Technologically-sustained ecological monitoring of a coastal fish community with a highly integrated biological and environmental data

PhD Thesis

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Technologically-sustained ecological monitoring of a coastal fish community with a highly integrated biological and environmental data

Monitoreo ecológico de una comunidad de peces costeros con datos biológicos y ambientales mediante nuevas tecnologías

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“Technologically-sustained ecological
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ABSTRACT

The monitoring of coastal marine ecosystems has been traditionally carried out with man and vessel-assisted methodologies. In the past, trawling survey, trammel net fishing, and SCUBA divers' visual census were used to achieve relevant ecological knowledge on marine coastal fishes, being in the past decades progressively integrated by platforms with different levels of tele-operated autonomy such as Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and more recently seafloor cabled observatories. All these platforms are equipped with High Definition (HD) video cameras, in order to obtain biological data from the identification of individuals, their classification, resulting in species spatiotemporal counting and sizing (to obtain density and biomass estimates).

Seafloor cabled video-observatories, connected to the shore for power and real-time data transmission, are being increasingly used to monitor fish behaviour at the temporal scales of activity, growth, and reproduction rhythms, the resulting communities' turnover, and the overall environmental control, with no unifying data collection and elaboration protocols. In fact, seafloor observatories can provide big amount of biological and environmental data in real-time for long periods of time (i.e., from days, weeks, and months to years, and even decades). Video-counted animals are a proxy of species local abundances, being the chance of spotting animals proportional to the quantity of them appearing into the observatory deployment area. Unfortunately, biological data are provided by cameras, through the manual counting and classification of organisms. New routines for automated organisms' classification are required to autonomously compile time-series of biological data, to be used for posterior analysis.

Temporally-intensive (i.e., at min sampling period) time series of animals' counts, continuously complied across consecutive seasons, allow the picturing of phenology of portrayed species (e.g., the dynamic of reproduction and growth). When long time series are obtained, they can be used as proxy for species changes in abundance at diel, seasonal, and even yearly scales, being the amplitudes of counts fluctuations also related to underlying climatic regime shifts. In fact, massive populational displacements occur during the 24-h in the water column (pelagic species), between the seabed and water column (benthopelagic species), and on the seafloor (benthic and necto-benthic species), being those movements modulated by reproductive and growth cycles. The investigation on these behavioural rhythms is of value for fishery stock assessment (e.g., tune demographic estimations based on rhythmic movements in and out of our sampling windows). With temporal studies, comparing biological and environmental data across years, we can also observe the effects of different oceanographic and meteorological variables on species phenology.

This Thesis central objectives is to develop practices for data collection and analysis in relation to the marine ecological monitoring with cabled observatory technologies. For that purpose, the Thesis was carried out using a nearly decadal image data set of biological data (i.e., fish counts for 37 fish taxa) and synchronous multiparametric oceanographic (water temperature, salinity, change of depth as shift in water pressure, and current velocity and direction) and meteorological (air temperature, wind speed and direction, sun irradiance,

and rain) data provided by the seafloor cabled video-observatory OBSEA (www.obsea.es). This is located in the north-western Mediterranean, 4 km off Vilanova i la Geltrú (Barcelona, Spain) at 20 m depth.

This Thesis first chapter hence focuses on the autecology of an important fishery resource, the common dentex (*Dentex dentex*), to set the guidelines for the processing and analysis of high-frequency (30 min), large (i.e. decadal), multiparametric time series (i.e., fish counts and oceanographic plus meteorological data), in order to efficiently describe diel and seasonal counts fluctuations (as proxy for local abundance).

The Thesis' second chapter is centred on the development of pipelines to automatically detect fishes and classify them into species as categories, to speed up the treatment of big amounts of image/video material, as application context for ecological video-monitoring practices. This can be possible only with the development of automated processing routines, trained with ground-truthed tagged datasets. For this reason, the second chapter describes the creation of a training reference dataset of tagged species of two years length temporally collated with the environmental information, as quality indicator of pictures clearness.

Finally, the third chapter of the Thesis focuses on the monitoring of the scavenging dynamic of a cetacean carcass, in coastal areas. A specific experimental planning was deployed as *in situ* experiment, to understand the impact of large punctual organic inputs on coastal marine communities in a framework of increasing global large marine animal species stranding on the coasts.

Keywords: cabled observatories, environmental monitoring, monitoring methodologies, shallow water ecosystems, fish behaviour, cetacean carcasses, scavenger community, machine learning, artificial intelligence.

RESUMEN

El monitoreo de ecosistemas marinos costeros tradicionalmente se ha llevado a cabo con metodologías asistidas por el hombre y/o embarcaciones. En el pasado, el monitoreo con arrastre, pesca con trasmallo y censos visuales con buzos se utilizaron para profundizar el conocimiento ecológico sobre los peces marinos costeros. En las últimas décadas han sido progresivamente integradas nuevas tecnologías gracias a plataformas con diferentes niveles de autonomía tele operada, como "Remotely Operated Vehicles" (ROV), "Autonomos Underwater Vehicles" (AUV) y, más recientemente, los observatorios cableados de fondo marino. Todas estas plataformas están equipadas con videocámaras de alta definición (HD), con el fin de obtener datos biológicos a partir de la clasificación de los individuos identificados, dando como resultado un conteo espaciotemporal de las diferentes especies y sus dimensionamientos (para obtener estimaciones de densidad y biomasa).

Los video-observatorios cableados de fondo marino, conectados a la costa para la transmisión de energía y datos en tiempo real, se utilizan cada vez más para monitorear el comportamiento de los peces a diferentes escalas temporales de actividad, crecimiento y reproducción, la resultante rotación de comunidades y control ambiental general, pero desafortunadamente, son sin protocolos estandarizados de recogida y procesado de datos. De hecho, los observatorios pueden proporcionar una gran cantidad de datos biológicos y ambientales en tiempo real durante largos períodos de tiempo (es decir, de días, semanas y de meses hasta años, e incluso décadas). Los conteos de los animales pueden ser considerados como una aproximación de la local abundancia de las diferentes especies, siendo la probabilidad de detectar animales proporcionales a la cantidad de apariciones de estos en la zona de despliegue del observatorio. Desafortunadamente, los datos biológicos son proporcionados por cámaras a través del conteo y clasificación manual de organismos. Por esto, se requieren nuevas rutinas para la clasificación automatizada de organismos para recopilar de forma autónoma series temporales de datos biológicos, los cuales se utilizarán para análisis posteriores.

Las series temporales de conteos de animales intensivas (es decir, con periodos de adquisición de minutos), recopiladas continuamente durante temporadas consecutivas, permiten representar la fenología de las especies capturadas (p. ej., la dinámica de reproducción y crecimiento). Cuando se compilan series temporales largas, estas pueden ser usadas como aproximación del cambiamiento en abundancia de las diferentes especies a nivel diario, estacional, y también anual, siendo las amplitudes de las fluctuaciones de los conteos relacionadas también al subyacente régimen de cambio climático. De hecho, se producen desplazamientos poblacionales masivos durante las 24 horas en la columna de agua (especies pelágicas), entre el fondo marino y la columna de agua (especies bento-pelágicas), y en el fondo marino (especies bentónicas y necto-bentónicas), siendo esos movimientos modulados por ciclos reproductivos y de crecimiento. La investigación de estos ritmos de comportamiento es valiosa para la evaluación de las poblaciones de peces (p. ej., ajustar las estimaciones demográficas en función de los movimientos rítmicos dentro y fuera de nuestras ventanas de muestreo). Con estudios temporales, comparando datos biológicos y ambientales a lo largo de los años, también podemos observar los efectos de diferentes variables oceanográficas y meteorológicas en la fenología de las especies.

Los objetivos principales de esta tesis doctoral contribuyen a la metodología en la recopilación de datos y análisis en relación al monitoreo ecológico marino a través de observatorios cableados. Por este motivo, esta tesis se llevó a cabo utilizando un conjunto de datos de imágenes de casi una década de datos biológicos (es decir, conteos de peces costeros de 37 taxones) con datos oceanográficos (temperatura del agua, salinidad, cambio de profundidad resultante del cambio de presión, velocidad y dirección de la corriente) y meteorológicos (temperatura del aire, velocidad y dirección del viento, irradiancia solar y lluvia) multiparamétricos sincrónicos proporcionados por el video-observatorio cableado de fondo marino OBSEA (www.obsea.es). Éste está situado en el Mediterráneo noroccidental, a 4 km de Vilanova i la Geltrú (Barcelona, España) y a 20 m de profundidad.

El primero capítulo de la tesis se centra en la autoecología de un importante recurso pesquero, el déntol (*Dentex dentex*), para establecer directivas para el procesamiento y análisis de series temporales multiparamétricas de alta frecuencia (30 minutos), largas (es decir, decenales) y multiparamétricas (es decir, conteos de peces con datos oceanográficos y meteorológicos), para describir con eficacia las fluctuaciones diarias y estacionales (como proxy de la abundancia local).

El segundo capítulo está dedicado al desarrollo de procedimientos de captura y análisis de imágenes para detectar automáticamente peces y clasificarlos en especies como categorías, para acelerar el tratamiento de grandes cantidades de material de imágenes, en un contexto de aplicación para buenas prácticas de video-monitoreo ecológico. Esto solo puede ser posible con el desarrollo de rutinas de procesamiento de imágenes automatizadas, entrenadas con bases de datos etiquetados y verificados por expertos. Por esta razón, el segundo capítulo describe la creación de una base de datos para rutinas de procesamiento de imágenes automatizadas con especies etiquetadas de dos años de duración, con relativa información ambiental como indicador de calidad de la nitidez de las imágenes.

Finalmente, el tercer capítulo de la Tesis se enfoca en el monitoreo de la dinámica de carroñeros relacionados a carcasas de cetáceos en ambiente costero. Un experimento específico fue llevado a cabo desplegando la carcasa de un delfín en el observatorio como experimento *in situ*, para comprender el impacto de grandes aportes orgánicos puntuales en las comunidades marinas costeras en un marco de aumento global de especies de animales marinos de gran tamaño varados en las costas.

Palabras clave: observatorios cableados, monitoreo ambiental, metodologías de monitoreo, ecosistemas de aguas poco profundas, comportamiento de los peces, cadáveres de cetáceos, comunidad de carroñeros, aprendizaje automático, inteligencia artificial.

RESUM

La monitorització d'ecosistemes marins costaners tradicionalment s'ha dut a terme amb metodologies assistides per homes o embarcacions. En el passat es van utilitzar monitoratges amb arrossegament, pesca amb trasmallo i cens visual amb bussejadors per avançar en el coneixement ecològic sobre els peixos marins costaners. En les darreres dècades, noves tecnologies han estat progressivament integrades gràcies a plataformes amb diferents nivells d'autonomia teleoperada, com ara els “Remotely Operated Vehicles” (ROV), “Autonomous Underwater Vehicles” (AUV) i, més recentment, observatoris cablejats de fons marí. Totes aquestes plataformes estan equipades amb càmeres de vídeo d'alta definició (HD), per tal d'obtenir dades biològiques a partir de la classificació dels individus identificats, donant com a resultat un recompte espaciotemporal de les diferents espècies i els seus dimensionaments (per obtenir estimacions de densitat i biomassa).

Els videoobservatoris cablejats de fons marí, connectats per cable a la costa per a la transmissió d'energia i dades en temps real, s'utilitzen cada cop més per monitoritzar el comportament de peixos a escala temporal d'activitat diària, ritmes de creixement i reproducció, rotació de comunitats i control ambiental general, per malauradament sense protocols estandaritzats de recollida i processament de dades. De fet, els observatoris poden proporcionar una gran quantitat de dades biològiques i ambientals en temps real durant llargs períodes de temps (és a dir, de dies, setmanas, i mesos a anys, i fins i tot dècades). Els recomptes dels animals poden ser considerats com una aproximació de la abundància local de les diferents espècies, sent l'oportunitat de detectar animals proporcionals a la quantitat d'aparicions d'aquests a la zona de desplegament de l'observatori. Desafortunadament, les dades biològiques són proporcionades pel recompte i classificació manual dels organismes presents a les fotos i vídeos adquirits per les càmeres. Per això, es requereixen noves rutines per la classificació automatitzada d'organismes per recopilar de manera automàtica sèries temporals de dades biològiques, les quals s'utilitzaran per a anàlisis posteriors.

Les sèries temporals que inclouen comptatges d'animals intensives (és a dir, amb períodes d’adquisició de imatges de minuts), recopilades contínuament durant temporades consecutives, permeten representar la fenologia de les espècies presents a les imatges (p. ex., la dinàmica de reproducció i creixement). Quan es compilen sèries temporals llargues, aquestes poden ser usades com a aproximació del canvi en abundància de les diferents espècies a nivell diari, estacional, i també anual, sent les amplituds de les fluctuacions dels recomptes relacionades també al subjacent règim de canvi climàtic. De fet, es produeixen desplaçaments poblacionals massius durant les 24 hores a la columna d'aigua (espècies pelàgiques), entre el fons marí i la columna d'aigua (espècies bentopelàgiques), i al fons marí (espècies bentòniques i necto-bentòniques), sent aquests moviments modulats per cicles reproductius i de creixement. La investigació d'aquests ritmes de comportament és valuosa per a l'avaluació de les poblacions de peixos (p. ex., ajustar les estimacions demogràfiques en funció dels moviments rítmics dins i fora de les finestres de mostreig). Amb estudis temporals, comparant dades biològiques i ambientals al llarg dels anys, també podem observar els efectes de diferents variables oceanogràfiques i meteorològiques a la fenologia de les espècies.

Els objectius principals d'aquesta tesi doctoral contribueixen al desenvolupament de bones pràctiques per la recopilació de dades i anàlisis en relació al monitoratge ecològic marí a través d'observatoris cablejats. Per aquest motiu, aquesta tesi es va dur a terme utilitzant un conjunt de dades d'imatges de gairebé una dècada de dades biològiques (és a dir, recomptes de peixos costaners de 37 tàxons) amb dades oceanogràfiques (temperatura de l'aigua, salinitat, canvi de profunditat resultant del canvi de pressió, velocitat i direcció del corrent) i meteorològics (temperatura de l'aire, velocitat i direcció del vent, irradiància solar i pluja) proporcionats pel videoobservatori cablejat de fons marí OBSEA (www.obsea.es). Aquest està situat a la Mediterrània nord-occidental, a 4 km de Vilanova i la Geltrú (Barcelona, Espanya) i a 20 m de profunditat.

El primer capítul d’aquesta tesi es centra en l'autoecologia d'un important recurs pesquer, el dèntol (*Dentex dentex*), per establir directives per al processament i l'anàlisi de sèries temporals multiparamètriques d'alta freqüència (30 minuts), llargues (és a dir, decennals) i multiparamètriques (és a dir, recomptes de peixos amb dades oceanogràfiques i meteorològiques), per descriure amb eficàcia les fluctuacions diàries i estacionals (com a proxy de l'abundància local).

El segon capítol s'enfoca en el desenvolupament de procediments pel tractament i análisis d'imatges per detectar automàticament peixos i classificar-los en espècies per categories, per tal accelerar el tractament de grans quantitats d'imatges, en un context d'aplicació per a bones pràctiques de videomonitoreig ecològic. Això només pot ser possible amb el desenvolupament de rutines de processament d'imatges automatitzades, entrenades amb bases de dades etiquetades i verificades per experts. Per això, el segon capítol descriu la creació d'un base de dades per a rutines de processament d'imatges automatitzades amb espècies etiquetades de dos anys de durada i amb informació ambiental relativa, com a indicador de qualitat de la nitidesa de les imatges.

Finalment, el tercer capítol de la Tesi s'enfoca al monitoratge de la dinàmica de carronyaires relacionats amb carcasses de cetacis en ambient costaner. Un experiment específic va ser dur a terme desplegant la carcassa d’un dofí *in situ* al observatori OBSEA, per comprendre l'impacte de grans aportacions orgàniques puntuals a les comunitats marines costaneres en un marc d'augment global d'espècies d'animals marins de grans dimensions encallats a les costes.

Paraules clau: observatoris cablejats, monitoratge ambiental, metodologies de monitoratge, ecosistemes d'aigües poc profundes, comportament dels peixos, cadàvers de cetacis, comunitat de carronyers, aprenentatge automàtic, intel·ligència artificial.

PREFACE

“*Life clearly does more than adapt to the Earth. It changes the Earth to its own purposes. Evolution is a tightly coupled dance, with life and the material environment as partners. From the dance emerges the entity Gaia.*”

James Lovelock

To my family and all those who have supported me in this endeavour of professional and personal growth...

A mi familia y a todos los que me han apoyado en este empeño de crecimiento profesional y personal...

A la meva família i a tots els que m'han donat suport en aquest afany de creixement professional i personal...

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	Estimate	SE	z value	Pr(>|z|)
(Intercept)	5.32	3.11	1.709	0.08739
Water Temperature (°C)	$1.08*10^{-1}$	$7.10*10^{-3}$	15.151	$<2*10^{-16}$
Depth (m)	$-3.77*10^{-1}$	$1.36*10^{-1}$	-2.784	0.00536
Salinity (PSU)	$-9.07*10^{-2}$	$7.69*10^{-2}$	-1.18	0.23805
Wind Speed (km/h)	$3.20*10^{-2}$	$4.25*10^{-3}$	7.527	$5.17*10^{-14}$
Wind Direction (deg.)	$-1.37*10^{-4}$	$2.75*10^{-4}$	-0.5	0.61678
Solar Irradiance (W/m^2)	$1.56*10^{-3}$	$7.90*10^{-5}$	19.719	$<2*10^{-16}$
Rain (mm)	$6.65*10^{-3}$	$4.46*10^{-2}$	0.149	0.88148

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	Estimate	SE	z value	Pr(>|z|)
(Intercept)	-6.15	$1.16*10^{-1}$	-53.03	$<2*10^{-16}$
Water Temperature (°C)	$1.42*10^{-1}$	$5.61*10^{-3}$	25.34	$< 2*10^{-16}$
Wind Speed (km/h)	$2.63*10^{-2}$	$2.43*10^{-3}$	10.83	$< 2*10^{-16}$
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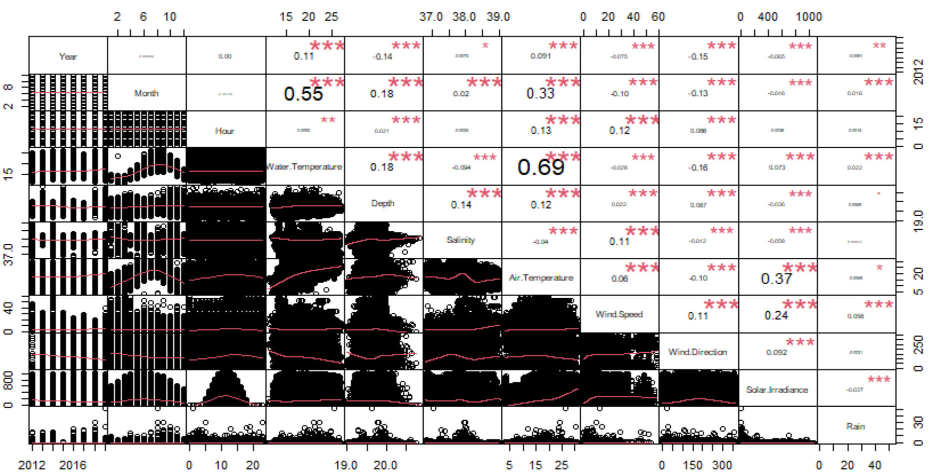

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	Estimate	SE	z value	Pr(>|z|)
(Intercept)	$-2.61*10^{2}$	70.9	-3.683	0.000231
Water Temperature (°C)	$6.28*10^{-2}$	$1.95*10^{-2}$	3.229	0.001242
Depth (m)	$-8.67*10^{-1}$	$3.86*10^{-1}$	-2.245	0.024749
Salinity (PSU)	$5.43*10^{-1}$	$2.01*10^{-1}$	2.701	0.006907
Wind Speed (km/h)	$1.84*10^{-2}$	$1.17*10^{-2}$	1.578	0.114656
Wind Direction (deg.)	$-9.10*10^{-4}$	$7.42*10^{-4}$	-1.226	0.220176
Solar Irradiance (W/m^2)	$-3.87*10^{-4}$	$2.20*10^{-4}$	-1.761	0.07819
Rain (mm)	$-7.96*10^{-2}$	$2.46*10^{-1}$	-0.324	0.74582
Hour	$3.19*10^{-2}$	$1.68*10^{-2}$	1.898	0.057703
Month	$-9.36*10^{-2}$	$3.03*10^{-2}$	-3.091	0.001997
Year	$1.27*10^{-1}$	$3.40*10^{-2}$	3.729	0.000192

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	Estimate	SE	z value	Pr(>|z|)
(Intercept)	$-3.87*10^{2}$	44.6	-8.668	$< 2*10^{-16}$
Water Temperature (°C)	$6.18*10^{-2}$	$1.50*10^{-2}$	4.136	$3.53*10^{-5}$
Solar Irradiance (W/m^2)	$-4.25*10^{-4}$	$1.71*10^{-4}$	-2.493	0.01267
Hour	$4.63*10^{-2}$	$1.30*10^{-2}$	3.575	0.00035
Month	$-6.57*10^{-2}$	$2.27*10^{-2}$	-2.893	0.00382
Year	$1.91*10^{-1}$	$2.21*10^{-2}$	8.61	$< 2*10^{-16}$

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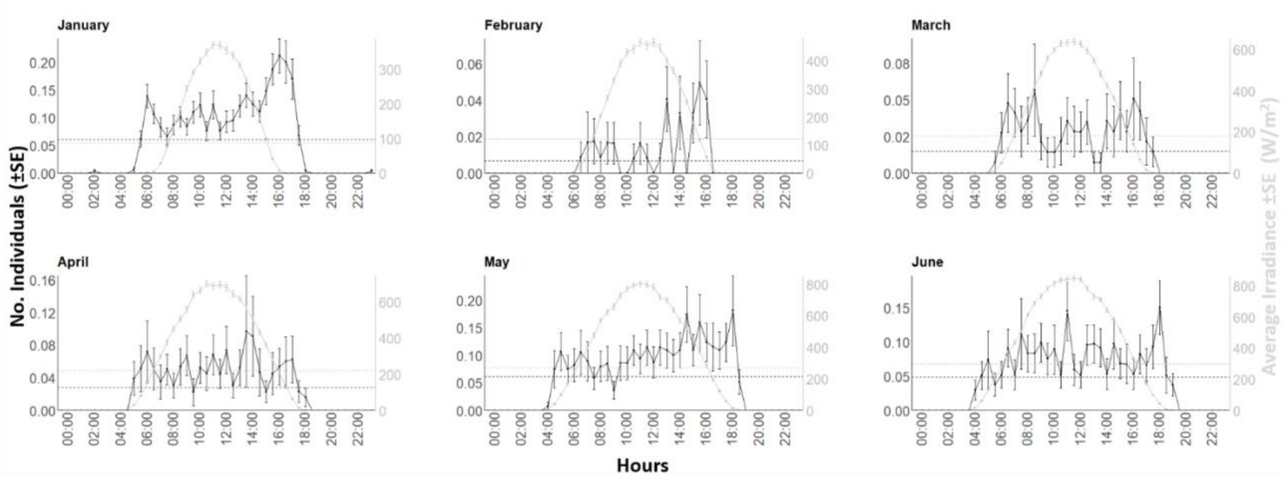

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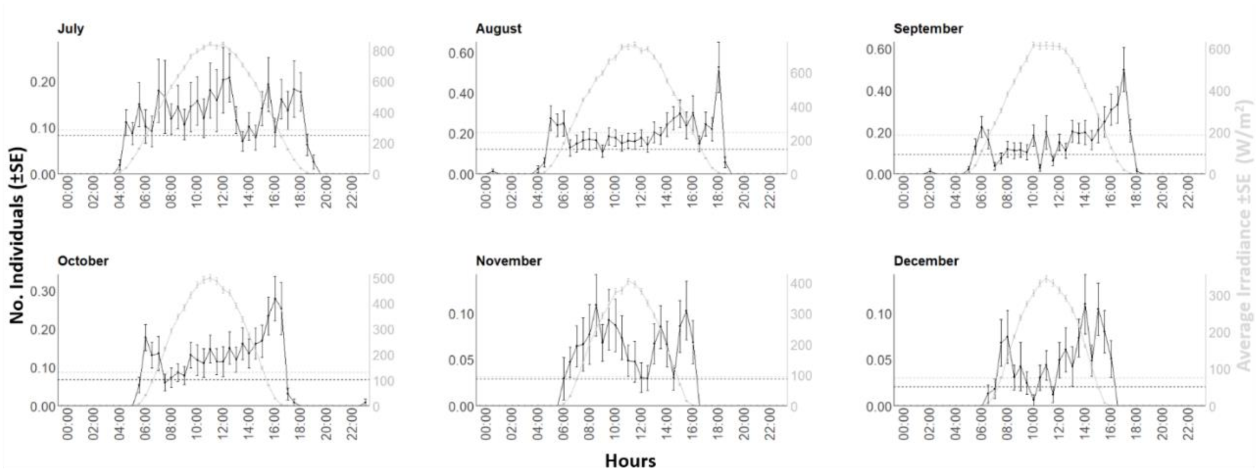

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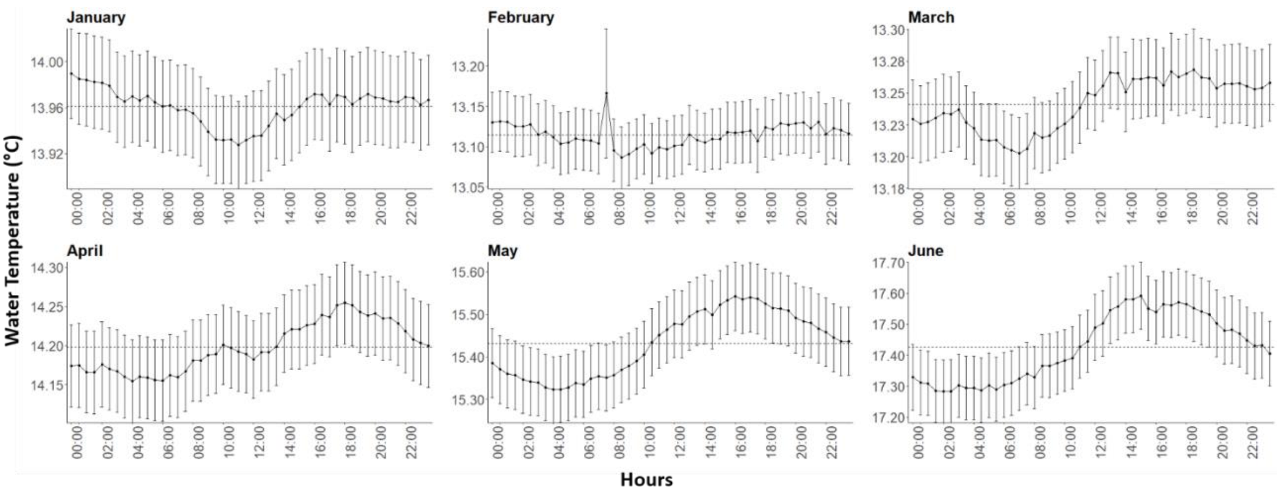
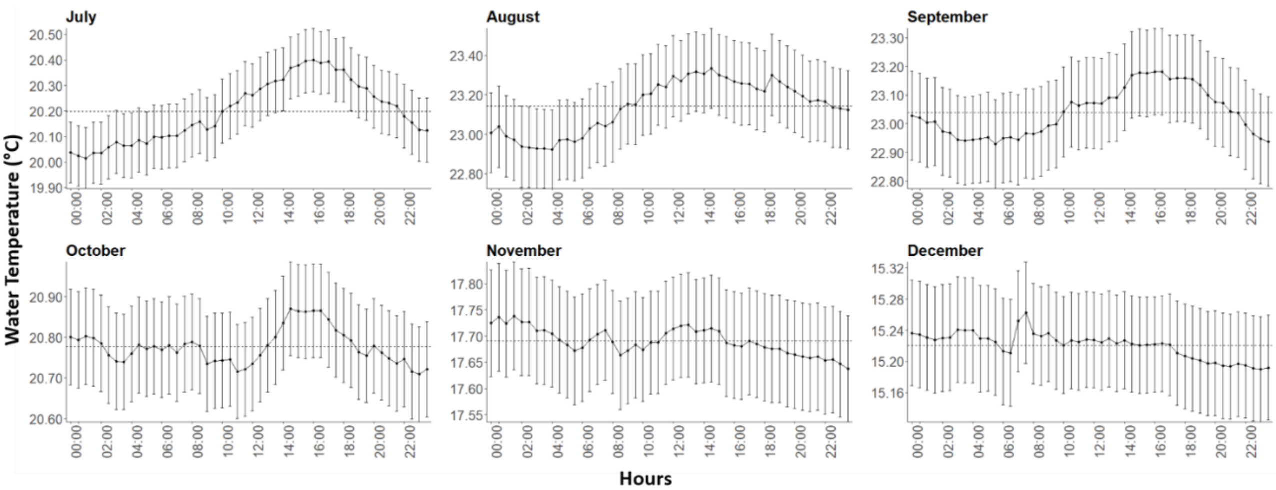


Appendix I. Waveform analysis output plots for water temperature, for July, August, September, October, November, and December, obtained from 8 years of observations at the OBSEA (from 2012 to 2019). The dashed horizontal line is the MESOR.



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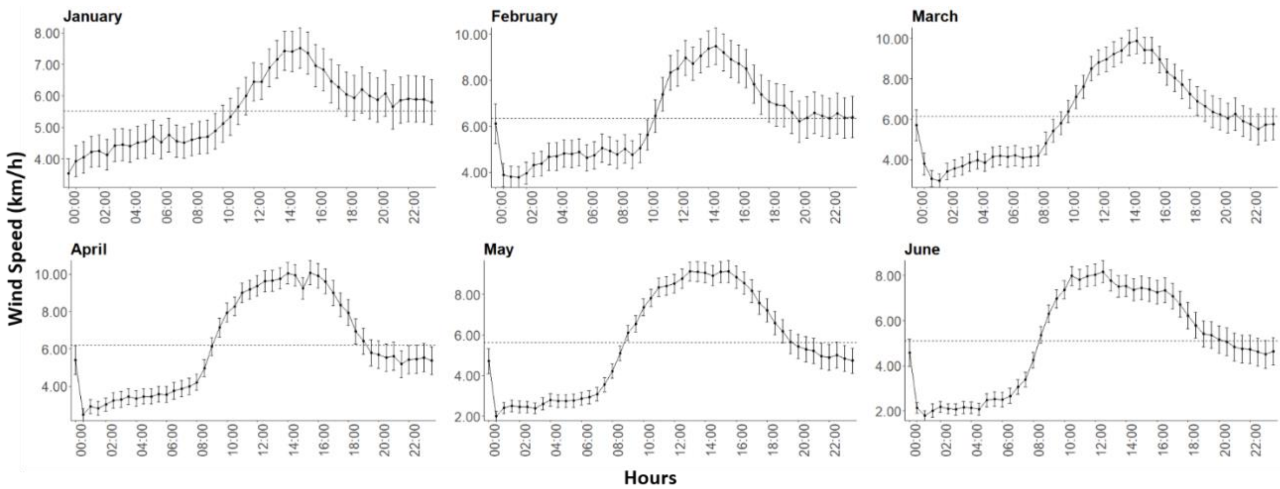
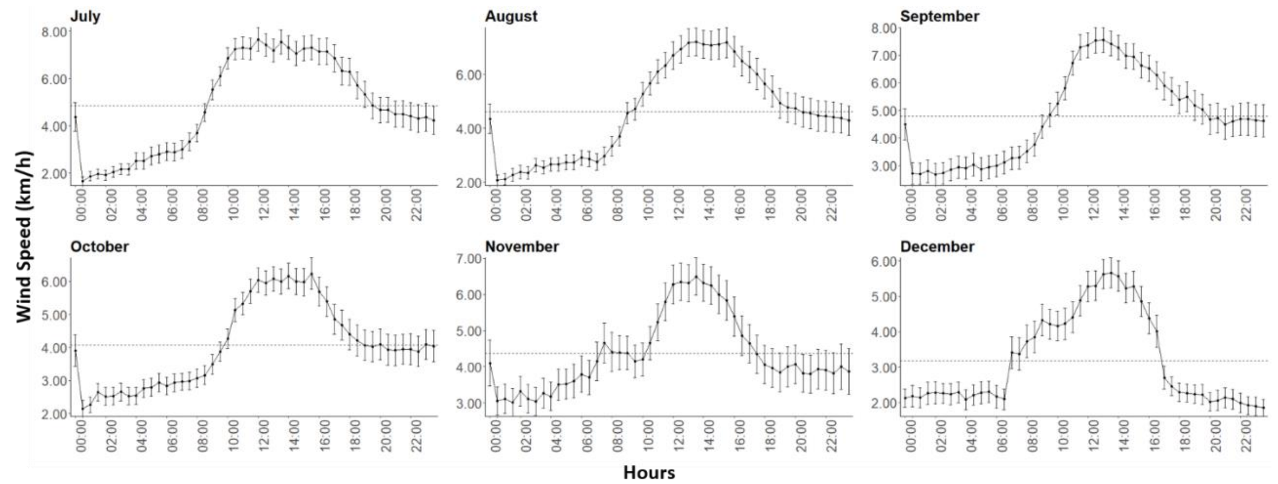


Appendix K. Waveform analysis output plots for wind speed, for July, August, September, October, November, and December, obtained from 8 years of observations at the OBSEA (from 2012 to 2019). The dashed horizontal line is the MESOR.



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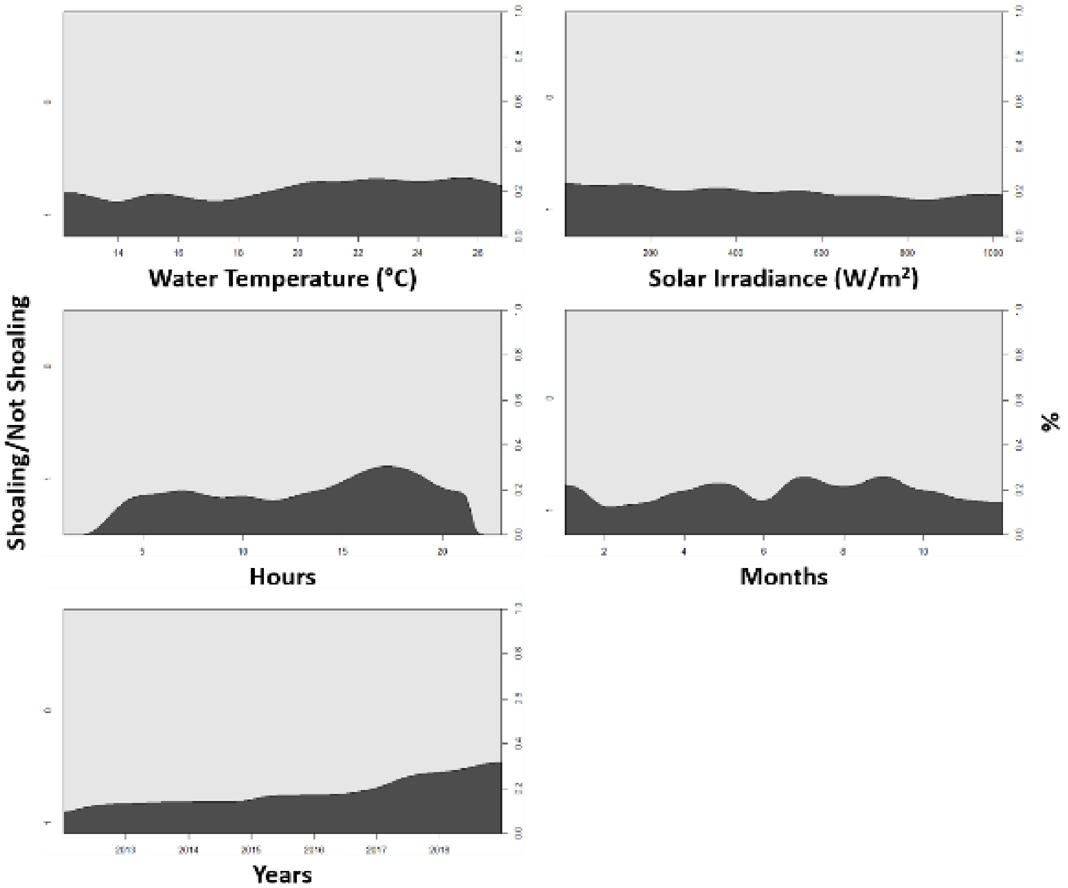

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INTRODUCTION

Oceans cover almost 70% of the planet Earth, being their role central in the development and history of humanity, as major providers of dispersion routes and a wide spectrum of resources (e.g., form fisheries to salt mining). In fact, human civilizations always built their most important cities across the coastal areas, because of the strategic position for trades and food goods [1]. Although their clear importance, we know more about the space than our oceans water masses and sea beds. This is proved by the discovery of hydrothermal vents in 1977, only after the landing of the first man on the Moon in 1969 [2]. This is mainly due to the depth remoteness of many marine environments and to extreme conditions of these areas (e.g., high pressures, low temperature, absence of solar light and corrosiveness) that limits the scientific accessibility [3]. In more accessible coastal areas, man presence is limited to approximately 60-80 m with current SCUBA equipment, being the duration of that presence severely constrained at few consecutive hours.

