Resource pulse in shallow waters: characterization of the scavenger community associated with a dolphin carcass

Francescangeli M.[1], Carandell M.[1], Mihai Toma D. [1], Martinez E. [1], Nogueras M. [1], Santin A. [2], Charzievangelou D. [2], Grinyo J. [3], Robinson J. N. [2], Navarro J.[2], Aguzzi J. [2,4], Del Rio J. [1]

[1] SARTI Research Group - Universitat Politècnica de Catalunya (UPC), 08800 Vilanova i la Geltrú, Spain.

[2] Instituto de Ciencias del Mar – Consejo Superior de Investigaciones Cientificas (ICM-CSIC), 08003 Barcelona, Spain.

[3] Department of Ocean System Sciences, NIOZ Royal Netherlands Institute for Research and Utrecht University, Den Burg, The Netherlands.

[4] Stazoione Zoologica Anthon Dorhrn of Napoles (SZN). Villa Comunale, 80121 Napoli, Italy

Corresponding author: *marco.francescangeli@upc.edu*

***Abstract*— Numerous studies have focused on the scavenger communities that feed on the carcasses of large marine animals, such as whales, in deep-sea habitats. Yet, there are far fewer studies in shallow water ecosystems and especially in the Mediterranean. Here, we performed an artificial cetacean fall in shallow waters in the northwestern Mediterranean. The cetacean carcass was monitored by via 30-min time-lapse photos using a fixed camera. We observed that bony fish were the main scavenger taxa. In addition, different species arrived at different times perhaps reflecting their role as scavengers or active predators.**

Keywords—Cetacean Carcasses, Fish community, Seafloor Observatory, Scavenging.

I. Introduction

The sinking bodies of cetaceans provide a huge, but infrequent, influx of food to the seafloor [1]. Knowledge of how these "whale falls" influence ecosystem dynamics is key to understanding how the decline in many whale populations worldwide has broad implications for benthic ecosystems [2]. In fact, a recent review reported that the number of stranded cetaceans has been increasing globally and has reached almost 1 stranding per year per km of coast in some areas [3]. Moreover, stranded cetacean carcasses always provided a rich and varied array of ecosystem services, comprehending provisioning, regulating, cultural and supporting services, to ancient and modern civilizations worldwide [3].

The study of whale falls has increased in the past decades providing important insights on their impact mainly on deep-sea habitats [2]. Whale carcasses in deep environments were reported to generally incur in four successional stages [2]. The first stage is characterized by dense aggregation of large active marine species, such as sharks and hagfishes, attracted by the scent of the dead carcass transported by water currents [4]. This stage can last from months to years, and is important for the removal of the soft tissue to hand the lipid rich content of the carcass bones to heterotrophic megafauna (e.g.; polychaetes and crustaceans) of the following enrichment-opportunist stage [2].

Previously, most research on whale falls has been conducted in deep-water and not shallow-water ecosystems [2]. However, few studies conducted in shallow marine habitats revealed that cetaceans' carcasses provide food for different marine species in these areas. Some examples are, [5] where various species of Annelida were detected in a cetacean carcass experiment at 30 m depth in Swedish fjord, [6] reported 18 species of macrofauna (including fishes, crustaceans and echinoderms) during video monitoring of five separate whale-fall deployments down to 30 m depth in Gullmarsfjorden (Sweden), and [7] characterized the Nematode community associated to a cetacean carcass implanted at 30 m depth in the East Sea, Peter the Great Bay analysing sediment samples. Moreover, floating whale carcasses were observed to be targeted by large marine top predators, such as sharks, before stranding [8], emphasizing their importance also before reaching the seabed.

