BIODIVERSITY AT THE WINDFLOAT ATLANTIC PROJECT
FLOATING OFFSHORE WIND FARM
VIANA DO CASTELO, PORTUGAL

NON-TECHNICAL SUMMARY

MARCH 2026

Biodiversity at WindFloat Atlantic, floating offshore wind farm Viana do Castelo, Portugal

Non-Technical Summary

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CONTENTS

EXECUTIVE SUMMARY

The WindFloat Atlantic (WFA) is a 25 MW floating offshore wind farm located approximately 18 km off the coast of Viana do Castelo, operating in water depths of 95–100 m since September 2020. Developed and operated by Ocean Winds, the project represents a pioneering pre-commercial application of floating wind technology and has already generated around 345 GWh of renewable electricity. Given its innovative character and offshore location, an extensive environmental monitoring program was implemented before installation and throughout operation to assess its effects on marine biodiversity and ecosystem functioning.

Monitoring covered plankton, nektobenthic invertebrates (including octopus), fish, marine growth on platforms, marine mammals, seabirds, and bats, supported by water quality and underwater noise measurements. A control–impact approach was adopted, comparing data from the wind farm area with adjacent reference zones, allowing statistical evaluation of spatial and temporal patterns.

Plankton communities, which form the base of the marine food web, showed no significant differences in abundance, biomass, or species composition between the wind farm and control areas. Similarly, no evidence was found that the presence or operation of the turbines altered overall ecosystem functioning. Plankton results indicate that natural seasonal and interannual variability is the main driver of ecological dynamics of these communities in the study area.

Clear spatial differences were, however, detected for fish, octopus, and certain nektobenthic invertebrates. Fish abundance and biomass were consistently higher within the wind farm area, and several commercially important species, including octopus and soles, were more abundant inside the WFA zone. These patterns are primarily attributed to the fishing exclusion zone associated with the wind farm, which functions as a refuge area. The absence of significant differences between locations near and farther from the platforms suggests that this effect is driven more by reduced fishing pressure than by simple aggregation around structures. Such conditions may contribute to spillover benefits to adjacent fishing grounds.

The floating platforms have also generated a “reef effect” through the introduction of hard substrate in an otherwise predominantly soft-bottom environment. Initial colonization was dominated by mussels, followed by barnacles and kelp, increasing structural complexity and local biomass. Although seven non-native species were recorded on the structures, their overall coverage remains low, apart from the alga *Undaria pinnatifida* (wakame), which is still being monitored. No evidence of invasive proliferation or ecosystem imbalance was detected during the study period.

Five marine mammal species were recorded, with common dolphins being the most frequent. Overall presence patterns did not indicate large-scale displacement, and dolphin acoustic activity was higher within the wind farm area, potentially reflecting increased prey availability. Harbour porpoise detections were somewhat lower inside the site after installation, a pattern consistent with observations from other offshore wind farms.

Seabird diversity was similar between impact and control areas, although overall abundance was higher within the wind farm during operation. Most birds were observed in transit flight, suggesting that the area functions mainly as a migratory corridor. Collision risk modelling identified a limited number of species flying at rotor-swept height, particularly large gulls and northern gannets, but no collision mortality was recorded.

Bat activity offshore was very low and restricted to migratory periods, with no indication that turbines are used for roosting or foraging.

In overall terms, the findings indicate that the WindFloat Atlantic project has not led to broad ecosystem disruption and that ecological patterns remain largely driven by natural seasonal and interannual variability. The fishing exclusion zone appears to generate localized increases in fish and octopus' abundance and biomass, contributing to habitat protection and potential spillover benefits. The reef effect associated with the floating platforms has enhanced structural complexity and supported diverse biological communities.

Biodiversity monitoring is still ongoing at the WindFloat Atlantic project to assess the community composition and trophic relationships. To ensure that these benefits translate into a net ecological gain, continuous environmental monitoring and integrated analysis of results would be essential, allowing the project's effects to be tracked over time, positive ecosystem service outcomes to be strengthened and potential negative impacts or ecological imbalances to be identified early and effectively mitigated.

WHAT IS THE WINDFLOAT ATLANTIC PROJECT?

The WindFloat Atlantic project is an offshore wind power plant located off Viana do Castelo coast (Northern Portugal), approximately 18 km offshore, in an area with water depths varying between 95 and 100 m. The electricity generated is transmitted to shore through a submarine cable (**Figure 1**). The installed capacity is 25 MW (3 × 8.3 MW), and the project comprises three systems, each consisting of a floating platform, a wind turbine, and an anchoring system. The project entered operation in September 2020 and has, to date, produced approximately 345 GWh of electricity for the public power grid.