In the last years, the fast development of new technologies is helping the humanity to reach marine environments from coastal areas to abyssal realms, using different class of platforms (i.e. with different levels of tele-operated autonomy in relation to supporting vessels), such as Remotely Operated Vehicles (ROVs) and towed sledges, or Autonomous Underwater Vehicles (AUVs), and or seafloor cabled observatories with their docked platforms such as crawlers, all equipped with cameras, that can be used as a remote open windows for ecological monitoring [3] These types of technologies have lower impact on the marine environment than more classical types of data collection methodologies, such as scientific trawling and visual census performed by divers [4], [5].

1. IMPORTANCE OF ECOLOGICAL MONITORING

1.1 A Context of Growing Impacts for Marine Communities

There is a growing context of human impacts in coastal communities (e.g., such as coral reefs, seagrass meadows, and mangroves) [6] related to the concentration of chemical compounds, such as pollutants and xenobiotics, as well as noise along with habitat loss for progressive urbanization [7] Adding to those impacts, climate change trends in species changes and biodiversity variations are occurring [8]. Those changes are due to environmental drivers in water temperature and salinity, with alterations in primary productivity, turbidity and de-oxygenation [9].

1.2 Ecological Monitoring for Policy Metrics

Ecological monitoring was defined as the process of gathering information about the state of ecosystems structure, functions and services, at different points in time and space, in order to infer what causes changes in ecosystem state variables [10], [11]. This is required for management of the natural resources, and to establish the causes of observed patterns. Therefore, in a context of global climate change and increasing human impacts it is of pivotal importance to improve ecological monitoring in terms of practices/methodologies and technologies [8], [12].

A consensus on practices is required in spite of policy metrics items such as those of the Marine Strategy Framework Directive [13] with 11 Descriptors for the definition of the Good Environmental Status (GES), the Essential Ocean Variables (EOVs), and the Essential Biodiversity Variables (EBVs) [14]. The need of policy metrics is also highlighted by the recently started UN Decade of Ocean Science for Sustainable Development, focussing on restoration and technological advancement for ecological monitoring [15].

Considering the marine communities' study particular attention has to be addressed to megafaunal taxa, such as fish communities, for their important food provisioning services [16], [17]. Different types of methodologies could be performed in order to study targeted species, measurements have to be taken for richness and biodiversity indices in relation to species behaviour and responses to concomitant environmental changes at the level of animals' perceived seascape (e.g., salinity, temperature, overall turbidity for carbon and energy fluxes among others) and meteorology (e.g., wave agitation and precipitation) [12].

2. Traditional Monitoring Approaches for Coastal Fish Communities

The ecological monitoring to gather quantitative data on biological and environmental variables has to be enforced simultaneously, in order to derive community indicators, depicting their change at different temporal scales [18]. Such a data collection should also be performed at different spatial scales, in order to compare ecological information across sites, to better picture the ecosystem at the geographic scale set by its clines of variation or borders as ecotones [12].

Different methods have been traditionally used to sample coastal marine fish communities at different spatiotemporal scales. These are listed below, form more traditional to more technologically advanced. Generally, the space dimension of data collection replicability is favoured in man and vessels-assisted procedures [12]. Differently, with the creation of new technological platforms with different levels of tele-operated autonomy (i.e., vessel-independency), a more temporally-intensive data collection can be enforced at specific sites [18].

2.1 SCUBA Visual Censusing

The human assisted monitoring by SCUBA-divers Underwater Visual Census (UVC), as monitoring practice has been classified in major categories as [19]: transect survey (i.e., further subclassified based on if strip or line transects were performed), point counts survey, rapid visual technique, and other modified mixed techniques. The difference in the use of strip and line transects means that in the first one, two divers classify and measure length of fishes, sweeping side to side of a transect. In the second one the divers estimate also the distance and direction of the animals from the transect. During the point count survey, the divers scan an imaginary cylindrical area, from the bottom to the surface, referenced by a fixed point. While, in the rapid visual technique, divers are not restricted to transects of fixed point, but the time of survey is fixed.

Despite its importance in the environmental monitoring and its low impact on the marine environment, the UVC methodology has important drawbacks. The main one is the disturbance effect that the human presence has on the animal's behaviour (attraction or avoidance) [4]. Anyway, divers are highly restricted by diving's time duration, and frequency, environmental water temperature, and depth [19]. Furthermore, dissimilarities in counting between divers can derive from differences in their experience and training, difficulty in counting abundant species, fatigue, and disturbance from currents [20]. However, the UVC methodology with divers is still a highly used approach to monitor marine ecosystems, because it is a non-destructive, cost-effective, and flexible method [19]. In addition, this type of census necessitates of often cheap and easily accessible equipment, and short times to digitalize the data.

UVC can be performed with the help of technology. First of all, thanks to the increasing miniaturization of the environmental sensors, that can be carried by the divers, is possible to obtain environmental data concomitantly to visual census [12], allowing to obtain information on cause-effect relationship between community structure and environmental changes. Then, vessel drop and towed cameras can substitute divers in their censusing operations, with differences in the monitoring performances [4]. In particular, underwater videos by drop cams hinder the detection and classification of specimens in condition of high sediment resuspension, or if the individuals are far from the camera. On the other hand, the UVC carried out by divers takes more time to record for an individual, and this allows the highly motile fishes to enter or leave the censused area without been detected. This can also cause multiple annotations for the same individual or recording lesser species per survey. Moreover, SCUBA-diver survey without camera provide subjective annotations, being this drawback better solved with UVC with the use of cameras [4].

2.2 Fishery-Dependent Methods

Different tools, are used in fishery-dependent monitoring (fish traps, trammel nets, hook-and-line, and trawling, depending form location and depth) [19]. Fish traps target especially predator and scavenging species attracted by baits, and are particularly useful in structurally complex areas. Whilst, hook-and-line sampling is targeting, in particular, large predators that usually occur at low densities. Trammel nets are deployed according to different shoreline configurations and capture individuals that attempt to pass through [21]. Finally, trawling is a deeper extractive method acting on shelf and slope ranges of continental margins, having more impacts since the net dredging lift and disperse the sediment. The performance of these techniques can be measured as catch, effort and Catch Per Unit Effort (CPUE) and are, biased by size selectivity in the case of nets [19].

Trawl fishing in the Mediterranean Sea is currently limited from 5.5 km from the coasts and 50 m depth by the European Mediterranean fisheries Regulation (1967/2006). Thus, this method could not be used for coastal monitoring. However, data from trawling surveys in deeper areas can be used for fish community's richness and abundances comparisons [22]. Gear configuration and fishing efficiency were observed to affect the abundance estimations using this methodology. In fact, small trawl, such as Agassiz trawls, can sample benthic species with low motility and in permanent contact with the bottom [23]. On the other hand, bottom trawls, with their larger openings and higher speed, were considered a better tool for sampling high motile species [23]. However, Agassiz dredges have better manoeuvrability in complex geomorphology, and are lesser destructive on the seabed fauna [24].

Trawling nets can also be used to study the pelagic communities (i.e., mesozooplankton, micronekton, and nekton) estimating biomass per volume of water filtered [12]. In general, two types of nets are used in pelagic trawl survey: (1) rectangular midwater trawl (RMT), with opening/closing capability and flowmeter for quantitative measurements at discrete depth sampling, and (2) large, high-speed rope trawl for sampling larger fishes and squids. Finally, in the pelagic trawling the small mesh size imposes reduced towing speeds, allowing the fast motile micronekton (i.e., the smallest ecological sizes capable of autonomous movement and control in the water mass) to escape from capture and increasing the possibility of contamination between different depth strata [25].

Most of the concerns on the use of fishery-dependent techniques is their impact on the marine environment, extracting living biomass from the systems, and changing the substrate composition in the case of bottom trawling [26]. With the help of new technologies, it was observed that video-imaging is a good substitute of the trawling surveys, even though some differences in the assessments are detected, based on differential behavioural responses of species to both methods [22]. In particular, it was observed that comparing ROV and trawling assessments of the benthos, the first one reported higher number of high motile species (e.g., fishes and crustaceans), and the second one more lesser motile and sessile species [24]. In addition, ROV can be used to monitor areas where the trawling cannot technically be performed, and it has lesser impact on the marine ecosystems [27].

3. NEW TECHNOLOGIES TO MONITOR THE MARINE ENVIRONMENT

The environmental monitoring of marine ecosystems with autonomous platforms (i.e., with progressively reduced tele-operated control) is becoming widespread in marine ecology at all depths of the continental margin, being more widespread in the deep-sea due to the remoteness of studied environments [28]. Recently, coastal ecology is also benefitting of that advancement, adopting the use of cabled-video observatories for ecological monitoring [29] in combination with others more specific for that context: Unmanned Arial Vehicles (UAVs, as drones) and Autonomous Surface Vessels (ASV, as unmanned ships), deployed from shores. Their data collection action is being associated to that of research vessels and their assisted ROVs, drop-cameras, and even AUVs.

3.1 Sensors Payloads for Ecological Monitoring

Sensors technologies are required for the effective monitoring of animals’ behaviour (i.e., activity rhythms) and habitat use, ecosystems biodiversity and functioning, and in exploring seabed areas before unreachable to humans (e.g., the deep sea) [30]. This type of monitoring, centred on megafauna and its processes at different spatiotemporal scales, is deemed in the management of important marine ecosystem services, for example the fish-stocks and in the assessment of their surrounding biodiversity, according to ecosystem-based monitoring approaches [31].

High Definition (HD) cameras can be used for the portraying of the ecosystems' living component at ecological sizes above 2-3 centimetres [32]. The detection and classification of the specimens is difficult for the researchers that analyse this video-image material. For this reason, the cross-validation of the taxa classification with specimens direct sampling, such as by sledges, trawls, and corers, is necessary for the evaluation of visual census reliability [12]. In particular, the cameras do not allow to recognize specimens hiding in the seafloor substrate (e.g., sand and mud infauna) and smaller than 1 cm, in general.

Artificial Intelligence (AI) pipelines are required to automatically analyse the large amount of video/image material collected by this type of sensors [31]. Comparable data to experts' identification and classification of specimens could be obtained after proper calibration and tuning of machine learning algorithms using ground-truthed datasets [33]. Thus, cameras could be transformed into biological sensors that can automatically compute biodiversity and abundance assessments of the marine macrofauna [18].

Recently, HD imaging monitoring capability has been complemented by optoacoustic technologies such as multi-beam acoustic cameras: dual-frequency identification sonars and adaptive resolution imaging sonars [18]. These devices can add new demographic information to the classical video cameras, delivering data on the size of spotted animals and inspecting larger volumes of water in comparison to HD light-dependent imaging. They can be used to track small-scale animal movements into a larger visual monitoring cone, than video cameras [34]. This type of monitoring avoids photic contamination, such as the one produced for deep-sea or night monitoring with classic LED lights [35]. However, lacking of colorimetric and texture information, the use of sonar for monitoring has problems in the classification of specimens, which can be determined only when markedly different in their morphology (i.e., morphospecies level).

The marine sounds can be detected passively by hydrophones (i.e., Passive Acoustic Monitoring as PAM). This methodology is generally used to measure the marine anthropogenic noise, as well as studying cetacean movements, population structure, and communication [18]. Nevertheless, many other marine organisms can produce sounds, that if appropriately filtered can be a source of biodiversity and abundance data [36]. Unfortunately, there is scarce information on the sounds produced by marine animals, and cross-referencing the presence/absence data with other types of monitoring (e.g., optoacoustic imaging) would help to identify sound-producing species and their vocal behaviour. PAM can be also used to detect acoustic tags (emitting individualized specific frequencies of sound) attached to marine animals, in order to track their movements and acquire more data on their habitat use when those move across listening stations [37], or within an area with several moored arrays [38]–[40]. Anyway, PAM devices can be used to amplify the monitoring areas because of their large monitoring range, that can reach also remote locations where other types of monitoring cannot [41].

The study of environmental genetic material in the sea water and seafloor sediment, such as environmental DNA (eDNA), could be used to detect rare species or species that could not be visually identified, or that occur beyond the reach of passive acoustic and optoacoustic technologies [18]. Automatic sensors that can autonomously filter and fix the water or sediment samples and analyse their molecular composition by metabarcoding (for the whole community) or with specific primers (for certain species) are under development [42]. This type of sensors could allow to perform biodiversity assessments regardless the size of the organisms. However, this type of technology still has limitations [43]. For example, it has been observed that eDNA studies could result in false positives, when a species is detected even if it is absent in the area, and false negatives (i.e., species undetected when individuals are in fact present) [44]. But, major difficulties occur for the general lack of taxonomy knowledge, as well as the absence of appropriate datasets of species-specific markers sequences [45].

The neutrino telescopes with attached Photo-Multiplier Tubes (PMT) were identified as brand-new technologies to detect bioluminescent organisms living in the water column continuously [46]. Studies with this type of technologies were observed to be useful for abundance assessment, but not when measuring biodiversity. In this last case, the coupling with cameras' data is of pivotal importance for the taxonomic classification.

3.2 Mobile Platforms

Mobile platforms, with different levels of autonomy in relation to tele-operation control from vessels, such as ROVs, hybrid ROVs, towed sledges, and AUVs, are becoming common tools to study benthic communities' distribution and diversity, and to characterize the seabed features, such as sessile species composition, becoming important tools for ecosystems mapping [12], [47].HD cameras can be installed on the mobile vehicles, for which it is important that the navigation speed is slow enough for the identification and classification of the specimens by human operators.

As new tools for benthic assessments, autonomous crawlers are becoming central elements for ecological monitoring, because operating as tethered to cabled observatories [48]. However, new class of non-tethered benthic crawlers capable of automatically return to docked station to recharge and transfer data start to be employed in scientific research [18]. Crawlers can also share infrastructure services' tasks with ROVs to carry larger payloads. However, all the described mobile platforms can have impacts on the local ecosystems for the production of noise, the introduction of artificial light, and, in the case of crawlers, physical disturbance of the seabed with their moving tracks.

Considering the pelagic monitoring, ROVs and AUVs can also be docked to seafloor fixed infrastructures for recharging and data transmission, as for crawlers [18]. These mobile platforms allow water column high-frequency monitoring across different depths, permitting habitat and biota distributional mapping if equipped with imaging and acoustic devices. The ROVs has the additional advantage of bearing manipulator arms, that can be used for maintenance tasks of the fixed platforms (e.g., manipulative experiments or placing autonomous recorders) [18]. AUVs and ROVs have mainly sound and light introduction impacts, in particular the ROVs' thrusters produce high level of noise.

3.3 Cabled Video-Observatories

Cabled observatories are deployed on the seafloor at virtually any depth of the continental margin down to the abyssal plains, allowing to monitor the marine environment with sensors and cameras. These can be connected with fibreoptic or telecommunication cables to a shore station, or communicate with this last one *via* wireless through buoys [49]. Being deployed on a specific fixed point, the data these platforms deliver do not have great ecological representation power [50].

Despite this drawback, cabled observatories are becoming important tools to monitor the marine environment in a remote, continuous, high-frequency (i.e., >1Hz as real time), and long-term (up to decades) fashion [18]. Some of those platforms are acquiring datasets for the study of the home range of marine and terrestrial species *via* visual census that are temporally and spatially representative (i.e., larger than 1.7 years; [51]). Therefore, the development of this type of infrastructure is of extreme importance to obtain data on a continuously changing environment. Indeed, the concomitant acquisition of biological (e.g., species counts and classification) and environmental data is strategic to disclose cause-effect relationships between these two compartments (i.e., how the environmental drivers affect ecosystem changes) [50].

The connection of cabled observatories with docked mobile platforms with their monitoring sensor assets, allow the expansion of monitoring spatial radius [30]. Also, with the building of a network of fixed satellite re-deployable platforms (i.e., landers), the monitoring of spatially complex benthic environments, is at hand [18]. In fact, the use of standard seafloor observatory modules (i.e., landers with standardized set of sensors) as nodes, connected between each other in a network, could allow us to detect environmental or habitat gradients [18].

Cabled observatories and landers can be improved to monitor also the pelagic realm, adding moored water column projections and surface buoys, connecting the underwater monitoring capability with the data collection action of satellites, when considering that local data can be sued to calibrate remote readings into a kilometre cell [18]. Furthermore, ROV and AUV mobile platforms can be used for the study of pelagic organisms as well. These can be integrated in the fixed cable observatory using docked stations where they can recharge and transfer data to the central station [18]. Furthermore, also neutrino telescopes equipped with PMT can be attached to these fixed platforms for benthopelagic monitoring [18].

4. THE OBSEA CABLED VIDEO-OBSERVATORY

A continually changing environment, where different anthropogenic impacts interplay together, and the potential occurrence of geo-hazard (e.g., earthquakes, volcanic eruptions, and tsunamis) is present, require the improvement in our capability to measure multiple and complex stress factors. In order to understand these phenomena, new environmental Research Infrastructures (RIs) have been deployed in different European seas as powerful tools to monitor the effects of global change and occasionally catastrophic events [52]. In this framework, Europe is developing innovative RIs that are assuming a central importance in the global scientific and technological development scenario, offering significant socio-economic benefits [53].

4.1 The EU Policy Context of Permanent Marine Infrastructures

There are 5 type of major international consortia in Europe, controlling different technological infrastructural networks. The European ERICs (Environmental Research Infrastructure Consortium; www.eric-forum.eu) contributes to the international networks COPERNICUS (www.copernicus.eu), and the Global Earth Observing System of Systems (GEOSS; www.earthobservations.org). It also includes the cabled observatory network deployed in all European seas named as EMSO-ERIC (European Multidisciplinary Seafloor and water-column Observatories; www.emso.eu). EMSO-ERIC comprises seven regional observatory facilities (Azores, EMSO Canarias, Porcupine Abyssal Plain, Ligurian Sea, Western Ionian, Hellenic Arc, and Black Sea) and three testing sites (Smartbay, Molène Island, and OBSEA), to record physical and environmental parameters to understand the complex interactions between geosphere, biosphere and hydrosphere.

There are also the Euro-Argo (www.euro-argo.eu), ICOS-marine (Integrated Carbon Observation System; www.icos-cp.eu), LifeWatch (www.lifewatch.eu), and EMBRC-ERIC (European Marine Biological Resource Center; www.embrc.eu) [52]. Briefly, Euro-Argo ERIC is a global free-drifting float of temperature and salinity buoy profilers, which aims are to understand the warming of the ocean and the evolution of the marine ecosystems. Instead, ICOS-marine measures greenhouse gas fluxes from ecosystems and oceans, and study their effects on the marine ecosystems. LifeWatch is the European e-Infrastructure on Biodiversity and Ecosystem Research. This RI studies the biodiversity loss and its consequences as decreasing ecosystem functioning, and its derived impacts on the well-being of today's society. Its mission is to be the main global provider of contents and services to the European Biodiversity community. Finally, the EMBRC-ERIC is designed for further fundamental and applied ecological research. Its vision is to become the global reference RI for fundamental and applied marine biology, and ecology research. In particular, EMBRC-ERIC has a central importance in the development and validation of comprehensive approaches to study the marine environment, contributing to the development of the new generation ocean observatories.

4.2 The OBSEA Testing Site

The Observatory of the Sea (OBSEA; www.obsea.es) seafloor cabled video-platform was deployed at 20 m depth in 2009, as an EMSO Testing Site, 4 km off Vilanova i la Geltrú (Barcelona, Spain) harbour. It is located in a fishing protected area characterized by the seagrass *Posidonia oceanica* within a Natura 2000 marine reserve named "*Colls and Miralpeix*" [54]. It is operated by the "Development Center of Remote Acquisition and Information Processing Systems" group (SARTI; www.cdsarti.org) of the Universitat Politècnica de Catalunya (UPC).

The observatory comprises a coastal cabled system to a junction box (seabed platform), feeding a complex array of sensors including a HD camera plus oceanographic probes (i.e., water salinity, temperature, and column pressure by CTD, current speed and direction by ADCP), a hydrophone (i.e., for Passive Acoustic Monitoring, PAM), plus a sea surface buoy equipped with meteorological station (i.e., reading solar irradiance, air temperature and humidity). As additional data to the environmental monitoring, solar irradiance, air temperature, and rain can also be obtained from a nearby (5 km away) meteorological station in Cunit (Barcelona, Spain; www.meteo.cat). The OBSEA also bears a seismometer connected to a moored-buoy to collect near real-time seismic data from the coastal ocean [55]. However, the ecological video monitoring of the OBSEA lacks of spatial representativeness. To increment the monitored area further activities are focussed on the use of mobile platforms, such as mobile crawler [56] and underwater legged robot (Silver2) [57] currently under development (https://crawler.obsea.es/).

OBSEA provides power supply, Ethernet and serial communication and synchronization of the installed sensors with the land station. The OBSEA offers also the possibility to deploy different types of measurement instruments and real-time communication with the deployed devices, allowing the remote control of measurements along sensors testing trials to help manufacturers, platform operators and scientist to validate their instruments. Various devices were tested and experiments performed at the OBSEA. The most important case was represented by the EMSO Generic Instrument Module (EGIM) as a multiparametric probe module that could be equipped with cameras in the future [58]. The observatory was also used to carry out an experiment on movements of crustacean decapods fishery resources such as *Palinurus mauritanicus* and *Maja squinado* using acoustic tracking [59].

The OBSEA HD camera is focussing an artificial reef at 3.5 m distance to study the local fish community, being fish species good indicators for climate change [60]. The OBSEA camera is producing a great amount of video-image material operating since 2009 and taking a photo each 30 min, continuously at day and night, thanks to artificial LED illumination. In order to extract relevant biological information from this large quantity of raw material, efforts on the development of an automatic identification of fish specimens has been performed to accelerate the time-consuming manual analysis of photos by human operators [61], [62]. From these trials, water turbidity, superimposition of fish individuals, and biofouling on the camera have been identified as main concerns in the development of the automated processing of the OBSEA image material. Moreover, the change of species as a product of seasonal abundance turnover varies the accuracy of the automated identification and classification of fishes (i.e., the concept drift phenomenon; [62]).

5. The OBSEA Technology Applied to the Monitoring of Coastal Fish Communities at Different Time Scales

Different marine species can perform migrations in the water column (epi- and meso- pelagic species), between the water column and the seabed (benthopelagic species), and on the seabed (nekto-, epi- and endo-benthic species) [25], [63]. These migrations are driven by environmental seasonal changes. The main factor shaping these rhythmic movements is light in relation to intensity and photoperiod length, as well as tides and inertial currents (i.e., changes of water column pressure and speed) [64], [65]. However, these drivers can interact with other environmental variables to modulate the marine species rhythmic behaviour, such as in the case of the water temperature [66]. Diel (i.e., 24-h based) rhythms related to water temperatures changes were found in particular in fish species [63], [67], providing us important information on their possible presence/absence in determinate areas and times for fishery management [31].

5.1 Temporal Changes in Mediterranean Fish Communities

Different activity rhythms of Mediterranean fishes have been reported as strictly diurnal, mainly diurnal, crepuscular, mainly nocturnal, strictly nocturnal, cathemeral (lack of discernible temporal patterns), and vertical migrators, rhythmically moving across water column depths during 24-hours [68]. Authors described those behavioural patterns compiling information from different sampling sources and approaches. Human assisted sampling methodologies, as fishing nets, has been cyclically used to sample fish at different hours evidencing associated communities' turnovers. A trawling survey in the Gulf of Fos (France) detected diel and seasonal changes in the feeding behaviour of four species of flatfish [69]. Furthermore, trammel nets were used in a lagoon of Minorca (Balearic Island, Spain) to study the diel and seasonal feeding rhythms of *Liza saliensis* [70]. Diel feeding rhythms were also studied for three species of grey mullets in a coastal lagoon of the Canal Vell (Spain) with nets [71]. Differences in the stomach contents of two anglerfish species captured in the continental shelf and slope of the Ebro River delta (Spain) with fishing nets, were interpreted also as rhythmic changes in temporal activity of fishes [72]. Finally, studies with beach seine nets in Stagnone di Marsala (Italy) reported temporal niche overlaps between *Diplodus puntazzo* and *Sarpa salpa* [73]. Only one SCUBA diving hourly monitoring was performed in Linosa (Sicily, Italy) revealing day-night changes in fish community associated to a rocky reef [74].

The use of technology to study the fish rhythms is becoming widespread, in particular with the use of cameras. In fact, camera systems were used in the two rocky reef areas of the French Riviera to characterize the diel activity rhythms of *Coris julis* and *Diplodus vulgaris* [75]. Temporal changes in the fish community with cameras were also detected in Šibenik (Croatia) [76]. Other technology-based methodologies used to study fish behavioural rhythms in the Mediterranean Sea were using acoustic tags (and hydrophones) to track temporal variations in their presence (*via* the emission of specific tag frequencies). One telemetry study found in bibliography investigated the bluefish species *Pomatomous saltatrix* revealing that this fish species occurred during spring and early summer, close to fish farms in the south-eastern Spanish coast for feeding [77]. Furthermore, telemetry was used also in Lampedusa (Italy) to characterize the seasonal and diel rhythm of *D. vulgaris* [78]. In addition to the use of cameras and acoustic tags, activity rhythms were studied *via* PAM as soundscape composition changes in a rock reef in the Adriatic Sea (Italy), being identified as proxy of diel changes in biodiversity of fishes and crustaceans, as these taxa are well known to produce sounds [79].

Moreover, passive acoustic studies were also used to detect the presence of *Sciaena umbra* in Venice lagoon (Italy) for breeding [80].

5.2 The Fish Activity Rhythms Studies at the OBSEA

The comparative analysis of biological and environmental time series (i.e., fish species counts *versus* oceanographic, bio-geochemical, and meteorological synchronous data) was used to disclose cause-effect principles at the OBSEA [81]. The study of the environmental control of fish behaviour at different time scales (i.e., day-night, seasonal, and multi-annual) over image material collected during approximately a decade at frequency of minutes, is of great importance to disclose biodiversity turnover and its relationships with changing climatic trends [54]. Furthermore, this investigation has been relevant to study the autecological traits of several local fish species [82], [83].

Three of these studies were performed to understand the seasonality of the local fish species using only one-year time series [29], [82], [84]. However, two of these tried to relate the different fish species presence/absence to environmental variables (e.g., light intensity and water temperature) [29], [84]. Other two published studies at the OBSEA depicted the diel activity rhythm of the local fish community [81], [83]. One using only a month time series [83], and the other one using a more representative time series of three years [81]. In particular, the last one related the diel presence/absence of six Sparidae species (*Dentex dentex, Diplodus sargus, D. vulgaris, Diplodus annularis, D. puntazzo* and *Diplodus cervinus*) to three environmental variables (i.e., water temperature, light intensity and salinity).

5.3 Coastal Fish Communities' Alterations Due to Cetacean Falls

Whales transport nutrients, horizontally and vertically, performing migration and falling on the seabed when they die [85]. The decline in numbers of marine mammals after the advent of the industrial whaling is disrupting their ecological functionalities in the marine ecosystems as nutrient transporters, in addition to their role as predators of small fish and invertebrate, and preys of other large marine animals (e.g., sharks) [85], [86]. In particular, small cetaceans provide important ecosystem services, such as provisioning, regulating, cultural, and supporting services, also after death [87]. However, the hypothesized decrease in stranded cetacean carcasses, due to decrease in living whales, in particular in the Mediterranean coasts, can disrupt their important functionalities as carcasses in terrestrial and marine ecosystems, being target of many scavenger animals [88]. Thus, more studies on their importance must be performed to better understand their role when they sink on the sea bottom or strand on the coasts to better manage their carcasses, considering their ecological role as transporters of big amount of nutrients.

The occasional presence of corpses of large marine animals, such as cetaceans, represent a major pulse of nutrients from the sea surface to oligotrophic deep-sea habitats [89]. Huge literature exists on the role of those pulses on species behaviour at scavenging and colonization (e.g., [85], [90]–[92]). Although this ephemeral contribution has been studied for decades in deep-sea habitats (e.g., [90]), its relevance and ecosystem importance are still very little known in the ecological context of more dynamic coastal environments. One way to better understand the importance of these nutrient pulses is to monitor their dynamics on an experimentally recreated event in shallow areas, where the carcasses of beach stranded large marine animals are deployed in controlled cabled observatory locations, to be monitored in remote by video cameras for days, weeks, even months.

The temporal intensive monitoring with cameras of large marine animals' carcasses has already been performed in the deep-sea bottom of Sagami Bay (Japan), and in the Swedish west coast [93], [94] These experiments were the first attempts to describe the day-night behavioural rhythm of a scavenger community associated to a whale fall. Similar experiment could be carried out also on coastal areas to better observe the successional and rhythmic pattern of scavengers associated to large marine animal carcasses also in shallow habitats.

6. THESIS HYPOTHESES AND OBJECTIVES

In this Thesis, advanced monitoring methodologies for the use of cabled observatories have been presented in relation to the study of behaviour rhythms and interactions of coastal fish species in different conditions. The implementation of those methodologies was based on the following key assumptions/hypotheses:

1. Nearly decadal time series in fish counts at a high frequency (i.e., time-lapse at 30 min), can efficiently describe seasonal and diel rhythms of iconic fish species, despite the interannual marked differences,
2. Multiannual biological and environmental synchronous data acquisition is useful to characterize the environmental control of fish behavioural rhythms,
3. Episodic massive food falls generated by cetacean carcasses affect the fish community turnover.

Accordingly, the following Thesis' objectives are presented for cabled observatory ecological monitoring:

1. Describe the environmental niche of one ecologically and economically iconic fish species (autecology) using long time-series of individuals counts fluctuations and environmental data,
2. Create an exhaustive fish richness inventory, as labelled dataset to be used for the future development of algorithms that could automatically detect and classify fish specimens,
3. Prove the importance of cetacean carcasses on shallow water ecosystems for the coastal fish community, evidencing the occurrence of a scavenging dynamics, depicting the community turnover in terms of richness and relative abundance changes before and after the complete consumption of an experimentally deployed dolphin carcass, as use case implementing the previously proposed methodologies.

This Thesis presents an important dataset of labelled images with tags for fish specimens, adding classification labels for the different detected fish species. This will be important for the development of machine learning algorithms to accelerate the image processing of the large repositories of the cabled observatories equipped with cameras. Moreover, the Thesis evidenced the importance for long-term cable observatories ecological monitoring to prove the effects of the environmental variables on a local fish species as strategic approach to the study their ecological niche. In order to demonstrate this, this Thesis proposes the use of a decadal time-series of photo and concomitant environmental data at a frequency of 30 min, weighting this relationship with multivariate statistical models. Moreover, the image analysis of a cetacean carrion fall experiment has been carried out to evidence the importance of underwater platforms equipped with cameras and environmental sensors to innovatively study how fish species successions and rhythms influence the turnover of a coastal community.

CHAPTER 1 – LONG-TERM MONITORING OF DIEL AND SEASONAL RHYTHM OF *DENTEX DENTEX* AT AN ARTIFICIAL REEF

1. ABSTRACT

Behavioural rhythms are a key aspect of species fitness, since optimize ecological activities of animals in response to a constantly changing environment. Cabled observatories enable researchers to collect long-term biological and environmental data in real-time, providing relevant information on coastal fishes' ecological niches and their temporal regulation (i.e., phenology). In this framework, the platform OBSEA (an EMSO Testing-Site in the NW coastal Mediterranean) was used to monitor the 24-h and seasonal occurrence of an ecologically iconic (i.e., top-predator) coastal fish species, the common dentex (*Dentex dentex*). By coupling image acquisition with oceanographic and meteorological data collection at a high-frequency (30 min), we compiled 8 years' time-series of fish counts, showing daytime peaks by waveform analysis. Peaks of occurrence followed the photophase limits as an indication of photoperiodic regulation of behaviour. At the same time, we evidenced a seasonal trend of counts variations under the form of significant major and minor increases in August and May, respectively. A progressive multiannual trend of counts increase was also evidenced in agreement with the NW Mediterranean expansion of the species. In GLM and GAM modelling, counts not only showed significant correlation with solar irradiance but also with water temperature and wind speed, providing hints on the species reaction to projected climate change scenarios. Grouping behaviour was reported mostly at daytime. Results were discussed assuming a possible link between count patterns and behavioural activity, which may influence video observations at different temporal scales.

Keywords: day-night rhythms, photoperiodism, imaging, cabled observatories, visual predator, temporal niche, habitat use, monitoring footprint.

2. Introduction

Diel (i.e., 24-h based) and seasonal biological processes of species inhabiting temperate regions, are synchronized to changes in photoperiod length and overall levels of environmental illumination [95]–[98]. In marine coastal fishes, the photoperiod light intensity is among the most important environmental variables controlling biological rhythms and overall phenology [99]. For example, environmental illumination determines the timing of activity of predators and preys, that perform their ecological tasks according to a trade-off between maximum opportunities of visual-based feeding and minimum mortality risk [100]–[102]. However, the exposure of marine costal ecosystems to solar light produces a seasonal co-variation of photoperiod length with other habitat variables that also affect biological rhythms. For example, temperature can have strong effects on fishes at day-night and seasonal scales [67], [101]. Combined photoperiod length and temperature cycles regulate physiological processes over the day-night alternation, resulting in global growth and reproduction patterns at a seasonal level [103]–[105]. Nevertheless, many marine species can also follow the lunar or tidal cycle to carry out their biological processes within the lunar day of 24.8-h [99]. In particular, tidal rhythms in marine species were related to locomotion and reproduction [65], [106].

The interaction of activity rhythms of all species within a marine community may affect the estimation of its overall biodiversity. This is particularly significant for ecologically important species, such as top-predators, that play a critical role in maintaining the structure and stability of communities and affect ecosystem functioning [107]–[109]. Sampling should be repeated at a frequency sufficient to grasp the whole alternation between consecutive peak and through in population abundances as a product of massive rhythmic displacement [110]. Moreover, that sampling has to be repeated in association with concomitant data collection to understand how photoperiod length, light intensity and other environmental variables modulate behavioral responses [111]. Similar temporal effects exist on fish grouping behaviour [112], whose strategy can be related to foraging, spawning and predator evasion [113]–[115]. Moreover, environmental modulation of grouping behaviour of fish has been observed in association to photoperiod changes [116], [117]. Changes on grouping behaviour, driven by human activities such as fishing, could affect the ecosystem functioning, and have repercussions for biodiversity conservation and fisheries management strategies [118].

Data on the phenology of marine fishes, as a product of a variation in local abundances, can be studied by cabled observatories for their capability to perform high-frequency, continuous and long-lasting imaging along with a concomitant multiparametric oceanographic data acquisition [18], [28], [30], [31], [50], [119]. In particular, cabled systems have the capacity to host many environmental sensors at high resolution, collecting many habitat variables, thus giving a better instrumental field approach to fishes' ecological niches [120]. Stand-alone or lander-based cameras are also good tools to study those aspects of species (e.g., [121], [122]). But, given to energy constrains, a limited set of environmental variables is usually acquired. Each environmental variable measured by the installed sensor (e.g., essential environmental variables) can add habitat information for each imaged species [30]. Time-lapse imaging studies with that technology have been efficiently used to describe diel and seasonal patterns in fish counts as a proxy for behavior rhythms, resulting in projected abundance changes at all depths of the continental margin (e.g., [123]–[127]). In fact, in the marine three-dimensional scenario of the seabed and the water-column, day-night and seasonal shifts in populations bathymetric distributions, displacement ranges, and overall activity, influence the number of collectable animals into our sampling windows (e.g., [25], [128], [129]). A variation in counted animals produce changes in estimated abundances for a species in comparison to all the others (i.e., evenness; [110]). When rhythmic abundance changes are not carefully considered at sampling, their effect transcend to the computed biodiversity [130].

The use of cabled observatories for the monitoring of economically or ecologically important fish species is of relevance for the international conservation strategy agendas [76]. Here, we used a coastal cable observatory to video-monitor the 24-h and seasonal occurrence of a top-predator, the common dentex (*Dentex dentex*; hereafter refers to as *Dentex*), at an artificial reef at high frequency over almost a decade. This species represents an iconic study case also for its value in commercial and recreational fisheries [131], [132], and a previous time-lapse study at the same artificial reef using the same cabled observatory suggested a relationship of fish presence with temperature, salinity and photoperiod length [81]. Here, we moved a step forward and attempted to measure the association of count patterns over the 24-h to the photoperiod length, scaling this phenomenon over the whole seasonal cycle (i.e., photoperiodism). In doing so, we evaluated which of the measured oceanographic and meteorological variables mostly affected the reported count patterns. At the same time, we innovatively quantified the occurrence and the temporal dynamic of grouping behavior, also relating this phenomenon to the environmental variation.

3. Materials and Methods

3.1 The OBSEA Platform Location and Equipment

The coastal Seafloor Observatory (OBSEA; www.obsea.es) is a cabled observatory platform located at 4 km off Vilanova i la Geltrú (Catalonia, Spain) at 20 m depth within the Colls i Miralpeix Natura 2000 area ([54], [133]; **Figure 1A,B**). The observatory is equipped with an OPT-06 Underwater IP Camera (OpticCam), which can acquire images/footages of the surrounding environment with a resolution of 640 x 480 pixels.

