP ≈ 50- 90	(3)
LLALB ≈ 12* LLAM ≈ 70* LLHB ≈ 30- 50 LLJAP ≈ 30*	(4)
LLALB ≈ 30- 90	(5)

***** Set depth provided instead a depth range. Unique depth used this information as maximum depth for drifting longline mean range characterization.

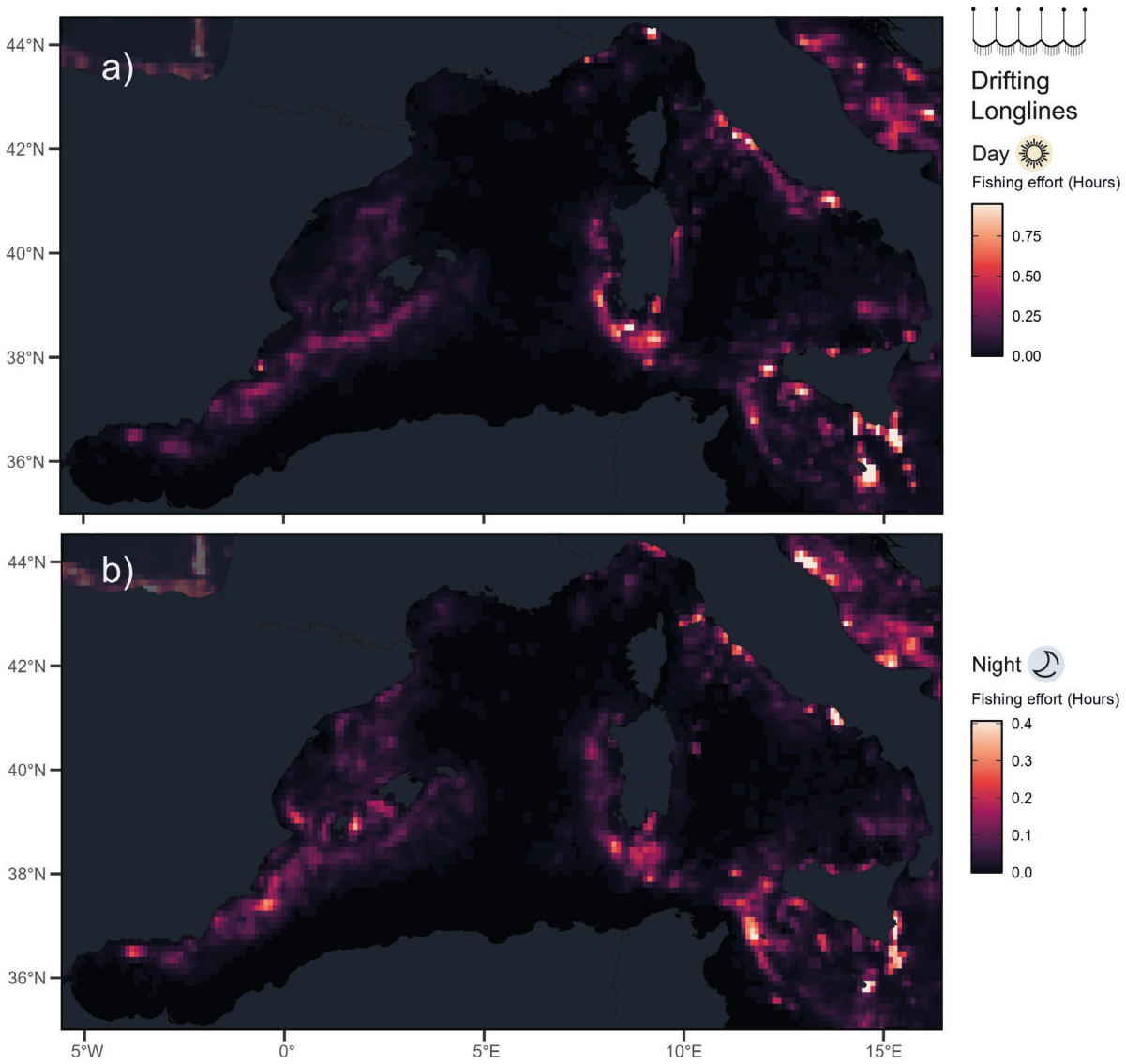
Supplementary Table S5. Distribution of maximum dives depths reached by tagged loggerhead sea turtles across depth strata. Data represent the frequency and percentage of total recorded dives (*n* = 52,312) within specified depth ranges, based on 28 satellite-tagged individuals

Depth range	Number of dives	Percentage of total (%)
0 - 10	4119	7.87
10 - 20	15867	30.33
20 - 30	9859	18.85
30 - 40	6549	12.52
40 - 50	4597	8.79
50 - 60	3734	7.14
60 - 70	2690	5.14
70 - 80	2066	3.95
80 - 90	1279	2.44
90 - 100	700	1.34
100 - 120	621	1.19
120 - 140	123	0.24
140 - 160	42	0.08
160 - 180	26	0.05
180 - 200	11	0.02
200 - 240	21	0.04
240 - 280	7	0.01
280 - 320	1	0.002

