Supplementary Material

# Supplementary Figures and Tables

**Figure S1:** Spatial distribution maps for *Merluccius merluccius* in winter **(A)** and summer **(B)**. The size of the red dots represents the amount of mean weight (kg/n) on each location.

**Figure S2.** Spatial distribution of the potential prey abundances (in n/km2) **(A)**, **(B)**, **(C)**, **(D)** and mean weights (in kg/n) **(E)**, **(F)**, **(G)**, **(H)** for fish and crustaceans in winter and summer. Spatial distributions of the topological and environmental variables are represented in maps: **(I)** and **(J)** for sea bottom temperature of winter and summer, respectively (SBT, in ºC) and **(K)** for bathymetry (in m). Raster maps were generated in QGIS software with a 0.1 x 0.1 degree spatial resolution. In large Figure **(A)** both seasons share a common scale, whereas in large Figure **(B)** each variable has an individual scale to show the range and within season spatial variability.

**Figure S3**: Hierarchical cluster dendogram illustrating isotopic signature aggregation (δ13C and δ15N) of the different potential sources contributing to European hake’s diet. The Y-axis represents the unitless measure of linkage similarity, with linkages being more dissimilar at the top. The cluster analysis breaks into five main clusters; In brown, **Cluster 1**: *Cepola macrophthalma, Boops boops, Spicara maena, Spicara smaris, Argentina sphyraena, Trisopterus minutus, Lepidopus caudatus, Sardina pilchardus, Maurolicus muelleri, Gadiculus argenteus* and  *Micromesistius poutassou;* in green, **Cluster 2**: *Chlorotocus crassicornis*, *Nematoscelis megalops* and *Phronima sedentaria*; in blue, **Cluster 3**:, *Vibilia armata*; in violet, **Cluster 4**: *Anchialina agilis* and *Meganyctiphanes norvegica* and in aquamarine, **Cluster 5**: *Engraulis encrasicolus, Plesionika heterocarpus, Sardinella aurita* and *Solenocera membranacea*.

**Figure S4:** Simulated mixing polygon. Consumers (European hake) are represented by the black dots and potential prey sources by the coloured dots: in brow, **Cluster 1**, in green **Cluster 2**, in blue **Cluster 3**, in violet **Cluster 4** and in aquamarine **Cluster 5***.* (error bars showing confidences intervals). The black lines represent each 10% probability level.

**Figure S5:** Linear regressions of isotopic signatures (δ13C and δ15N) of European hake data *vs* individuals’ length (in centimetres, cm). Vertical dotted line represents the division between juveniles (< 25 cm) cm and adults (>25 cm).

**Figure S6:**Response curves of European hake (in mean weight estimates) to the explanatory variables in winter (***Model 1 and 2***) and summer models (***Model 3 and 4***). Variables acronyms are: SBT (Sea Bottom Temperature, ºC), bathymetry in meters (m) and “Fish” and “Crustaceans” abundance and mean weight are in in n/km2 and kg/n, respectively.

**Figure S7:** MixSIAR model results showing estimated diet proportions of each potential prey cluster (1, 2, 3, 4 and 5) (median, 95% CI) contributing to European hake diet, as a function of length (in cm) for each season (A: winter and B: summer). **Cluster 1**: *Cepola macrophthalma, Boops boops, Spicara maena, Spicara smaris, Argentina sphyraena, Trisopterus minutus, Lepidopus caudatus, Sardina pilchardus, Maurolicus muelleri, Gadiculus argenteus* and  *Micromesistius poutassou*, **Cluster 2**: *Chlorotocus crassicornis*, *Nematoscelis megalops* and *Phronima sedentaria*, **Cluster 3**: *Vibilia armata*, **Cluster 4**: *Anchialina agilis* and *Meganyctiphanes norvegica* and **Cluster 5**: *Engraulis encrasicolus, Plesionika heterocarpus, Sardinella aurita* and *Solenocera membranacea.*

**Figure S8:** Correlation matrix of explicative continuous variables used in the Bayesian species distribution models (B-SDM) for *Model 1, Model 2, Model 3* and *Model 4*.