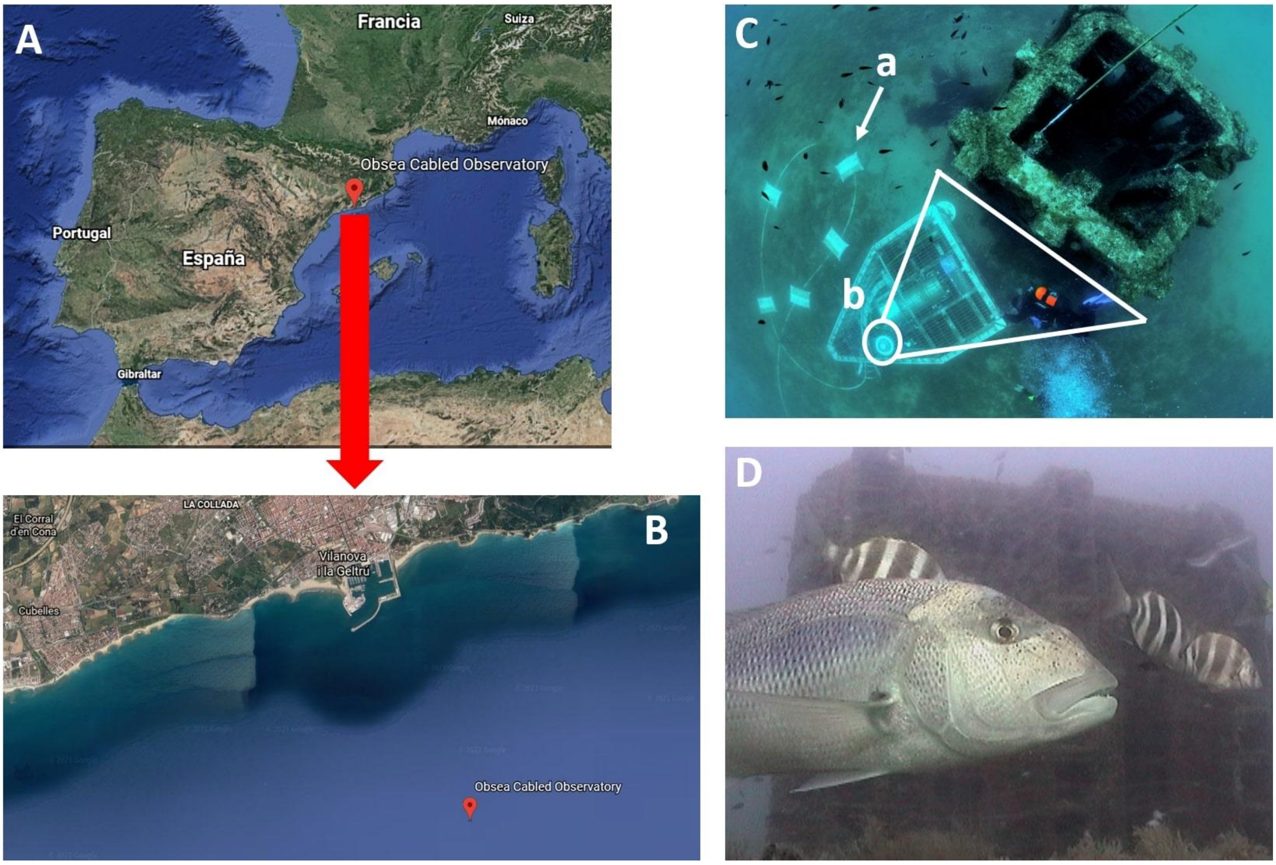

Figure 1. Location of the OBSEA video platform in the NW Mediterranean (A) with specifications for the Catalan coasts, indicating its position off the harbour of Vilanova i la Geltrú (B). The OBSEA platform is connected to shore with an Ethernet powering/data transfer cable (C. point a), camera focusing on the artificial reef (C. point b), where the number of individuals per photo of *D. dentex* can be observed and counted within a constant field of view (D).

OBSEA is also equipped with two custom developed white LEDs (2,900 lumen; color temperature of 2,700 K), located besides the camera (with an angle of 120°) at 1 m distance from each other to allow image acquisition at night [133]. A procedure controlling the ON-OFF status of lighting immediately before and after image acquisition, was performed because of the artificial photic footprint on species (e.g., [65], [134]). The lights were switched ON and OFF (lasting for 3 s) by a LabView application that also controlled their white balance.

3.2 Image Acquisition, Fish Counting and Environmental Data Processing

We acquired 70,254 images with a 30 min time-lapse mode, continuously during 8 years (2012-2019), preserving the same field of view, centred on the artificial reef at 3.5 m in front of the OBSEA (see **Figure 1C**). Individuals of *Dentex* were manually counted for each image (**Figure 1D**) by a trained operator following procedures by [82] and [83].

Temperature (°C), salinity (PSU), and depth (m) were measured by the CTD probe installed aside the camera [133]. Furthermore, we collected data of air temperature (°C), wind speed (km/h), and wind direction (deg.) from the meteorological station located on SARTI (Development Centre of Remote Acquisition and

Information Processing Systems) rooftop in Vilanova i la Geltrú. We also gathered sun irradiance (W/m^2) and rain (mm) from the Catalan Meteorological Service station in San Pere de Ribes (6 km away from the OBSEA). Time series for all the environmental data compiled by selecting and extracting only readings contemporary to the timing of all acquired images.

We applied range filters for the fluctuation of environmental variables in order to remove out-layer data (i.e., due to instruments malfunctioning). [135] was referenced for water temperature and salinity (i.e., ranges of 11-28°C and 36.80-39.67 PSU, respectively), since authors have a 10 years' time series of readings from a nearby station in Barcelona (Spain). For air temperature and wind speed (ranges of 3-31°C and 0-60 km/h, respectively) we used an online website (www.meteoblue.com) with 30 years of hourly weather modeled data. Rain and solar irradiance were not filtered since downloaded from an Institutional and already filtered source (www.meteo.cat).

3.3 Multivariate Statistic

Prior to the multivariate analysis, we transformed the number of individuals of *Dentex* per photo into nominal presence/absence response variable [136]. In order to obtain an optimized model for fish presence/absence, we then executed a correlation analysis on the environmental variables, to group the highly-correlated ones, removing the lesser representative from further analyses [136]. We used a General Linear Model (GLM) and a General Additive Model (GAM) using a binomial distribution, to identify which selected environmental variables mostly affected fish presence/absence, and compared the results between those analyses. We tested both methods because we did not have a priori reason for using a particular model.

We proceeded with the same multivariate analyses to describe the grouping behaviour of *Dentex*. In order to do so, we firstly ranked images depending on variable number of pictured individuals (i.e., starting from 1). That frequency of groups of individuals was compiled into a frequency histogram plot. Then, we transformed the number of individuals into a nominal variable for grouping or not grouping behavior (i.e., "0" when in the photo there was only one individual, and "1" there was more than one individual). Then, we added this column of values to the temporal variables (i.e., hours, months and years), to detect any temporal pattern for this social behaviour and identify which environmental variables affect it. We interpreted the data based on ethological common use of the wording (as per the general definition [137]). Thus, we consider the occurrence of the grouping behaviour as the co-presence of fishes in the same field of view of the camera.

The correlation analysis was carried out with the library "PerformanceAnalytics," and GLM and GAM models were executed using the libraries "gdata" and "mgcv" of R software.

3.4 Time Series Analysis

In order to obtain a global overview of *Dentex* diel and seasonal behavioural rhythms across consecutive years, we first plotted the 8-years visual counts time series computing the means and standard errors (SE) values per each month of the time series. Temporal gaps in image acquisition were evidenced by line discontinuity. Time series analysis was performed separately for time series of fish counts and each relevant environmental variable for the presence/absence of *Dentex* evidenced by GLM and GAM modelling (see previous Section). All graphic outputs were again plotted in local time.

Waveform analysis was carried out to describe the diel and seasonal pattern of activity rhythm of the species. Waveforms computing was as follows: time series of visual counts were subdivided in 30 min time-series and averaged together over a standard 24-h period (i.e., 48 values per segment). A consensus averaged fluctuation over that standard 24-h period was then obtained by averaging all values of the different segments at the corresponding timings. The resulting means (±SE) were plotted to identify peaks and troughs in the waveform profile. The peaks temporal amplitude (i.e., the phase) was then computed according to the Midline Estimating Statistic of Rhythm (MESOR) method [138], by re-averaging all waveform averages and the resulting value was represented as a threshold horizontal line superimposed onto the waveform plot. The Onset and Offset timings of activity (delimiting peaks intervals) were estimated by considering the first and the last waveform value above the MESOR. The peak was considered as continuous if no more than 3 values occurred below the MESOR [111]. All waveform analyses were carried out using the library “ggplot2” of R software.

That waveform analysis was firstly conducted on the fish 8-years count time series and solar irradiance data, to visualize the general peaks as a proxy for the solar-driven, behaviourally induced changes in abundance as a product of behavioural activity (i.e., the photic character of the species ecological niche). Then, the same waveform analysis was repeated for each month and each season, by joining time series counts for winter (i.e., December, January, and February), spring (i.e., March, April, and May), summer (June, July, and August), and autumn (i.e., September, October, and November), to assess peaks’ timings and amplitude variations as marker of photoperiodic regulation of behavioural rhythms. Moreover, to better describe the seasonal behaviour of *Dentex*, and its relation with the photoperiod, we plotted the mean values (±SE) and MESORs of number of counts and solar irradiance of each month of the year. Finally, the same waveform analysis was performed for those environmental variables selected by models of presence/absence data (see previous Section).

Additionally, we assessed precisely the average values of those environmental variables selected by GLM and GAM modelling for presence/absence data (see previous Section) at *Dentex* waveform peaks crossing MESOR (see above), in order to add information on the species multidimensional niche (sensu [139]). At the same time, to better describe the environmental and temporal pattern of grouping behaviour, we additionally plotted conditional densities of the environmental variables selected by GLM and GAM models of grouping or not grouping behavioural data.

An integrated chart depicting the temporal relationships of waveform peaks (i.e., the phases) in fish counts and the solar irradiance was created month by month over the whole 8 years of data acquisition [29], [140]. The values of each monthly waveform were compared with the respective MESOR through an inequality function in Excel (i.e., each waveform value per 30 min automatically resulted as “major” or “minor” in relation to the MESOR). All waveforms values identified as greater than the MESOR (i.e., the peak duration) were then plotted as horizontal continuous bar per each month. That operation was repeated for solar irradiance.

4. Results

A total of 140257 photos should have been obtained during 8-years of monitoring (i.e., one per 30 min, from 2012 to 2019), but due to several malfunctioning problems creating gaps in the time series, we were able to analyse only 7,0254 photos (50.09% out of the total expected photos). The 95.99% of analysed images (67438 photos) contained no *Dentex* (i.e., has "zero" as count value), and a few observations had high abundance (e.g., in only 5 photos there were more than 8 individuals; 0.18%).

We counted a total of 3,747 individuals of *Dentex*. The three months with the highest number of individuals were (**Table 1**): August with 649 number of individuals of *Dentex* (17.32%), July with 615 counts (16.41%), and finally October with 494 individuals of *Dentex* counted (13.18%).

Offset	**Irr. Onset (W/m^2)**	**Irr. Offset (W/m^2)**	**Water Temp. Onset (°C)**	**Water Temp. Offset (°C)**	**Wind Speed Onset (km/h)**	**Wind Speed Offset (km/h)**
16:30	3.64	7.42	13.96	13.97	4.55	6.83
16:30	25.34	57.25	13.10	13.12	5.06	8.50
17:30	48.37	14.83	13.21	13.26	4.21	7.71
17:30	31.40	61.87	14.16	14.25	3.57	8.36
18:30	39.83	14.23	15.33	15.51	2.75	6.59
19:00	59.24	6.36	17.30	17.54	2.47	5.41
18:30	38.01	35.27	20.07	20.32	2.72	5.72
18:30	47.04	7.19	22.96	23.30	2.74	5.37
18:00	39.59	1.65	22.95	23.16	3.00	5.39
17:00	40.79	4.40	20.78	20.84	2.93	4.85
16:30	6.28	1.28	17.69	17.68	3.71	4.86
16:30	76.30	0.49	15.24	15.22	3.73	4.01
18:30	3.00	4.50	17.00	17.13	3.35	5.58

	No. Individuals	Average	%	MESOR	Onset
January	93	0.016	2.48	0.012	7:00
February	39	0.007	1.04	0.007	7:00
March	102	0.016	2.72	0.015	6:30
April	181	0.031	4.83	0.028	5:30
May	405	0.065	10.81	0.062	5:00
June	312	0.052	8.33	0.049	5:00
July	615	0.092	16.41	0.083	5:00
August	649	0.135	17.32	0.122	5:30
September	474	0.104	12.65	0.092	6:00
October	494	0.078	13.18	0.068	6:30
November	223	0.036	5.95	0.029	6:30
December	160	0.027	4.27	0.020	8:00
Total	3747	0.053	100	0.049	5:30

Table 1. Monthly *D. dentex* visual counts number (Num.), average and relative percentage (%) out of the total within the 2012-2019 monitoring period. N was estimated by summing counts from all equivalent months in the 8-years' time series. Additional parameters per month are (i.e., averaging together equivalent months): Midline Estimated Statistic of Rhythm (MESOR), the starting and ending hours of the phase of activity (onset and offset, respectively), and average values of environmental variables selected by statistical models for presence/absence data of *D. dentex* at those onset and offset values.

By compiling this time series into monthly estimates (±SE), we observed a consistent seasonal trend in *Dentex* counts (**Figure 2**). A major peak occurred in spring-summer and its height progressively increased over the consecutive years.

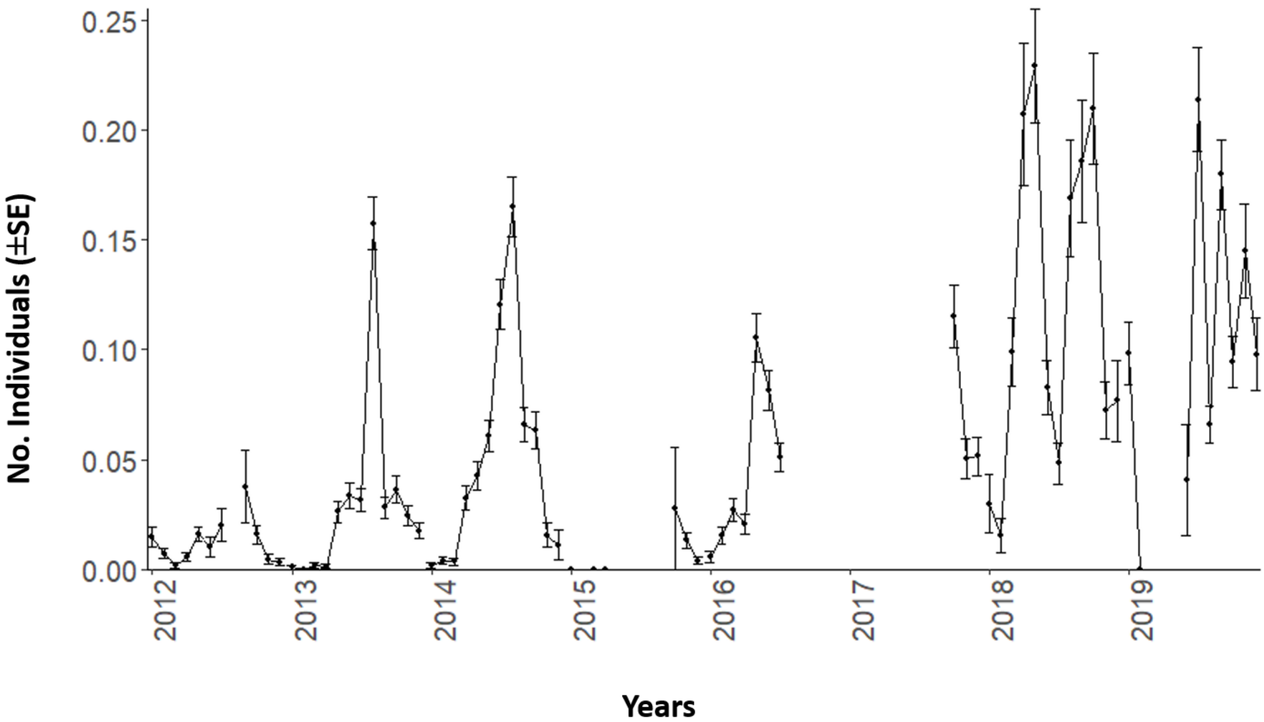

Figure 2. Mean values and standard errors (±SE) per each month of the *D. dentex* counts time series during 8 years (from 2012 to 2019) of monitoring at the OBSEA video platform. Temporal gaps in image acquisition are evidenced by line discontinuities.

4.1 Multivariate Statistic

From the correlation analysis among the environmental variables, we observed a significant relationship between water and air temperatures (Correlation Index=0.69) (**Figure 3**). Accordingly, we removed the air temperature as explanatory variable from the further analysis. We did not eliminate water temperature because it was considered a more biologically important variable for *Dentex*.

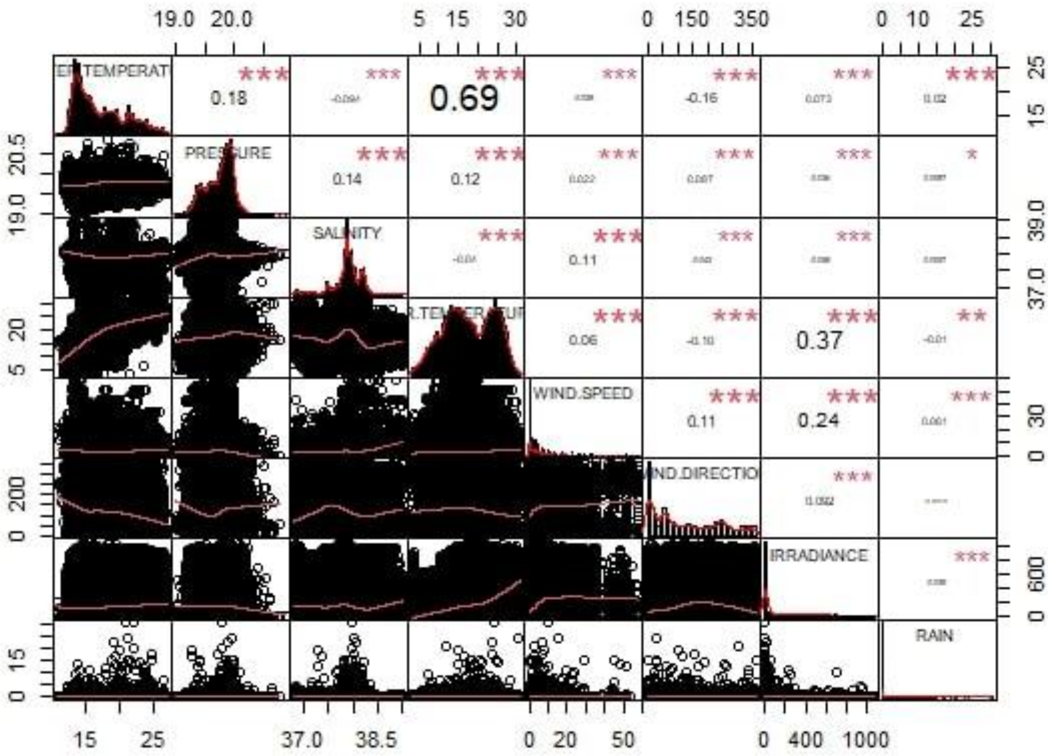

Figure 3. Correlation chart among the environmental variables. The name of each variable is shown on the diagonal. Below the diagonal the bivariate scattered plots with the fitted line in red are displayed. Above the diagonal the value of the correlation plus the significance level as stars: to p-values of 0, 0.001, 0.1, 0.05, 0.1, and 1 correspond respectively “***”, “**”, “*”, “.”, and “”.

We observed that in both GLM and GAM models on presence/absence data all the variables were significant at the 5% level, except for salinity, wind direction and rain (**Appendix A**). Both approaches gave a model where water temperature, wind speed and solar irradiance were selected (**Table 2** and **Appendix B**). So, we selected these variables for the next time series analysis.

	Estimate	SE	z value	Pr(>|z|)
(Intercept)	-6.15	$1.16*10^{-1}$	-53.03	$< 2*10^{-16}$
Water Temperature (°C)	$1.42*10^{-1}$	$5.61*10^{-3}$	25.34	$< 2*10^{-16}$
Wind Speed (km/h)	$2.63*10^{-2}$	$2.43*10^{-3}$	10.83	$< 2*10^{-16}$
Solar Irradiance (W/m^2)	$1.21*10^{-3}$	$6.68*10^{-5}$	18.08	$< 2*10^{-16}$

Table 2. Results from the most representative GAM modelling for the presence/absence data of *D. dentex*, where metrics are also indicated: SE is the Standard Error of the estimated fitted mean parameter. z value is the value of the statistic used for testing the hypothesis that the regression coefficient is zero, and Pr (> |z|) is the p-value.

To study the grouping behaviour of *Dentex*, we computed the percentage on the total number of images where it was present (2816 photos; **Figure 4**). Mostly, it was observed as solitary (2231 photos; 79.23%), but more rarely it appeared in pairs or in larger groups. In particular, in 395 photos (14.03%) it occurred in pairs, in 169 photos (6%) it occurred in groups of 3-5 individuals. Finally, it was observed in groups of 6-8 or more individuals (i.e., 16 and 5 photos respectively, equal to 0.57 and 0.18%). The maximum number of individuals in a single photo has been detected during 27th July 2019 at 8:00 in a group of 11 individuals.

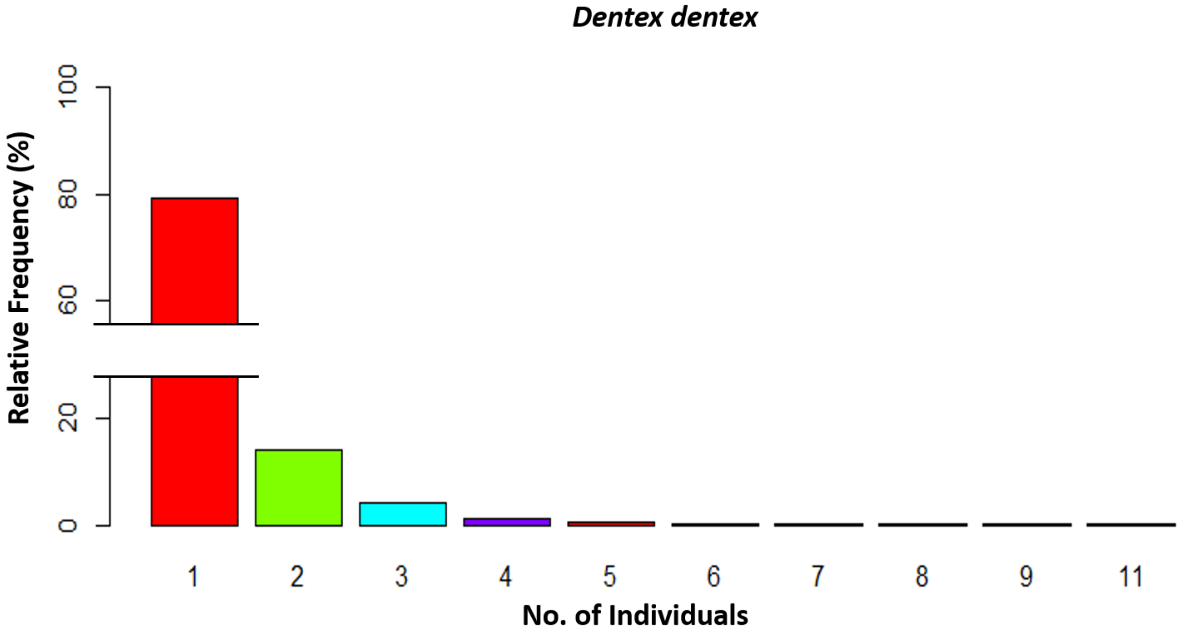

Figure 4. Histogram depicting the relative percentage of images with variable number of individuals of *D. dentex*, where fishes of this species were present, as a quantification of grouping behaviour.

Afterward, we carried out correlation analysis between environmental and temporal variables observing that there was a significant relationship between water and air temperature (Correlation Index = 0.69) (**Appendix C**). As before, we removed air temperature as explanatory variable.

Then, we performed GLM and GAM models on the grouping or not grouping behavioural data (respectively when *Dentex* was observed alone or in group of two or more individuals) with the selected environmental and temporal variables. In both models all the variables were significant at the 5% level, except for wind speed and direction, solar irradiance, rain and hours (

Appendix *D*). We observed in both approaches that water temperature, solar irradiance, hours, months and years were selected as relevant variables for the grouping behaviour of the *Dentex* (**Table 3**) (**Appendix E**). It has to be noted that solar irradiance and month were slightly less significant than the other variables regarding the p-values (respectively Pr (> | z|) = $1.27*10^{-02}$ and Pr (> | z|) = $3.82*10^{-03}$).

	Estimate	SE	z value	Pr(>|z|)
(Intercept)	$-3.87*10^{2}$	44.6	-8.668	$< 2*10^{-16}$
Water Temperature (°C)	$6.18*10^{-2}$	$1.50*10^{-2}$	4.136	$3.53*10^{-5}$
Solar Irradiance (W/m^2)	$-4.25*10^{-4}$	$1.71*10^{-4}$	-2.493	0.01267
Hour	$4.63*10^{-2}$	$1.30*10^{-2}$	3.575	0.00035
Month	$-6.57*10^{-2}$	$2.27*10^{-2}$	-2.893	0.00382

Year	$1.91*10^{-1}$	$2.21*10^{-2}$	8.61	$< 2*10^{-16}$

Table 3. Results from the most representative GAM modelling for the grouping or not grouping behavioral data of *D. dentex*, where metrics are also indicated: SE is the Standard Error of the estimated fitted mean parameter. z value is the value of the statistic used for testing the hypothesis that the regression coefficient is zero, and Pr (> |z|) is the p-value.

We decided to report only GAMs upon GLMs results for both presence/absence and grouping or not grouping behavioural data, even if the two methods obtained same outputs, because GAMs models were considered an extension of GLMs.

4.2 Diel and Seasonal Fish Count Patterns

The waveform analysis on the 8-years' time series showed the occurrence of a solid diurnal peak, defining an increase of occurrence in the light hours (**Figure 5**). That waveform analysis repeated at the seasonal level (**Figure 6**) evidenced the photoperiodic regulation of occurrence with transient uni- and bimodality in counts peaks: crepuscular and diurnal peaks during respectively short and long photophases (i.e., autumn-winter versus spring-summer). Also peaks temporal limits are following irradiance temporal limits.

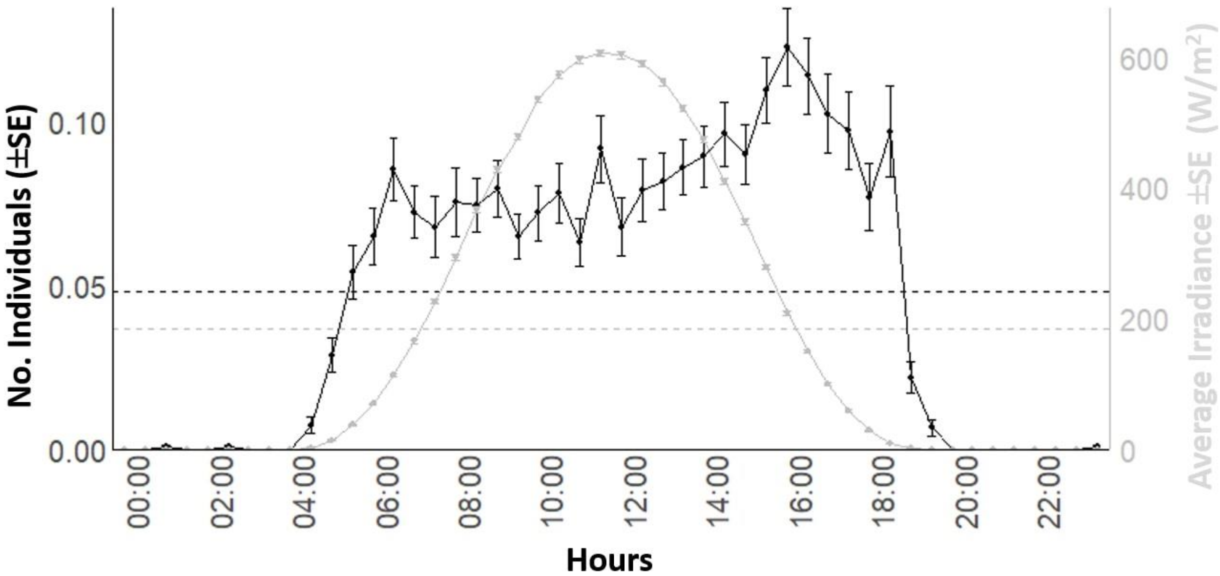

Figure 5. Global waveform analysis output plot for the *D. dentex* visual count and solar irradiance time series from 8 years (i.e., 2012–2019) of monitoring at the OBSEA video platform. The dashed horizontal line is the MESOR.

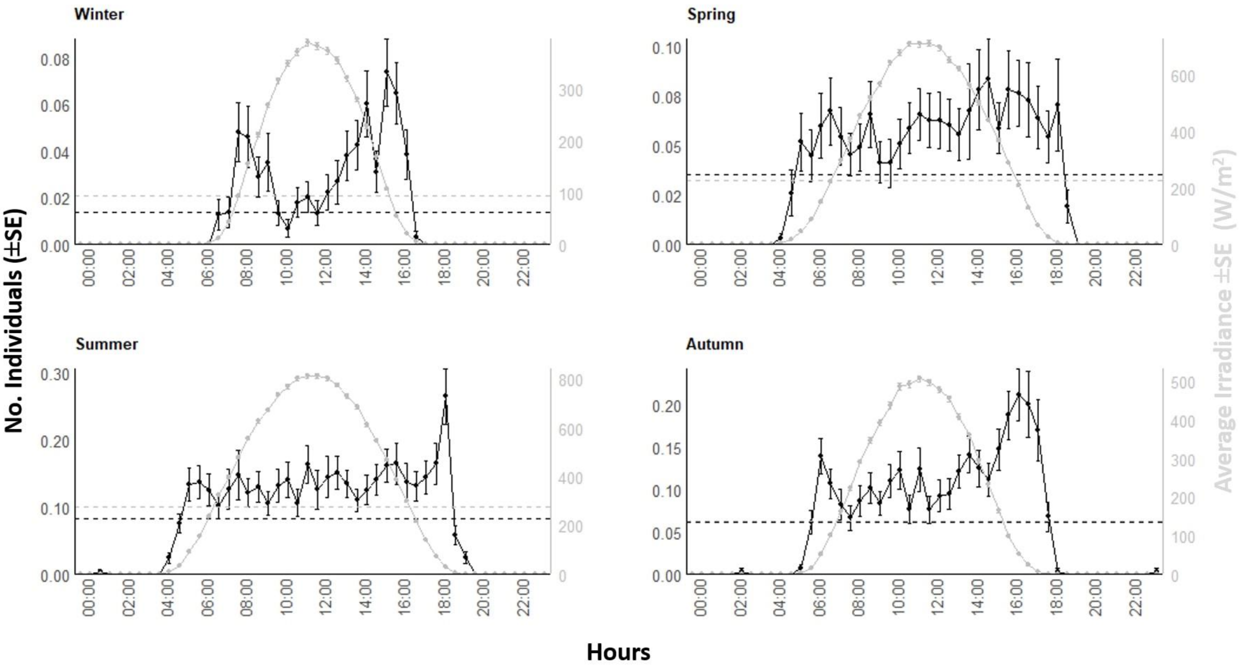

Figure 6. Waveform analysis output plots for visual counts of *D. dentex* and solar irradiance during different seasons (i.e., winter, spring, summer, and autumn) from 8 years (i.e., 2012–2019) of monitoring at the OBSEA video platform. The dashed horizontal line is the MESOR.

In the plotting of mean counts per month of *Dentex* vs. mean solar irradiance depicting the overall seasonal fluctuation trend in local abundance evidenced a general increase from winter to summer, with two peaks, a major on August and a minor on May (**Figure 7**). The increase of the solar irradiance follows a similar pattern but with a peak in June (**Figure 7**). In accordance, the waveforms MESORs values of *Dentex* for the different months (see **Table 1**) is increasing from February, when this average value is at the minimum, to August, when this average value is at the maximum (i.e., 0.007 and 0.122 individuals per photo, respectively). At the same time, the MESORs values of the solar irradiance are increasing from a minimum in December to a maximum in June (i.e., from 76.23 to 297.95 W/m^2, respectively) (**Table 4**).

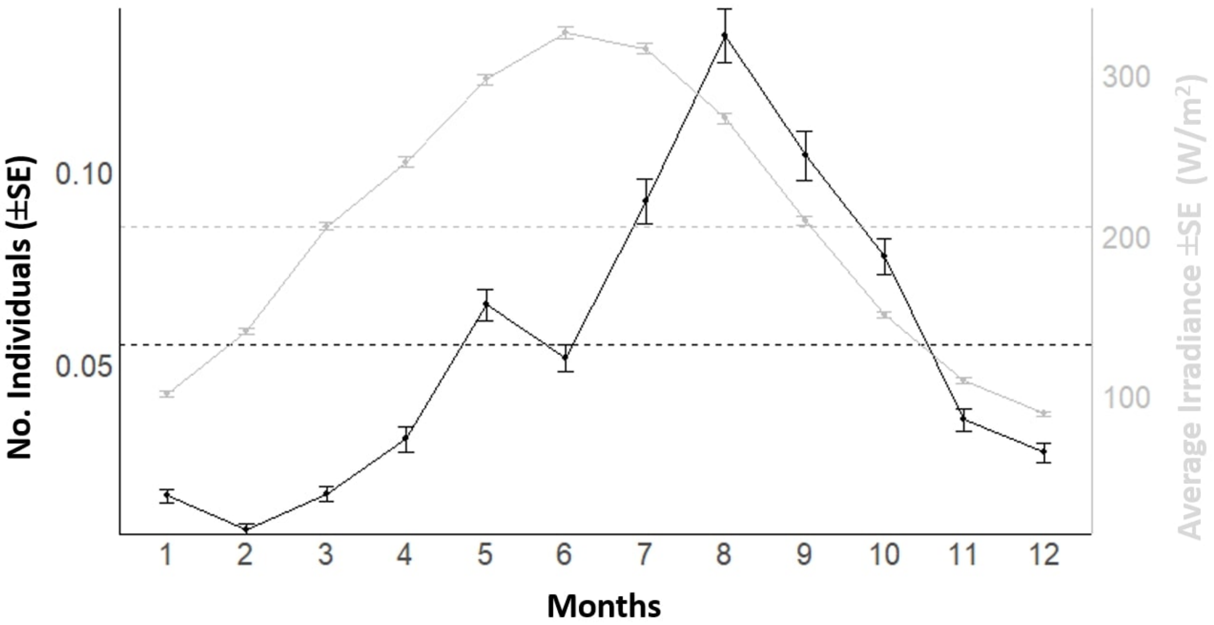

Figure 7. Plot of mean counts (±SE) per each month of the year of *D. dentex* visual counts and solar irradiance recorded during 8 years (i.e., 2012–2019) of observations at the OBSEA. The dashed horizontal line is the MESOR.

	Wind Speed (km/h)			Water Temperature (°C)			Solar Irradiance (W/m^{-2})		
	Off-set	**On-set**	**MESOR**	**Offset**	**Onset**	**MESOR**	**Offset**	**Onset**	**MESOR**
January	23:30	11:00	5.52	6:30	15:30	13.96	15:30	8:30	86.91
February	23:30	10:30	6.34	3:30	15:30	13.11	15:30	8:00	121.94
March	21:00	10:00	6.15	23:30	11:30	13.24	16:00	7:30	181.39
April	19:00	9:30	6.21	23:30	13:30	14.2	16:00	7:00	220.02
May	19:30	9:00	5.62	23:30	10:30	15.43	16:30	7:00	269.95
June	20:00	8:30	5.09	23:00	11:00	17.43	16:30	7:00	297.95
July	19:00	9:00	4.87	21:30	10:30	20.2	16:30	7:00	288.77
August	20:00	9:30	4.61	22:00	9:00	23.14	16:00	7:00	245.68
September	19:30	9:30	4.8	21:00	10:00	23.04	16:00	7:30	186.15
October	20:00	10:00	4.08	20:00	13:00	20.78	15:30	7:30	131.59
November	17:00	7:30	4.37	7:30-15:00	0:00-11:30	17.69	15:00	8:00	94.42
December	16:30	7:00	3.18	17:00	0:00	15.22	15:00	8:00	76.23

Table 4. Midline Estimated Statistic of Rhythm (MESOR), onset and offset timings (hours) per each month, within the 2012-2019 monitoring period, for the environmental variables selected by GLM and GAM modeling for presence/absence data.