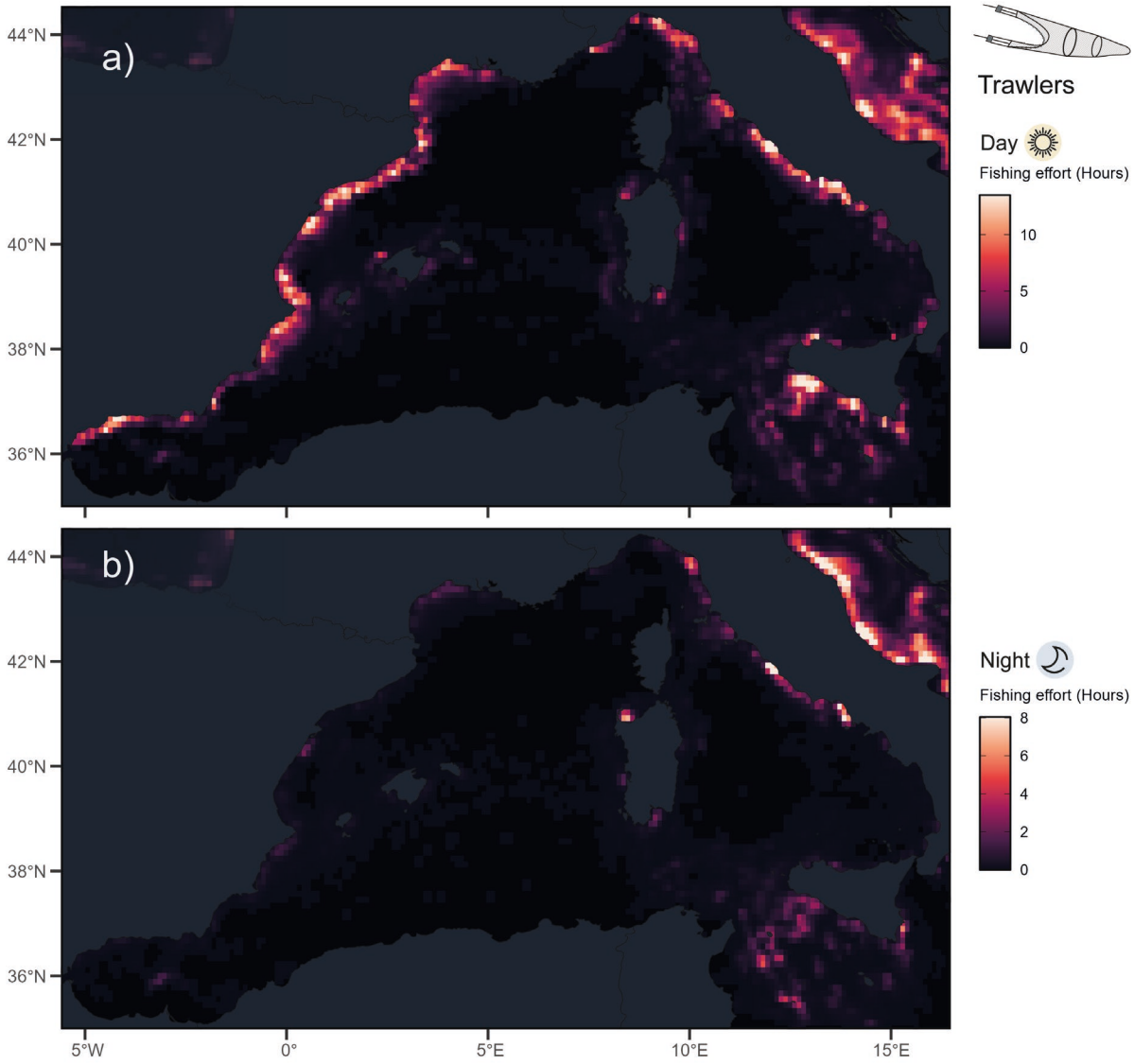
Supplementary Table S6. Summary of day / night-specific Utilization Distributions (UDs) for each tagged sea turtle in the study. Metrics include 50% core area UDs and 95% home-range UDs derived from both 2D (area, km^2) and 3D (volume / km^3) analyses.