**Table S1:** Summary of the body lengths (in cm) of the individual*s* of European hakecollected for stable isotope analysis in winter and summer and divided by adults and juveniles**.** It includes the mean, the median, the standard deviation (SD), the minimum (Min) and the maximum (Max). It also includes the number of individuals sampled on each category (n).

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Winter** |  | **Summer** |
| **Stage** | **Adult** | **Juvenile** |  | **Adult** | **Juvenile** |
| **n** | 27 | 28 |  | 13 | 35 |
| **Mean** | 33.03 | 14.86 |  | 31.64 | 15.66 |
| **Media** | 32.20 | 14.25 |  | 30.50 | 15.20 |
| **SD** | 6.64 | 4.42 |  | 4.90 | 5.03 |
| **Min** | 25.10 | 9.20 |  | 26.30 | 7.30 |
| **Max** | 50.20 | 22.20 |  | 44.50 | 24.50 |

**Table S2**: Summary table of the papers analysing stomach content analysis for European hake in the western Mediterranean Sea. “%W” stands for percentage of weight and “%IRI” for percentage of index of relative importance. “Y” stands for “Yes” and “N” for “No”. These two columns describe if the stomach content data in the paper was presented in “%W” or /and “%IRI”.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Published research paper | Area of study | Time of the year when the data was collected | Stage of individuals analsed | %W | %IRI | Main preys detected on the stomach content analysis/ General observations |
| (Ferraton et al., 2007) | Gulf of Lion | MEDITS sampling(Spring-Summer) | Juvenile(5 to 19 cm) | Y | Y | -Crustaceans predominate on individuals from 5-9 cm (99.4% IRI) and 10-14 cm (78.4% IRI). On the smaller individuals, euphasiids and mysids predominate with 52.6% IRI and 33.2% IRI, respectively. For the larger individuals, is the other way around; mysids represent a 38.5% IRI and euphaisiids a 17.9% IRI.-Natantias also have a high percentage with 9% for size class 1 (5-9 cm) and 15.2% for size class 2 (10-14 cm).-Diet changes for size class 3 (15 to 19 cm) where there is a shift to teleost ingestion with a 92% IRI (teleost diet is only 0.6% and 21.5% for size class 1 and 2). For size class 3 crustaceans only represent a 7.9% and with the highest values being for Natantia with a 3.7%. |
| (Bozzano et al., 2005) | Catalan shelf | One year monthly data | Juvenile | Y | Y | \*Note that for this paper, they differentiate between European hake captured with pelagic net and with bottom trawl.- In pelagic net: Osteichthyes represent the main percentage of their diet with *Gadiculus argenteus* represening a 4.13% IRI and *Maurolicus muelleri*a 20.17% IRI. The second highest diet group is crustacean decapoda with 23.91 % IRI.- In bottom trawl: crustacean decapoda dominate the diet with a 59.06% IRI, followed by Osteichthyes with a 30.66% IRI.-In general, there is a more diversified diet for benthic hake and a more specialized diet for pelagic hake. |