In the integrated chart comparing *Dentex* waveforms peaks (i.e., means values higher than the MESOR as horizontal continuous band) (**Figure 8,** and **Appendix F** and **Appendix G**) we could observe counts increases form December to June, with onset and offset timings that shift form 8:00 and 16:30, to 5:00 and

19:00, respectively (see **Table 1**). For solar irradiance peaks amplitude also varied from December to May, with onset and offset at 8:00/15:00 and 7:00/16:30, respectively (see **Table 4**). The integrated chart (see **Figure 8**) indicated that *Dentex* counts followed the solar irradiance pattern, with values of onset and offset that could anticipate and are delayed to the irradiance onset of maximum 2 and 2.5-h, respectively.

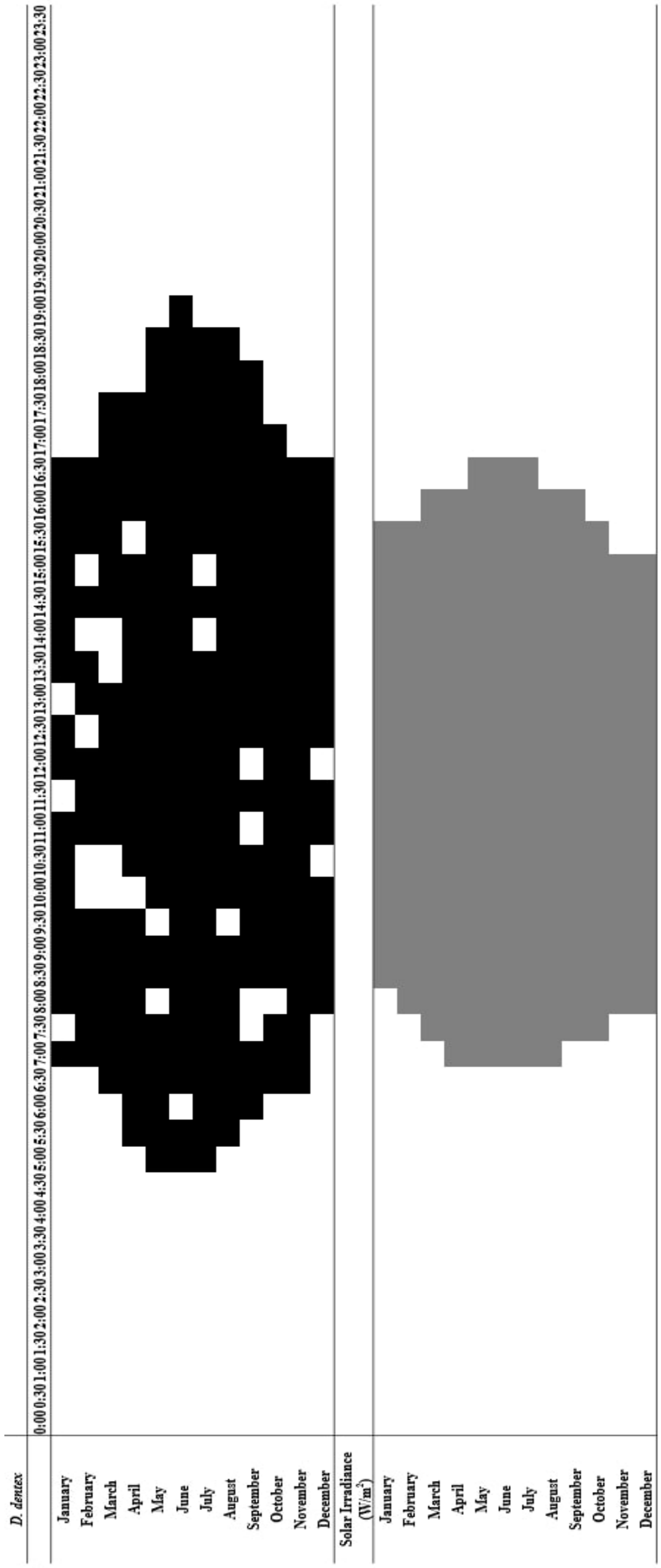

Figure 8. Integrated chart depicting the temporal relationships of *D. dentex* active phase between months of the year (black), and periods of the diel cycle when the solar irradiance showed significantly increased values along the different months of the year (gray).

In order to describe the photic niche of *Dentex*, we noted that the average values of irradiance when *Dentex* averaged counts start spiking (i.e., is becoming active) as the peak onset; these are between 3 and 76.3

W/m^2 (see **Table 1,** and **Appendix F** and **Appendix G**). Inactivity (i.e., offset) occurs for average values of solar irradiance between 0.49 and 61.87 W/m^2 (**Table 1,** and **Appendix F** and **Appendix G**).

4.3 Environmental Cycles

In **Table 4**, we reported MESOR values, onset and offset per each month of the year for the environmental variable previously selected by GLM and GAM models for presence/absence data (i.e., water temperature, wind speed, and solar irradiance). The temporal dynamic of those variables is described below, but not for solar irradiance that was already described (see previous Section).

The water temperature cycle (**Appendix *H*** and **Appendix I**) had a phase shift to early hours from January, with an onset and offset at 15:30 and 6:30 respectively, to December, with onset and offset at 0:00 and 17:00 respectively. Furthermore, we reported that the water temperature had a minimum and a maximum MESOR value in February and August (i.e., 13.11°C and 23.14°C, respectively). One should notice that those two months also correspond to the minimum and maximum for *Dentex*.

The wind speed cycle (**Appendix J** and **Appendix K**) followed the same pattern of solar irradiance and fish visual counts (see previous Section). Its onset anticipated its timing from January at 11:00 to June at 8:30. Whilst, the offset progressively delayed from December at 16:30 to June at 20:00. Furthermore, we noticed that wind speed has a minimum and a maximum MESOR value in December and February of 3.18 km/h and 6.34 km/h, respectively.

In order to describe the ecological niche of *Dentex*, we annotated the average values of the detected relevant variables from the statistical models when *Dentex* started and finished its active phase (i.e., onset and offset, respectively) (see **Table 1,** and **Appendix F**, **Appendix G, Appendix *H*, Appendix I, Appendix J** and **Appendix K**). Indeed, when this species started to spike (i.e., is becoming active) as the peak onset, the values of water temperature and wind speed were, respectively, between 13.1-22.96°C and 2.47-5.06 km/h (see **Table 1**). Instead, inactivity (i.e., offset) occurs, in average values, between 13.12-23.3°C water temperature, and 4.01-8.5 km/h wind speed.

Plotting conditional densities for the most important explanatory variables of the grouping or not grouping behavioural data of *Dentex* (i.e., the distribution of the nominal variable for the grouping behaviour of *Dentex* given a certain value of environmental and temporal driver) (**Appendix L**), we observed that *Dentex* form groups during the day or at dusk and down, but not during the night. Moreover. The frequency of grouping increased along the years of observation. No particular seasonal pattern along the months of the year has been observed for grouping behaviour. Furthermore, we could not obtain particular information on the relationship between grouping and the environmental variables selected by the models for this behaviour.

5. Discussion

We described the occurrence of diel and seasonal behavioural patterns in a coastal marine top predator, *Dentex*, by analysing 8-years of high-frequency and continuous time series of visual counts plus concomitant multiparametric oceanographic and meteorological data. Firstly, we detected a relationship between fish counts and the solar irradiance as a proxy for rhythmic activity. Then, a seasonal variation in video-counts was evidenced with a major peak in August and a minor one in May, suggesting for local abundance changes, possibly linked to population dynamics (e.g., seasonal migration). Also, the species counts were significantly correlated to water temperature and wind speed. Finally, we detected the occurrence of grouping behavior correlated to solar irradiance and water temperature, suggesting an effect of the environment as a regulator of grouping behaviour.

5.1 Limitations in Cabled Observatory Monitoring Strategies

Cabled observatories provide a spatially limited data acquisition (a single platform can provide a relatively narrow field of view of few m^2). Another problem is that with this methodology it is not possible to separate the influence of abundance variation from activity variation, and the first one certainly affects the results of the second. Anyway, general inferences can be made on activity rhythms with spatially limited sampling windows [141]–[144]. Even trawling, which is the more spatially representative tool, is still anyway limited in comparison to the real extent of marine species distributions [145]–[147]. Furthermore, [51] recently reviewed some methods to inference abundance from visual counts with cameras stating that averaged estimates of animal density do not show any substantial improvement after an adequate sampling effort (i.e., number of cameras and deployment time).

In our monitoring, fish were observed during daytime and this could cause more observations per day in summer than in winter, being the photoperiodic difference between months the cause for an increased probability in observing fishes in a summer day rather than in a winter day. In any case, there are diurnal species that are sampled more in winter for a reason that is related to an increase in their abundance and not to the possible effect of increasing photoperiod [29], [82]. Here, it is difficult to methodologically distinguish this abundance/activity/photoperiod phenomenon with the present methodology.

In order to acquire more representative results on rhythmic movements and habitat use of fishes at the scale of species distribution a better spatial coverage in monitoring would be needed [148]. Networks of cameras with synchronous image acquisition routines may be required to track the species movements across different levels of habitat heterogeneity (e.g., [30], [50], [130]). Such a synchronous image acquisition could clarify if the peaks in video counts of *Dentex* in different areas are associated to a different habitat uses (e.g., preying vs. resting), and then could be used to relate this information to the activity rhythms. Inspiration on how to set the network monitoring may be drown from spatially extended surveys with camera traps, aiming at the visual census of fauna in terrestrial environments (e.g., [149], [150]).

OBSEA data collection could be implemented with other complementary actions within the monitoring area, such as the classic visual census sampling by divers [17], [151], and collected data could be cross-checked with information provided by telemetry. This technology allows the tracking of particular individuals over large period of times [152]–[155]. Acoustic telemetry could help achieving continuous long-term tracking of single individuals to study the habitat use of fish species [152], [156], [157], overcoming the spatial and temporal bias of fixed-point video monitoring for a reliable evaluation of population demography and local biodiversity [30], [31]. It is impossible with fixed cameras imaging technologies to support for fish “site fidelity” when this area specificity is not a clear life trait of the species (e.g., territoriality, burrowing, etc.). We have no morphological tools to identify the individuals, whose position and orientation changes within the field of view. For this reason, we may need acoustic tagging coupled with imaging to enforce such a site specificity study.

Cabled observatory imaging equipment could have some monitoring footprint on coastal areas for the introduction of light at nocturnal image sampling, which can induce behavioral disturbance on the local fauna (e.g., [158]–[161]). Nevertheless, in our case it is unlikely that the OBSEA lightening system, active every 30 min for about 3 s, affected the reported *Dentex* count patterns, being the individuals of this species absent at nighttime all the yearlong (see previous Section). However, the environmental footprint of future long-term monitoring could be reduced with the use of acoustic multi-beam cameras [18].

Despite the evidenced monitoring limitations, we would like to stress out that one positive aspect of cabled observatory use is the low-invasive character at data collection. For example, visual census obtained by divers implies a factor of disturbance on the organisms as human presence [4], [74], [162]–[165].

5.2 How to Interpret Day-Night Rhythms in Dentex *Visual Counts*

Counts peaks timing and amplitude followed the photophase. In our case, the interpretation of video-counts peaks in terms of increase or decrease activity should be carried out with precaution. A similar precaution is adopted when evaluating the ecological meaning of species peaks in catches or visual census; i.e., animals captures or spotting are provoked by their increased availability in the sampling area for their resting or because of their activity [25], [166]. Notwithstanding, many species of fishes display activity rhythms (e.g., [167]–[169]) that drive changes in abundance between day and night in coastal areas, as detected by different sampling systems and methodologies (e.g., [83], [170], [171]). Diurnal, nocturnal, and crepuscular activity is often described as a product of fish behavioural response to solar irradiance variations [169], [172].

In this scenario, almost no *Dentex* was consistently detected at night time over several consecutive years. This observation suggests that video-counts peaks are a product of an increase activity at daytime. Laboratory data on fish behaviour and physiology may provide a first insight on this phenomenon, assuming a link between visual counts and activity. Photoperiodic regulation of fish physiology and swimming behaviour occur for the modulation that light intensity and temperature exert on the production of hormones (e.g., [105], [173], [174]). Fish melatonin measures environmental light levels and, as a result, variable rates of swimming occur [175].

A daytime activity increases for *Dentex* resulting in the increment of video-spotting at the OBSEA can be postulated for the following reasons. First, animals rest at night-time within Posidonia seagrass beds [176]. Second, the species has a home range of less than 1 km2 in specific period of the year [177], with the exception of moments in which a migration may follow bathymetric changes related to optimal water temperature ([178]; see next Section). Third, *Dentex* is a visual predator whose prey spotting is optimized during light hours [131].

Our data suggest an increase of activity during daytime (and consequent resting at night), which implies a visual oriented hunting strategy as already indicated by [131]. This diurnal temporal character of Dentex ecological niche (i.e., sensu [179]) matches the daytime video occurrence increases of its fish preys within the Spariformes order [180], that were spotted at the OBSEA [83], but also observed to be present in other Mediterranean areas [75], [181]–[183]. For example, *Diplodus vulgaris*, *Oblada melanura*, and *Spicara maena* are preys of *Dentex* [180] with diurnal increases in presence and activity that are sustained also at twilight conditions [75], [78], [184]. Predators and preys seek for temporal overlapping (predators) or avoidance (preys) of their activity phases over the 24-h cycle (e.g., [185]–[190]).

5.3 Seasonal Fluctuation in Fish Video-Counts

Here, we reported a seasonal rhythm in visual counts of *Dentex*, with a significant increase in August and a second minor peak in May, as consistent across multiple years. In the past study of [81] at the OBSEA, the major peak in counts of *Dentex* on August was detected, but not the minor one of May. This points out the strategic importance of a prolonged monitoring activity at the OBSEA. That seasonal pattern has been also detected with recreational fishing data for the Italian coasts [132].

We interpreted the first large peak of August as the product of thermocline regulation on fish behavior. *Dentex* shows a preference for warm suprathermoclinal waters, whose shallowest depths (i.e., between 20-30 m) are usually reached in our monitoring geographic zone (i.e., the NW Mediterranean) in July and August [178]. The OBSEA is placed within that depth range and this fact may explain the count increase of summer.

Another explanation could be that *Dentex* seasonal counts increase are synchronized upon maximum abundances of its preys (see previous Section), that augment in the OBSEA area in spring-summer; e.g., *D. vulgaris* from June to October, *O. melanura* in May and June, and *S. maena* from May to July [29]. Seasonally synchronic abundance changes may occur between fish predators and preys [191]–[194]. Possibly, the presence of artificial reef structures nearby the OBSEA attract fish preys and consequently concentrate the presence of the *Dentex* as well.

We observed a second, minor peak of *Dentex* counts in May that can be discussed in relation to the phenology of breeding. If from one side, the species migrates deeper to reproduce in areas at 40-100 m depth from March to June [131], [195], from the other we did not observe a temporally concomitant drop in counts at the OBSEA location in May (as an indication for a deeper migration of individuals in that period). Possibly, some individuals that have finished the reproduction (or with no mature gonads), return (or stay) to shallower depths for foraging. In fact, regressing ovaries in females and late developing testes of *Dentex* were already reported during May [195].

5.4 Species Relationship with the Water Temperature and Wind Speed

The oceanographic and meteorological monitoring was dedicated to understand the species tolerance to certain ranges in the variation of selected measured habitat variables, as an indication of the effects that climate change may exert on fish's phenology [196]. Those ranges have a practical value for ecological monitoring, since indicate a roadmap to develop smart sampling procedures in marine species: i.e., the optimum time window when to expect a maximum presence of individuals, according to the fluctuation status of key environmental drivers [30].

Here, counts of *Dentex* were related to the water temperature, being the seasonal peak always reported above an averaged threshold of 13.1°C. A past study at the OBSEA with 3 years' time-series detected the increase in number counts of *Dentex* above 20°C [81]. This highlight the importance of pursuing the monitoring activities at the OBSEA to better characterize the environmental preference of this species.

The importance of water temperature as environmental driver has already been described in many fish species [197], [198]. Temperature deeply affects fish presence (or absence), because it influences directly species physiological performance [199]–[202]. *Dentex* can cope with temperature range above our reported threshold, as also indicated by the current trend of geographic expansion in the North Mediterranean [203], [204]. We confirmed that trend by a progressive increase in counts over the years (i.e., see **Figure 2**), which would possibly continue in the next decade, when temperature is expected to grow in the NW Mediterranean [205]. This indicates the value of cabled-observatory assets to disclose the occurrence of progressive trends in population shifts beyond more contingent seasonal dynamics due to the climate forcing.

We found a significant relationship between *Dentex* counts and wind speed. This variable affects the population distribution in some fish species [206]–[211], based on upwelling nutrient inputs [208], [210], [212] although this phenomenon is not relevant in a shallow costal area, such as the one where the OBSEA is deployed.

The changes in wind speed and direction could also affect indirectly other environmental variables, that consequently affect the marine biota. For example, it was observed that changes in wind affected salinity in the North Sea and in the Baltic Sea [213], which had negative consequences on cod recruitment in both areas [210]. In our case, salinity was not significantly associated to counts of *Dentex* nor to wind. Hence, the same dynamic reported for cod recruitment in the North Sea and Baltic Sea may not be valid in our case. Notwithstanding, wind speed may resuspend and mix seabed and water column nutrients at periods of blowing, hence influencing the coastal food web with the consequent overall increase of trophism at all predator levels of the trophic food web [212]. For the overall increase in pray abundance, *Dentex* counts may consequently increase at moments of wind blowing.

5.5 The Grouping Behaviour of the Species

We reported data on the grouping behaviour of *Dentex*, that showed a clear 24-h modulation. Here, the formation of groups of *Dentex* significantly occurred more during daytime (including twilight hours) than night-time, given the broad phase relationship between all visual counts and solar irradiance as a proxy for diurnal activity rhythms (see previous Section). Differently, no peaking was reported over different seasons. A seasonality for *Dentex* grouping behaviour was described in rocky coastal areas for juveniles during summer [214], [215]. We did not observe this phenomenon, but we could not resolve if our video-monitoring were composed by individuals in this stage of development, since no tools for body sizing (e.g., lasers) were present aside the camera; however, we can assume that the majority of individuals were adults. Indeed, for adults *Dentex*, groups of individuals may be detected during the spawning season in spring, between 40 and 100 m depth [131], but, given the shallower depth of OBSEA deployment, we did not observe this phenomenon (see previous Section).

The grouping behaviour of *Dentex* was associated to solar irradiance and water temperature. Grouping has been already broadly correlated to the environmental variation in previous works for different fish species [116], [117], [216], [217]. In particular, the formation of fish groups has been related to light intensity [116], [117] and to water temperature [116], [217]–[219]. Also, the weak increase of grouping behaviour reported across consecutive years of observations (see **Appendix L**) is likely the result of the increasing abundance of this species in the OBSEA area (see also previous Section).

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CHAPTER 2 - IMAGE DATASET FOR BENCHMARKING AUTOMATED FISH DETECTION AND CLASSIFICATION ALGORITHMS

1. ABSTRACT

Multiparametric video-cabled marine observatories are becoming strategic to monitor remotely and in real-time the marine ecosystem. Those platforms can achieve continuous, high-frequency and long-lasting image data sets that require automation in order to extract biological time series. The OBSEA, located at 4 km from Vilanova i la Geltrú at 20 m depth, was used to produce coastal fish time series continuously over the 24-h during 2013–2014. The image content of the photos was extracted *via* tagging, resulting in 69917 fish tags of 30 taxa identified. We also provided a meteorological and oceanographic dataset filtered by a quality control procedure to define real world conditions affecting image quality. The tagged fish dataset can be of great importance to develop Artificial Intelligence routines for the automated identification and classification of fishes in extensive time-lapse image sets.

2. Background and Summary

In a context of global climate change and increasing human impact in coastal marine areas, the monitoring of changes in fish behaviour and population abundances is becoming strategic to provide data on ecosystem productivity, functioning and derived services (e.g., the status of already overexploited stocks) [220]–[222]. For this reason, monitoring the temporal dynamics of fish communities is of pivotal importance to distinguish the variability in species composition, due to diel and seasonal activity rhythms, from more long-lasting trends of change [29], [140]. The temporal trend of fish presence and abundance, obtained from the analysis of imagery data, is produced by the rhythmic migration of populations into the marine 3D space seabed and water column scenario [76], [124], [127]. The information derived from such dynamics coupled with environmental (oceanographic and meteorological) data provide useful information regarding species ecological niche [30], [120], [179], and allow understanding and forecasting the impact of anthropic activities (e.g., commercial fishing, urban and port expansion) and the consequent mitigation actions (e.g., establishment of marine protected areas) [28], [31], [76].

Cabled video-observatory monitoring technology is considered as the core of growing *in situ* and robotized marine ecological laboratories in coastal and deep-sea areas [18], [50]. International initiatives about marine observatories infrastructures, like for example the European Multidisciplinary Seafloor and water column Observatory (EMSO-ERIC), the Joint European Research Infrastructure of Coastal Observatories (JERICO-RI), or the Ocean Network Canada (ONC) are becoming widespread all over the world [223], and increasingly install multiparametric sensors that, beside the imaging depicting biological information, also acquire oceanographic and geo-chemical data [31], [111].

Unlike other types of data, the scientific content of videos and images is not immediately usable. To overcome this problem, the image content is often inspected by trained operators in order to manually extract relevant biological information, such as the number of individuals and the corresponding classification into species [224]–[226]. This manual process requires a considerable human effort, and it is really time demanding. For this reason, automated image analysis methodologies for the extraction and coding of the image content need to be urgently defined and developed in order to transform imaging devices into actual biological tools for the underwater observing systems [227], [228].

This article describes a dataset of underwater images suitable for studying, developing and testing methodologies for automated image analysis. The images were acquired at the seafloor cabled multiparametric video-platform "Observatory of the Sea" (OBSEA; www.obsea.es), located in a fishing protected area, 20 m depth, 4 km off the Vilanova i la Geltrú coast, near Barcelona (Spain) [54], [133]. The image dataset consists of 33805 images containing 69917 manually tagged fish specimens, acquired every 30 minutes over day and night, during two consecutive years (i.e., from 1st January 2013 to 31st December 2014). The dataset encompasses and replicates the most relevant seasonal dynamics of environmental change affecting fish species abundance and assemblage at the study site [82]. In fact, coastal fish physiology and behaviour are highly responsive to changes in photo-period (i.e., light intensity and photophase duration) [99], nutrients and pollutants [212], [229] and oceanographic regimes (i.e., currents, temperature, and salinity) [198], [210], [230]. Thus, OBSEA monitoring area represents a real-world operational context common to many other temperate coastal underwater observing systems.

Together with the image dataset, we also provided oceanographic and meteorological time series, whose readings have been averaged and recorded synchronously with time-lapse images. Those data are for water temperature, change in depth, salinity, air temperature, wind speed and direction, solar irradiance and water precipitation. We added those environmental time series as contemporarily acquired, in order to provide a quality aspect to the real-time world context of image acquisition, to be used as metrics for image processing efficiency [61]. Moreover, the use of those data has been of relevance to provide hints in cause-effect studies linking fish presence and behaviour upon changing environmental conditions, being already successfully exploited for automated fish recognition [61], and for studying the temporal modulation of the species niches [81], [231].

The manually tagged fish individuals for each image make the dataset a valuable benchmark for the multidisciplinary marine science community consisting of biologists, oceanographers, and a growing community of computer scientists and mathematicians skilled in Artificial Intelligence and data science. Methodological comparison could be not only specifically conceived for fish detection and classification, such as Fish4Knowledge [232], but also for the emerging approaches for active and incremental learning [233]–[235], or for techniques aimed at mitigating the "Concept Drift" phenomenon, when the classification performance drops for varying species assemblages at changing environmental conditions and training need to be updated [62], [236]–[238].

Finally, the reported dataset of labelled images is worthwhile for global image repositories that aim to reduce annotation effort, such as Fathomnet [239], and, thanks to the tags and the bounding boxes associated to each individual, it can be easily split into training, validation, and test subsets (e.g., K-fold Cross-validation) in order to fit the needs of the specific image analysis algorithm used on the image dataset [61], [62], [240]–[243].

3. METHODS

3.1 OBSEA Video-Image Underwater Platform and Routine

The OBSEA seafloor cabled observatory was deployed in 2009 within a Natura 2000 marine reserve, named "*Colls i Miralpeix*", at 20 m depth and at 4 km off Vilanova i la Gertrú harbour (i.e., the Catalan coast of the NW Mediterranean, Spain: 41°10′54.87″N and 1°45′8.43″E) (**Figure 9**). The cable observatory is located on a mixed sand and seagrass meadows (*Posidonia oceanica*) bed, being surrounded by artificial concrete reefs, deployed to protect the area from illegal trawling [54], [133].

Figure 9. Location of the OBSEA cabled observatory in the North-Western (NW) Mediterranean. The figure indicates the "Development Centre of Remote Acquisition and Information Processing" (SARTI) and the Sant Pere de Ribes Meteorological Station (Sant Pere Met.) positions relative to the Catalan coasts (a), indicating also the OBSEA position off the harbour of Vilanova i la Geltrú (b). Power and broadband Ethernet communications are provided to OBSEA through an underwater cable from the SARTI building (green and red tracks). The OBSEA platform is surrounded by three biotopes (c) and focusing on one of them (Biotope 1, in c).

The OBSEA node structure has a size in terms of width, height, and length of 1x2x1 m, respectively, with an overall weight of 5 tons. The observatory is equipped with a camera approximately at 3.5 m distance from one of these artificial reefs, with a Field of View (FOV) area of about 3 × 3 m, resulting in a 10.5 m3 of imaged volume (**Figure 10**).

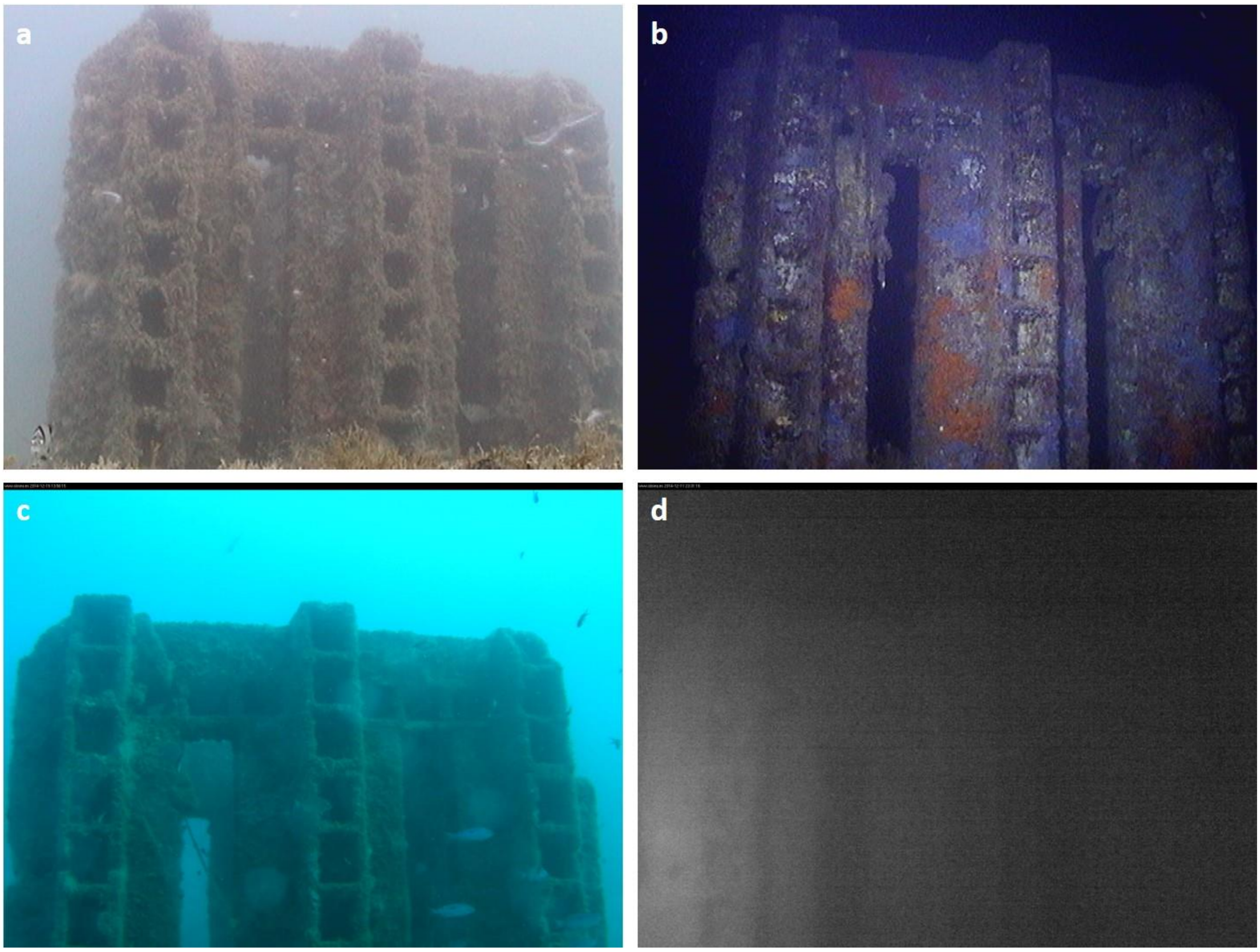

Figure 10. Examples of photos acquired by the different cameras used at the OBSEA. The Sony SNC-RZ25N (CAM1) (a, b) and the Axis P1346-E (CAM2) (c, d) cameras’ acquired photos during day and night.

The image monitoring was performed in a 30 min time-lapse mode, by synchronising illumination at night time at the moment of shooting. To shoot photos at night, the camera was associated with two illuminators located beside the camera at 1 m distance from each other, each one consisting of 13 high-luminosity white LEDs. The lights were emitting 2900 lumens, with a colour temperature of 2700 kelvin and an illumination angle of 120°. An automated protocol, controlled by a LabView application, switched on-and-off the lights before and after the camera shooting, resulting in a 30 s light-on period, to allow the lights to warm up and attain the maximum amount of homogeneous illumination.

Two different cameras were used during the monitoring period: an OPT-06 Underwater IP Camera (Sony SNC-RZ25N) from 1st January 2013 to 11th December 2014, and an Axis P1346-E Camera thereafter until 31st December 2014 (**Table 5**). The selected resolution of images for the first cameras was 640 × 480 pixels, whereas the second camera image resolution was 2048 × 1536 pixels (**Figure 10**). The acquired images have a JPEG format for both cameras.

	Sony SNC-RZ25N (CAM1)	Axis P1346-E (CAM2)
Num. of Pixels	3.8 MP	3 MP
Varifocal	4.1 - 73.8 mm	3.5 - 10 mm
Pan Angle	-170° - 170°	72°-27°
Tilt Angle	-90° - 30°	/
Focal Length-Aperture ratio	F1.4	F1.6
Light Sensitivity	0.7 lux	0.5 lux
Day-Night Function	Yes	Yes
Infrared Filter	Yes	Yes
Zoom	18x	Digital Zoom
Image Sensor	1/4 type CCD Imager	CMOS RGB of progressive scan 1/3”
Obturation Speed	/	1/35500 - 1/6 sec
Image Size	640x480, 480x360, 384x288, 320x240, 256x192, 160x120	from 2048x1536 to 160x90

Table 5. Technical characteristic of the two cameras used for the monitoring at the OBSEA. Technical characteristics of the two cameras (i.e., Sony SNC-RZ25N and Axis P1346-E) used between 2013–2014 at the OBSEA platform: number of pixels (N. of Pixels), varifocal, pan and tilt angle, focal length-aperture ratio, light sensitivity, presence/absence of the day-night filter, zoom, image sensor, obturation speed, and size of the saved images.

3.2 Fish Tags and Annotation Procedure

In order to tag the relevant biological content of the images (i.e., fish individuals), a Python code was developed based on the OpenCV framework for Python (https://opencv.org/) [244] (**Figure 11**).

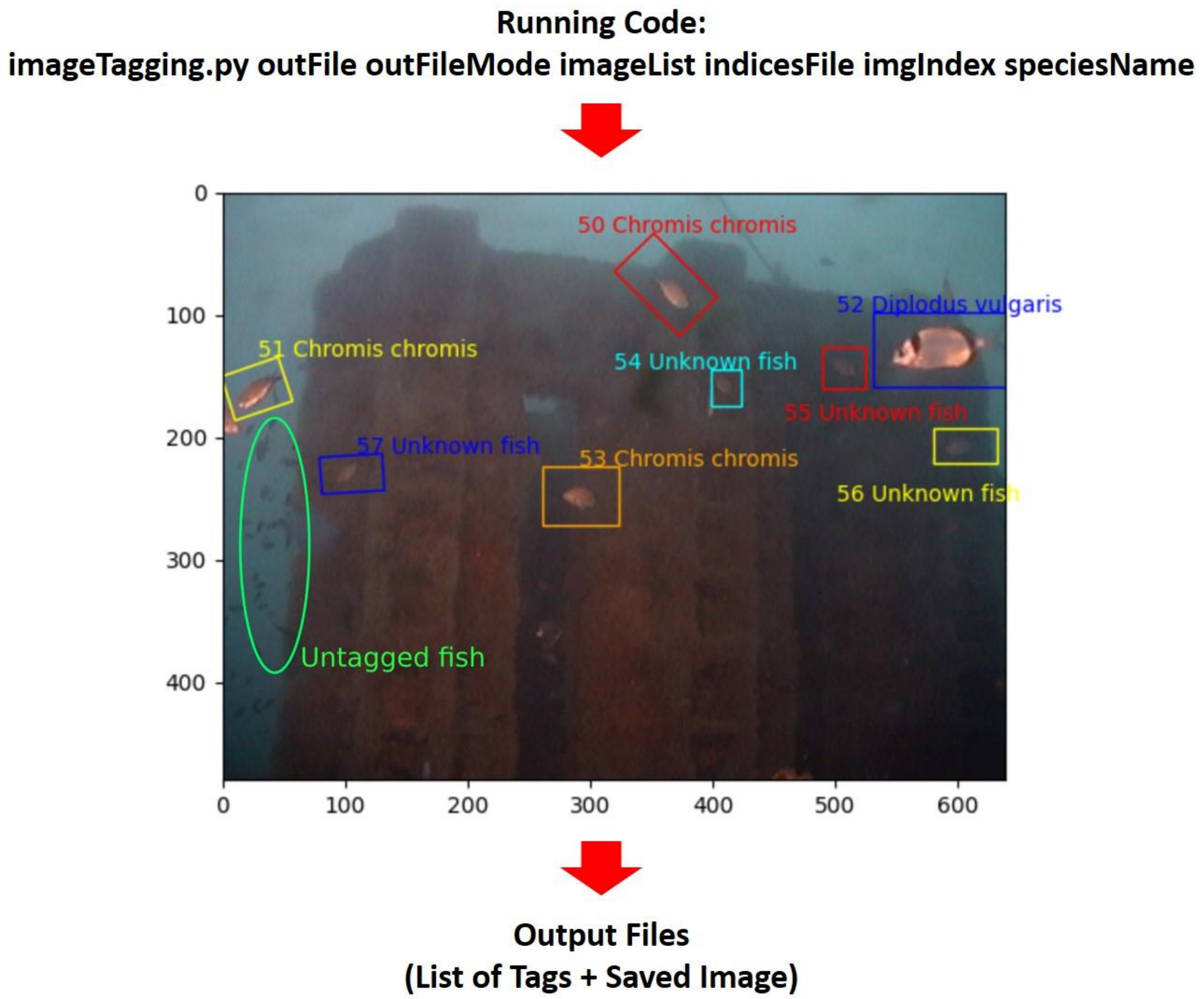

Figure 11. Flowchart for the tagging procedure. The tagging procedure of the photos were carried out with a Python code, at the end of which it releases as output a list of tags in text format and save the images with their bounding boxes (rectangles of different colours). Here, we report an example of a processed photo with tagged specimens and untagged fishes (green circle).

The script allowed tracing a line around the biological subjects, calculating afterwards a bounding box (bbox). The script and all the instructions of the tagging procedure are available through the Zenodo repository [245].

The species classification was performed according to FISHBase [246]. In those cases where the fish was not fully classifiable because too distant or badly positioned within the FOV we classified them as “Unknown fish”. This is because these unclassified fishes are important for the estimate of fish biomass (**Figure 11**). Some examples deal with individuals appearing in the photo like dots. Other examples deal with overlapping fishes, such as when they form schools.

3.3 Oceanographic and Meteorological Data Acquisition and Processing.

The OBSEA was equipped with a CTD probe to measure the water temperature, salinity, and the changes of depth, calculated from shifts in water pressure (as proxy for tides). During the period between 2013–2014, two CTD probes were sequentially deployed to avoid data gaps during sensor maintenance operations (**Table 6**). In **Table 7** the deployment periods of both CTD probes are depicted.