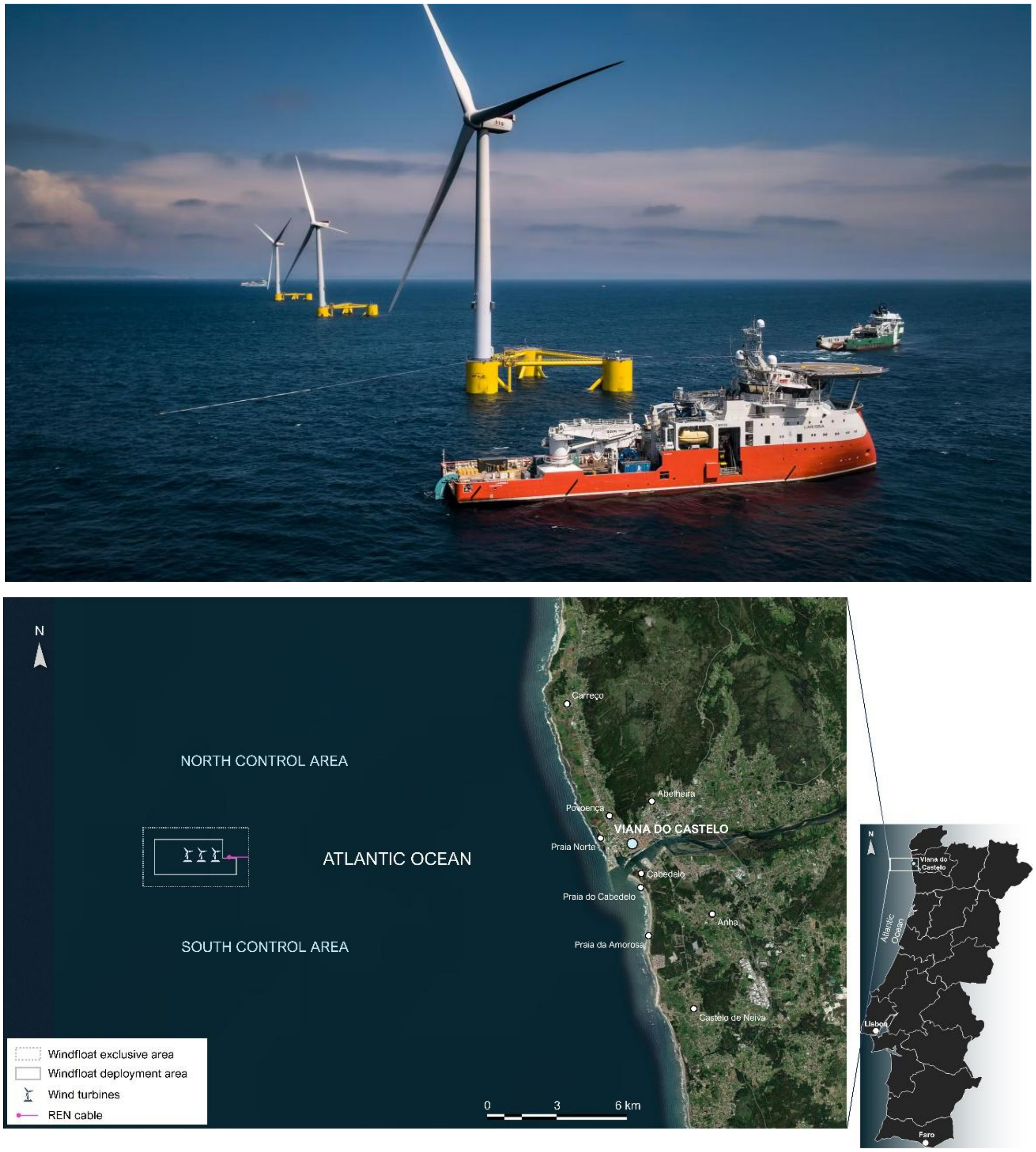


Figure 1 – WindFloat Atlantic project and its location.

Ocean Winds, hereinafter referred to as OW, is the owner and operator of the WindFloat Atlantic floating offshore wind farm. OW is a joint venture between EDP-Renewables (EDPR) and ENGIE, dedicated to offshore wind energy. Based on the belief that offshore wind energy is an essential part of the global energy transition, OW develop, finance, build and operate offshore wind farm projects all around the world. OW's portfolio of offshore wind projects reached close to 19 GW in 8 countries, including 1.5 GW in full operation and over 2 GW under construction.