| (Cartes et al., 2009) | Balearic | August-September / November/February/ April/June | Recruits (less than 18 cm)/ post-recruits ( 18 to 21.9 cm)/ adults >= 22 cm | Y | N | -Authors show that stomach fullness had seasonal fluctuations at 150-250 m depth.-Site and individuals size also influenced stomach fullness.-Among recruits, euphasiids were the dominant prey in number with *Nyctiphanes couchii* dominanting in individuals from the southern area and *Meganyctiphanes norvegica* in the northwestern area. Mysids were also important and *Maurolicus muellerii*.-For post recruits, large euphasiids, Norvegica and mesopelagic *Maurolicus mueller*i were the most important preys in number but also Myctophidae and Argentinidae were important.- For adults, fish were the main prey and Myctophidae and Argentinidae were dominant.-Together with some Sparidae and *Peidopus caudatus,* in the South area, decapodes crustacean were also important for adults. |
| (Bozzano et al., 1997) | Port de la Selva | Monthly data | From 8 cm to 65 cm | Y | Y | - Pisces dominate the diet with 60 % IRI, being the unidentified Osteichthys the highest percentage (44% IRI). Followed by *Sardina pilchardus* (3.0% IRI). Euphasiiacea were the second most important diet group with a 29.8% IRI.-In spring euphasiids were found in large quantities in hake stomachs. Whereas fish preys were greater in summer.-Individuals smaller than 14 cm feed mainly on mysids all year round except in spring when they eat euphasiids too.-For hake between 14.5 and 39.5cm they fed mainly on fish; More specifically, gobid for hake between 14.5 and 24.5 cm and small pelagic fish for hakes between 25 and 39.5 cm. Largest fish feed in winter in *S. membranacea* and sardine and in spring and summer on *C. rubsecens* (and *S. pilchardus* in autumn). |
| (Mellon-Duval et al., 2017) | GoL | Spring-Autumn | From 5 to 74 cm | Y | N | -MixSIAR output.-SCA: Results by size classes (5-6 cm) (7-14 cm) (15-24 cm) (25-39 cm) (40-49 cm) (50-74 cm) For size class 1 and 2 crustaceans dominate the diet with a 94.5% W and 16.6% W respectively.-In Class 1, amphipoda dominate with a 71.9%W followed by Sidicae (6.2%), Natantia (5.5%) and *Plesionkia* sp. (4.8%).-In class 2, Natantia dominate with (3.5%) followed by *Pleasionka* sp. (3%) Amphipod (1.9%) and Processidea (1.3%). In class 2 crustaceans diet is more diversified. In class 2 fish are more important than crustaceans with 82.1 % W. The highest percentage corresponding to pelagic fish (43.6%).-In the other class size fish prey dominate all the diet representing between 98.1 to 99.2%W. From class 3 to 5, pelagic fish dominate. In class 5 and 6 the demersal fish diet gains importance too. In class 3, 4, 5 and 6 crustaceans are insignificant in the diet contribution, representing less than a 1 % W. |
| (Cartes et al., 2004) | Iberian Peninsula |  | MEDITS sampling | Y | Y | -At the shelf, feed mainly on small crustaceans (mainly euphasiids (47.1%IRI) and mysids (17.4%IRI)).-Epipelagic fish preys (*Sardina pilchardus*, *Boops boops* and *Merluccius merluccius*, were secondary in terms of IRI but dominant un terms of weight.-On the slope, hake preferred fish, mainly Myctophidae (36.5%IRI) and unidentified Osteichthyes (31.4%IRI). Here, euphasiids, *Plesionika heterocarpus* and *Lipidopus caudatus* were secondary preys. |