	Variable	Range	Accuracy	Stability	Resolution	Time of Acquisition
SBE 37-SMP	**Conductivity**	0 - 7 S/m	0.0003 S/m	0.0003 S/m per month	0.00001 S/m	10 sec
	Temperature	-5°C - 35°C	0.002°C	0.0002°C per month	0.0001°C	10 sec
	Pressure	20-7000 m	0.1% of full-scale range	0.05% of full-scale range per year	0.002% of full-scale range	10 sec
SBE 16plus V2	**Conductivity**	0 - 9 S/m	0.0005 S/m	0.0003 S/m per month	0.00005 S/m	10 sec
	Temperature	-5°C - 35°C	0.005 °C	0.0002°C per month	0.0001°C	10 sec
	Pressure	20-7000 m	0.1% of full-scale range	0.1% of full-scale range per year	0.002% of full-scale range	10 sec
UPC Weather Station (Station 1)	**Air Temperature**	-40°C - 65°C	0.3°C	/	0.1°C	10 sec
	Wind Speed	0-322 km/h	3 km/h	/	1 km/h	10 min
	Wind Direction	0-360°	3°	/	1°	10 min
Sant Pere de Ribes Weather Station (Station 2)	**Solar Irradiance**	0 - 5000 W/m	typ. <3%, 5% maximum	/	1 W/m2	10 min
	Rain	0 - 20 mm/min	0.1 mm	/	0.001 mm	10 min

Table 6. Technical characteristics of the two CTD probes, and of the two meteorological stations. Technical characteristic of the two CTD sensors (i.e., SBE16 and SBE37) installed at the OBSEA, the meteorological station of the Polytechnic University of Catalonia (UPC) in Vilanova i la Geltrú (i.e., Station 1), and the meteorological station of Sant Pere de Ribes (i.e., Station 2) present during the period between 2013–2014.

Sensor	Deployment	Recovery
SBE 16plus V2	09/01/2013	10/04/2013
SBE 37-SMP	10/04/2013	19/04/2013
SBE 16plus V2	19/04/2013	05/12/2013
SBE 37-SMP	05/12/2013	20/03/2014
SBE 16plus V2	20/03/2014	12/09/2014
SBE 37-SMP	12/09/2014	31/12/2014

Table 7. Deployment periods of the CTD sensors of the OBSEA. Details of the deployment and recovery of the CTD probes during the period between 2013–2014.

Moreover, meteorological variables were measured from the meteorological station on the roof of the Polytechnic University of Catalonia (UPC) building in Vilanova i la Geltrú, and from the meteorological station of Sant Pere de Ribes, Spain (www.meteo.cat) (see **Table 6**). The first one was a Vantage Pro2 meteorological station. This station was installed to collect data on the air temperature, wind speed and direction. Furthermore, we compiled data for solar irradiance and rain from the meteorological station in Sant Pere de Ribes. This station was equipped with a Pyranometer SKS 1110 to measure solar irradiance, and a Rain[e] sensor for the rain.

All the oceanographic and meteorological data were averaged every 30 min, in order to have mean and standard deviation measurements contemporary to the timing of all acquired images (see above), except for the irradiance and rain, that were compiled selecting and extracting only readings correspondent to the acquired image timings (see above).

In order to filter these data, we applied a Quality Control (QC) procedure for all the environmental variables except for the solar irradiance and rain, considered prefiltered and institutional data. This procedure is based on the guidelines from the Quality Assurance of Real-Time Oceanographic Data (QARTOD), issued by the United States Integrated Ocean Observing System (US-IOOS) Program Office, as part of its Data Management and Cyberinfrastructure (DMAC) (https://ioos.noaa.gov/project/qartod/). This QC procedure was based on the IOOS QC python tools (https://github.com/ioos/ioos_qc). Following the QARTOD guidelines, the following tests were applied:

- Gross Range test. Highlight data points that exceeded sensors or operator selected minimum and maximum levels.
- Climatology test. Data points that fall outside the seasonal ranges introduced by the operator.
- Spike test. Data points n-1 that exceeded a selected threshold relative to adjacent points.
- Rate of change test. Examination of excessive rises or falls in the data.
- Flat line test. Examination of invariant values in the data.

Each time that the quality test was run, each value of the dataset was flagged with a quality control code. The QC flags and meanings are shown in **Table 8**.

Flag Value	**Flag Meaning**
1	*Good Data*
2	*QC Not Applied*
3	*Suspicious Data*
4	*Bad Data*
9	*Missing Data*

Table 8. Quality control flags' codes and meanings. Quality control flags values and respective meanings applied to the environmental data.

The oceanographic and meteorological data were annotated into Comma Separated Values (CSV) files with additional information on QC flags, time stamps, and measurement devices used for their acquisition [247]–[249].

4. Data Records

4.1 Tagging Outputs

All time-lapse images were saved with the filename indicating the date (i.e., the year, the month, and the day), the timestamp in Universal Time Coordinates (UTC) (i.e., hour, minutes and seconds), the name of the platform, and finally the camera used for the acquired image [244]. As a result, we had an inspected dataset of 33805 images, depicting a total of 69917 manually tagged fish specimens, 36777 of which pertaining to 29 different taxa (**Figure 12**) (**Table 9**). The remaining specimens (i.e., 33140) were attributed to the unclassified category (see previous section).

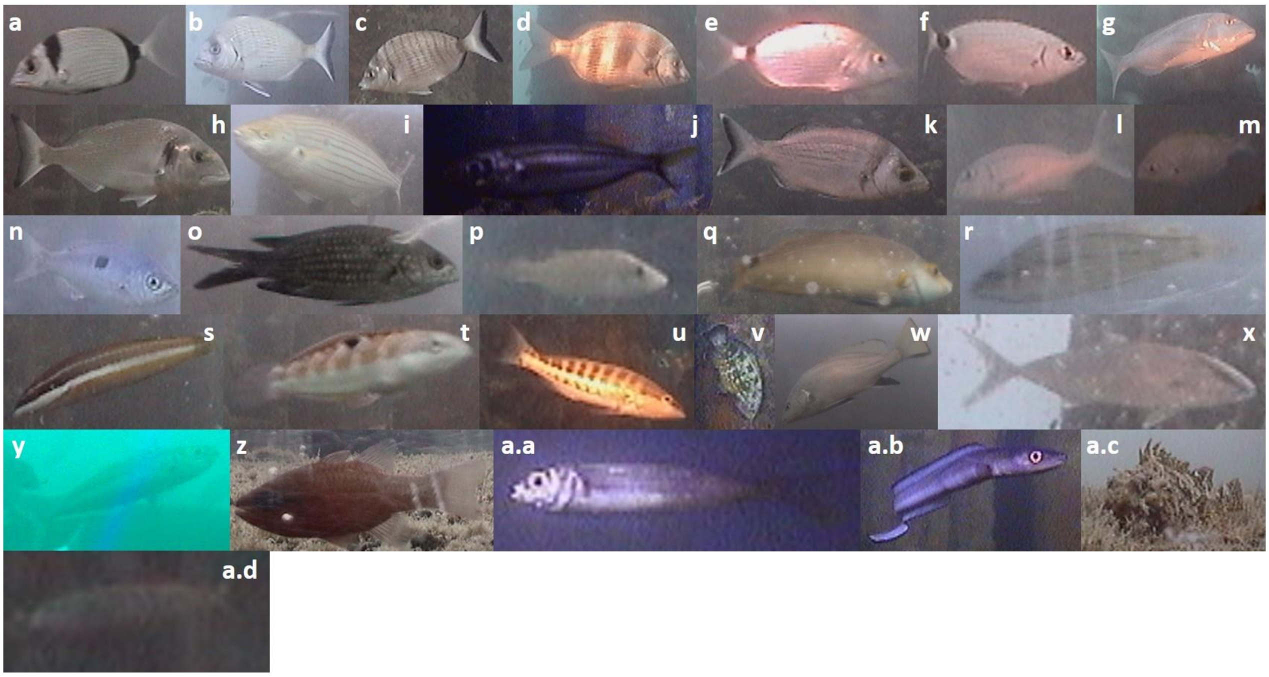

Figure 12. Photomosaic of the fish taxa encountered during the tagging procedure. Examples of photos of the 29 fish taxa recognized during the tagging, plus an example of an unclassified fish: (a) *Diplodus vulgaris*, (b) *Diplodus sargus*, (c) *Diplodus puntazzo*, (d) *Diplodus cervinus*, (e) *Diplodus annularis*, (f) *Oblada melanura*, (g) *Dentex dentex*, (h) *Sparus aurata*, (i) *Sarpa salpa*, (j) *Boops boops*, (k) *Spondyliosoma cantharus*, (l) *Pagrus pagrus*, (m) *Pagellus* sp., (n) *Spicara maena*, (o) *Chromis chromis*, (p) *Symphodus tinca*, (q) *Symphodus mediterraneus*, (r) *Symphodus cinereus*, (s) *Coris julis*, (t) *Thalassoma pavo*, (u) *Serranus cabrilla*, (v) *Epinephelus marginatus*, (w) *Sciaena umbra*, (x) *Seriola dumerili*, (y) *Trachurus* sp., (z) *Apogon* sp., (a.a) *Atherina* sp., (a.b) *Conger conger*, (a.c) *Scorpaena* sp., and (a.d) Unknown fish.

Taxa	Num.	%
Diplodus vulgaris	14328	20.49
Diplodus sargus	2727	3.90
Diplodus puntazzo	374	0.53
Diplodus cervinus	415	0.59
Diplodus annularis	1268	1.81
Oblada melanura	6898	9.87
Dentex dentex	615	0.88
Sparus aurata	34	0.05
Sarpa salpa	208	0.30
Boops boops	10	0.01
Spondyliosoma cantharus	1001	1.43
Pagrus pagrus	50	0.07
Pagellus sp.	9	0.01
Spicara maena	1826	2.61
Chromis chromis	2762	3.95
Symphodus tinca	7	0.01
Symphodus mediterraneus	209	0.30
Symphodus cinereus	54	0.08
Coris julis	1589	2.27
Thalassoma pavo	53	0.08
Serranus cabrilla	258	0.37
Epinephelus marginatus	5	0.01
Sciaena umbra	50	0.07
Seriola dumerili	72	0.10
Trachurus sp.	1	0.00
Apogon sp.	822	1.18
Atherina sp.	101	0.14
Conger conger	14	0.02
Scorpaena sp.	1017	1.45
Unknown fish	33140	47.40
Total	69917	100.00

Table 9. List of fish taxa with their respective number of tags and relative percentage. Number of tags (N) and relative percentage (%) for each fish taxa, unclassified individuals and total of fishes detected during 2013 and 2014 at the OBSEA platform.

In the dataset file for manual tagging [244], we reported the timestamp in UTC (yyyy-mm-ddThh:mm:ss) and the filename (e.g., timestamp associated) of the tagged image, plus the fish taxa name and the image vertices' coordinates of the bounding box (bbox) containing the identified specimens in the OBSEA photo (**Figure 12**). In order to improve the reuse of this dataset, we report here its details, described also in the PANGEA repository [244], in **Table 10**.

Column Labels	Description
Event	"OBSEA:CAM1:2013_14" if the Sony SNC-RZ25N camera was used to take the photo, or "OBSEA:CAM2:2013_14" if the Axis P1346-E camera was used.
Date/Time	The time stamp information in UTC with "yyyy-mm-ddThh:mm:ss" as format
IMAGE	The image name in the repository that include the time stamp and the type of camera used to take the photo
Species	The species' Latin name checked with the taxonomy site www.fishbase.org
bboxx1 [pixel]	abscissa value of the first vertex of the tag
bboxy1 [pixel]	ordinate value of the first vertex of the tag
bboxx2 [pixel]	abscissa value of the second vertex of the tag
bboxy2 [pixel]	ordinate value of the second vertex of the tag
bboxx3 [pixel]	abscissa value of the third vertex of the tag
bboxy3 [pixel]	ordinate value of the third vertex of the tag
bboxx4 [pixel]	abscissa value of the fourth vertex of the tag
bboxy4 [pixel]	ordinate value of the fourth vertex of the tag

Table 10. Details of the dataset with the tags of the fish specimens. The details of each variable of the dataset for the manual tagging of the OBSEA photos for the years 2013 and 2014 are reported here, with the timestamp in Universal Time Coordinates (UTC) and the bounding boxes (bbox) coordinates.

The proposed dataset can be used with any image analysis methodology, including the popular Deep Learning (DL) approaches, thanks to the annotated bboxs and related species labels for each fish individual. The bboxs proposed in this work are rotated rectangles that tightly fit each tagged fish individual. Image analysis approaches based on convolutional operators need the bboxs to be rectangles with the edges parallel to the image borders and, depending on the specific implementation, the bboxs could have different encoding. An example is the rectangle encoding for the "You Only Look Once" (YOLO) approach [250], for which it is very easy to transform the general-purpose rectangle encoding suggested in our work into the YOLO encoding and *vice-versa*.

A recent work on Deep Learning (DL) methods for automatic recognition and classification of fish specimens [251] identified the paucity of multiple species labelled datasets created by specialists, and with a community-oriented approach as major constraint for this methodology. In our dataset, ground-truthed by specialists, we labelled multiple species of fishes with a great number of tags, and with images taken from a camera focussing the same artificial reef during the whole monitoring period. For this reason, this dataset can be a good material for DL procedures and Artificial Intelligence based approaches in general.

4.2 Oceanographic and Meteorological Datasets

The measurements from the CTD device of the OBSEA, the meteorological stations of "Development Centre of Remote Acquisition and Information Processing" (SARTI, https://www.sarti.webs.upc.edu/web_v2/) rooftop and the Sant Pere de Ribes station were stored in a

PANGEA repository [247]–[249]. In order to better use this dataset we report the details of these datasets in **Table 11**, **Table 12** and **Table 13**, respectively.

Column Labels	Description
Date/Time	The time stamp information in UTC with "yyyy-mm-ddThh:mm:ss", as format
Temp [°C]	average value of water temperature
QF Water Temperature	Quality Flag of the water temperature measurement
Temp std dev [±]	standard deviation of the water temperature measurement
Cond [mS/cm]	average value of conductivity
QF conduct	Quality Flag of the conductivity measurement
Cond std dev [±]	standard deviation of the conductivity measurement
Press [dbar]	average value of water pressure
QF water press	Quality Flag of the water pressure measurement
Press std dev [±]	standard deviation of the water pressure measurement
Sal	average value of water salinity
QF sal	Quality Flag of the water salinity measurement
Sal std dev [±]	standard deviation of the water salinity measurement
SV [m/s]	average value of sound velocity
QF SV	Quality Flag of the sound velocity measurement
SV std dev [±]	standard deviation of the sound velocity measurement
Event	"OBSEA:SBE16:2013_14" if the SEA-BIRD SBE16plus V2 SeaCAT device was used for the measurement, or "OBSEA:SBE37:2013_14" if the SEA-BIRD SBE 37-SMP MicroCAT device was used.

Table 11. Details of the CTD probes measurements' dataset. The details of each variable of the dataset for the OBSEA CTD probes for the years 2013 and 2014 are reported here with the timestamp in Universal Time Coordinates (UTC).

Column Labels	Description
Date/Time	The time stamp information in UTC with "yyyy-mm-ddThh:mm:ss" as format
T air [K]	average value of air temperature
QF air temp	Quality Flag of the air temperature measurement
TTT std dev [±]	standard deviation of the air temperature measurement
ff [m/s]	average value of wind speed
QF wind speed	Quality Flag of the wind speed measurement
ff std [±]	standard deviation of the wind speed measurement
dd [deg]	average value of wind direction
QF wind dir	Quality Flag of the wind direction measurement
PPPP [hPa]	average value of atmospheric pressure
QF atmos press	Quality Flag of the atmospheric pressure measurement
PPPP std [±]	standard deviation of the atmospheric pressure measurement
RH [%]	average value of relative humidity
QF RH	Quality Flag of the relative humidity measurement
RH std [±]	standard deviation of the relative humidity measurement

Table 12. Details of the SARTI rooftop meteorological station dataset. The details of each variable of the dataset for the “Development Centre of Remote Acquisition and Information Processing” (SARTI) meteorological station for the years 2013 and 2014 are reported here with the timestamp in Universal Time Coordinates (UTC).

Column Labels	Description
Date/Time	The time stamp information in UTC with "yyyy-mm-ddThh:mm:ss" as format
E [W/m**2]	value of Irradiance heat flux density measurement
Rain [mm]	value of rainfall measurement

Table 13. Details of the Sant Pere de Ribes meteorological station dataset. The details of each variable for the years 2013 and 2014 are reported with the timestamp in Universal Time Coordinates (UTC).

Environmental data had temporal gaps in their time series due to sensor malfunction or power/communications loss. The temporal coverage for each variable is detailed in **Table 14**.

Station	Variable	Temporal Coverage (%)
OBSEA	*sea water temperature*	*93.49*
OBSEA	*sea water electrical pressure*	*93.49*
OBSEA	*sea water salinity*	*89.74*
UPC	*air temperature*	*94.68*
UPC	*wind speed*	*94.68*
UPC	*wind direction*	*94.68*
St Pere	*solar irradiance*	*75.77*
St Pere	*rain intensity*	*51.42*

Table 14. Temporal coverage of the different environmental data. Temporal coverage as percentage (%) for the environmental data acquired at the OBSEA, and at the meteorological stations on the Polytechnic University of Catalonia (UPC) building in Vilanova i la Geltrù and in Sant Pere de Ribes during 2013 and 2014.

5. Technical Validation

The manual tagging fish classification was performed following the FishBase website [244], consulting local fish faunal guides [176], [252], [253]. The operator that carried out the tagging trained in the fish classification using the Citizen Science tool of the OBSEA website (https://www.obsea.es/citizenScience/). Furthermore, to better classify the recognizable fish specimens we cross-checked our fish identification with specialists in fish classification from the Institut de Ciències del Mar of Barcelona (ICM-CSIC, https://www.icm.csic.es).

Here, we report the time series for the three most abundant fish taxa (i.e., *Diplodus vulgaris, Oblada melanura* and *Chromis chromis*) and total fish counts detected during the tagging procedure in order to ensure that there are not large gaps in the image acquisition at the OBSEA during 2013 and 2014, and that the data encompass all the seasons to detect and classify the highest number of species of the local changing fish community (**Figure 13**).

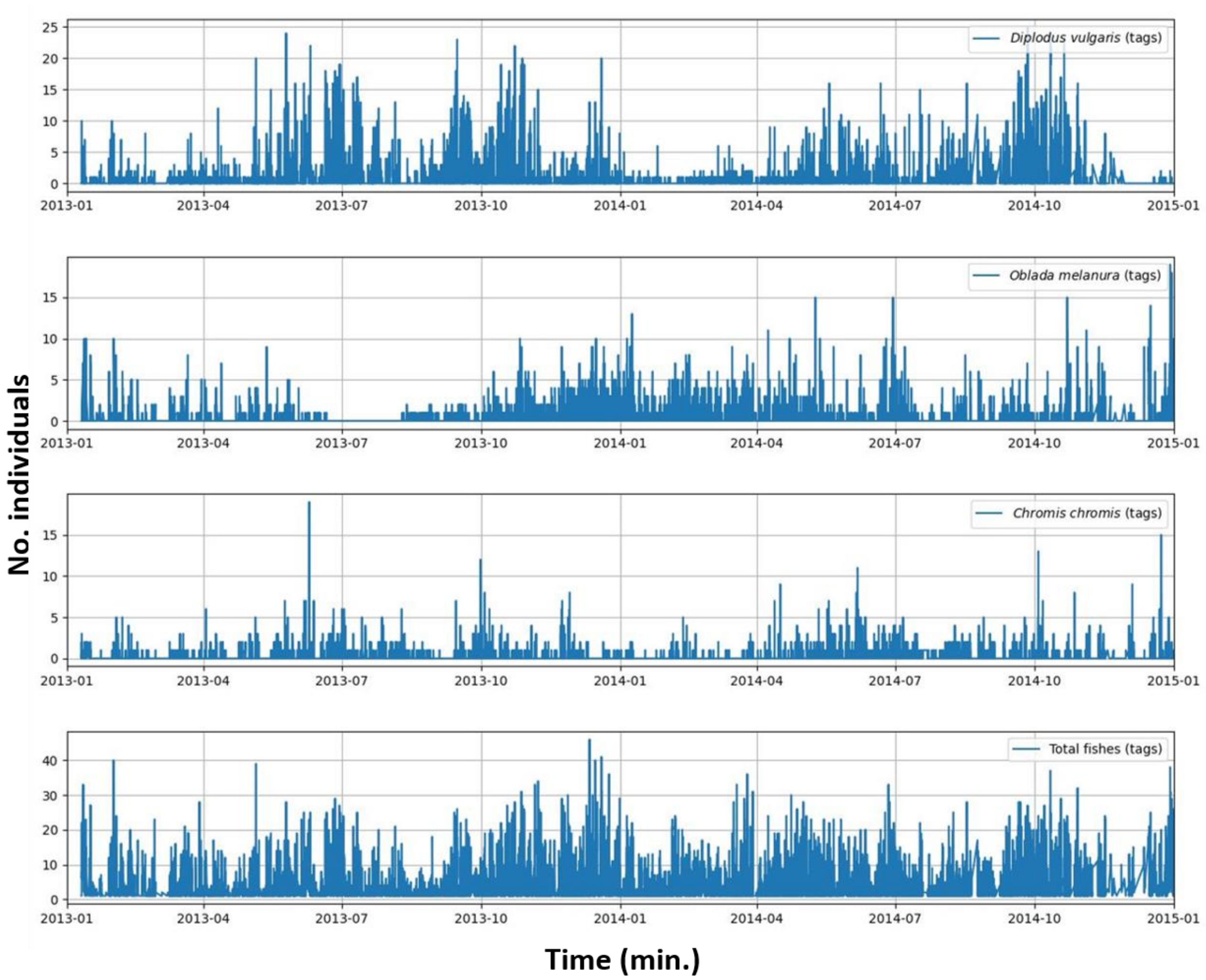

Figure 13. Time series plots of counted fish individuals per each 30 min. Here we report the time series for the 3 most abundant species (i.e., *Diplodus vulgaris*, *Oblada melanura*, and *Chromis chromis*) and total of individuals for the tagged fishes at the OBSEA platform between 2013 and 2014.

We also reported the time series of the environmental variables measured at the OBSEA platform, and at the two different meteorological stations on the "Development Centre of Remote Acquisition and Information Processing" (SARTI) rooftop and in Sant Pere de Ribes between 2013 and 2014. These time series are displayed with their respective Quality Control (QC) Indexes highlighted by different colours, in order to ensure the good quality of these data and show the low occurrence of gaps in the time series (see previous section) (**Figure 14**).

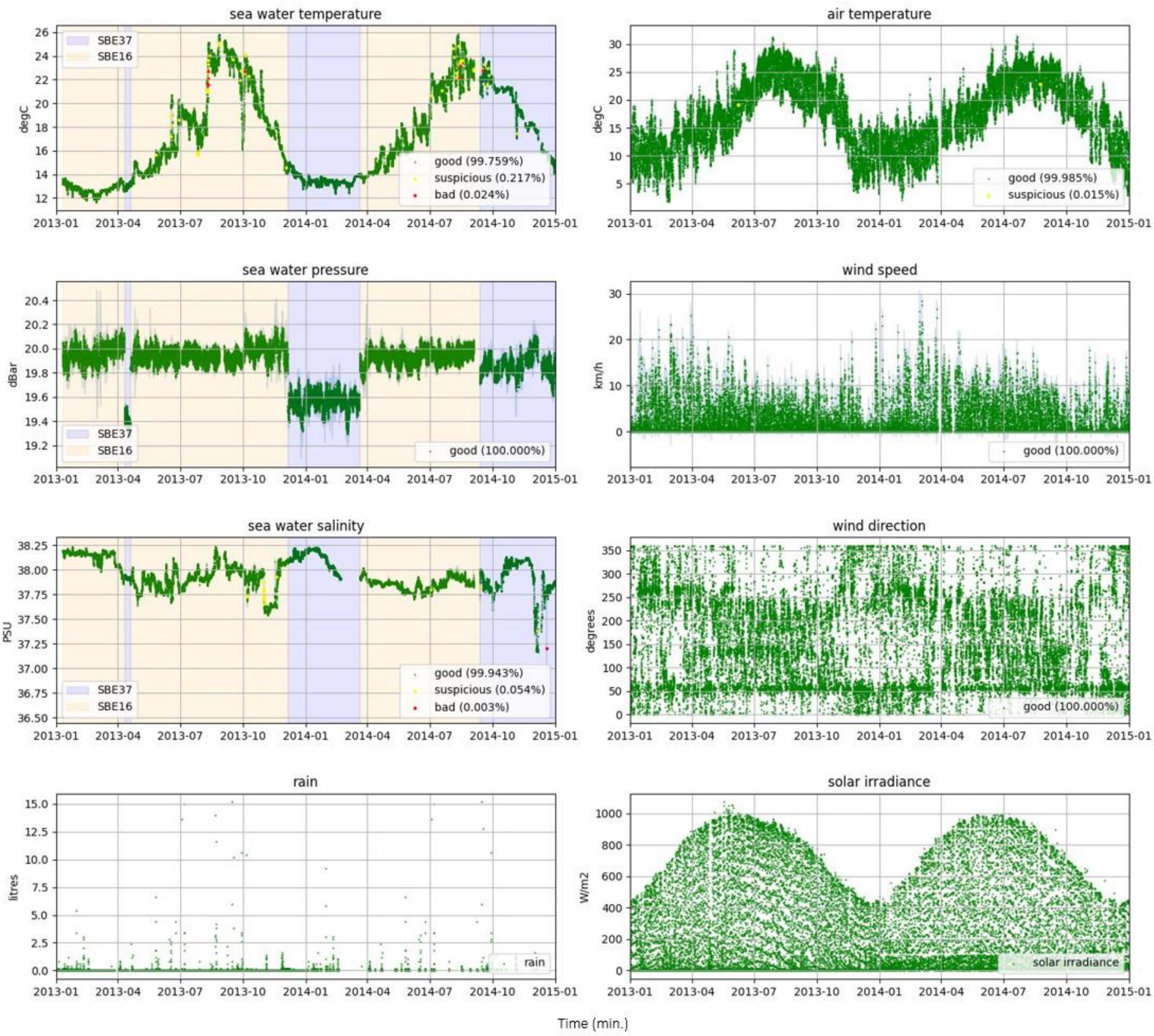

Figure 14. Time series plots of the environmental variables' measurements acquired each 30 min. Here we report the time series for the three oceanographic variables (i.e., water temperature, salinity and depth), and the five meteorological variables (i.e., air temperature, wind speed and direction, solar irradiance and rain) at the OBSEA platform, and meteorological stations on the "Development Centre of Remote Acquisition and Information Processing" (SARTI) rooftop and in Sant Pere de Ribes between 2013 and 2014. In the seawater temperature, pressure and salinity graphs we highlighted the use of SBE37 CTD probe with grey bands, and the SBE16 CTD probe with light yellow bands. The green points in the time series are the good quality data, the yellow ones the suspicious and the red ones the bad. Relative percentage of each QC Indexes was reported in the time series, except for rain and solar irradiance data, considered a prefiltered and institutional source (see previous section).

As a result, we also show here the resulting graphs from the diel waveform analysis of the tagging data for the three most abundant species and the total number of individuals of fishes related to the solar irradiance respective values to identify the phase of rhythms (i.e., the peak averaged timing as a significant increase in fish counts) in relation to the photoperiod (solving *via* data averaging the problems of gaps in data acquisition) (**Figure 15**).

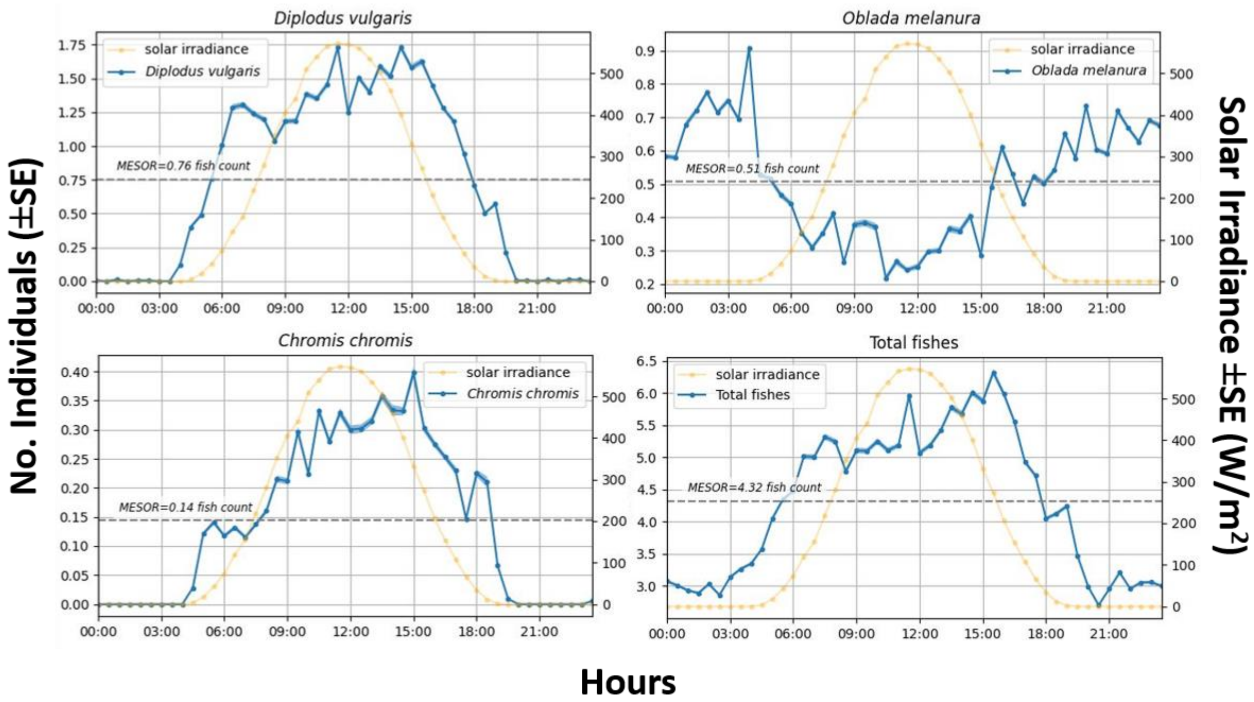

Figure 15. Waveform analysis plots. We reported here the waveforms of the 3 most abundant species (i.e., *Diplodus vulgaris, Oblada melanura*, and *Chromis chromis*) and total of fishes at the OBSEA platform during 2013 and 2014 for the tagged fishes (blue line) related to the photoperiod (yellow line). Time series of visual counts and solar irradiance were subdivided in 30 min time series, and then averages and standard errors (SE) were computed over a standard 24 hours period.

It can be observed that in general the species are diurnal as reported in literature [83]. The only exception is *O. melanura* that was observed more active during crepuscular hours [83], but in our case was tagged more during nighttime. This could be explained by the better visualisation of this species with illumination, lacking of well recognizable marks for its classification. Therefore, it could be inferred that, in general, the tags for the different species are proportional to the local abundances, except for the certain species, such as *O. melanura*. This last statement is based on a recent article [51] describing a method for the estimation of organisms' abundance from visual counts with cameras. The article proposes a Bayesian framework that, under appropriate assumptions, allows to estimate the animals' density in a single survey without the need to track the movement of the single specimens.

6. USAGE NOTES

As can be observed in **Table 9** the classes of the inspected dataset are imbalanced (e.g., there are 14328 *Diplodus vulgaris* tags and only 1 *Trachurus* sp. tag). This characteristic has to be managed by applications dealing with Artificial Intelligence for the automated interpretation of the image content. In case the image analysis method could not manage unbalanced datasets [254], [255], data augmentation approaches could be used for generating new reliable individuals starting from the classes tagged in the dataset [256]–[258].

7. Code availability

The developed Python code for tagging and labelling the images is available through the Zenodo repository [245]. Another device that can be used for tagging fishes is the public Label Image tool (https://github.com/tzutalin/labelImg).

8. Acknowledgement

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CHAPTER 3 – RESOURCE PULSE IN SHALLOW WATERS: CHARACTERIZATION OF THE SCAVENGER COMMUNITY ASSOCIATED WITH A DOLPHIN CARCASS

1. 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 north-western 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.

2. Introduction

The sinking bodies of cetaceans provide a huge, but infrequent, influx of food to the seafloor [85]. 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 [90]. 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 [87]. 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 [87].

The study of whale falls has increased in the past decades providing important insights on their impact mainly on deep-sea habitats [90]. Whale carcasses in deep environments were reported to generally incur in four successional stages [90]. 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 [93]. 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 [90].

Previously, most research on whale falls has been conducted in deep-water and not shallow-water ecosystems [90]. However, few studies conducted in shallow marine habitats revealed that cetaceans' carcasses provide food for different marine species in these areas. Some examples are, [259] where various species of Annelida were detected in a cetacean carcass experiment at 30 m depth in Swedish fjord, [94] 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 [260] 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 [261], 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., [262]). 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 [87]. 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) [54] from 22nd December 2020 to 4th February 2021.

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 (**Figure 16A, 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 Centre of Remote Acquisition and Information Processing Systems” (SARTI) research group from “Universitat Politècnica de Catalunya” (UPC).

Figure 16. 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 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 [18]. This type of technology has already been used to monitor a whale-fall decomposition process in Sagami-Bay (Japan) [93]. 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.

3. Materials and Methods

The carcass of a juvenile male striped dolphin (*Stenella coeruleoalba*) (**Figure 16C**) 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 (**Figure 16D**). 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 (**Figure 16D**).

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 [263], 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).

4. Results

We analysed a total of 840 images, resulting in 8415 counted individuals from 12 species (**Figure 17**). The three most frequently observed species were *Diplodus sargus* with 4081 counts, *Oblada melanura* with 917 counts, and *Coris julis* with 180 counts (**Table 15**). While the three lesser sighted species were *Diplodus vulgaris* and *Diplodus cervinus* with both two counts, and *Serranus cabrilla* with only one count (**Table 15**). 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 15**).

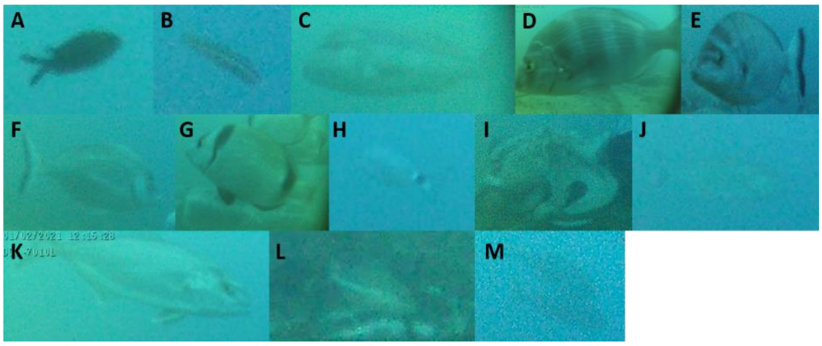

Figure 17. Images of the 12 marine species detected during the video monitoring of a dolphin carcass at the OBSEA in alphabetical order: A) *Chromis chromis*, B) *Coris julis*, C) *Dentex dentex*, D) *Diplodus cervinus*, E) *Diplodus puntazzo*, F) *Diplodus sargus*, G) *Diplodus vulgaris*, H) *Oblada melanura*, I) *Octopus vulgaris*, J) *Sarpa salpa*, K) *Seriola dumerili*, L) *Serranus cabrilla*, and M) unknown fish taxa.

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±0.3	OA	Multi-habitat	1
Unknown fish	/	/	/	2962
Total	/	/	/	8415

Table 15. 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.

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 (**Figure 18**). 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 (**Figure 18**). 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.