	2D				3D			
	Day		Night		Day		Night	
organismID	50 UD	95 UD	50 UD	95 UD	50 UD	95 UD	50 UD	95 UD
138120	1100	4700	1200	4300	15	266	17	93
151933	7400	30800	8600	37300	217	1426	121	757
151934	2800	11800	3200	14000	102	744	62	438
151935	11300	46000	12300	48600	357	2408	294	1697
151936	12100	55200	14500	67800	345	2357	171	1099
176001	7400	33600	9200	38900	279	1919	224	1367
176002	13500	62400	14000	62500	345	3307	228	1598
176003	16700	92400	17100	94100	512	5298	338	3231
176004	14100	58100	15900	65000	202	1653	239	1463
176005	5400	23500	5300	24100	104	957	96	648
181761	1100	3500	1100	3200	16	181	34	189
181762	22000	119300	28700	139500	494	4943	424	3397
200043	10300	42500	11600	47800	577	3330	308	1813
200044	7900	41000	8600	41500	242	2114	106	672
200045	1700	7600	2000	12000	71	422	51	395
200046	7100	33300	11300	36600	148	1206	231	970
222014	15600	100400	19600	125900	551	5500	288	2871
222015	32700	160300	42200	174000	1119	10012	1025	6079
222016	19300	166500	29500	202300	402	7333	404	3930
222017	17000	85800	19400	88400	387	6955	250	2946
235395	5600	37000	7700	41600	173	1942	175	1477
235396	16500	108500	26100	139300	708	7046	558	4020
235397	21900	143000	24700	134700	987	11061	589	5810
34319	5700	33300	6200	28900	321	2359	85	866
34321	8400	39900	7100	35100	225	2250	131	1328
34322	4400	17700	4400	19700	115	994	77	589
34326	11100	55000	12700	59600	163	1439	211	1446
34327	15900	69300	15800	68200	275	2201	242	1585

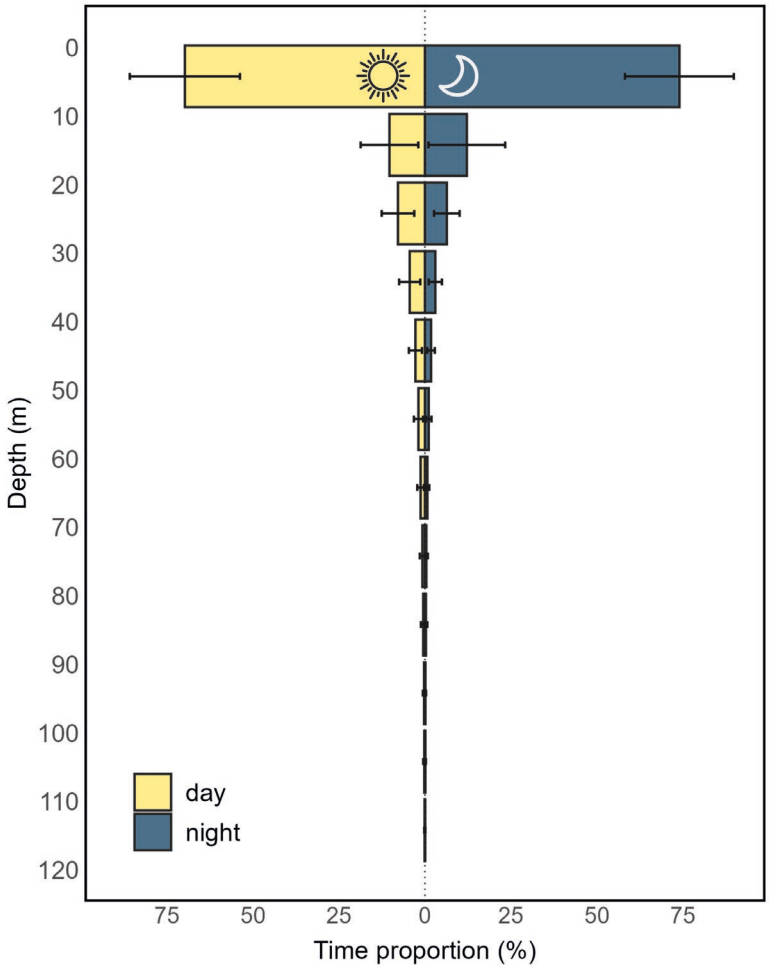
Supplementary Figures



Supplementary Figure S1. Mean annual fishing effort (hours) from Global Fishing Watch (GFW) *Fishing Event* data per (a) day and (b) night in the period 2012-2024 by *Drifting Longlines* gear type in the study area. These data are used to assess interactions with the 2D/3D home ranges of tagged sea turtles in the study. The spatial resolution is 0.1° (≈ 10 km²).



Supplementary Figure S2. Mean annual fishing effort (hours) from Global Fishing Watch (GFW) *Fishing Event* data per (a) day and (b) night in the period 2012-2024 by Trawlers gear type in the study area. These data are used to assess interactions with the 2D/3D home ranges of tagged sea turtles in the study. The spatial resolution is 0.1° (≈ 10 km²).



Supplementary Figure S3. Proportion of time spent by sea turtles at different depth ranges during days (*n* = 320) and nights periods (*n* = 352) . Horizontal bars represent the percentage of time (%) spent at each depth range (in meters), with yellow indicating daytime and blue indicating nighttime. The dotted grey line at 0% serves as a reference for difference day and night time. Error bars indicate standard deviations (SD), periods refer to nights or days where depth records were obtained.

Extended information for main figures

Supplementary 360° fly-around visualization of the 3D plots in figure 3 and 6 of main text are available in:

jmenblaz.github.io/page_seaturtle_3dhomerange_results

Supplementary References

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5. Camiñas JA, Rivetti N, de Urbina JO, Garcia-Barcelona S, Rioja P, Gómez-Vives MJ, et al. Analysis of the loggerhead (Caretta caretta) bycatch in mediterranean surface longlines from depth sensors data. Vol. 27. 2016;27(2):49–51.