Particularly in the Mediterranean there is dearth of information on cetacean falls and decomposition. In this area many studies focused on fossils' analysis to describe these rare events and their associated communities (e.g.; [9]). For this reason, the study of the impact of cetacean falls on the scavenger community in the Mediterranean Sea (deep and shallow habitats) is of pivotal importance considering the high number of their strandings on the Mediterranean coasts [3]. In this context, we aimed to characterize the local scavenger community in a shallow water area of the northwestern Mediterranean associated with an artificial cetacean fall. The video monitoring of the consumption process was performed with a seafloor cabled observatory camera, the Observatory of the Sea seafloor platform (OBSEA, www.obsea.es) [10] from 22nd December 2020 to 4th February 2021.

This work was undertaken within the framework of the Research Unit Tecnoterra (ICM-CSIC/UPC) and the following project activities: RESBIO (TEC2017-87861-R; Ministerio de Ciencia, Innovación y Universidades), JERICO-S3 (Horizon 2020; Grant Agreement no. 871153), LIFE-ECOREST (LIFE20NAT/ES/001270) and PLOME (PLEC2021-007525/AEI/10.13039/501100011033). This work used the EGI infrastructure with the dedicated support of INFN-CATANIA-STACK. The first author was supported by an FPI pre-doctoral research fellowship (ref. PRE2018-083839).

The OBSEA provides time-lapse, real-time images and environmental data at 20 m depth and 4 km off the Vilanova i la Geltrú harbour (Barcelona), Spain (Fig.1A, B). This platform is a European Multidisciplinary Seafloor and water column Observatory (EMSO) testing site and has been operating since 2009. It is located near an artificial reef in a fishing protected area located in the natural reserve of "Els Colls i Miralpeix". With this platform shallow-water experiments can be performed. This underwater observatory is maintained by the "Development Center of Remote Acquisition and Information Processing Systems" (SARTI) research group from "Universitat Politècnica de Catalunya" (UPC).

The use of seafloor observatories is becoming widespread because of its low impact on the marine environment and its capability to perform continuous (i.e.; one photo each 30 min.) and long-lasting monitoring (up to decades) of the marine ecosystems [11]. This type of technology has already been used to monitor a whale-fall decomposition process in Sagami-Bay (Japan) [4]. This type of monitoring would allow to obtain data on the temporal partitioning between scavenger and predator species analysing their time of occurrence during the day, along with the characterization of the scavenger community.

II. Materials and Methods

The carcass of a juvenile male striped dolphin (*Stenella coeruleoalba*) (Fig. 1C) was found in a beach close to Vilanova i la Geltrú (i.e. Blanes, Catalonia, Spain) on the 21st December 2020. The dolphin was 180 cm in length and weighed 66.5 kg. A necropsy was performed on this specimen by the members of the Faculty of Veterinary of the "Universitat Autònoma de Barcelona" (UAB) before the deployment, whose results proved the absence of any pathogens, and indicated gas embolism as the cause of death.

The dolphin carcass was deployed in front of the camera system of the OBSEA (Fig. 1D). Photos were taken every 30 min. after the deployment of the dolphin carcass during daylight hours, until and after the complete consumption of the soft tissue (i.e. until only the bones remained), due to lack of artificial illumination to capture night photos. The OBSEA camera focused the carcass with a 45° angle from a distance of ~3 m (Fig. 1D).

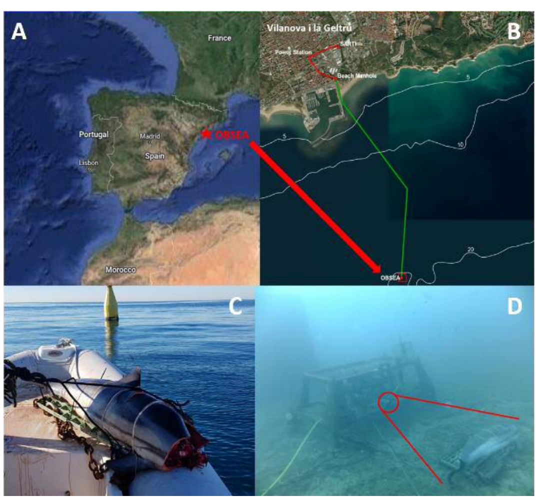

Fig. 1. OBSEA seafloor observatory setting (A) off the coast of Vilanova i la Geltrú (northweastern Mediterranean, Spain) (B). Deployment of the dolphin carcass (C) in front of the OBSEA camera (D).