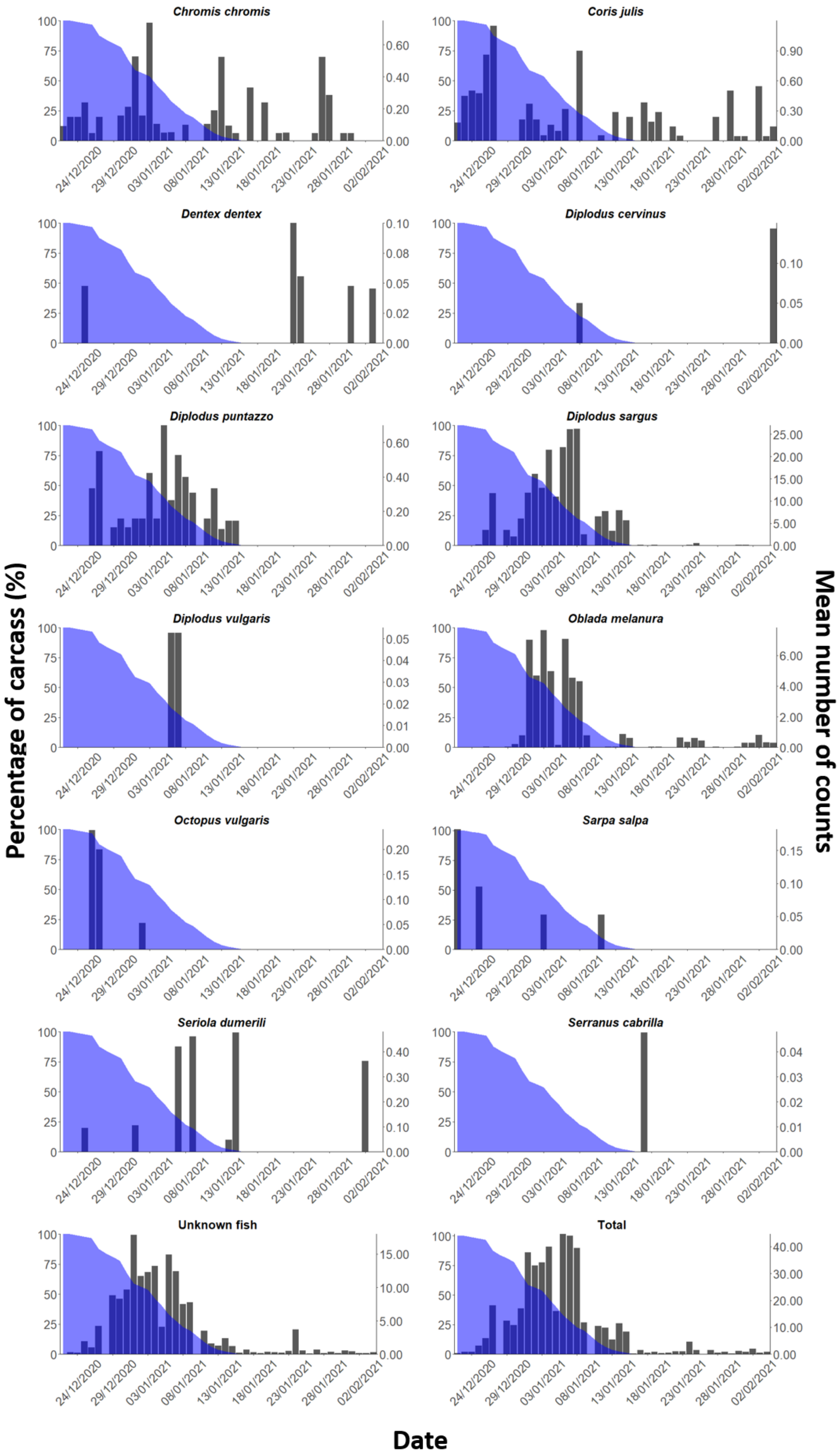

Figure 18. Time-series of mean number of counts per day for each detected marine taxon (grey histograms), and of the progressive consumption of the dolphin carcass in percentage (blue shadow) during an experiment at the OBSEA platform.

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 α = 0.01), as well as for *S. salpa* (at α = 0.05) (**Table 16**).

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 16. 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.

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 α = 0.01) higher than the expected ones based on the proportion of images analysed per period (**Table 17**).

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

Table 17. The binomial test results with the number of counts for each detected marine taxon before (Carcass Presence) and after (Carcass Absence) the skeletonization of the carcass during an experiment at the OBSEA platform.

5. 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.

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 [264] 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 [231]. 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 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 [82].

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 [94]. 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 [94], [259], [260]. 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 [259]. 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 [93].

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 [265]. 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).

6. Acknowledgement

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DISCUSSION

1. DISCUSSION

This Thesis wants to highlight the importance of the procedures to be used in studies about long-term time series of video counts of marine coastal fishes (and other marine fauna) concomitantly with environmental data acquisition in a time intensive (i.e., minutes) and continuous (i.e., consecutive day-night cycles and replicated seasons across years) fashion for the ecosystem monitoring. That multidisciplinary data collection serves the need of ecological niche characterization for an iconic species (see next section). In addition, this Thesis aimed to contribute on best practices for video/image annotations that will be useful for ecological studies with cabled observatories and other fixed camera sources worldwide. That effort was related to the obtention of an exhaustive richness list and it was also related to the further step of training by machine learning algorithms at automatization in image processing for species classification and counting. That latter issue is of relevance when automated routines will be used with image material form robotic platforms with different levels of tele-operated autonomy (e.g., ROVs, AUVs, crawlers, and seafloor cabled observatories).

In marine ecosystems' monitoring there has always been the duality of temporal or spatial representativeness of collected data [18]. Also, in non-technologically supported methodologies for marine environmental sampling (e.g., SCUBA divers and fishing nets-based methods), the spatial representativeness goes at the expenses of the temporal one [4], [147], including ROV and AUV surveys, the former for the high-costs of vessels limiting sampling replicability and the latter for , limited autonomy; e.g., battery life cycle and duration [18]. A too temporally scattered sampling frequency can bias our perception of species abundances, richness, and overall biodiversity because of species activity rhythms (i.e., displacements at tidally, diel, and seasonally cycles) [63]. The behavioural reaction of the individuals to light intensity and photophase duration as well as water flow cycles, vary the probability of encountering (and hence sampling) them into our monitoring seabed and water column windows [25], [99], [266].

New technologies could increase the temporal and spatial representative power of data collection for monitoring [18]. Although seafloor marine cabled observatories are fixed platform, thus not capable to spatially collect data representative of their surrounding spatial heterogeneity (e.g., habitat clines), networks of biological (e.g., cameras) and environmental (e.g., CTDs) sensors could concomitantly acquire data in a synchronous fashion over a larger area, hence allowing the picturing of individuals, schools, and population displacements across clines of environmental variations [30], complementing individual tracking technologies (e.g., acoustic and data logging telemetry; [37]). In addition, the integration of those local data with those achieved from nearby-operating mobile platforms, such as ROVs and AUVs, could enlarge the marine environmental monitoring scale [18]. Those mobile platforms could indeed make transects acquiring images and environmental data in a concomitant way to the observatory fixed and satellite cameras. A similar approach is being used on a small scale with docked mobile crawlers as an Internet Operated Vehicles (IOVs). Based on the experience at the ONC with the docked Wally I, operating since more than 10 years, OBSEA has built its own mobile tethered platform that will soon be used to perform linear transects in a SCUBA-diving mode, around the observatory [56].

Although fixed cameras and environmental sensors do not collect spatially representative data, high-frequency and multiannual image acquisition (see above) produce time series of animals' counts that can be used to disclose species trends of change in abundance (i.e., cunts are a proxy of the populations' abundances status) [124]. Furthermore, the correlation of species counts' time series with concomitantly acquired environmental data has been used to disclose cause-effect relationships, evidencing the habitat variables acting as drivers for species demographic status changes, hence adding new information on the species niche [61]. Thus, the first objective of this Thesis was to prove the importance of long-term, continuous and high-frequency time-series acquired from a cabled observatory for the marine environmental monitoring of a commercially and ecologically iconic predator fish species (the common dentex, *Dentex dentex*), as use case for this objective.

However, in the specific case of using camera sensors, the big amount of raw data acquired from cameras (i.e., videos and images) is a highly time-consuming procedure and needs a lot of effort from scientific experts to manually extract the meaningful biological content, as species taxonomical classification and their individual counting [30]. For this reason, the second objective of this Thesis was to highlight the importance on the methodology used for building repositories of labelled images compliant with processing and format requirements of major international images archives around the World (e.g., FathomNet; https://fathomnet.org/fathomnet/#/). In this aspect, this Thesis indicated how to build a proper dataset for fish detection and classification using large image repository from any shallow seafloor cabled observatory worldwide.

Finally, the effect of large marine animals' falls was already largely studied in deep-sea benthic communities, in particular with whale-falls experiments [90]. However, the impact of those exceptional events on coastal areas and in particular on resident fish communities and other fauna are almost unknown. Therefore, the third objective of this Thesis focussed on the deployment and monitoring of the scavenging process of a dolphin carcass in the cabled observatory camera field of view. The protocols developed in Chapter 1 and the labelling capabilities relying on richness knowledge of Chapter 2 allowed to picture the dynamic of body consumption, based on several fish species succession. We discovered a progressive increase in number of counts for several detected species while the flesh was being consumed, and an afterwards decrease when only bones remained. Several rare species (i.e., poorly represented in the multiannual image data set) were also observed. As important findings, this innovative experiment, thanks to the high-frequency sampling from camera, found for the first time the attractive effects of a large marine animal carcass for various marine species (predominantly fish species) in a coastal Mediterranean ecosystem, allowing us also to better characterize some fish species diet.

1.1 First Objective: Describe the Environmental Niche of One Ecologically and Economically Iconic Fish Species (Autecology) Using Long Time-Series of Individuals Counts Fluctuations and Environmental Data

Marine motile species such as fishes perform diel and seasonal rhythmic migrations across different depths and geographical areas [63], [99]. These behaviours were discovered to be a source of bias when communities' sampling is not temporally repeated at one location, and does not cover in frequency of repetition the day-night and the seasonal cycle [25]. These sampling requirements could be reached with new technologies, such as seafloor cabled video-observatories equipped with cameras and environmental sensors (e.g., [125]). In particular, the concomitant acquisition of images and environmental data can give us relevant hints on species behaviour and environmental control [29].

For this reason, in Chapter 1 of this Thesis, an 8 years' time-series of visual counting at 30 min frequency, of a fishing target species of the north-western Mediterranean Sea, the common dentex (hereafter *Dentex*), was correlated to concomitant oceanographic and meteorological data from the OBSEA, and nearby meteorological centre [54]. This temporally intensive data set allowed to set the statistic approaches to characterize in a quantitative manner fishes' autecological trait in relation to activity rhythms and sociality.

The greatest concern of poor cabled observatories' spatial data representativeness (i.e. fixed cameras' FOVs of only few m^2), can be dismissed for some relevant reason. A recent review on camera-based methods for estimating animals' absolute abundances, considering their home range, stated that with a network of 10 cameras and 250 consecutive frames acquired at around 3 min frequency (i.e., less than 1 hour approximately) are needed to calculate a marine bony fish species abundances, considering *Chaetodon baronessa* as model species for this taxon [51]. Thus, in the case of Chapter 1 the use of only one OBSEA camera could be applied for the computing of a fish species local abundance, given the multiannual continuous duration of frames acquisition (i.e., for *Dentex*, a total of 70,254 frames were analysed). Although fixed cameras can picture the relative abundance of fish species when such a temporally intensive sampling is performed, more calibration studies are needed with docked mobile platforms (i.e., whose automated visual census transects may replace camera networks in coastal areas) (see next section).

To increase the spatial representativeness of fixed cabled observatories monitoring, networks of cameras and docked crawlers all performing synchronous image acquisition routines, could be deployed [50]. Such solution could be inspired with already used methods in the terrestrial habitats with extended networks of camera traps [150]. Furthermore, cameras installed on mobile platforms, such as ROVs and crawlers, or the use of other technologies with higher monitoring radius, such as acoustic cameras, could help in the increase in extension of the video monitored area [18]. However, there is still scarcity of information on the statistical methods on how to interpolate data from different cameras (acoustic or not) detections [50].

A study on *Dentex* seasonality was performed at the OBSEA previously to the work presented in Chapter 1 [81]. Even though the three years of that previous study are included in the 8-years monitoring data of the OBSEA used for Chapter 1, additional information on the seasonality of this species was obtained. The occurrence of a seasonally-variable and minor peak in visual counts on May was emerging in addition to the greatest one of August. This peak was related to the period of reproduction of *Dentex*, that breeds at 40-100 m of depth from March to June [131]. That study comparison of data sets at the same station but with different temporal length confirm the importance of video observations longer than three years to add novel biological information.

The cabled observatory data can be used also to add new information on the Hutchinson niche [120] of marine species. Hutchinson idea was that one can represent the environmental boundaries where an organism can survive as an abstract space with multiple axes corresponding to gradual variation of represented environmental factors (both biotic and abiotic), the status of which affect the organism survival performance (and hence detectability). Long-lasting and multiparametric data collection can depict species counts within ranges of fluctuations for the different habitat variables measured. In Chapter 1, that was achieved for the *Dentex* compared to previous studies in the same area with lower duration and number of monitored habitat variables [81]. In fact, compared to the previous study [81], Chapter 1 work detected a seasonal peak in activity above an averaged threshold of 13.1°C, while in the past study this was at 20°C. Furthermore, *Dentex* counts were statistically related to water temperature, salinity and daily photoperiod in the past study using only these three drivers as explanatory variables, while in Chapter 1 work *Dentex* counts were related to solar irradiance, water temperature (as the previous study) and wind speed with a larger set of acquired oceanographic (water temperature, salinity and depth) and meteorological (air temperature, wind speed and direction, sun irradiance, and rain) variables.

Phenology is a relevant feature of species niche and the results of this Thesis add new information on reproductive and growth cycles. Phenological changes on marine species could be detected as temporal shifts in life history events [267]. These types of investigation with fish species have found evidence of shifts in important life stages (i.e., spawning, hatching, and migration), even if the bony fishes (Osteichthyes) are poorly studied in comparison to other taxonomical groups. Furthermore, fish species are considered good biological indicators for climate change due to their high motility and quick response to changes in the environmental quality, directly affecting their physiological status [60], [268]. As confirmed by Chapter 1 study case temperature and photoperiod are considered as the most important recognized drivers for *Dentex* phenology [269]. Excluding the well-studied effect of light intensity on marine species [99], increasing temperature is a driver that affect fish physiology, accelerating gonadal developments, thus having important consequences on spawning timings [269]. In particular, increasing water temperatures were observed to advance the spawning period when the fish species are at their spawning grounds [270]. Positive shifts in water temperatures were also related to earlier general migration starts [271], further proving the importance of this driver in fish phenology, as it was also here described for *Dentex*. Although the relationship with fish counts, and solar irradiance and water temperature could be easily explained, the one with wind speed is lesser clear. This relationship was attempted to be explained in Chapter 1 by the possible upwelling effect of along shore winds, its resuspending nutrients' effects in shallow water habitats, and its influence on different environmental variables, as salinity [210], [212], [213].

The trends observed in *Dentex* nearly decadal counting should be also discussed in relation to multiannual trends for climate change. As climate change was observed affecting the whole marine life, not only in their physiological, but also distributional and demographical aspects [9], similar Chapter 1 analyses could be performed on different marine species in order to understand the climate change effect on the marine inhabitants. In Chapter 1, the statistical comparison with General Additive Models (GAMs) between fish counts and concomitant environmental variables' measurements showed that presence/absence of fish species and their grouping behaviour could significantly change in relation to environmental drivers, such as water temperature, wind speed, and solar irradiance (as observed in *Dentex*). This could be a clear example on how cabled observatory temporal representativity along long periods of time is important to manage fishery resources in a context of increasing climate change and human impact scenario. In fact, as *Dentex* was already observed to expand its geographical range in the North Mediterranean for the increasing water temperatures [203], [204], the *Dentex* time-series of Chapter 1 showed a progressive increase in counts over the years (**Figure 2**), that could possibly continue in the next decade for the predicted increasing water temperatures' trend in the north-western Mediterranean [205] impacting the fishery industry of this important commercial species.

The results of this Thesis should also be compared with the general literature on the effects that key habitat drivers exert on fish (and other marine taxa) physiology. Mediterranean marine communities, including bony fishes, were observed to be affected by nutrient concentration (e.g., Chlorophyll-a) [272], pollutants (e.g., wastewaters) [273], warming [274]–[278], acidification [279], oxygen [280], climatic oscillations (e.g., North Atlantic Oscillation) [280], [281], and salinity [282]. Also, in other oceans, fish species were discovered to be impacted by climate change in all the different stages of their life cycle [268], [283], especially by warming temperatures [284], [285]. These impacts were detected also in other marine taxa, such as invertebrates for temperatures [285] and oxygen [286]. Overall, low motile species, as molluscs, were discovered to be more sensitive to climate change compared to other taxa [287]. No data comparison can be drawn here at the OBSEA since few molluscs' species (i.e. cephalopods) have been pictured over the decadal time series of images. Furthermore, in the case of the Mediterranean Sea, due to climate change and human impacts the number of invasive species, in particular from the Suez Canal, is increasing, expanding their geographical northern ranges [288]–[291]. That aspect was not observed at the OBSEA since no invasive species was recorded over 10 years. Additionally, it was suggested that the future modelling approaches to understand the effects of climate change on marine resources have to consider multiple factors (changes in temperature and pH, reduction in water quality due to eutrophication, alien invasive species, and overexploitation) [292]. These statements further evidence the importance to enlarge the environmental monitoring with multiple cameras and sensors using cabled observatory as suggested in Chapter 1.

1.2 Second Objective: Create an Exhaustive Fish Richness Inventory, as Labelled Dataset to Be Used for the Future Development of Algorithms that Could Automatically Detect and Classify Fish Specimens

Today, several cabled seafloor observatories' networks have been deployed in all oceans, and, when these bear cameras acquiring high frequency videos or photos over long period of times, large amount of image material is produced. That material is hard to be manually analysed by expert for species counting and classification. In fact, none of the video-cabled platforms so far is backed up by online algorithms for the identification, classification, tracking and counting of animals, even the most advanced ones such as the ONC. That infrastructure has a cyber asset named Ocean 3.0 that acts as global repository, presently storaging thousands of terabytes of imaging material, still with almost no automated processing (i.e., which leaves the biological content still undisclosed since manual classification is neither expensively tackled). For this reason, properly built datasets with labelled images are needed for the training of machines in the automatic identification and classification of meaningful biological objects (e.g., fishes) from these big image repositories.

In Chapter 2, how to build such datasets was described using two years of acquired images of the OBSEA seafloor cabled observatory. During the construction of this dataset the directives of a past work made with images of the same platform were carefully considered [61]. For this reason, in the published dataset were also added environmental data as real-world conditions affecting image quality (and hence, implemented AI routines efficiency). This work identified problems in the object identification from the machine when fishes were labelled in the presence of biofouling on the camera, or in high turbidity condition, and when fishes were tagged also if superimposed one on the other (i.e., school formation). Moreover, two years of acquired images were used considering the seasonality of the presence-absence and changes in abundance across seasons and time of the day of the different classified species [82].

Part of this dataset (using only the tagged photos from the 2013 year) was already used to describe the Concept Drift effect at the OBSEA [62]. This effect consists in a progressive decrease of automated detection and classification efficiency over time (in the case of this dataset was observed to be months) due to natural (e.g., biofouling) and artificial (e.g., camera settings) factors, as well as for the seasonal species composition turnover. This effect could be mitigated by different methods, but the most promising ones were identified in the active [233] and incremental learning [234]. Furthermore, within that work also a change in camera angle was observed as a problem when training the machine in the classification of fish species, but not much in the identification, proving that the different colour balance mechanisms of different cameras can affect the classification performance of the machine, suggesting the retraining of the machine after any change in cameras' device or setting.

A recent work on the best practices for creating a dataset for automatic fish detection and classification took in consideration also the dataset used for Chapter 2 [293]. Authors discovered that YOLOv5 was the best tool to create algorithms for the automatic detection of Mediterranean fishes, and they also pointed out the importance of well labelled datasets. Indeed, authors highlighted the importance of having fishes' full body within the bounding boxes, and that the bounding boxes have not to be too small relative to the image dimension as best practices for future generation of such datasets.

The proposed dataset in Chapter 2 was recognized to be worthy for global, public image repositories that aim to reduce annotation effort, such as FathomNet and Fish4Knowledge [232], [239]. In fact, these types of repositories are of great interest not only for the marine ecology community, but also for the computer science and mathematician community interested in the development of AI and in data science.

1.3 Third objective: Prove the Importance of Cetacean Carcasses on Shallow Water Ecosystems for the Coastal Fish Community, Evidencing the Occurrence of a Scavenging Dynamics, Depicting the Community Turnover in Terms of Richness and Relative Abundance Changes Before and After the Complete Consumption of an Experimentally Deployed Dolphin Carcass, as Use Case Implementing the Previously Proposed Methodologies

To understand the hypothesized impacts of a small cetacean carcass on shallow water ecosystems in Chapter 3 of this Thesis, a dolphin dead body was artificially deployed in front of the OBSEA camera to detect which fish species could act as scavengers and which community turnover could have been occurring along the decomposition process. For that reason, the protocol elaborated in Chapter 3 of high-frequency (30 min) time-lapse image acquisition across consecutive day-night cycles and months was actuated. Significant increases in counts of different fish and invertebrate species, that were directly observed exploiting the carcass, were reported before and after the cetacean carcass' skeletonization (i.e., the full meat consumption, exposing the bones). Marked species presence turnover was also detected, that along with species counts' increases, confirm the importance of cetacean falls for locally altering the dynamic of coastal communities, with transient impacts on biodiversity. Moreover, the artificial deployment of cetacean carcasses is of utility to enrich species lists (i.e., archived richness) at cabled observatories, because of specie that may exist in nearby, not monitored areas. A similar effort is ongoing with automated food dispensers in the deep-sea area of Barkley canyon (ONC), where imaging is being used to capture at an hourly frequency during several month the variation in specie abundances and overall richness upon temporally scheduled food bait releases (data under processing for publication).

Generally, stranded cetaceans' carcasses found in European coasts are dolphin and porpoises [87]. In a framework of increasing climate change and human impact stranded carcasses of cetaceans are predicted to decrease, reflecting species demographic declines, provoking still not completely understood ecological effects [85]. In fact, its possible effect on the trophic food web structure is still unknown since the spatio-temporal scale of this phenomenon is not yet understood. In Chapter 3 case common sighted coastal species at the OBSEA, such as *Coris julis* and *Diplodus sargus* [82], that normally have a diet based on polychaetes, bivalve and gastropods and are well known coastal species [294], were observed to directly exploit the cetacean carcass. This opportunistic behaviour was unknown before this experiment, increasing our knowledge on the possible feeding interaction in coastal marine food webs in the Mediterranean Sea. Also, the invertebrate *Octopus vulgaris*, that is not commonly sighted at the OBSEA, were observed to be actively exploiting the carcass. This opportunistic species commonly feeds on other molluscs, crustaceans, and fishes [295], and has a bathymetric range from shallow to about 300 m depth [296]. Its opportunistic feeding behaviour could be further confirmed with the study of Chapter 3, evidencing importance of dead animals for its diet. In addition to these species also *Diplodus puntazzo, Diplodus vulgaris,* and *Oblada melanura* were significantly increasing in counts probably due to the presence of their invertebrates' preys attracted as well by the carcass (not detected by camera because of their small dimension, lesser than 2 cm, or buried in the sediment) [294].

As the presence of stranded cetacean on the beach could result in a biohazard for the human population that lives on the coasts, their carcasses are generally incinerated or buried in special areas at a high cost [87]. However, these carcasses in particular cases were proposed to be redeployed in marine areas after necropsy (to check for possible pathogens or contaminants harmful for the ecosystems) to reduce the disposal costs. This is the case of the Spanish legislation (Regulation 1069/09), that allows the reintegration of stranded cetacean carcasses, allowing the use of the OBSEA platform (Vilanova i la Geltrú, Spain) for the Chapter 3 experiment. This experiment proved the importance of returning cetacean carcasses' biomass into the marine environment, when animals are found dead stranded on the coasts, because of the increasing number of the marine species probably attracted by the carcass scent, and its related community. This solution is supported by a recent review on the ecosystem services provided by cetacean carcasses, encouraging "the implementation of innovative science outreach via citizen science and education to foster enhanced local ecological knowledge and appreciation of ecosystem services provided by cetacean carcasses, which may lead towards more sustainable practices" [87].

Finally, the artificial food fall experiment and consequent long-lasting multiparametric monitoring described in Chapter 3 was the first carried out in coastal areas of the Mediterranean, to the best of the authors' knowledge. In general, cetacean experimental falls were carried out in deep-sea habitat evidencing four stages (i.e., mobile scavenger, enrichment-opportunistic, sulfophilic, and reef stage) [90], with only few works outside the Mediterranean Sea at shallow depths (i.e., about 30 m) [94], [259], [260]. Only the scavenger stage was studied in Chapter 3 for methodological constrains (i.e., only organisms bigger that 2 cm could be spotted with the current HD camera quality setting). Furthermore, this study highlighted the importance of using high-frequency sampling methods with new technologies, as proposed in previous works, to diminish the sampling bias at only light or night hours, and thus properly study the behaviour and turnover of scavenging species within the coastal community [93], [94].

2. FUTURE PERSPECTIVES

In future perspective in the use of seafloor cabled observatories for environmental monitoring, the EMSO testing site OBSEA could be used to try new cameras' settings to augment the ecological representativeness of fixed platforms' monitoring. In this perspective, a recent deployment of a crawler equipped with camera at the OBSEA proved the importance of concomitant image acquisition with the use of different platforms [56]. In particular, it was observed that while the OBSEA camera was focussing the water column above the sea bottom, the crawler focussed on the layer between the benthos and the water column (Benthic Boundary Layer), resulting in different species composition of the same monitored area (i.e., not only fishes but a wide set of invertebrates). This highlight the importance to develop cameras' networks focussing on different marine domains to have a better picture of the ongoing changes affecting the benthic and pelagic communities. In particular, this has to be performed with concomitant video/image acquisition (e.g., mobile platforms performing one minute transects concomitantly to the image acquisition of the fixed cameras) over long period of time (i.e., years). These benthic platforms will help also in the construction of photo mosaics of the cable observatory surroundings for seabed exploration, and in the detection of benthic macro-invertebrates to enlarge the monitored area and ecological representativeness.

Also, the environmental variables are important when considering the technologically advanced monitoring of the marine environment. For example, a test for the EMSO Generic Instrument Module (EGIM) at the OBSEA expanded the previous payload adding information on the concentration of oxygen in the water, as important Essential Oceanic Variable (EOV) to determine the environmental status [58]. This trial deployment added information on the detected species temporal niche thanks to the concomitant image acquisition from two cameras focussing the EGIM multiparametric platform. As EGIM lacks of cameras (i.e., biological information), long-term deployment of such multiparametric sensors with concomitant synchronized image acquisition, as landers, in a spatial representative network will be a key factor in the marine ecological monitoring. Also, remote sensing, as satellites, can help in the environmental data acquisition enlarging the monitored area taking averaged measurements of 1 km radius pixel of the water surface [297]. But, unfortunately, they were resulted to be representative only of the few centimetres below the water surface, resulting ineffective for the monitoring of subsurface oceanic strata [18].

After spent time to the Acqua Alta Oceanographic Tower in Venice (www.ismar.cnr.it/infrastructures/piattaforma-acqua-alta) and in SmartBay platform in Ireland (www.smartbay.ie) during the development of this Thesis, similar constrains raised when considering the great efforts that experts have to involve when processing the video/image platforms repositories. This problem could be solved by using machine learning procedures, developing algorithms that can automatically recognize important image content for the scientists in the different repositories. Even if the algorithms to train the machines in this job are already well developed, such as in the case of YOLO [298], video/image repositories properly labelled by experts are scant. For this reason, my advice for future annotations of the video/image repositories from underwater platforms is to use labelling tools, such as BIIGLE (www.biigle.de), to create important datasets for both biological/ecological studies and for AI development.

Under the guidelines of a recent work for fish identification and classification with Mediterranean shallow water images' material and YOLOv5 [293], working with few hundred labelled objects per species is a cost-efficient solution to develop algorithms that can automatically detect and classify fishes. However, as pointed out in Chapter 2 it is important to train the machine with images acquired across different seasonal and diel (i.e., day and night) cycles, because of the temporal exchange in species due to migrations, in particular with actively mobile species, as fishes, and in areas with marked seasonal changes, as the Mediterranean. Another recommendation is to train again the machine when using different cameras with different colours balance settings for fish classification, as observed in a recent article using part of this dataset for machine learning procedures [62].

Finally, to study large animals' food falls impact in coastal areas, in particular in the Mediterranean Sea where the information is almost inexistent, the study presented in Chapter 3 will be replicated for the four seasons of the temperate Mediterranean region to detect any changes in the scavenger species composition following a similar experiment performed in the Salish Sea, in British Columbia [265]. This will clarify the importance of large marine animals falls, such as cetaceans, in shallow water habitats to better manage this important organic nutrient resources for the marine opportunistic scavenger communities. As observed in Chapter 3, this artificial food falls could be performed in oligotrophic areas to restore marine areas impacted by human activities (as Vilanova i la Geltrú port, where the OBSEA was closely deployed). Today large animals stranded carcasses are generally incinerated or disposed as waste after necropsy with related high economical costs [87]. Instead, the proposed deployment of these carcasses in the marine environment where does not create problems to the human society, in addition to the described positive impact on the opportunistic scavenger community, it has also a positive economic impact saving money used for the carcass's incineration or disposal.

3. CONCLUSIONS

- Even if the use of fixed platforms is not spatially representative of the environmental heterogeneity in the monitoring area, when high-frequency and multiannual continuous time series are achieved their statistical treatment could provide important hints on species abundances local dynamics and trends. This is also evidenced by the relevance of that technology to study activity rhythms and their diel and seasonal modulation in relation to seasonally-driven growth and reproduction abundance changes.

- However spatial representativeness could be reached with networks of cameras, more studies are required in order to calibrate time series of counts with abundance data achieved in the same areas with other sampling platforms, such as docked crawlers (short range; hundreds of meters) and ROVs (large range; tens of kilometres).

- Concomitant biological (i.e., animals' count and classification) and environmental data acquisition from cabled observatories is of pivotal importance to study the reaction of species to climate change scenarios, as in the case of *Dentex* where animals may increase in abundance over the next decade due to warming water temperatures as this is a fish thermophilic species.

- Decadal high-frequency monitoring by cabled observatories can help the scientific community to disclose important biological information on marine species Hutchinson's niche, starting for a precise definition of its temporal components in relation to the expression of biological rhythms, and how those rhythms are modulated by the different measured habitat variables.

- The use of new technologies is recommended as marine ecosystems' management tool thanks to its low impact on the marine environment compared to human-based methodologies, such as SCUBA divers visual census and trawling surveys.

- The importance of high-quality image data repositories with manually tagged and classified animals to be used as training sets to implement AI routines for the automated extraction of the meaningful biological information from the video/images acquired at cabled seafloor observatories' platforms.

- The high-frequency video-monitoring of species abundance (proxied by counts) and succession at a dolphin carcass are useful for describing a previously poorly known aspect of coastal ecosystem food web dynamic, setting the bases to perform a diversified range of in situ-experiments, with different species including turtles and monitoring platforms (e.g., crawlers wandering around).

- Artificial food falls monitoring trials are of strategic importance to provide management guidelines for body disposals at lower costs into marine ecosystems, with a protocol for quantifying the impact on resident communities. These types of studies are particularly important in the Mediterranean Sea and in shallow water habitats, where the information is almost inexistent.

REFERENCES

[1] R. López de la Lama, S. de la Puente, J. C. Sueiro, and K. M. A. Chan, "Reconnecting with the past and anticipating the future: A review of fisheries-derived cultural ecosystem services in pre-Hispanic Peru," *People Nat.*, vol. 3, pp. 129–147, 2021, doi: 10.1002/pan3.10153.

[2] W. Martin, J. Baross, D. Kelley, and M. J. Russell, "Hydrothermal vents and the origin of life," *Nat. Rev. Microbiol.*, vol. 6, pp. 805–814, 2008, doi: 10.1038/nrmicro1991.

[3] B. Yang, Yeyao Liu, and Jiawei Liao, "Manned Submersibles—Deep-sea Scientific Research and Exploitation of Marine Resources. Bulletin of Chinese Academy of Sciences, 36(5), 622-631.," *Bull. Chinese Acad. Sci. (Chinese Version)*, vol. 36, pp. 662–631, 2021, doi: 10.16418/j.issn.1000-3045.20210408004.

[4] J. Assis, B. Claro, A. Ramos, J. Boavida, and E. A. Serrão, "Performing fish counts with a wide-angle camera, a promising approach reducing divers' limitations," *J. Exp. Mar. Bio. Ecol.*, vol. 445, pp. 93–98, 2013, doi: 10.1016/j.jembe.2013.04.007.

[5] E. Ramirez-Llodra *et al.*, "Man and the last great wilderness: Human impact on the deep sea," *PLoS One*, vol. 6, p. e22588, 2011, doi: 10.1371/journal.pone.0022588.

[6] B. S. Halpern *et al.*, "Recent pace of change in human impact on the world's ocean," *Sci. Rep.*, vol. 9, pp. 1–8, 2019, doi: 10.1038/s41598-019-47201-9.

[7] Q. He and B. R. Silliman, "Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene," *Curr. Biol.*, vol. 29, pp. R1021–R1035, 2019, doi: 10.1016/j.cub.2019.08.042.

[8] C. Simeoni *et al.*, "Evaluating the combined effect of climate and anthropogenic stressors on marine coastal ecosystems: Insights from a systematic review of cumulative impact assessment approaches," *Sci. Total Environ.*, vol. 861, p. 160687, 2023, doi: 10.1016/j.scitotenv.2022.160687.

[9] E. S. Poloczanska *et al.*, "Responses of marine organisms to climate change across oceans," *Front. Mar. Sci.*, vol. 3, pp. 1–21, 2016, doi: 10.3389/fmars.2016.00062.

[10] N. G. Yoccoz, J. D. Nichols, and T. Boulinier, "Monitoring of biological diversity in space and time," *Trends Ecol. Evol.*, vol. 16, pp. 446–453, 2001, doi: 10.1016/S0169-5347(01)02205-4.

[11] J. P. G. Jones, "Monitoring species abundance and distribution at the landscape scale," *J. Appl. Ecol.*, vol. 48, pp. 9–13, 2011, doi: 10.1111/j.1365-2664.2010.01917.x.

[12] L. Woodall *et al.*, "A Multidisciplinary Approach for Generating Globally Consistent Data on Mesophotic, Deep-Pelagic, and Bathyal Biological Communities," *Oceanography*, vol. 31, pp. 76–89, 2018, doi: 10.5670/oceanog.2018.301.

[13] R. Long, “The Marine Strategy Framework Directive: A New European Approach to the Regulation of the Marine Environment, Marine Natural Resources and Marine Ecological Services,” *J. Energy Nat. Resour. Law*, vol. 29, pp. 1–44, 2011, doi: 10.1080/02646811.2011.11435256.

[14] F. E. Muller-Karger *et al.*, “Advancing marine biological observations and data requirements of the complementary Essential Ocean Variables (EOVs) and Essential Biodiversity Variables (EBVs) frameworks,” *Front. Mar. Sci.*, vol. 5, pp. 1–15, 2018, doi: 10.3389/fmars.2018.00211.

[15] V. Ryabinin *et al.*, “The UN decade of ocean science for sustainable development,” *Front. Mar. Sci.*, vol. 6, pp. 1–10, 2019, doi: 10.3389/fmars.2019.00470.

[16] G. T. Pecl *et al.*, “Rapid assessment of fisheries species sensitivity to climate change,” *Clim. Change*, vol. 127, pp. 505–520, 2014, doi: 10.1007/s10584-014-1284-z.

[17] X. Grane-Feliu, S. Bennett, B. Hereu, E. Aspillaga, and J. Santana-Garcon, “Comparison of diver operated stereo-video and visual census to assess targeted fish species in Mediterranean marine protected areas,” *J. Exp. Mar. Bio. Ecol.*, vol. 520, p. 151205, 2019, doi: 10.1016/j.jembe.2019.151205.

[18] J. Aguzzi *et al.*, “New High-Tech Flexible Networks for the Monitoring of Deep-Sea Ecosystems,” *Environ. Sci. Technol.*, vol. 53, pp. 6616–6631, 2019, doi: 10.1021/acs.est.9b00409.

[19] H. M. Murphy and G. P. Jenkins, “Observational methods used in marine spatial monitoring of fishes and associated habitats: A review,” *Mar. Freshw. Res.*, vol. 61, pp. 236–252, 2010, doi: 10.1071/MF09068.

[20] I. D. Williams, W. J. Walsh, B. N. Tissot, and L. E. Hallacher, “Impact of observers’ experience level on counts of fishes in underwater visual surveys,” *Mar. Ecol. Prog. Ser.*, vol. 310, pp. 185–191, 2006, doi: 10.3354/meps310185.

[21] C. R. Priester, L. Martínez-Ramírez, K. Erzini, and D. Abecasis, “The impact of trammel nets as an MPA soft bottom monitoring method,” *Ecol. Indic.*, vol. 120, p. 106877, 2021, doi: 10.1016/j.ecolind.2020.106877.

[22] S. N. De Mendonça and A. Metaxas, “Comparing the Performance of a Remotely Operated Vehicle, a Drop Camera, and a Trawl in Capturing Deep-Sea Epifaunal Abundance and Diversity,” *Front. Mar. Sci.*, vol. 8, pp. 1–17, 2021, doi: 10.3389/fmars.2021.631354.

[23] S. Tecchio *et al.*, “Seasonal fluctuations of deep megabenthos: Finding evidence of standing stock accumulation in a flux-rich continental slope,” *Prog. Oceanogr.*, vol. 118, pp. 188–198, 2013, doi: 10.1016/j.pocean.2013.07.015.

[24] A. Ayma *et al.*, “Comparison between ROV video and Agassiz trawl methods for sampling deep

water fauna of submarine canyons in the Northwestern Mediterranean Sea with observations on behavioural reactions of target species," *Deep. Res. Part I Oceanogr. Res. Pap.*, vol. 114, pp. 149–159, 2016, doi: 10.1016/j.dsr.2016.05.013.

[25] J. Aguzzi and J. B. Company, "Chronobiology of Deep-Water Decapod Crustaceans on Continental Margins," *Adv. Mar. Biol.*, vol. 58, pp. 155–225, 2010, doi: 10.1016/B978-0-12-381015-1.00003-4.