**Table S3:** Species of **(A)** “Fish” and **(B)** “Crustaceans” included in the preys’ layers for the winter and summer species distribution models. The preys included were selected based on a literature review and depending on data availability from literature and from the ECOTRANS survey.

|  |
| --- |
| (A) FISH |
| **Winter** | **Summer** |
| *Aphia minuta* | *Aphia minuta* |
| *Argentina sphyraena* | *Argentina sphyraena* |
| *Boops boops* | *Boops boops* |
| *Capros aper* | *Capros aper* |
| *Cepola macrophthalma* | *Cepola macrophthalma* |
| *Ceratoscopelus maderensis* | *Ceratoscopelus maderensis* |
| *Chlorophthalmus agassizi* | *Conger conger* |
| *Conger conger* | *Crystallogobius linearis* |
| *Deltentosteus quadrimaculatus* | *Deltentosteus quadrimaculatus* |
| *Engraulis encrasicolus* | *Engraulis encrasicolus* |
| *Epigonus denticulatus* | *Epigonus denticulatus* |
| *Gadiculus argenteus* | *Gadiculus argenteus* |
| Gobiidae | *Gadiculus argenteus* |
| *Gobius niger* | *Gobius niger* |
| *Helicolenus dactylopterus* | *Helicolenus dactylopterus* |
| *Lepidopus caudatus* | *Lepidopus caudatus* |
| *Lepidotrigla cavillone* | *Lepidotrigla cavillone* |
| *Lesueurigobius friesii* | *Lesueurigobius friesii* |
| *Maurolicus muelleri* | *Micromesistius poutassou* |
| *Merluccius merluccius* | *Mullus barbatus* |
| *Micromesistius poutassou* | *Mullus surmuletus* |
| *Mullus barbatus* | *Notoscopelus elongatus* |
| *Mullus surmuletus* | *Phycis blennoides* |
| Myctophidae | *Sardina pilchardus* |
| *Notoscopelus bolini* | *Sardinella aurita* |
| *Phycis blennoides* | *Scomber scombrus* |
| *Phycis phycis* | *Spicara maena* |
| *Sardina pilchardus* | *Spicara smaris* |
| *Scomber colias* | *Sprattus sprattus* |
| *Scomber scombrus* | *Trachurus mediterraneus* |
| *Spicara maena* | *Trachurus picturatus* |
| *Spicara smaris* | *Trachurus trachurus* |
| *Spicara* spp. | *Trisopterus minutus* |
| *Sprattus sprattus* |  |
| *Trachurus mediterraneus* |  |
| *Trachurus picturatus* |  |
| *Trachurus trachurus* |  |
| *Trisopterus minutus* |  |

|  |
| --- |
| (B) Crustaceans |
| ***Winter*** | **Summer** |
| *Alpheus glaber* | *Alpheus glaber* |
| Brachyura | Brachyura |
| *Chlorotocus crassicornis* | *Chlorotocus crassicornis* |
| *Liocarcinus depurator* | Isopoda |
| *Meganyctiphanes norvegica* | *Liocarcinus depurator* |
| *Parapenaeus longirostris* | *Parapennaeus longirostris* |
| *Pasiphaea sivado* | *Pasiphaea sivado* |
| *Plesionika antigai* | *Plesionika antigai* |
| *Plesionika edwardsii* | *Plesionika edwardsii* |
| *Plesionika gigliolii* | *Plesionika gigliolii* |
| *Plesionika heterocarpus* | *Plesionika heterocarpus* |
| *Pontocaris lacazei* | *Pontophilus spinosus* |
| *Pontophilus spinosus* | *Processa canaliculata* |
| *Processa canaliculata* | *Scyllarus* spp. |
| *Solenocera membranacea* | *Solenocera membranacea* |
|  |  |

**Table S4:** List of the 21 species selected from the literature review and included as potential preys’ sources of European hake on the MixSIAR analyses.

|  |
| --- |
| Species included |
| *Argentina sphyraena* |
| *Boops boops* |
| *Cepola macrophthalma* |
| *Engraulis encrasicolus* |
| *Gadiculus argenteus* |
| *Lepidopus caudatus* |
| *Maurolicus muelleri* |
| *Micromesistius poutassou* |
| *Sardina pilchardus* |
| *Sardinella aurita* |
| *Spicara maena* |
| *Spicara smaris* |
| *Trisopterus minutus* |
| *Anchialina agilis* |
| *Chlorotocus crassicornis* |
| *Meganyctiphanes norvegica* |
| *Plesionika heterocarpus* |
| *Solenocera membranacea* |
| *Nematoscelis megalops* |
| *Phronima sedentaria* |
| *Vibilia armata* |

**Table S5:** Comparison of the predictive accuracy of the different MixSIAR models. Where “LOOic” is the approximate leave-one-out-cross-validation with its associated stander error (SE), dLOOic is the difference between each model and the model with the lowest values of LOOIc and “Weight” is the weight assigned to each of the models built and can be read as the probability of being the best model. DIC: Deviance Information criterion.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Model** | **LOOic** | **Se(LOOic)** | **dLOOic** | **SE(dLOOic)** | **Weight** | **DIC** |
| **Length + Season** | 190 | 29.8 | 0 | NA | 1 | 204.48 |
| **Length** | 242.8 | 23 | 52.8 | 13.7 | 0 | 251.96 |
| **Season + Stage** | 319.3 | 22.4 | 129.3 | 20.6 | 0 | 336.04 |
| **Stage** | 333.8 | 23.4 | 143.8 | 22.8 | 0 | 335.20 |
| **Season** | 481.8 | 23.2 | 291.8 | 33.4 | 0 | 488.80 |
| **Null** | 508.2 | 19.1 | 318.2 | 31.9 | 0 | 508.90 |