The macro-faunal scavenger community exploiting the carcass was characterized using images from the OBSEA camera system. The images were manually analysed by a trained operator to count and classify the specimens. The Trophic Level (TL), Functional Trophic Group (TFG) and habitat use of the different species were reported following [12], and SeaLifeBase (www.sealifebase.org). The state of the carcass during consumption was also characterized via visual percentage of the remaining body. Finally, changes in the composition of the scavenger community were assessed as the soft tissues were consumed.

Daily mean number of counts per each species and consumption rate were plotted with the *ggplot2* package of R software. Furthermore, we performed General Additive Models (GAMs) for each marine taxa time series, as response variable, and the percentage of carcass remained, as predictor, using Restricted Maximum Likelihood (REML) method and adding a Autoregressive Model (AR), in order to assess the relationship between the carcass consumption and the daily-averaged counts of each detected taxa. These models were carried out using the library "mgcv" of R software. Finally, we summed counts per each detected taxa when the carcass was present and when it was absent and compared the differences in counts between the two periods of the experiment using binomial tests with the R package *stats*, under the assumption that every count corresponds to a distinct specimen (so that sightings of each individual in any of the two periods are mutually exclusive).

III. Results

We analysed a total of 840 images, resulting in 8415 counted individuals from 12 species (Fig. 2). The three most frequently observed species were *Diplodus sargus* with 4081 counts, *Oblada melanura* with 917 counts, and *Coris julis* with 180 counts (TABLE I). While the three lesser sighted species were *Diplodus vulgaris* and *Diplodus cervinus* with both two counts, and *Serranus cabrilla* with only one count (TABLE I). Most of the observed species were omnivorous with the exception of *Chromis chromis, Dentex dentex, Octopus vulgaris,* and *Seriola dumerili* (which are all carnivorous) (TABLE I).

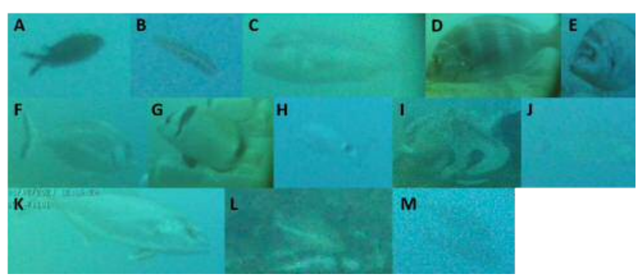

Fig. 2 Images of the 12 marine species detected during the video monitoring of a dolphin carcass at the OBSEA in alphabetical order: A) *Chromis chromis*, B) *Coris julis*, C) *Dentex dentex*, D) *Diplodus cervinus*, E) *Diplodus puntazzo*, F) *Diplodus sargus*, G) *Diplodus vulgaris*, H) *Oblada melanura*, I) *Octopus vulgaris*, J) *Sarpa salpa*, K) *Seriola dumerili*, L) *Serranus cabrilla*, and M) unknown fish taxa.

TABLE I. Trophic Level (TL), Functional Trophic Group (FTG; CC for carnivores with a preference for fish and cephalopods, CD for carnivores with a preference for decapods and fish, OA for omnivores with a preference for animal material, and OV omnivores with a preference for plants), and habitat of the 12 marine species detected during the video monitoring period of a dolphin carcass at the OBSEA. Total number of counts (Tot.) per each marine taxon and overall counts (Total) are also reported.