The Environmental Appraisal (EIncA - *Estudo de Incidências Ambientais*) for the WFA project was submitted to the authorities (CCDR-Norte) at the preliminary design stage of the project on 25 June 2015. The corresponding statement (DIncA – *Decisão de Incidências Ambientais*) was issued by CCDR-Norte on 24 November 2015, with a "favourable with conditions" decision. Subsequently, the Environmental Compliance Report for the detailed design stage of the project (RECAPE – *Relatório de Conformidade Ambiental do Projeto de Execução*) was submitted in 2018, and the corresponding statement (DCAPE – *Decisão de Conformidade Ambiental do Projeto de Execução*) – also "favourable with conditions" – was issued by CCDR-Norte on 3 October 2018. The EIncA proposed several environmental monitoring programs, which were further detailed in the RECAPE and formally incorporated into the DCAPE as binding obligations of the project proponent.

WHAT IS THE PURPOSE OF THIS DOCUMENT?

The purpose of a Non-Technical Summary is to promote transparency and public access to information, ensuring that relevant information is made available in a form that is understandable to all. It is a condensed and accessible version of a technical document, designed to communicate effectively with a non-specialist audience.

This document includes not only the results of the environmental monitoring carried out by OW in fulfilment of its legal environmental obligations, but also the results of scientific studies undertaken to address aspects that were not required under the issued licences but are recognised as important for the further understanding of the project's environmental impacts on the marine environment on the marine environment, particularly with regard to local biodiversity in the surrounding area.

WHY MONITORING EFFECTS ON BIODIVERSITY?

Offshore wind energy is recognized, by international organizations, financial institutions, development banks, energy and environmental associations, research centres, etc., as one of the most reliable sources for expanding renewable energy production. However, like all human activities, it can have environmental impacts, the significance of which depends on the scale of the projects and the sensitivity of the sites where they are installed. The growth of offshore wind has been accompanied by extensive environmental monitoring, conducted both as part of licensing processes and through complementing research studies, to understand and quantify the effects resulting from the interaction of artificial structures and their operation with the natural marine environment.

Assessing the environmental impacts of offshore wind projects, and biodiversity in particular, is crucial because these projects introduce new infrastructure and activities into marine ecosystems that are often poorly understood. Among other aspects, rigorous assessment allows not only for potential risks, but also potential opportunities (including positive effects) to be anticipated, informs project design, and helps ensuring the energy transition is carried out in a sustainable manner.

The WFA project is a pre-commercial project, and therefore the environmental analysis can provide relevant information for the planning, construction, operation, and maintenance of future projects, particularly in the following areas:

- **Modification of marine ecosystems**: floating platforms, moorings, and submarine cables can affect seabed habitats, planktonic communities, and mobile species such as fish, seabirds, and marine mammals. Studying these effects helps identify direct impacts (e.g., physical disturbance of the seafloor) and indirect impacts (e.g., changes in food webs or behavioural patterns).
- **Noise and disturbance**: installation, maintenance, and operation generate underwater noise and increased human activity, which can interfere with the communication, navigation, and reproduction of sound-sensitive species. Monitoring allows for the establishment of acceptable limits and the implementation of effective mitigation measures.
- **Interaction with birds and bats**: wind turbines may pose collision risks or alter migratory routes. Environmental assessment is essential to understand these risks, to adjust mitigation measures and to optimize the location and spatial arrangement of wind farms.
- **Assessment of cumulative effects**: floating wind projects often coexist with other uses of the sea, such as fishing, shipping, and other energy infrastructure. Environmental studies help evaluate cumulative and synergistic effects that may not be apparent when assessing a single project in isolation.
- **Support for decision-making and permitting**: reliable scientific evidence is essential for Environmental Impact Assessment (EIA) processes, ensuring compliance with national and international legislation and fostering social acceptance among coastal communities and stakeholders.
- **Technological optimization and sustainable innovation**: Understanding environmental impacts enables improvements in the design of platforms, mooring systems, and cables, reducing negative effects and, in some cases, enhancing positive outcomes, such as the creation of artificial reefs.

In summary, studying the environmental impacts of floating offshore wind energy is crucial to balance the need for renewable energy production with the conservation of marine ecosystems and the responsible use of maritime space.

Following the environmental licensing process, OW implemented a range of environmental monitoring programs, which began several months prior to installation and have continued to the present. These programs were designed in accordance with the requirements established by the Portuguese licensing authorities, as well as the company’s need to gain a comprehensive understanding of the project’s effects on the marine environment, considering both negative and positive impacts. In this way, since 2023, additional studies have been carried out to complement the monitoring programs established under the environmental licensing, particularly focusing on descriptors that were not initially considered, including fish, nektobenthic invertebrates and plankton.

WHAT ASPECTS WERE MONITORED?

Offshore wind farms should be monitored in an integrated manner, considering environmental, physical, biological and socio-economic components throughout the installation, operation, and decommissioning phases. **Figure 2** illustrates the most relevant components that are typically monitored, although these can be defined in advance based on the natural characteristics and sensitivity of the site, as well as on the scale and design of the project.