**Table S6**. Mean weight data of European hake for both seasons (winter and summer) with the geographical position (coordinates X and Y) used for the B-SDMs.

|  |  |  |  |
| --- | --- | --- | --- |
| **Y** | **X** | **mean weight (kg/n)** | **Season** |
| 41.1101 | 1.5564 | 0.0419 | Summer |
| 40.2423 | 0.5727 | 0.0208 | Summer |
| 40.1587 | 0.7423 | 0.0166 | Summer |
| 40.0301 | 0.8711 | 0.0135 | Summer |
| 40.3878 | 0.5582 | 0.0095 | Summer |
| 40.3231 | 0.7831 | 0.0318 | Summer |
| 40.2475 | 1.0294 | 0.0422 | Summer |
| 40.4466 | 0.7024 | 0.0112 | Summer |
| 40.3364 | 0.9971 | 0.0257 | Summer |
| 40.9169 | 1.1833 | 0.0348 | Summer |
| 40.8267 | 1.0311 | 0.0347 | Summer |
| 40.7400 | 1.0752 | 0.0279 | Summer |
| 40.4019 | 0.5678 | 0 | Summer |
| 40.4217 | 0.7867 | 0.0256 | Summer |
| 40.1069 | 0.2817 | 0.0145 | Summer |
| 40.4989 | 0.9442 | 0.0255 | Summer |
| 40.5725 | 1.0885 | 0.0291 | Summer |
| 40.5783 | 0.8743 | 0 | Summer |
| 40.8573 | 1.1192 | 0 | Summer |
| 40.9163 | 1.0367 | 0.0466 | Summer |
| 39.9192 | 0.1344 | 0.0198 | Summer |
| 41.1048 | 1.4133 | 0.0332 | Summer |
| 41.1446 | 1.6842 | 0.0266 | Summer |
| 41.1900 | 1.8900 | 0 | Summer |
| 41.1459 | 1.9002 | 0.074 | Summer |
| 40.0243 | 0.8640 | 0.0241 | Summer |
| 40.0256 | 0.5686 | 0.0144 | Summer |
| 39.9867 | 0.3492 | 0.0258 | Summer |
| 39.9051 | 0.4838 | 0.0195 | Summer |
| 40.2620 | 0.4748 | 0.0124 | Summer |
| 40.2468 | 1.1696 | 0.017 | Summer |
| 40.2918 | 1.2277 | 0.0155 | Summer |
| 40.7108 | 1.2192 | 0.0291 | Summer |
| 40.8942 | 1.2936 | 0.0267 | Summer |
| 40.0586 | 1.0033 | 0.0254 | Summer |
| 40.4178 | 1.2515 | 0.0139 | Summer |
| 40.5548 | 1.3467 | 0.0517 | Summer |
| 41.0179 | 1.3740 | 0.0212 | Summer |
| 40.2222 | 1.2438 | 0 | Summer |
| 41.0103 | 1.5594 | 0.218 | Summer |
| 40.7242 | 1.3728 | 0.0149 | Summer |
| 40.9405 | 1.4341 | 0.1032 | Summer |
| 40.9953 | 1.4152 | 0.0277 | Summer |
| 41.0726 | 1.7820 | 0.0002 | Summer |
| 41.1133 | 2.0034 | 0.3043 | Summer |
| 41.1833 | 2.0187 | 0.193 | Winter |
| 40.9219 | 1.1800 | 0.0437 | Winter |
| 40.9107 | 1.0355 | 0.0477 | Winter |
| 40.8392 | 1.1234 | 0.0343 | Winter |
| 40.7505 | 1.0839 | 0.0133 | Winter |
| 40.8093 | 1.0308 | 0.037 | Winter |
| 41.1857 | 1.8858 | 0 | Winter |
| 40.4948 | 0.9145 | 0.0695 | Winter |
| 40.3992 | 0.5667 | 0.276 | Winter |
| 40.1720 | 0.7524 | 0.0412 | Winter |
| 40.2795 | 0.4963 | 0.231 | Winter |
| 40.4458 | 0.6891 | 0.2261 | Winter |
| 40.3278 | 0.7847 | 0.0673 | Winter |
| 40.2388 | 1.0256 | 0.0088 | Winter |
| 41.1483 | 1.9096 | 0 | Winter |
| 40.4304 | 0.7874 | 0.0413 | Winter |
| 40.3350 | 0.9938 | 0.0283 | Winter |
| 40.5800 | 0.8683 | 0.0555 | Winter |
| 40.5817 | 1.0775 | 0.0226 | Winter |
| 40.8578 | 1.1370 | 0 | Winter |
| 41.1448 | 1.7018 | 0.0315 | Winter |
| 41.1117 | 1.5636 | 0.006 | Winter |
| 41.1028 | 1.4199 | 0.0219 | Winter |
| 40.8958 | 1.2922 | 0.0133 | Winter |
| 40.7356 | 1.2190 | 0.0801 | Winter |
| 40.5728 | 1.3496 | 0.0368 | Winter |
| 40.4297 | 1.2576 | 0.0177 | Winter |
| 40.0633 | 1.0072 | 0.0172 | Winter |
| 40.2491 | 1.1753 | 0.0256 | Winter |
| 40.2925 | 1.2293 | 0.02 | Winter |
| 41.0213 | 1.3787 | 0.0187 | Winter |
| 40.9962 | 1.4173 | 0.0708 | Winter |
| 40.9308 | 1.4228 | 0.048 | Winter |
| 40.7262 | 1.3729 | 0.2213 | Winter |
| 40.2387 | 1.2521 | 0.036 | Winter |
| 41.0698 | 1.7623 | 0.0512 | Winter |
| 41.0119 | 1.5656 | 0.1946 | Winter |