Species	TL	FTG	Habitat	Tot.
Chromis chromis	3.8±0.4	CD	Hard bottom	110
Coris julis	3.4±0.1	OA	Multi-habitat	180
Dentex dentex	4.5±0.4	CC	Hard bottom	6
Diplodus cervinus	3.0±0.4	OA	Hard bottom	2
Diplodus puntazzo	3.2±0.0	OA	Hard bottom	101
Diplodus sargus	3.4±0.1	OA	Multi-habitat	4081
Diplodus vulgaris	3.5±0.1	OA	Multi-habitat	2
Oblada melanura	3.4±0.4	OA	Multi-habitat	917
Octopus vulgaris	3.9±0.1	CD	Hard bottom	10
Sarpa salpa	2.0±0.0	OV	Multi-habitat	6
Seriola dumerili	4.5±0.0	CC	Pelagic	37
Serranus cabrilla	3.4±0.30	OA	Multi-habitat	1
Unknown fish	/	/	/	2962
Total	/	/	/	8415

Within 25 days, all flesh has been removed from the carcass and only bones remained. Comparing the fluctuations in mean number of counted individuals per day for the different detected marine taxa with the percentage consumption of the carcass it can be noted that there were more counts during the presence of the carcass than after the carcass's consumption for some species (Fig. 3). These species are *C. julis, Diplodus puntazzo, D. sargus, D. vulgais, O. melanura, O. vulgaris, Sarpa salpa* and *S. dumerili*. Moreover, it can be observed also that the unknown fish taxa and overall counts' averages drastically diminish after the consumption of the carcass (Fig. 3). The first species to appear after the deployment are *C. chromis, C. julis, O. vulgaris* and *S.salpa* (the other species are appearing after some time from the deployment). Specimens of *D. dentex* mainly appeared only after the complete consumption of the carcass.

The GAM models between the remaining percentage of the carcass and the daily-averaged counts revealed significant relationships for *C. julis, D. puntazzo, D. sargus, D. vulgaris, O. melanura, O. vulgaris,* unknown fish taxa and for the overall counts (at $\alpha = 0.01$), as well as for *S. salpa* (at $\alpha = 0.05$) (TABLE II).

Finally, the binomial tests revealed that the counts for *C. chromis, C. julis, D. puntazzo, D. sargus O.melanura, O. vulgaris,* unknown fish taxa and overall counted individuals during the presence of the dolphin carcass were significantly (at $\alpha = 0.01$) higher than the expected ones based on the proportion of images analysed per period (TABLE III).

IV. Discussion

The results showed how the local scavenger community changed before and after the complete consumption of the flesh of the carcass. Specifically, the number of counts of several taxa increased while flesh was being consumed and then decreased when only the bones remained. The scavenger community at this site was also mainly characterized by mobile animals, in particular bony fishes, with omnivorous diets.