[26] J. Martín, P. Puig, A. Palanques, and A. Giamportone, "Commercial bottom trawling as a driver of sediment dynamics and deep seascape evolution in the Anthropocene," *Anthropocene*, vol. 7, pp. 1–15, 2014, doi: 10.1016/j.ancene.2015.01.002.

[27] A. Eleftheriou, *Methods for the study of marine benthos*, 4th ed. Chichester, West Sussex, UK: Wiley Blackwell, 2013.

[28] R. Danovaro *et al.*, "An ecosystem-based deep-ocean strategy," *Science (80-.).*, vol. 355, pp. 452–454, 2017, doi: 10.1126/science.aah7178.

[29] J. Aguzzi *et al.*, "Coastal observatories for monitoring of fish behaviour and their responses to environmental changes," *Rev. Fish Biol. Fish.*, vol. 25, pp. 463–483, 2015, doi: 10.1007/s11160-015-9387-9.

[30] J. Aguzzi *et al.*, "The hierarchic treatment of marine ecological information from spatial networks of benthic platforms," *Sensors*, vol. 20, p. 1751, 2020, doi: 10.3390/s20061751.

[31] J. Aguzzi *et al.*, "The potential of video imagery from worldwide cabled observatory networks to provide information supporting fish-stock and biodiversity assessment," *ICES J. Mar. Sci.*, vol. 77, pp. 2396–2410, 2020, doi: 10.1093/icesjms/fsaa169.

[32] R. Danovaro *et al.*, "Ecological variables for developing a global deep-ocean monitoring and conservation strategy," *Nat. Ecol. Evol.*, vol. 4, pp. 181–192, 2020, doi: 10.1038/s41559-019-1091-z.

[33] N. MacLeod, M. Benfield, and P. Culverhouse, "Time to automate identification," *Nature*, vol. 467, pp. 154–155, 2010, doi: 10.1038/467154a.

[34] R. E. Jones, R. A. Griffin, and R. K. F. Unsworth, "Adaptive Resolution Imaging Sonar (ARIS) as a tool for marine fish identification," *Fish. Res.*, vol. 243, p. 106092, 2021, doi: 10.1016/j.fishres.2021.106092.

[35] T. W. Davies and T. Smyth, "Why artificial light at night should be a focus for global change research in the 21st century," *Glob. Chang. Biol.*, vol. 24, pp. 872–882, 2018, doi: 10.1111/gcb.13927.

[36] C. M. Duarte *et al.*, "The soundscape of the Anthropocene ocean," *Science (80-.).*, vol. 371, p.

eaba4658, 2021, doi: 10.1126/science.aba4658.

[37] J. Reubens, K. Aarestrup, C. Meyer, A. Moore, F. Okland, and P. Afonso, “Compatibility in acoustic telemetry,” *Anim. Biotelemetry*, vol. 9, pp. 1–6, 2021, doi: 10.1186/s40317-021-00253-z.

[38] J. Aguzzi *et al.*, “Burrow emergence rhythms of deep-water Mediterranean Norway lobsters (Nephrops norvegicus) revealed by acoustic telemetry,” *Rev. Fish Biol. Fish.*, pp. 1–18, 2023, doi: 10.1007/s11160-023-09787-2.

[39] M. Vigo *et al.*, “Spatial ecology of Norway lobster Nephrops norvegicus in Mediterranean deep-water environments: implications for designing no-take marine reserves,” *Mar. Ecol. Prog. Ser.*, vol. 674, pp. 173–188, 2021, doi: 10.3354/meps13799.

[40] I. Masmitja *et al.*, “Mobile robotic platforms for the acoustic tracking of deep-sea demersal fishery resources,” *Sci. Robot.*, vol. 5, no. 48, 2020, doi: 10.1126/scirobotics.abc3701.

[41] D. Cato, R. McCauley, T. Rogers, and M. Noad, “Passive acoustics for monitoring marine animals - Progress and challenges,” in *Proceedings of ACOUSTICS 2006*, 2006, no. 20-22 November, pp. 453–460.

[42] E. A. Ottesen, “Probing the living ocean with ecogenomic sensors,” *Curr. Opin. Microbiol.*, vol. 31, pp. 132–139, 2016, doi: 10.1016/j.mib.2016.03.012.

[43] S. Stefanni *et al.*, “Framing Cutting-Edge Integrative Deep-Sea Biodiversity Monitoring via Environmental DNA and Optoacoustic Augmented Infrastructures,” *Front. Mar. Sci.*, vol. 8, pp. 1–17, 2022, doi: 10.3389/fmars.2021.797140.

[44] L. Mirimin *et al.*, “Don’t catch me if you can – Using cabled observatories as multidisciplinary platforms for marine fish community monitoring: An in situ case study combining Underwater Video and environmental DNA data,” *Sci. Total Environ.*, vol. 773, pp. 1–11, 2021, doi: 10.1016/j.scitotenv.2021.145351.

[45] F. Sinniger *et al.*, “Worldwide analysis of sedimentary DNA reveals major gaps in taxonomic knowledge of deep-sea benthos,” *Front. Mar. Sci.*, vol. 3, p. 92, 2016, doi: 10.3389/fmars.2016.00092.

[46] J. Aguzzi *et al.*, “Inertial bioluminescence rhythms at the Capo Passero (KM3NeT-Italia) site, Central Mediterranean Sea,” *Sci. Rep.*, vol. 7, pp. 1–13, 2017, doi: 10.1038/srep44938.

[47] E. Raugel, J. Opderbecke, M. C. Fabri, L. Brignone, and V. Rigaud, “Operational and scientific capabilities of Ariane, Ifremer’s hybrid ROV,” in *OCEANS 2019*, 2019, vol. June 2019, pp. 1–7, doi: 10.1109/OCEANSE.2019.8867102.

[48] A. Purser *et al.*, “Temporal and spatial benthic data collection via an internet operated Deep Sea Crawler,” *Methods Oceanogr.*, vol. 5, pp. 1–18, 2013, doi: 10.1016/j.mio.2013.07.001.

[49] M. Lin and C. Yang, “Ocean Observation Technologies: A Review,” *Chinese J. Mech. Eng.*, vol. 33, pp. 1–18, 2020, doi: 10.1186/s10033-020-00449-z.

[50] R. A. Rountree *et al.*, “Towards an optimal design for ecosystem-level ocean observatories,” in *Oceanography and Marine Biology*, S. J. Hawkins, A. L. Allcock, A. E. Bates, A. J. Evans, L. B. Firth, C. D. McQuaid, B. D. Russell, I. P. Smith, S. E. Swearer, and P. A. Todd, Eds. Milton Park: Taylor and Francis, 2020, pp. 79–106.

[51] A. Campos-Candela, M. Palmer, S. Balle, and J. Alós, “A camera-based method for estimating absolute density in animals displaying home range behaviour,” *J. Anim. Ecol.*, vol. 87, pp. 825–837, 2018, doi: 10.1111/1365-2656.12787.

[52] J. J. Dañobeitia *et al.*, “Towards a comprehensive and integrated strategy of the European Marine Research Infrastructures for Ocean Observations,” *Front. Mar. Sci.*, vol. 7, p. 180, 2020, doi: 10.3389/fmars.2020.00180.

[53] J. J. Dañobeitia *et al.*, “The role of the marine research infrastructures in the European marine observation landscape: present and future perspectives,” *Front. Mar. Sci.*, vol. 10, pp. 1–13, 2023, doi: 10.3389/fmars.2023.1047251.

[54] 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.

[55] X. Roset *et al.*, “Real-time seismic data from the bottom sea,” *Sensors*, vol. 18, pp. 1–15, 2018, doi: 10.3390/s18041132.

[56] A. Falahzadeh *et al.*, “A New Coastal Crawler Prototype to Expand the Ecological Monitoring Radius of OBSEA Cabled Observatory,” *J. Mar. Sci. Eng.*, vol. 11, pp. 1–25, 2023, doi: 10.3390/jmse11040857.

[57] G. Picardi, M. Chellapurath, S. Iacoponi, S. Stefanni, C. Laschi, and M. Calisti, “Bioinspired underwater legged robot for seabed exploration with low environmental disturbance,” *Sci. Robot.*, vol. 5, pp. 1–15, 2020, doi: 10.1126/SCIROBOTICS.AAZ1012.

[58] N. Lantéri *et al.*, “The EMSO Generic Instrument Module (EGIM): Standardized and Interoperable Instrumentation for Ocean Observation,” *Front. Mar. Sci.*, vol. 9, pp. 1–17, 2022, doi: 10.3389/fmars.2022.801033.

[59] I. Masmitja, S. Gomariz, J. Del-Rio, and J. Aguzzi, “OBSEA: A test site to develop marine ecosystems monitoring techniques by acoustic devices,” in *2019 IMEKO TC19 International*

Workshop on Metrology for the Sea, pp. 151–155.

[60] N. K. Dulvy, S. I. Rogers, S. Jennings, V. Stelzenmüller, S. R. Dye, and H. R. Skjoldal, "Climate change and deepening of the North Sea fish assemblage: A biotic indicator of warming seas," *J. Appl. Ecol.*, vol. 45, pp. 1029–1039, 2008, doi: 10.1111/j.1365-2664.2008.01488.x.

[61] S. Marini, E. Fanelli, V. Sbragaglia, E. Azzurro, J. Del Rio Fernandez, and J. Aguzzi, "Tracking Fish Abundance by Underwater Image Recognition," *Sci. Rep.*, vol. 8, pp. 1–12, 2018, doi: 10.1038/s41598-018-32089-8.

[62] E. Ottaviani, M. Francescangeli, N. Gjeci, J. del Rio Fernandez, J. Aguzzi, and S. Marini, "Assessing the Image Concept Drift at the OBSEA Coastal Underwater Cabled Observatory," *Front. Mar. Sci.*, vol. 9, pp. 1–13, 2022, doi: 10.3389/fmars.2022.840088.

[63] D. H. Secor, *Migration ecology of marine fishes*, 1st ed. Baltimore, Maryland: Johns Hopkins University Press, 2015.

[64] J. Aguzzi, J. B. Company, P. Abelló, and J. A. García, "Ontogenetic changes in vertical migratory rhythms of benthopelagic shrimps Pasiphaea multidentata and P. sivado," *Mar. Ecol. Prog. Ser.*, vol. 335, pp. 167–174, 2007, doi: 10.3354/meps335167.

[65] J. Aguzzi *et al.*, "Behavioral rhythms of hydrocarbon seep fauna in relation to internal tides," *Mar. Ecol. Prog. Ser.*, vol. 418, pp. 47–56, 2010, doi: 10.3354/meps08835.

[66] N. S. Häfker, G. Andreatta, A. Manzotti, A. Falciatore, F. Raible, and K. Tessmar-Raible, "Rhythms and Clocks in Marine Organisms," *Ann. Rev. Mar. Sci.*, vol. 15, pp. 509–538, 2023, doi: 10.1146/annurev-marine-030422-113038.

[67] J. F. López-Olmeda, J. A. Madrid, and F. J. Sánchez-Vázquez, "Light and temperature cycles as zeitgebers of zebrafish (Danio rerio) circadian activity rhythms," *Chronobiol. Int.*, vol. 23, pp. 537–550, 2006, doi: 10.1080/07420520600651065.

[68] E. Arndt and J. Evans, "Diel activity of littoral and epipelagic teleost fishes in the Mediterranean Sea," *Rev. Fish Biol. Fish.*, vol. 32, pp. 497–519, 2022, doi: 10.1007/s11160-022-09697-9.

[69] A. M. Darnaude, M. L. Harmelin-Vivien, and C. Salen-Picard, "Food partitioning among flatfish (Pisces: Pleuronectiforms) juveniles in a mediterranean coastal shallow sandy area," *J. Mar. Biol. Assoc. United Kingdom*, vol. 81, pp. 119–127, 2001, doi: 10.1017/S0025315401003460.

[70] L. Cardona, "Seasonal changes in the food quality, diel feeding rhythm and growth rate of juvenile leaping grey mullet Liza saliens," *Aquat. Living Resour.*, vol. 12, pp. 263–270, 1999, doi: 10.1016/S0990-7440(00)86637-1.

[71] E. Gisbert, L. Cardona, and F. Castelló, “Diel feeding rhythm of grey mullet fry in northeastern Spain,” *Vie Milieu / Life Environ.*, vol. 47, pp. 47–51, 1997.

[72] N. López, J. Navarro, C. Barría, M. Albo-Puigserver, M. Coll, and I. Palomera, “Feeding ecology of two demersal opportunistic predators coexisting in the northwestern Mediterranean Sea,” *Estuar. Coast. Shelf Sci.*, vol. 175, pp. 15–23, 2016, doi: 10.1016/j.ecss.2016.03.007.

[73] L. Lopiano, S. Mirto, D. Scilipoti, and A. Mazzola, “Diel Feeding Features of Juveniles of Two Sparids in the Stagnone di Marsala Coastal Sound (Western Sicily, Italy),” in *Mediterranean Ecosystems*, F. M. Faranda, L. Guglielmo, and G. Spezie, Eds. Milano: Springer, 2001, pp. 209–214.

[74] E. Azzurro, J. Aguzzi, F. Maynou, J. J. Chiesa, and D. Savini, “Diel rhythms in shallow Mediterranean rocky-reef fishes: A chronobiological approach with the help of trained volunteers,” *J. Mar. Biol. Assoc. United Kingdom*, vol. 93, pp. 461–470, 2013, doi: 10.1017/S0025315412001166.

[75] F. Witkowski, A. Vion, and M. Bouchoucha, “Temporal partitioning of diurnal behavioural patterns of Coris julis and Diplodus vulgaris (Actinopterygii: Perciformes) in Mediterranean coralligenous habitats,” *Acta Ichthyol. Piscat.*, vol. 46, pp. 171–183, 2016, doi: 10.3750/AIP2016.46.3.02.

[76] J. Aguzzi *et al.*, “Ecological video monitoring of Marine Protected Areas by underwater cabled surveillance cameras,” *Mar. Policy*, vol. 119, p. 104052, 2020, doi: 10.1016/j.marpol.2020.104052.

[77] P. Arechavala-Lopez, D. Izquierdo-Gomez, I. Uglem, and P. Sanchez-Jerez, “Aggregations of bluefish Pomatomus saltatrix (L.) at Mediterranean coastal fish farms: seasonal presence, daily patterns and influence of farming activity,” *Environ. Biol. Fishes*, vol. 98, pp. 499–510, 2015, doi: 10.1007/s10641-014-0280-5.

[78] G. La Mesa, I. Consalvo, A. Annunziatellis, and S. Canese, “Spatio-temporal movement patterns of Diplodus vulgaris (Actinopterygii, Sparidae) in a temperate marine reserve (Lampedusa, Mediterranean Sea),” *Hydrobiologia*, vol. 720, pp. 129–144, 2013, doi: 10.1007/s10750-013-1631-5.

[79] N. Pieretti, M. Lo Martire, A. Farina, and R. Danovaro, “Marine soundscape as an additional biodiversity monitoring tool: A case study from the Adriatic Sea (Mediterranean Sea),” *Ecol. Indic.*, vol. 83, pp. 13–20, 2017, doi: 10.1016/j.ecolind.2017.07.011.

[80] M. Picciulin, R. Fiorin, C. Facca, and S. Malavasi, “Sound features and vocal rhythms as a proxy for locating the spawning ground of Sciaena umbra in the wild,” *Aquat. Conserv. Mar. Freshw. Ecosyst.*, vol. 30, pp. 1299–1312, 2020, doi: 10.1002/aqc.3340.

[81] V. Sbragaglia *et al.*, “Annual rhythms of temporal niche partitioning in the Sparidae family are correlated to different environmental variables,” *Sci. Rep.*, vol. 9, pp. 1–11, 2019, doi: 10.1038/s41598-018-37954-0.

[82] F. Condal *et al.*, “Seasonal rhythm in a Mediterranean coastal fish community as monitored by a cabled observatory,” *Mar. Biol.*, vol. 159, pp. 2809–2817, 2012, doi: 10.1007/s00227-012-2041-3.

[83] J. Aguzzi *et al.*, “Daily activity rhythms in temperate coastal fishes: Insights from cabled observatory video monitoring,” *Mar. Ecol. Prog. Ser.*, vol. 486, pp. 223–236, 2013, doi: 10.3354/meps10399.

[84] E. Fanelli *et al.*, “Seasonal changes in coastal fish assemblages by multiparametric video-observatory monitoring,” in *IMEKO TC19 Workshop on Metrology for the Sea*, 2017, vol. October 11, pp. 13–16.

[85] J. Roman *et al.*, “Whales as marine ecosystem engineers,” *Front. Ecol. Environ.*, vol. 12, pp. 377–385, 2014, doi: 10.1890/130220.

[86] J. J. Kiszka, M. S. Woodstock, and M. R. Heithaus, “Functional Roles and Ecological Importance of Small Cetaceans in Aquatic Ecosystems,” *Front. Mar. Sci.*, vol. 9, pp. 1–7, 2022, doi: 10.3389/fmars.2022.803173.

[87] M. M. Quaggiotto *et al.*, “Past, present and future of the ecosystem services provided by cetacean carcasses,” *Ecosyst. Serv.*, vol. 54, p. 101406, 2022, doi: 10.1016/j.ecoser.2022.101406.

[88] K. L. Laidre, I. Stirling, J. A. Estes, A. Kochnev, and J. Roberts, “Historical and potential future importance of large whales as food for polar bears,” *Front. Ecol. Environ.*, vol. 16, pp. 515–524, 2018, doi: 10.1002/fee.1963.

[89] R. Danovaro, P. V. R. Snelgrove, and P. Tyler, “Challenging the paradigms of deep-sea ecology,” *Trends Ecol. Evol.*, vol. 29, pp. 465–475, 2014, doi: 10.1016/j.tree.2014.06.002.

[90] 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.

[91] A. J. Gooday, C. M. Turley, and J. A. Allen, “Responses by Benthic Organisms to Inputs of Organic Material to the Ocean Floor: A Review.,” *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.*, vol. 331, pp. 119–138, 1990, doi: 10.1098/rsta.1990.0060.

[92] J. C. Britton and B. Morton, “Marine carrion and scavengers,” in *Oceanography and Marine Biology: An Annual Review*, A. D. Ansell, R. N. Gibson, and M. Barnes, Eds. London, UK: UCL Press, 1994, pp. 369–434.

[93] J. Aguzzi *et al.*, “Faunal activity rhythms influencing early community succession of an implanted whale carcass offshore Sagami Bay, Japan,” *Sci. Rep.*, vol. 8, pp. 1–15, 2018, doi: 10.1038/s41598-018-29431-5.

[94] A. G. Glover *et al.*, “A live video observatory reveals temporal processes at a shelf-depth whale-fall,”

Cah. Biol. Mar., vol. 51, pp. 1–7, 2010.

[95] R. G. Foster and L. Kreitzman, *Seasons of life: the biological rhythms that enable living things to thrive and survive*. New Haven, CT: Yale University Press, 2010.

[96] M. E. Visser, S. P. Caro, K. Van Oers, S. V. Schaper, and B. Helm, “Phenology, seasonal timing and circannual rhythms: Towards a unified framework,” *Philos. Trans. R. Soc. B*, vol. 365, pp. 3113–3127, 2010, doi: 10.1098/rstb.2010.0111.

[97] B. Helm *et al.*, “Annual rhythms that underlie phenology: Biological time-keeping meets environmental change,” *Proc. R. Soc. B*, vol. 280, p. 20130016, 2013, doi: 10.1098/rspb.2013.0016.

[98] N. Kronfeld-Schor, G. Bloch, and W. J. Schwartz, “Animal clocks: When science meets nature,” *Proc. R. Soc. B*, vol. 280, p. 2013135420131354, 2013, doi: 10.1098/rspb.2013.1354.

[99] E. Naylor, *Chronobiology of marine organisms*. New York, NY: Cambridge University Press, 2010.

[100] S. Daan, “Adaptive Daily Strategies in Behavior,” in *Biological Rhythms*, J. Aschoff, Ed. Boston, MA: Springer, 1981, pp. 275–298.

[101] S. G. Reebs, “Plasticity of diel and circadian activity rhythms in fishes,” *Rev. Fish Biol. Fish.*, vol. 12, pp. 349–371, 2002, doi: 10.1023/A:1025371804611.

[102] G. G. Mittelbach, N. G. Ballew, and M. K. Kjelvik, “Fish behavioral types and their ecological consequences,” *Can. J. Fish. Aquat. Sci.*, vol. 71, pp. 927–944, 2014, doi: 10.1139/cjfas-2013-0558.

[103] J. Falcón, H. Migaud, J. A. Muñoz-Cueto, and M. Carrillo, “Current knowledge on the melatonin system in teleost fish,” *Gen. Comp. Endocrinol.*, vol. 165, pp. 469–482, 2010, doi: 10.1016/j.ygcen.2009.04.026.

[104] M. Bulla, T. Oudman, A. I. Bijleveld, T. Piersma, and C. P. Kyriacou, “Marine biorhythms: Bridging chronobiology and ecology,” *Philos. Trans. R. Soc. B*, vol. 372, p. 20160253, 2017, doi: 10.1098/rstb.2016.0253.

[105] M. Cowan, C. Azpeleta, and J. F. López-Olmeda, *Rhythms in the endocrine system of fish: a review*, vol. 187. Springer Berlin Heidelberg, 2017.

[106] H. J. Wagner, K. Kemp, U. Mattheus, and I. G. Priede, “Rhythms at the bottom of the deep sea: Cyclic current flow changes and melatonin patterns in two species of demersal fish,” *Deep. Res. Part I Oceanogr. Res. Pap.*, vol. 54, pp. 1944–1956, 2007, doi: 10.1016/j.dsr.2007.08.005.

[107] M. R. Heithaus, A. Frid, A. J. Wirsing, and B. Worm, “Predicting ecological consequences of marine top predator declines.,” *Trends Ecol. Evol.*, vol. 23, pp. 202–210, 2008, doi: 10.1016/j.tree.2008.01.003.

[108] M. R. Heithaus, A. J. Wirsing, and L. M. Dill, “The ecological importance of intact top-predator populations: A synthesis of 15 years of research in a seagrass ecosystem,” *Mar. Freshw. Res.*, vol. 63, pp. 1039–1050, 2012, doi: 10.1071/MF12024.

[109] E. E. Byrnes, R. Daly, V. Leos-Barajas, R. Langrock, and A. C. Gleiss, “Evaluating the constraints governing activity patterns of a coastal marine top predator,” *Mar. Biol.*, vol. 168, pp. 1–15, 2021, doi: 10.1007/s00227-020-03803-w.

[110] J. Aguzzi, V. Sbragaglia, S. Tecchio, J. Navarro, and J. B. Company, “Rhythmic behaviour of marine benthopelagic species and the synchronous dynamics of benthic communities,” *Deep. Res. Part I Oceanogr. Res. Pap.*, vol. 95, pp. 1–11, 2015, doi: 10.1016/j.dsr.2014.10.003.

[111] J. Aguzzi *et al.*, “Multiparametric monitoring of fish activity rhythms in an Atlantic coastal cabled observatory,” *J. Mar. Syst.*, vol. 212, p. 103424, 2020, doi: 10.1016/j.jmarsys.2020.103424.

[112] I. I. Rodriguez-Pinto, G. Rieucau, N. O. Handegard, and K. M. Boswell, “Environmental context elicits behavioural modification of collective state in schooling fish,” *Anim. Behav.*, vol. 165, pp. 107–116, 2020, doi: 10.1016/j.anbehav.2020.05.002.

[113] J. R. Ford and S. E. Swearer, “Two’s company, three’s a crowd: Food and shelter limitation outweigh the benefits of group living in a shoaling fish,” *Ecology*, vol. 94, pp. 1069–1077, 2013, doi: 10.1890/12-1891.1.

[114] N. C. Makris *et al.*, “Instantaneous areal population density of entire Atlantic cod and herring spawning groups and group size distribution relative to total spawning population,” *Fish Fish.*, vol. 20, pp. 201–213, 2019, doi: 10.1111/faf.12331.

[115] K. O. Lear, N. M. Whitney, J. J. Morris, and A. C. Gleiss, “Temporal niche partitioning as a novel mechanism promoting co-existence of sympatric predators in marine systems,” *Proc. R. Soc. B*, vol. 288, p. 20210816, 2021, doi: 10.1098/rspb.2021.0816.

[116] J. J. Meager *et al.*, “Environmental regulation of individual depth on a cod spawning ground,” *Aquat. Biol.*, vol. 17, pp. 211–221, 2012, doi: 10.3354/ab00469.

[117] M. Georgiadis, N. Mavraki, C. Koutsikopoulos, and E. Tzanatos, “Spatio-temporal dynamics and management implications of the nightly appearance of Boops boops (Acanthopterygii, Perciformes) juvenile shoals in the anthropogenically modified Mediterranean littoral zone,” *Hydrobiologia*, vol. 734, pp. 81–96, 2014, doi: 10.1007/s10750-014-1871-z.

[118] V. Sbragaglia, J. W. Jolles, M. Coll, and R. Arlinghaus, “Fisheries-induced changes of shoaling behaviour: mechanisms and potential consequences,” *Trends Ecol. Evol.*, vol. 35, pp. 885–888, 2021, doi: 10.1016/j.tree.2021.06.015.

[119] P. V. R. Snelgrove, S. F. Thrush, D. H. Wall, and A. Norkko, "Real world biodiversity-ecosystem functioning: A seafloor perspective," *Trends Ecol. Evol.*, vol. 29, pp. 398–405, 2014, doi: 10.1016/j.tree.2014.05.002.

[120] G. E. Hutchinson, "Concluding Remarks," *Cold Spring Harb. Symp. Quant. Biol.*, vol. 22, pp. 415–427, 1957, doi: 10.1101/sqb.1957.022.01.039.

[121] T. Langlois *et al.*, "A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages," *Methods Ecol. Evol.*, vol. 11, pp. 1401–1409, 2020, doi: 10.1111/2041-210X.13470.

[122] J. C. Drazen, A. B. Leitner, D. O. B. Jones, and E. Simon-Lledó, "Regional Variation in Communities of Demersal Fishes and Scavengers Across the CCZ and Pacific Ocean," *Front. Mar. Sci.*, vol. 8, pp. 1–18, 2021, doi: 10.3389/fmars.2021.630616.

[123] S. K. Juniper, M. Matabos, S. Mihály, R. S. Ajayamohan, F. Gervais, and A. O. V. Bui, "A year in Barkley Canyon: A time-series observatory study of mid-slope benthos and habitat dynamics using the NEPTUNE Canada network," *Deep. Res. Part II Top. Stud. Oceanogr.*, vol. 92, pp. 114–123, 2013, doi: 10.1016/j.dsr2.2013.03.038.

[124] C. Doya *et al.*, "Diel behavioral rhythms in sablefish (Anoplopoma fimbria) and other benthic species, as recorded by the Deep-sea cabled observatories in Barkley canyon (NEPTUNE-Canada)," *J. Mar. Syst.*, vol. 130, pp. 69–78, 2014, doi: 10.1016/j.jmarsys.2013.04.003.

[125] M. Matabos, A. O. V. Bui, S. Mihály, J. Aguzzi, S. K. Juniper, and R. S. Ajayamohan, "High-frequency study of epibenthic megafaunal community dynamics in Barkley Canyon: A multi-disciplinary approach using the NEPTUNE Canada network," *J. Mar. Syst.*, vol. 130, pp. 56–68, 2014, doi: 10.1016/j.jmarsys.2013.05.002.

[126] M. Matabos, N. Piechaud, F. De Montigny, P. M. Sarradin, and J. Sarrazin, "The VENUS cabled observatory as a method to observe fish behaviour and species assemblages in a hypoxic fjord, Saanich inlet (British Columbia, Canada)," *Can. J. Fish. Aquat. Sci.*, vol. 72, pp. 24–36, 2015, doi: 10.1139/cjfas-2013-0611.

[127] R. J. Milligan *et al.*, "Evidence for seasonal cycles in deep-sea fish abundances: A great migration in the deep SE Atlantic?," *J. Anim. Ecol.*, vol. 89, pp. 1593–1603, 2020, doi: 10.1111/1365-2656.13215.

[128] F. Scapini, "Behaviour of mobile macrofauna is a key factor in beach ecology as response to rapid environmental changes," *Estuar. Coast. Shelf Sci.*, vol. 150, pp. 36–44, 2014, doi: 10.1016/j.ecss.2013.11.001.

[129] D. Chatzievangelou *et al.*, "Integrating Diel Vertical Migrations of Bioluminescent Deep Scattering

Layers Into Monitoring Programs," *Front. Mar. Sci.*, vol. 8, p. 615, 2021, doi: 10.3389/fmars.2021.661809.

[130] C. Doya *et al.*, "Seasonal monitoring of deep-sea megabenthos in Barkley Canyon cold seep by internet operated vehicle (IOV)," *PLoS One*, vol. 12, p. e0176917, 2017, doi: 10.1371/journal.pone.0176917.

[131] M. Marengo, E. D. H. Durieux, B. Marchand, and P. Francour, "A review of biology, fisheries and population structure of Dentex dentex (Sparidae)," *Rev. Fish Biol. Fish.*, vol. 24, pp. 1065–1088, 2014, doi: 10.1007/s11160-014-9363-9.

[132] V. Sbragaglia, R. A. Correia, S. Coco, and R. Arlinghaus, "Data mining on YouTube reveals fisher group-specific harvesting patterns and social engagement in recreational anglers and spearfishers," *ICES J. Mar. Sci.*, vol. 77, pp. 2234–2244, 2020, doi: 10.1093/icesjms/fsz100.

[133] J. Aguzzi *et al.*, "The new seafloor observatory (OBSEA) for remote and long-term coastal ecosystem monitoring," *Sensors*, vol. 11, pp. 5850–5872, 2011, doi: 10.3390/s110605850.

[134] M. Matabos *et al.*, "Multi-parametric study of behavioural modulation in demersal decapods at the VENUS cabled observatory in Saanich Inlet, British Columbia, Canada," *J. Exp. Mar. Bio. Ecol.*, vol. 401, pp. 89–96, 2011, doi: 10.1016/j.jembe.2011.02.041.

[135] J. Guillén *et al.*, "Coastal oceanographic signatures of heat waves and extreme events of dense water formation during the period 2002-2012 (Barcelona, NW Mediterranean)," *Sci. Mar.*, vol. 82, pp. 189–206, 2018, doi: 10.3989/scimar.04766.26A.

[136] A. Zuur, E. N. Ieno, and G. M. Smith, *Analyzing ecological data*, 1st ed. New York, NY: Springer, 2007.

[137] T. J. Pitcher, "Heuristic definitions of fish shoaling behaviour," *Anim. Behav.*, vol. 31, pp. 611–613, 1983, doi: 10.1016/S0003-3472(83)80087-6.

[138] J. Aguzzi, N. M. Bullock, and G. Tosini, "Spontaneous internal desynchronization of locomotor activity and body temperature rhythms from plasma melatonin rhythm in rats exposed to constant dim light," *J. Circadian Rhythms*, vol. 4, pp. 1–6, 2006, doi: 10.1186/1740-3391-4-6.

[139] A. Pocheville, "The ecological niche: history and recent controversies," in *Handbook of Evolutionary Thinking in the Sciences*, T. Heams, P. Huneman, G. Lecointre, and M. Silberstein, Eds. Dordrecht: Springer, 2015, pp. 547–586.

[140] J. Aguzzi *et al.*, "Challenges to the assessment of benthic populations and biodiversity as a result of rhythmic behaviour: Video solutions from cabled observatories," in *Oceanography and Marine Biology: An Annual Review*, vol. 50, R. N. Gibson, R. J. A. Atkinson, J. D. M. Gordon, R. N. Hughes,

D. J. Hughes, and I. P. Smith, Eds. Taylor & Francis, 2012, pp. 235–286.

[141] T. L. Hansteen, H. P. Andreassen, and R. A. Ims, "Effects of spatiotemporal scale on autocorrelation and home range estimators," *J. Wildl. Manage.*, vol. 61, pp. 280–290, 1997, doi: 10.2307/3802583.

[142] R. Refinetti, G. Cornélissen, and F. Halberg, "Procedures for numerical analysis of circadian rhythms," *Biol. Rhythm Res.*, vol. 38, pp. 275–325, 2007, doi: 10.1080/09291010600903692.

[143] H. Bu, F. Wang, W. J. McShea, Z. Lu, D. Wang, and S. Li, "Spatial Co-occurrence and activity patterns of mesocarnivores in the temperate forests of Southwest China," *PLoS One*, vol. 11, p. e0164271, 2016, doi: 10.1371/journal.pone.0164271.

[144] L. Gaudiano, L. Pucciarelli, and E. Mori, "Livestock grazing affects movements and activity pattern of Italian roe deer in Southern Italy," *Eur. J. Wildl. Res.*, vol. 67, pp. 1–8, 2021, doi: 10.1007/s10344-021-01506-1.

[145] A. Cama, P. Josa, J. Ferrer-Obiol, and J. M. Arcos, "Mediterranean Gulls Larus melanocephalus wintering along the Mediterranean Iberian coast: Numbers and activity rhythms in the species' main winter quarters," *J. Ornithol.*, vol. 152, pp. 897–907, 2011, doi: 10.1007/s10336-011-0673-6.

[146] M. Sonnewald and M. Türkay, "Abundance analyses of mega-epibenthic species on the Dogger Bank (North Sea): Diurnal rhythms and short-term effects caused by repeated trawling, observed at a permanent station," *J. Sea Res.*, vol. 73, pp. 1–6, 2012, doi: 10.1016/j.seares.2012.05.015.

[147] A. Ünlüoğlu, "Diel Variability in the Bottom-Trawl Catch Rates of Sparid Fishes in İzmir Bay (Central-Eastern Aegean Sea)," *Nat. Eng. Sci.*, vol. 6, pp. 138–154, 2021, doi: 10.28978/nesciences.1036842.

[148] R. D. Holt, "Bringing the Hutchinsonian niche into the 21st century: Ecological and evolutionary perspectives," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 106, pp. 19659–19665, 2009, doi: 10.1073/pnas.0905137106.

[149] L. Beaudrot *et al.*, "Standardized Assessment of Biodiversity Trends in Tropical Forest Protected Areas: The End Is Not in Sight," *PLoS Biol.*, vol. 14, p. e1002357, 2016, doi: 10.1371/journal.pbio.1002357.

[150] M. S. Norouzzadeh *et al.*, "Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 115, pp. E5716–E5725, 2018, doi: 10.1073/pnas.1719367115.

[151] M. A. Samoilys and G. Carlos, "Determining methods of underwater visual census for estimating the abundance of coral reef fishes," *Environ. Biol. Fishes*, vol. 57, pp. 289–304, 2000, doi: 10.1023/A:1007679109359.

[152] N. E. Hussey *et al.*, “Aquatic animal telemetry: A panoramic window into the underwater world,” *Science (80-.).*, vol. 348, p. 6240, 2015, doi: 10.1126/science.1255642.

[153] D. Villegas-Ríos, D. Réale, C. Freitas, E. Moland, and E. M. Olsen, “Individual level consistency and correlations of fish spatial behaviour assessed from aquatic animal telemetry,” *Anim. Behav.*, vol. 124, pp. 83–94, 2017, doi: 10.1016/j.anbehav.2016.12.002.

[154] J. W. Brownscombe *et al.*, “A practical method to account for variation in detection range in acoustic telemetry arrays to accurately quantify the spatial ecology of aquatic animals,” *Methods Ecol. Evol.*, vol. 11, pp. 82–94, 2020, doi: 10.1111/2041-210X.13322.

[155] J. K. Matley *et al.*, “Global trends in aquatic animal tracking with acoustic telemetry,” *Trends Ecol. Evol.*, vol. 37, pp. 79–94, 2022, doi: 10.1016/j.tree.2021.09.001.

[156] D. M. Dominoni, S. Åkesson, R. Klaassen, K. Spoelstra, and M. Bulla, “Methods in field chronobiology,” *Philos. Trans. R. Soc. B*, vol. 372, p. 20160247, 2017, doi: 10.1098/rstb.2016.0247.

[157] R. J. Lennox *et al.*, “Envisioning the Future of Aquatic Animal Tracking: Technology, Science, and Application,” *Bioscience*, vol. 67, pp. 884–896, 2017, doi: 10.1093/biosci/bix098.

[158] T. W. Davies, M. Coleman, K. M. Griffith, and S. R. Jenkins, “Night-time lighting alters the composition of marine epifaunal communities,” *Biol. Lett.*, vol. 11, p. 20150080, 2015, doi: 10.1098/rsbl.2015.0080.

[159] R. H. J. M. Kurvers, J. Drägestein, F. Hölker, A. Jechow, J. Krause, and D. Bierbach, “Artificial Light at Night Affects Emergence from a Refuge and Space Use in Guppies,” *Sci. Rep.*, vol. 8, p. 14131, 2018, doi: 10.1038/s41598-018-32466-3.

[160] M. Czarnecka, T. Kakareko, Ł. Jermacz, R. Pawlak, and J. Kobak, “Combined effects of nocturnal exposure to artificial light and habitat complexity on fish foraging,” *Sci. Total Environ.*, vol. 684, pp. 14–22, 2019, doi: 10.1016/j.scitotenv.2019.05.280.