**Bibliography**

Bozzano, A., Recasens, L., and Sartor, P. (1997). Diet of the european hake Merluccius merluccius (Pisces: Merluciidae) in the Western Mediterranean (Gulf of Lions). *Sci. Mar.* 61, 1–8.

Bozzano, A., Sardà, F., and Ríos, J. (2005). Vertical distribution and feeding patterns of the juvenile European hake, Merluccius merluccius in the NW Mediterranean. *Fish. Res.* 73, 29–36. doi:10.1016/j.fishres.2005.01.006.

Cartes, J. E., Hidalgo, M., Papiol, V., Massutí, E., and Moranta, J. (2009). Changes in the diet and feeding of the hake Merluccius merluccius at the shelf-break of the Balearic Islands: Influence of the mesopelagic-boundary community. *Deep. Res. Part I Oceanogr. Res. Pap.* 56, 344–365. doi:10.1016/j.dsr.2008.09.009.

Cartes, J. E., Rey, J., Lloris, D., and Gil De Sola, L. (2004). Influence of environmental variables on the feeding and diet of European hake (Merluccius merluccius) on the Mediterranean Iberian coasts. *J. Mar. Biol. Assoc. United Kingdom* 84, 831–835. doi:10.1017/S0025315404010021h.

Ferraton, F., Harmelin-Vivien, M., Mellon-Duval, C., and Souplet, A. (2007). Spatio-temporal variation in diet may affect condition and abundance of juvenile European hake in the Gulf of Lions (NW Mediterranean). *Mar. Ecol. Prog. Ser.* 337, 197–208. doi:10.3354/meps337197.

Mellon-Duval, C., Harmelin-Vivien, M., Métral, L., Loizeau, V., Mortreux, S., Roos, D., et al. (2017). Trophic ecology of the European hake in the Gulf of Lions, northwestern Mediterranean Sea. *Sci. Mar.* 81, 7. doi:10.3989/scimar.04356.01a.