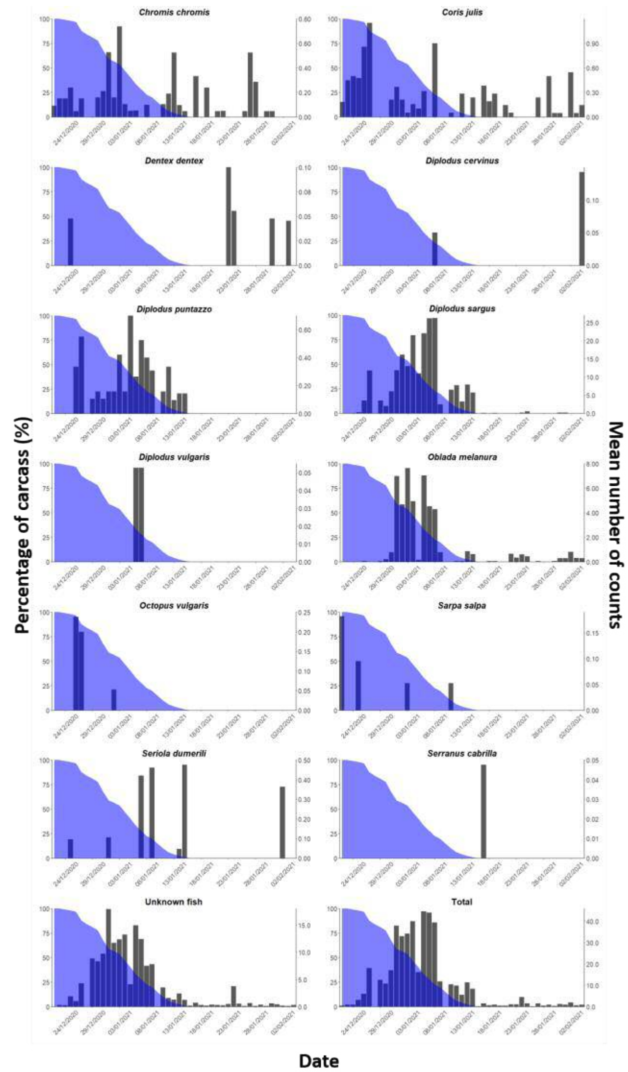

Fig. 3. Time-series of mean number of counts per day for each detected marine taxa (grey histograms), and of the progressive consumption of the dolphin carcass in percentage (blue shadow) during an experiment at the OBSEA platform.

The number of counted individuals for some species (i.e. *C. julis, D. puntazzo, D. sargus, O. melanura, O. vulgaris,* and *S. salpa)* were directly correlated to the presence of the carcass. However, looking at the video records of the experiment [13] it could be observed that only *C. julis, D. sargus* and *O. vulgaris* were actively exploiting the dolphin carcass. The top predator *D. dentex* has been observed to be more present after the complete consumption of the carcass, probably proving that it is not a scavenger species [14]. Instead the carnivorous species *S. dumerili* and *O. vulgaris* were observed during the carcass consumption stage. The first one was observed mainly when the carcass was almost skeletonized, probably taking advantage of the attraction of its preys from the carcass scent. Instead, the

TABLE II. General Additive Model results using daily-averaged counts time series of each marine taxa detected against the percentage of dolphin carcass remained as predicting variable, during the deployment period of a dolphin carcass at the OBSEA (i.e., until its full consumption). DF is the degree of freedom value. "*", "**", and "***" indicate significance at level α = 0.05, 0.01, and 0.001, respectively. R^2 measures the proportion of the response variable variance that can be explained by the predicting variable.

Species	DF	p value	R^2	Deviance Explained (%)
Chromis chromis	2.28	0.348	0.04	8.34
Coris julis	1.14	0.009**	0.14	16.40
Dentex dentex	1.70	0.537	0.01	3.85
Diplodus cervinus	1.00	0.429	-0.01	1.49
Diplodus puntazzo	5.45	<0.001***	0.59	62.90
Diplodus sargus	5.39	<0.001***	0.74	76.70
Diplodus vulgaris	8.98	<0.001***	0.84	86.90
Oblada melanura	8.83	<0.001***	0.84	86.80
Octopus vulgaris	1.00	0.009**	0.13	15.20
Sarpa salpa	2.79	0.019*	0.19	23.60
Seriola dumerili	1.94	0.622	0.01	4.34
Serranus cabrilla	1.00	0.439	-0.01	1.43
Unknown fish	5.38	<0.001***	0.83	84.60
Total	5.59	<0.001***	0.82	83.90

TABLE III The binomial test results with the number of counts for each detected marine taxa before (Carcass Presence) and after (Carcass Absence) the skeletonization of the carcass during an experiment at the OBSEA platform.