[161] M. B. Lucena, T. C. Mendes, M. C. Barbosa, C. A. M. M. Cordeiro, L. M. Eggertsen, and C. E. L. Ferreira, “Does the colors of light matter? Testing different light color in nocturnal underwater visual censuses,” *Mar. Environ. Res.*, vol. 166, p. 105261, 2021, doi: 10.1016/j.marenvres.2021.105261.

[162] M. L. Harmelin-Vivien and P. Francour, “Trawling or Visual Censuses? Methodological Bias in the Assessment of Fish Populations in Seagrass Beds,” *Mar. Ecol.*, vol. 13, pp. 41–51, 1992, doi: 10.1111/j.1439-0485.1992.tb00338.x.

[163] F. A. Januchowski-Hartley, N. A. J. Graham, D. A. Feary, T. Morove, and J. E. Cinner, “Fear of fishers: Human predation explains behavioral changes in coral reef fishes,” *PLoS One*, vol. 6, p. e22761, 2011, doi: 10.1371/journal.pone.0022761.

[164] M. J. Emslie, A. J. Cheal, M. A. MacNeil, I. R. Miller, and H. P. A. Sweatman, “Reef fish communities are spooked by scuba surveys and may take hours to recover,” *PeerJ*, vol. 6, p. e4886, 2018, doi: 10.7717/peerj.4886.

[165] M. P. Pais and H. N. Cabral, “Effect of underwater visual survey methodology on bias and precision of fish counts: A simulation approach,” *PeerJ*, vol. 6, p. e5378, 2018, doi: 10.7717/peerj.5378.

[166] J. Aguzzi and N. Bahamon, “Modeled day-night biases in decapod assessment by bottom trawling survey,” *Fish. Res.*, vol. 100, pp. 274–280, 2009, doi: 10.1016/j.fishres.2009.08.010.

[167] L. O. Erikkson, “Nocturnalism versus diurnalism-dualism within fish individuals,” in *Rhythmic Activity of Fishes*, J. E. Thorpe, Ed. New York, NY: Academic Press, 1978, pp. 69–89.

[168] K. Muller, “Locomotor activity of fish and environmental oscillations,” in *Rhythmic activity of fishes*, J. E. Thorpe, Ed. London, UK: Academic Press, 1978, pp. 1–19.

[169] G. S. Helfman, “Fish behaviour by day, night, and twilight,” in *Behaviour of Teleost Fishes*, T. J. Pitcher, Ed. Boston, MA: Springer, 1986, pp. 366–387.

[170] K. L. Hawley, C. M. Rosten, T. O. Haugen, G. Christensen, and M. C. Lucas, “Freezer on, lights off! Environmental effects on activity rhythms of fish in the Arctic,” *Biol. Lett.*, vol. 13, p. 20170575, 2017, doi: 10.1098/rsbl.2017.0575.

[171] G. Schalm *et al.*, “Finding Nemo’s clock reveals switch from nocturnal to diurnal activity,” *Sci. Rep.*, vol. 11, pp. 1–11, 2021, doi: 10.1038/s41598-021-86244-9.

[172] D. P. Coles, “Dusk Transition in Sub-Tropical Reef Fish Communities Off of North and South Carolina,” The Graduate School of the College of Charleston, 2014.

[173] M. Pavlidis, L. Greenwood, M. Paalavuo, H. Mölsä, and J. T. Laitinen, “The effect of photoperiod on diel rhythms in serum melatonin, cortisol, glucose, and electrolytes in the common dentex, Dentex dentex,” *Gen. Comp. Endocrinol.*, vol. 113, pp. 240–250, 1999, doi: 10.1006/gcen.1998.7190.

[174] F. J. Sánchez-Vázquez, J. F. López-Olmeda, L. M. Vera, H. Migaud, M. A. López-Patiño, and J. M. Míguez, “Environmental cycles, melatonin, and circadian control of stress response in fish,” *Front. Endocrinol. (Lausanne).*, vol. 10, p. 279, 2019, doi: 10.3389/fendo.2019.00279.

[175] S. Saha, K. M. Singh, and B. B. P. Gupta, “Melatonin synthesis and clock gene regulation in the pineal organ of teleost fish compared to mammals: Similarities and differences,” *Gen. Comp. Endocrinol.*, vol. 279, pp. 27–34, 2019, doi: 10.1016/j.ygcen.2018.07.010.

[176] M. Zabala, A. García-Rubies, and J. Corbera, *Els peixos de les illes Medes i del litoral català: guia per observar-los al seu ambient*. Centre d’Estudis Marins de Badalona, 1992.

[177] E. Aspillaga, K. Safi, B. Hereu, and F. Bartumeus, “Modelling the three-dimensional space use of aquatic animals combining topography and Eulerian telemetry data,” *Methods Ecol. Evol.*, vol. 10, pp. 1551–1557, 2019, doi: 10.1111/2041-210X.13232.

[178] E. Aspillaga *et al.*, “Thermal stratification drives movement of a coastal apex predator,” *Sci. Rep.*, vol. 7, pp. 1–10, 2017, doi: 10.1038/s41598-017-00576-z.

[179] R. A. Hut, N. Kronfeld-Schor, V. van der Vinne, and H. De la Iglesia, “In search of a temporal niche: Environmental factors,” *Prog. Brain Res.*, vol. 199, pp. 281–304, 2012, doi: 10.1016/B978-0-444-59427-3.00017-4.

[180] B. Morales-Nin and J. Moranta, “Life history and fishery of the common dentex (Dentex dentex) in Mallorca (Balearic Islands, western Mediterranean),” *Fish. Res.*, vol. 30, pp. 67–76, 1997, doi: 10.1016/S0165-7836(96)00560-7.

[181] G. D’Anna, F. Badalamenti, M. Gristina, and C. Pipitone, “Influence of artificial reefs on coastal nekton assemblages of the Gulf of Castellammare (northwest Sicily),” *Bull. Mar. Sci.*, vol. 55, pp. 418–433, 1994.

[182] E. Azzurro, A. Pais, P. Consoli, and F. Andaloro, “Evaluating day-night changes in shallow mediterranean rocky reef fish assemblages by visual census,” *Mar. Biol.*, vol. 151, pp. 2245–2253, 2007, doi: 10.1007/s00227-007-0661-9.

[183] A. Lök, B. Gül, A. Ulaş, F. Ozan Düzbastilar, and C. Metin, “Diel variations on the fish assemblages at artificial reefs in two different environments of the Aegean sea (western coast of Turkey),” *Turkish J. Fish. Aquat. Sci.*, vol. 8, pp. 79–85, 2008.

[184] M. N. Santos, C. C. Monteiro, and M. B. Gaspar, “Diurnal variations in the fish assemblage at an artificial reef,” *ICES J. Mar. Sci.*, vol. 59, pp. S32–S35, 2002, doi: 10.1006/jmsc.2001.1166.

[185] N. Kronfeld-Schor and T. Dayan, “Partitioning of time as an ecological resource,” *Annu. Rev. Ecol. Evol. Syst.*, vol. 34, pp. 153–181, 2003, doi: 10.1146/132435.

[186] D. J. McCauley, E. Hoffmann, H. S. Young, and F. Micheli, “Night shift: Expansion of temporal niche use following reductions in predator density,” *PLoS One*, vol. 7, p. e38871, 2012, doi: 10.1371/journal.pone.0038871.

[187] K. A. Kerr, A. Cornejo, F. Guichard, A. C. C. Abril, and R. Collin, “Planktonic predation risk: Effects of diel state, season and prey life history stage,” *J. Plankton Res.*, vol. 37, pp. 452–461, 2015, doi: 10.1093/plankt/fbv006.

[188] N. G. Andersen, B. Lundgren, S. Neuenfeldt, and J. E. Beyer, “Diel vertical interactions between Atlantic cod Gadus morhua and sprat Sprattus sprattus in a stratified water column,” *Mar. Ecol. Prog.*

Ser., vol. 583, pp. 195–209, 2017, doi: 10.3354/meps12319.

[189] M. Olivares, P. Tiselius, A. Calbet, and E. Saiz, "Non-lethal effects of the predator Meganyctiphanes norvegica and influence of seasonal photoperiod and food availability on the diel feeding behaviour of the copepod Centropages typicus," *J. Plankton Res.*, vol. 42, pp. 742–751, 2020, doi: 10.1093/plankt/fbaa051.

[190] P. Priou *et al.*, "Dense mesopelagic sound scattering layer and vertical segregation of pelagic organisms at the Arctic-Atlantic gateway during the midnight sun," *Prog. Oceanogr.*, vol. 196, p. 102611, 2021, doi: 10.1016/j.pocean.2021.102611.

[191] R. J. Fox and D. R. Bellwood, "Unconstrained by the clock? Plasticity of diel activity rhythm in a tropical reef fish, Siganus lineatus," *Funct. Ecol.*, vol. 25, pp. 1096–1105, 2011, doi: 10.1111/j.1365-2435.2011.01874.x.

[192] C. A. Bustos, M. F. Landaeta, P. Palacios-Fuentes, N. Jahnsen-Guzmán, and F. Balbontín, "Comparing early life traits of hakes from Chilean Patagonian fjords inferred by otolith microstructure analysis," *Fish. Res.*, vol. 164, pp. 35–44, 2015, doi: 10.1016/j.fishres.2014.10.016.

[193] P. Mishra, A. K. Mohanty, R. Kumar Swain, A. Parganiha, and A. K. Pati, "Circannual production rhythms of seven commercially important fishes in the Chilika lagoon," *Biol. Rhythm Res.*, pp. 1–23, 2020, doi: 10.1080/09291016.2020.1750132.

[194] K. Liu *et al.*, "Spatiotemporal niche of major fish species in Pishan waters off Zhejiang Province, China," *Chinese J. Appl. Ecol.*, vol. 3, pp. 1069–1079, 2021, doi: 10.13287/j.1001-9332.202103.033.

[195] A. Grau *et al.*, "Reproductive strategy of common dentex Dentex dentex: management implications," *Mediterr. Mar. Sci.*, vol. 17, pp. 552–566, 2016, doi: 10.12681/mms.1156.

[196] T. J. Stevenson *et al.*, "Disrupted seasonal biology impacts health, food security and ecosystems," *Proc. R. Soc. B*, vol. 282, p. 20151453, 2015, doi: 10.1098/rspb.2015.1453.

[197] C. Vinagre *et al.*, "Vulnerability to climate warming and acclimation capacity of tropical and temperate coastal organisms," *Ecol. Indic.*, vol. 62, pp. 317–327, 2016, doi: 10.1016/j.ecolind.2015.11.010.

[198] K. A. Van Der Walt, F. Porri, W. M. Potts, M. I. Duncan, and N. C. James, "Thermal tolerance, safety margins and vulnerability of coastal species: Projected impact of climate change induced cold water variability in a temperate African region," *Mar. Environ. Res.*, vol. 169, p. 105346, 2021, doi: 10.1016/j.marenvres.2021.105346.

[199] V. E. Cussac, D. A. Fernández, S. E. Gómez, and H. L. López, "Fishes of southern South America: A story driven by temperature," *Fish Physiol. Biochem.*, vol. 35, pp. 29–42, 2009, doi: 10.1007/s10695-

008-9217-2.

[200] C. Freitas, E. M. Olsen, H. Knutsen, J. Albretsen, and E. Moland, “Temperature-associated habitat selection in a cold-water marine fish,” *J. Anim. Ecol.*, vol. 85, pp. 628–637, 2016, doi: 10.1111/1365-2656.12458.

[201] P. B. Day, R. D. Stuart-Smith, G. J. Edgar, and A. E. Bates, “Species’ thermal ranges predict changes in reef fish community structure during 8 years of extreme temperature variation,” *Divers. Distrib.*, vol. 24, pp. 1036–1046, 2018, doi: 10.1111/ddi.12753.

[202] C. Waldock, R. D. Stuart-Smith, G. J. Edgar, T. J. Bird, and A. E. Bates, “The shape of abundance distributions across temperature gradients in reef fishes,” *Ecol. Lett.*, vol. 22, pp. 685–696, 2019, doi: 10.1111/ele.13222.

[203] M. J. Orozco, J. L. S. Lizaso, and A. M. Fernández, “Capturas del dentón (Dentex dentex) en dos puertos del Mediterráneo ibérico,” *Mediterránea Ser. Estud. biológicos*, vol. 22, pp. 212–229, 2011, doi: 10.14198/MDTRRA2011.ESP.08.

[204] A. García-Rubies, B. Hereu, and M. Zabala, “Long-Term Recovery Patterns and Limited Spillover of Large Predatory Fish in a Mediterranean MPA,” *PLoS One*, vol. 8, p. e73922, 2013, doi: 10.1371/journal.pone.0073922.

[205] N. Bahamon *et al.*, “Stepped coastal water warming revealed by multiparametric monitoring at nw mediterranean fixed stations,” *Sensors*, vol. 20, p. 2658, 2020, doi: 10.3390/s20092658.

[206] G. M. Daskalov, “Long-term changes in fish abundance and environmental indices in the Black Sea,” *Mar. Ecol. Prog. Ser.*, vol. 255, pp. 259–270, 2003, doi: 10.3354/meps255259.

[207] S. L. H. Teo, A. M. Boustany, and B. A. Block, “Oceanographic preferences of Atlantic bluefin tuna, Thunnus thynnus, on their Gulf of Mexico breeding grounds,” *Mar. Biol.*, vol. 152, pp. 1105–1119, 2007, doi: 10.1007/s00227-007-0758-1.

[208] A. Bakun and S. J. Weeks, “The marine ecosystem off Peru: What are the secrets of its fishery productivity and what might its future hold?,” *Prog. Oceanogr.*, vol. 79, pp. 290–299, 2008, doi: 10.1016/j.pocean.2008.10.027.

[209] J. Selleslagh and R. Amara, “Environmental factors structuring fish composition and assemblages in a small macrotidal estuary (eastern English Channel),” *Estuar. Coast. Shelf Sci.*, vol. 79, pp. 507–517, 2008, doi: 10.1016/j.ecss.2008.05.006.

[210] K. Brander, “Impacts of climate change on fisheries,” *J. Mar. Syst.*, vol. 79, pp. 389–402, 2010, doi: 10.1016/j.jmarsys.2008.12.015.

[211] A. Kuparinen, T. Klefoth, and R. Arlinghaus, “Abiotic and fishing-related correlates of angling catch rates in pike (Esox lucius),” *Fish. Res.*, vol. 105, pp. 111–117, 2010, doi: 10.1016/j.fishres.2010.03.011.

[212] J. M. Bellido *et al.*, “Identifying essential fish habitat for small pelagic species in Spanish Mediterranean waters,” *Hydrobiologia*, vol. 612, pp. 171–184, 2008, doi: 10.1007/s10750-008-9481-2.

[213] C. Schrum, “Regionalization of climate change for the North Sea and Baltic Sea,” *Clim. Res.*, vol. 18, pp. 31–37, 2001, doi: 10.3354/cr018031.

[214] B. Chemmam-abdelkader and E. L. Abed, “Etude de l’age et de la croissance de deux especes de Dentes (Dentex dentex et de Dentex maroccanus) des cotes tunisiennes,” *Bull. l’institut Natl. des Sci. Technol. la mer*, vol. 31, pp. 43–51, 2004.

[215] R. Sahyoun, S. Bussotti, A. Di Franco, A. Navone, P. Panzalis, and P. Guidetti, “Protection effects on Mediterranean fish assemblages associated with different rocky habitats,” *J. Mar. Biol. Assoc. United Kingdom*, vol. 93, pp. 425–435, 2013, doi: 10.1017/S0025315412000975.

[216] F. C. Félix-Hackradt *et al.*, “Diel and tidal variation in surf zone fish assemblages of a sheltered beach in southern Brazil,” *Lat. Am. J. Aquat. Res.*, vol. 38, pp. 447–460, 2010, doi: 10.3856/vol38-issue3-fulltext-9.

[217] P. Palacios-Fuentes, M. Díaz-Astudillo, M. A. Reculé, F. Patricio Ojeda, and M. F. Landaeta, “Presettlement schooling behaviour of a rocky fish in a shallow area. Is it related to local environmental conditions?,” *Sci. Mar.*, vol. 84, pp. 243–252, 2020, doi: 10.3989/scimar.05043.19A.

[218] M. Power, M. J. Attrill, and R. M. Thomas, “Temporal abundance patterns and growth of juvenile herring and sprat from the Thames estuary 1977-1992,” *J. Fish Biol.*, vol. 56, pp. 1408–1426, 2000, doi: 10.1111/j.1095-8649.2000.tb02153.x.

[219] G. K. Davoren, J. T. Anderson, and W. A. Montevecchi, “Shoal behaviour and maturity relations of spawning capelin (Mallotus villosus) off Newfoundland: Demersal spawning and diel vertical movement patterns,” *Can. J. Fish. Aquat. Sci.*, vol. 63, pp. 268–284, 2006, doi: 10.1139/f05-204.

[220] W. W. L. Cheung *et al.*, “Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems,” *Nat. Clim. Chang.*, vol. 3, pp. 254–258, 2013, doi: 10.1038/nclimate1691.

[221] W. W. L. Cheung, R. Watson, and D. Pauly, “Signature of ocean warming in global fisheries catch,” *Nature*, vol. 497, pp. 365–368, 2013, doi: 10.1038/nature12156.

[222] R. Hilborn *et al.*, “Global status of groundfish stocks,” *Fish Fish.*, vol. 00, pp. 1–18, 2021, doi: 10.1111/faf.12560.

[223] J. Aguzzi *et al.*, “Developing technological synergies between deep-sea and space research,” *Elem. Sci. Anthr.*, vol. 10, p. 00064, 2022, doi: 10.1525/elementa.2021.00064.

[224] M. Matabos *et al.*, “Expert, Crowd, Students or Algorithm: who holds the key to deep-sea imagery ‘big data’ processing?,” *Methods Ecol. Evol.*, vol. 8, pp. 996–1004, 2017, doi: 10.1111/2041-210X.12746.

[225] A. Zuazo *et al.*, “An automated pipeline for image processing and data treatment to track activity rhythms of paragorgia arborea in relation to hydrographic conditions,” *Sensors (Switzerland)*, vol. 20, p. 6281, 2020, doi: 10.3390/s20216281.

[226] J. D. Dibattista, K. M. West, A. C. Hay, J. M. Hughes, A. M. Fowler, and M. A. McGrouther, “Community-based citizen science projects can support the distributional monitoring of fishes,” *Aquat. Conserv. Mar. Freshw. Ecosyst.*, vol. 31, pp. 3580–3593, 2021, doi: 10.1002/aqc.3726.

[227] K. Malde, N. O. Handegard, L. Eikvil, and A. B. Salberg, “Machine intelligence and the data-driven future of marine science,” *ICES J. Mar. Sci.*, vol. 77, pp. 1274–1285, 2020, doi: 10.1093/icesjms/fsz057.

[228] European Marine Board, “Big Data in Marine Science,” *European Marine Broad Advencing Seas & Ocean Science*, 2020. .

[229] J. S. Weis, G. Smith, T. Zhou, C. Santiago-Bass, and P. Weis, “Effects of contaminants on behavior: Biochemical mechanisms and ecological consequences,” *Bioscience*, vol. 51, pp. 209–217, 2001, doi: 10.1641/0006-3568(2001)051[0209:EOCOBB]2.0.CO;2.

[230] H. A. Viehman and G. B. Zydlewski, “Multi-scale temporal patterns in fish presence in a highvelocity tidal channel,” *PLoS One*, vol. 12, p. e0176405, 2017, doi: 10.1371/journal.pone.0176405.

[231] M. Francescangeli *et al.*, “Long-Term Monitoring of Diel and Seasonal Rhythm of Dentex dentex at an Artificial Reef,” *Front. Mar. Sci.*, vol. 9, pp. 1–17, 2022, doi: 10.3389/fmars.2022.837216.

[232] K. M. Knausgård *et al.*, “Temperate fish detection and classification: a deep learning based approach,” *Appl. Intell.*, vol. 52, pp. 6988–7001, 2022, doi: 10.1007/s10489-020-02154-9.

[233] J. Wu *et al.*, “Multi-Label Active Learning Algorithms for Image Classification: Overview and Future Promise,” *ACM Comput. Surv.*, vol. 53, pp. 1–35, 2020, doi: 10.1145/3379504.

[234] J. He, R. Mao, Z. Shao, and F. Zhu, “Incremental learning in online scenario,” in *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2020, pp. 13923–13932, doi: 10.1109/CVPR42600.2020.01394.

[235] D. W. Zhou, Y. Yang, and D. C. Zhan, “Learning to Classify With Incremental New Class,” *IEEE*

Trans. Neural Networks Learn. Syst., vol. 33, pp. 2429–2443, 2021, doi: 10.1109/TNNLS.2021.3104882.

[236] M. A. Hashmani, S. M. Jameel, H. Alhussain, M. Rehman, and A. Budiman, “Accuracy performance degradation in image classification models due to concept drift,” *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, pp. 422–425, 2019, doi: 10.14569/ijacsa.2019.0100552.

[237] D. Langenkämper, R. van Kevelaer, A. Purser, and T. W. Nattkemper, “Gear-Induced Concept Drift in Marine Images and Its Effect on Deep Learning Classification,” *Front. Mar. Sci.*, vol. 7, p. 506, 2020, doi: 10.3389/fmars.2020.00506.

[238] M. Kloster, D. Langenkämper, M. Zurowietz, B. Beszteri, and T. W. Nattkemper, “Deep learning-based diatom taxonomy on virtual slides,” *Sci. Rep.*, vol. 10, pp. 1–13, 2020, doi: 10.1038/s41598-020-71165-w.

[239] K. Katija *et al.*, “FathomNet: A global image database for enabling artificial intelligence in the ocean,” *Sci. Rep.*, vol. 12, pp. 1–14, 2022, doi: 10.1038/s41598-022-19939-2.

[240] R. Kohavi, “A Study of Cross-Validation and Bootstrap for Accuracy Estimation and Model Selection,” *Int. Jt. Conf. Artif. Intell.*, vol. 14, pp. 1137–1145, 1995.

[241] A. Tharwat, “Classification assessment methods,” *Appl. Comput. Informatics*, vol. 17, pp. 168–192, 2018, doi: 10.1016/j.aci.2018.08.003.

[242] C. Qi, J. Diao, and L. Qiu, “On Estimating Model in Feature Selection with Cross-Validation,” *IEEE Access*, vol. 7, pp. 33454–33463, 2019, doi: 10.1109/ACCESS.2019.2892062.

[243] V. Lopez-Vazquez, J. M. Lopez-Guede, S. Marini, E. Fanelli, E. Johnsen, and J. Aguzzi, “Video Image Enhancement and Machine Learning Pipeline for Underwater Animal Detection and Classification at Cabled Observatories,” *Sensors (Basel).*, vol. 20, p. 726, 2020, doi: 10.3390/s20030726.

[244] M. Francescangeli *et al.*, “Underwater camera photos with manual tagging of fish species at OBSEA seafloor observatory from 2013 to 2014,” *PANGEA*, 2022. [Online]. Available: https://doi.pangaea.de/10.1594/PANGAEA.946149.

[245] S. Marini, “Source code for: simoneMarinIsmar/Image-Tagging-tool: Image Tagging (v1.0),” *Zenodo*, 2022. [Online]. Available: https://doi.org/10.5281/%0Azenodo.6566282.

[246] R. Froese and D. Pauly, “FishBase,” *FishBase*, 2019. [Online]. Available: www.fishbase.org.

[247] E. Martinez Padro *et al.*, “CTD data acquired at the OBSEA seafloor observatory from 2013 to 2014,” *PANGEA*, 2022. [Online]. Available: https://doi.pangaea.de/10.1594/PANGAEA.946015.

[248] E. Martinez Padro *et al.*, “Meteorological data from a weather station at Vilanova i la Geltrú (Catalonia, Spain) from 2013 to 2014,” *PANGEA*, 2022. [Online]. Available: https://doi.pangaea.de/10.1594/PANGAEA.945911.

[249] E. Martinez Padro *et al.*, “Meteorological data from a weather station at Sant Pere de Ribes (Catalonia, Spain) from 2013 to 2014,” *PANGEA*, 2022. [Online]. Available: https://doi.pangaea.de/10.1594/PANGAEA.945906.

[250] J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, “You Only Look Once: Unified, Real Time Object Detection,” *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, pp. 779–788, 2016, doi: 10.1109/CVPR.2016.91.

[251] D. Marrable *et al.*, “Accelerating Species Recognition and Labelling of Fish From Underwater Video With Machine-Assisted Deep Learning,” *Front. Mar. Sci.*, vol. 9, p. 944582, 2022, doi: 10.3389/fmars.2022.944582.

[252] J. Cobrera, A. Sabatés, and A. García-Rubies, *Peces de mar de la península ibérica*. Planeta, 1996.

[253] L. Mercader, D. Lloris, and J. Rucabado, *Tots els peixos del mar Català: Diagnosis i claus d’identificació*. Institut d’Estudis Catalans, 2001.

[254] J. Jang and S. Yoon, “Feature Concentration for Supervised and Semisupervised Learning with Unbalanced Datasets in Visual Inspection,” *IEEE Trans. Ind. Electron.*, vol. 68, pp. 7620–7630, 2020, doi: 10.1109/TIE.2020.3003622.

[255] J. Zhang *et al.*, “Adaptive Vertical Federated Learning on Unbalanced Features,” *IEEE Trans. Parallel Distrib. Syst.*, vol. 33, pp. 4006–4018, 2022, doi: 10.1109/TPDS.2022.3178443.

[256] C. H. Lin, C. S. Lin, P. Y. Chou, and C. C. Hsu, “An Efficient Data Augmentation Network for Out-of-Distribution Image Detection,” *IEEE Access*, vol. 9, pp. 35313–35323, 2021, doi: 10.1109/ACCESS.2021.3062187.

[257] Y. Lu, D. Chen, E. Olaniyi, and Y. Huang, “Generative adversarial networks (GANs) for image augmentation in agriculture: A systematic review,” *Comput. Electron. Agric.*, vol. 200, p. 107208, 2022, doi: 10.1016/j.compag.2022.107208.

[258] N. Waqas, S. I. Safie, K. A. Kadir, S. Khan, and M. H. Kaka Khel, “DEEPFAKE Image Synthesis for Data Augmentation,” *IEEE Access*, vol. 10, pp. 80847–80857, 2022, doi: 10.1109/ACCESS.2022.3193668.

[259] 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, pp. 385–389, 2006.

[260] 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, pp. 181–188, 2009, doi: 10.1007/s12601-009-0016-1.

[261] 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.

[262] 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.

[263] 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, pp. 43–52, 2017, doi: 10.12681/mms.1968.

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

[265] 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, p. e0149107, 2016, doi: 10.1371/journal.pone.0149107.

[266] J. Aguzzi *et al.*, "Activity rhythms in the deep-sea: a chronobiological approach," *Front. Biosci. (Landmark Ed.*, vol. 16, pp. 131–150, 2011, doi: 10.2741/3680.

[267] C. Parmesan, "Influences of species, latitudes and methodologies on estimates of phenological response to global warming," *Glob. Chang. Biol.*, vol. 13, pp. 1860–1872, 2007, doi: 10.1111/j.1365-2486.2007.01404.x.

[268] P. Wright, J. K. Pinnegar, and C. Fox, "Impacts of climate change on coastal flooding, relevant to the coastal and marine environment around the UK," *MCCIP Sci. Rev.*, pp. 354–381, 2020, doi: 10.14465/2020.arc16.fsh.

[269] N. W. Pankhurst and M. J. R. Porter, "Cold and dark or warm and light: Variations on the theme of environmental control of reproduction," *Fish Physiol. Biochem.*, vol. 28, pp. 385–389, 2003, doi: 10.1023/B:FISH.0000030602.51939.50.

[270] R. G. Asch, C. A. Stock, and J. L. Sarmiento, "Climate change impacts on mismatches between phytoplankton blooms and fish spawning phenology," *Glob. Chang. Biol.*, vol. 25, pp. 2544–2559, 2019, doi: 10.1111/gcb.14650.

[271] L. Kuczynski, M. Chevalier, P. Laffaille, M. Legrand, and G. Grenouillet, "Indirect effect of temperature on fish population abundances through phenological changes," *PLoS One*, vol. 12, pp. 1–13, 2017, doi: 10.1371/journal.pone.0175735.

[272] J. Santana-Garcon, S. Bennett, N. Marbà, A. Vergés, R. Arthur, and T. Alcoverro, "Tropicalization shifts herbivore pressure from seagrass to rocky reef communities," *Proc. R. Soc. B*, vol. 290, p. 20221744, 2023, doi: 10.1098/rspb.2022.1744.

[273] M. Ourgaud, S. Ruitton, J. D. Bell, Y. Letourneur, J. G. Harmelin, and M. L. Harmelin-Vivien, "Response of a seagrass fish assemblage to improved wastewater treatment," *Mar. Pollut. Bull.*, vol. 90, pp. 25–32, 2015, doi: 10.1016/j.marpolbul.2014.11.038.

[274] C. Albouy *et al.*, "From projected species distribution to food-web structure under climate change," *Glob. Chang. Biol.*, vol. 20, pp. 730–741, 2014, doi: 10.1111/gcb.12467.

[275] S. Chaikin, S. Dubiner, and J. Belmaker, "Cold-water species deepen to escape warm water temperatures," *Glob. Ecol. Biogeogr.*, vol. 31, pp. 75–88, 2022, doi: 10.1111/geb.13414.

[276] N. Raventos, H. Torrado, R. Arthur, T. Alcoverro, and E. Macpherson, "Temperature reduces fish dispersal as larvae grow faster to their settlement size," *J. Anim. Ecol.*, vol. 90, pp. 1419–1432, 2021, doi: 10.1111/1365-2656.13435.

[277] K. Agiadi *et al.*, "Palaeontological evidence for community-level decrease in mesopelagic fish size during Pleistocene climate warming in the eastern Mediterranean," *Proc. R. Soc. B*, vol. 290, p. 20221994, 2023, doi: 10.1098/rspb.2022.1994.

[278] C. Albouy, F. Guilhaumon, M. B. Araújo, D. Mouillot, and F. Leprieur, "Combining projected changes in species richness and composition reveals climate change impacts on coastal Mediterranean fish assemblages," *Glob. Chang. Biol.*, vol. 18, pp. 2995–3003, 2012, doi: 10.1111/j.1365-2486.2012.02772.x.

[279] T. Lacoue-Labarthe *et al.*, "Impacts of ocean acidification in a warming Mediterranean Sea: An overview," *Reg. Stud. Mar. Sci.*, vol. 5, pp. 1–11, 2016, doi: 10.1016/j.rsma.2015.12.005.

[280] E. Fanelli, J. E. Cartes, V. Papiol, C. López-Pérez, and M. Carrassón, "Long-term decline in the trophic level of megafauna in the deep Mediterranean Sea: A stable isotopes approach," *Clim. Res.*, vol. 67, pp. 191–207, 2016, doi: 10.3354/cr01369.

[281] A. C. Tsikliras, P. Licandro, A. Pardalou, I. H. McQuinn, J. P. Gröger, and J. Alheit, "Synchronization of Mediterranean pelagic fish populations with the North Atlantic climate variability," *Deep. Res. Part II Top. Stud. Oceanogr.*, vol. 159, pp. 143–151, 2019, doi: 10.1016/j.dsr2.2018.07.005.

[282] L. Scapin *et al.*, "Expected shifts in nekton community following salinity reduction: Insights into restoration and management of transitional water habitats," *Water*, vol. 11, pp. 1–22, 2019, doi: 10.3390/w11071354.

[283] M. Huang, L. Ding, J. Wang, C. Ding, and J. Tao, "The impacts of climate change on fish growth: A summary of conducted studies and current knowledge," *Ecol. Indic.*, vol. 121, p. 106976, 2021, doi: 10.1016/j.ecolind.2020.106976.

[284] N. J. Clark, J. T. Kerry, and C. I. Fraser, "Rapid winter warming could disrupt coastal marine fish community structure," *Nat. Clim. Chang.*, vol. 10, pp. 862–867, 2020, doi: 10.1038/s41558-020-0838-5.

[285] W. W. L. Cheung *et al.*, "Marine high temperature extremes amplify the impacts of climate change on fish and fisheries," *Sci. Adv.*, vol. 7, pp. 1–15, 2021, doi: 10.1126/sciadv.abh0895.

[286] M. L. Pinsky, R. L. Selden, and Z. J. Kitchel, "Climate-Driven Shifts in Marine Species Ranges: Scaling from Organisms to Communities," *Ann. Rev. Mar. Sci.*, vol. 12, pp. 153–179, 2020, doi: 10.1146/annurev-marine-010419-010916.

[287] I. Gianelli *et al.*, "Sensitivity of fishery resources to climate change in the warm-temperate Southwest Atlantic Ocean," *Reg. Environ. Chang.*, vol. 23, pp. 1–18, 2023, doi: 10.1007/s10113-023-02049-8.

[288] K. Agiadi and P. G. Albano, "Holocene fish assemblages provide baseline data for the rapidly changing eastern Mediterranean," *The Holocene*, vol. 30, pp. 1438–1450, 2020, doi: 10.1177/0959683620932969.

[289] E. Azzurro *et al.*, "Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge," *Glob. Chang. Biol.*, vol. 25, pp. 2779–2792, 2019, doi: 10.1111/gcb.14670.

[290] D. Edelist, G. Rilov, D. Golani, J. T. Carlton, and E. Spanier, "Restructuring the Sea: Profound shifts in the world's most invaded marine ecosystem," *Divers. Distrib.*, vol. 19, pp. 69–77, 2013, doi: 10.1111/ddi.12002.

[291] E. Azzurro, G. La Mesa, and E. Fanelli, "The rocky-reef fish assemblages of Malta and Lampedusa islands (Strait of Sicily, Mediterranean Sea): A visual census study in a changing biogeographical sector," *J. Mar. Biol. Assoc. United Kingdom*, vol. 93, pp. 2015–2026, 2013, doi: 10.1017/S0025315413000799.

[292] M. A. Peck *et al.*, "Projecting changes in the distribution and productivity of living marine resources: A critical review of the suite of modelling approaches used in the large European project VECTORS," *Estuar. Coast. Shelf Sci.*, vol. 201, pp. 40–55, 2018, doi: 10.1016/j.ecss.2016.05.019.

[293] I. A. Catalán *et al.*, "Automatic detection and classification of coastal Mediterranean fish from underwater images: Good practices for robust training," *Front. Mar. Sci.*, vol. 10, pp. 1–11, 2023, doi: 10.3389/fmars.2023.1151758.

[294] D. Bănaru *et al.*, "Trophic structure in the Gulf of Lions marine ecosystem (north-western Mediterranean Sea) and fishing impacts," *J. Mar. Syst.*, vol. 111, pp. 45–68, 2013, doi: 10.1016/j.jmarsys.2012.09.010.

[295] R. Ajana, M. Techetach, and Y. Saoud, "Diet of Octopus vulgaris from the Moroccan Mediterranean Coast," *Thalass. An Int. J. Mar. Sci.*, vol. 34, pp. 415–420, 2018, doi: 10.1007/s41208-018-0084-z.

[296] L. Silva, I. Sobrino, and F. Ramos, "Reproductive biology of the common octopus, Octopus vulgaris cuvier, 1797 (Cephalopoda: Octopodidae) in the Gulf of Cádiz (SW Spain)," *Bull. Mar. Sci.*, vol. 71, pp. 837–850, 2002.

[297] R. Bernardello, E. Serrano, R. Coma, M. Ribes, and N. Bahamon, "A comparison of remote-sensing SST and in situ seawater temperature in near-shore habitats in the western Mediterra nean Sea," *Mar. Ecol. Prog. Ser.*, vol. 559, pp. 21–34, 2016, doi: 10.3354/meps11896.

[298] Y. Wang, Q. Wang, S. Jin, W. Long, and L. Hu, "A literature review of underwater image detection," in *Design Studies and Intelligence Engineering*, L. C. Jain, V. E. Balas, and Q. Wu, Eds. IOS Press, 2022, p. 480.

CREDITS

Chapter 1. Long-Term Monitoring of Diel and Seasonal Rhythm of *Dentex dentex* at an Artificial Reef.

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Francescangeli, M., Sbragaglia, V., Del Río Fernández, J., Trullols, E., Antonijuan, J., Massana, I., Prat, J., Nogeras Cervera, M., Toma, D. M., & Aguzzi, J. (2022).
Long-Term Monitoring of Diel and Seasonal Rhythm of *Dentex dentex* at an Artificial Reef. *Frontiers in Marine Science*, 9, 1-17. Under a CC BY 4.0 license. DOI: 10.3389/fmars.2022.837216

Chapter 2. Image Dataset for Benchmarking Automated Fish Detection and Classification Algorithms.

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Francescangeli, M., Marini, S., Martínez, E., Del Río Fernández, J., Toma, D. M., Nogeras Cervera, M., & Aguzzi, J. (2023).
Image Dataset for Benchmarking Automated Fish Detection and Classification Algorithms. *Scientific Data*, 10(1), 1-13. Under a CC BY 4.0 license. DOI: 10.1038/s41597-022-01906-1

Chapter 3. Resource Pulse in Shallow Waters: Characterization of the Scavenger Community Associated with a Dolphin Carcass.

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