Taxa	Carcass Presence	Carcass Absence	p value
Chromis chromis	76	34	<0.01
Coris julis	129	51	<0.01
Dentex dentex	1	5	0.12
Diplodus cervinus	1	1	1.00
Diplodus puntazzo	101	0	<0.01
Diplodus sargus	4051	30	<0.01
Diplodus vulgaris	2	0	0.50
Oblada melanura	834	83	<0.01
Octopus vulgaris	10	0	<0.01
Sarpa salpa	6	0	0.03
Seriola dumerili	29	8	0.03
Serranus cabrilla	0	1	0.47
Unknown	2769	193	<0.01
Total	8009	406	<0.01

second one was observed directly exploiting the carcass without any predatory behaviour, proving its presence only as a scavenger. Finally, *C. chromis* as a non-omnivorous species was probably present as a common species observed in this area during this period of the year [15].

In a similar experiment at the Swedish west coast similar monthly consumption rates (i.e.; almost 2 months vs 25 days in our study) were observed and compared to deeper large marine animals' deployments [6]. This comparison suggested a longer time to consume the carcass from scavengers in the shallow water ecosystems, probably due to the slow removal of the skin by scavenger and formation of possible toxic bacterial mat. As in this previous study at the Swedish coasts, also in our experiment the consumption rate of the carcass was observed to augment drastically after the removal of the skin, that in our case it was mainly performed by *O. vulgaris*.

In our study Osteichthyes was reported to be the main taxa exploiting the carcass, but in other similar studies also specimens of crustacean, echinoderm, hagfish, shark, Nematoda and Annelida were observed related to the presence of large animal carcasses [5]–[7]. In particular, in the Annelida phylum, specimens of *Osedax* sp. were reported at both shallow and deeper depths, proving the connectivity between these environments. Unfortunately, due to the quality of the images captured by the OBSEA camera and unavailability of proper laboratories to study organisms smaller than 2 centimetres, it was not possible to observe the formation of bacterial mats, or the presence of species characterizing hot vents and seeps. This was possible in a study in the North Sea that proved the presence of obligate fauna of seeps also at shallow depth [5]. However, in the area close to our study site it is not known any hydrothermal spring or cold seep that can influence the local faunal composition with larval transportation by currents.

In future experiments, we will add artificial illumination so that we can also characterize nocturnal species. Without this information it could not be performed waveform analysis to study the activity rhythms of the community associated with this experiment, and important information is missed. A previous work achieved this objective pointing out the importance of continuous monitoring in whale-fall experiments to better study the scavenger community rhythms [4].

Furthermore, we will replicate the experiment hopefully once per season (i.e.; winter, spring, summer and autumn) to observe if there are any changes in the faunal and scavenger composition across the seasonal cycle. A similar experiment has just been performed at the Salish Sea, in British Columbia, but at deeper depths [16]. This previous experiment highlighted the importance of the seasonal factor in the decomposition of the carcasses. Finally, in order to spatially expand the monitoring of the scavenging dynamics, further activities will be focused on the use of video camera equipped mobile crawler and underwater legged robot currently operating at the OBSEA infrastructure (https://crawler.obsea.es/; Silver2).

Acknowledgment

We thank the members of the "Departament de Territori i Sostenibilitat de la Generalitat de Catalunya" to giving us the permission of using dead stranded cetaceans collected by the "Xarxa Rescat Fauna Marina de la Generalitat de Catalunya" on the coasts of Catalonia. In particular, we thank Santiago Palazon and Jordi Ruiz (Generalitat de Catalunya) for facilitating permits for this study, and Pol Nebot for help during the transportation of the carcass. We thank the financial support from the Spanish government through the 'Severo Ochoa Centre of Excellence' accreditation (CEX2019-000928-S).

References

[1] J. Roman *et al.*, "Whales as marine ecosystem engineers," *Front. Ecol. Environ.*, vol. 12, no. 7, pp. 377–385, 2014, doi: 10.1890/130220.

[2] C. R. Smith, A. G. Glover, T. Treude, N. D. Higgs, and D. J. Amon, "Whale-fall ecosystems: Recent insights into ecology, paleoecology, and evolution," *Ann. Rev. Mar. Sci.*, vol. 7, pp. 571–596, 2015, doi: 10.1146/annurev-marine-010213-135144.

[3] M. M. Quaggiotto *et al.*, "Past, present and future of the ecosystem services provided by cetacean carcasses," *Ecosyst. Serv.*, vol. 54, no. February, 2022, doi: 10.1016/j.ecoser.2022.101406.

[4] J. Aguzzi *et al.*, "Faunal activity rhythms influencing early community succession of an implanted whale carcass offshore Sagami Bay, Japan," *Sci. Rep.*, vol. 8, no. 1, pp. 1–15, 2018, doi: 10.1038/s41598-018-29431-5.

[5] T. G. Dahlgren, H. Wiklund, B. Källström, T. Lundälv, C. R. Smith, and A. G. Glover, "A shallow-water whale-fall experiment in the north Atlantic," *Cah. Biol. Mar.*, vol. 47, no. 4, pp. 385–389, 2006.

[6] A. G. Glover *et al.*, "A live video observatory reveals temporal processes at a shelf-depth whale-fall," *Cah. Biol. Mar.*, vol. 51, no. 4, pp. 371–381, 2010.

[7] O. N. Pavlyuk, Y. A. Trebukhova, and V. G. Tarasov, "The Impact of Implanted Whale Carcass on Nematode Communities in Shallow Water Area of Peter the Great Bay (East Sea)," *Ocean Sci. J.*, vol. 44, no. 3, pp. 181–188, 2009, doi: 10.1007/s12601-009-0016-1.

[8] J. P. Tucker, B. Vercoe, I. R. Santos, M. Dujmovic, and P. A. Butcher, "Whale carcass scavenging by sharks," *Glob. Ecol. Conserv.*, vol. 19, p. e00655, 2019, doi: 10.1016/j.gecco.2019.e00655.

[9] A. Zazzera *et al.*, "Systematics, taphonomy and palaeobiogeography of a balaenopterid (Cetacea, Mysticeti) from the Early Pleistocene of southern Italy," *Geobios*, vol. 71, pp. 51–65, 2022, doi: 10.1016/j.geobios.2022.01.001.

[10] J. Del-Rio *et al.*, "Obsea: A Decadal Balance for a Cabled Observatory Deployment," *IEEE Access*, vol. 8, pp. 33163–33177, 2020, doi: 10.1109/ACCESS.2020.2973771.

[11] J. Aguzzi *et al.*, "New High-Tech Flexible Networks for the Monitoring of Deep-Sea Ecosystems," *Environ. Sci. Technol.*, vol. 53, no. 12, pp. 6616–6631, 2019, doi: 10.1021/acs.est.9b00409.

[12] P. K. Karachle and K. I. Stergiou, "An update on the feeding habits of fish in the Mediterranean Sea (2002-2015)," *Mediterr. Mar. Sci.*, vol. 18, no. 1, pp. 43–52, 2017, doi: 10.12681/mms.1968.

[13] M. Nogueras, "Vídeo dofí 22-12-2020," 2021. [Online]. Available: https://www.youtube.com/playlist?list=PLl8TAdfkI14pSGZu6P3l-Q9cFxHfSpWrd.

[14] M. Francescangeli *et al.*, "Long-Term Monitoring of Diel and Seasonal Rhythm of Dentex dentex at an Artificial Reef," *Front. Mar. Sci.*, vol. 9, no. March, pp. 1–17, 2022, doi: 10.3389/fmars.2022.837216.

[15] F. Condal *et al.*, "Seasonal rhythm in a Mediterranean coastal fish community as monitored by a cabled observatory," *Mar. Biol.*, vol. 159, no. 12, pp. 2809–2817, 2012, doi: 10.1007/s00227-012-2041-3.

[16] G. S. Anderson and L. S. Bell, "Impact of marine submergence and season on faunal colonization and decomposition of pig carcasses in the salish sea," *PLoS One*, vol. 11, no. 3, 2016, doi: 10.1371/journal.pone.0149107.