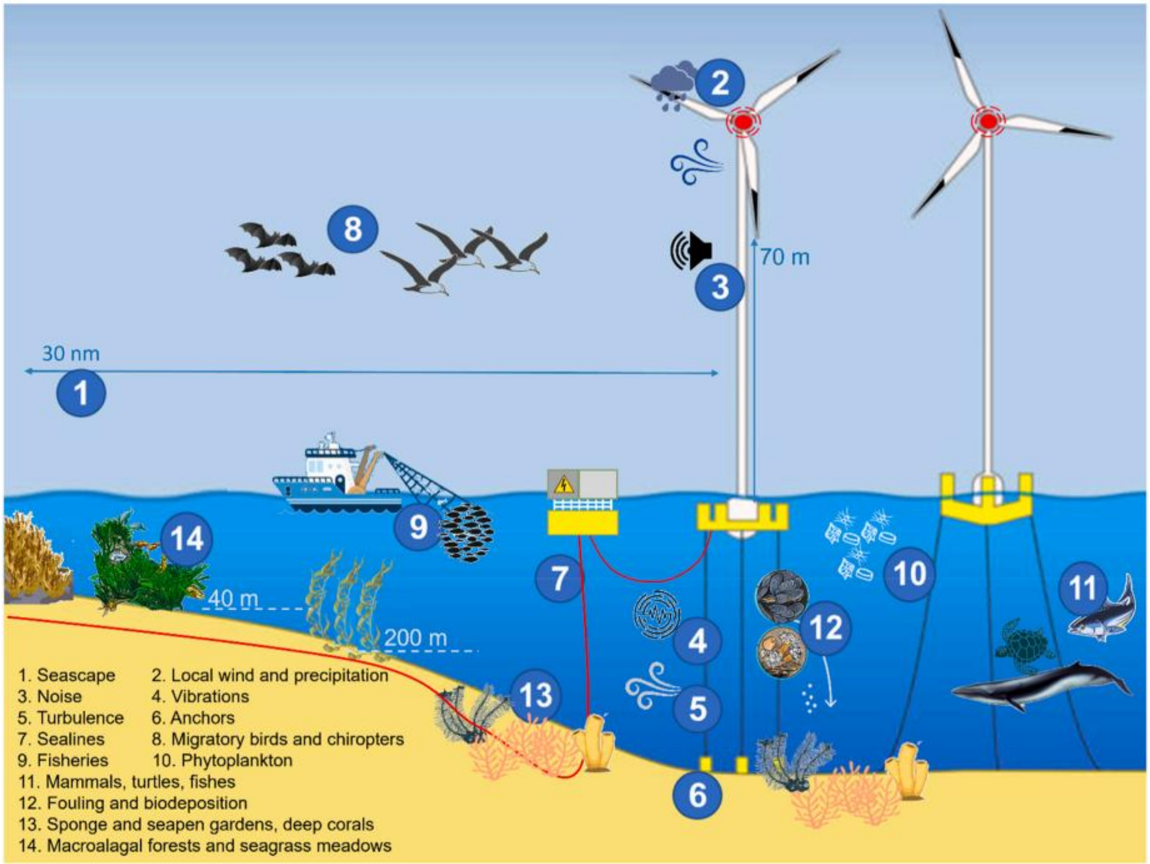


Figure 2 – General aspects monitored in floating offshore wind farms. Source: Danovaro et al., 2024: https://doi.org/10.1016/j.rser.2024.114386

In summary, monitoring of offshore wind farms should be multidisciplinary and continuous, ensuring a balance between renewable energy production, the protection of marine ecosystems, and coexistence with other maritime uses. In the case of the WFA project, the biological components monitored included the following groups:

- Algae (those colonizing the submerged surfaces of the WFA platforms),
- Plankton (phytoplankton and zooplankton),
- Nektobenthic invertebrates (those colonizing the platform surfaces and benthic communities on the seafloor at the WFA site; this group excludes invertebrates that live within the sediment, i.e., infaunal species),

- Fish,
- Marine mammals,
- Bats,
- Seabirds.

To provide context for this analysis, data were also collected on physical and chemical components supporting marine life, including water quality and underwater acoustic conditions and noise.

HOW AND WHEN WAS THE MONITORING CONDUCTED?

Data collection was carried out through monitoring campaigns, some conducted prior to the installation of the WFA (**Table 1**) to establish baseline conditions for the subsequent assessment of the project's impacts, and others after the project became operational (**Table 2**). The monitoring activities were carefully planned, with monitoring programs specifying the season, frequency, duration, locations, and methods for data collection.

Table 1 – Monitoring components and respective monitoring periods and methods before and during WFA installation.

Components	Monitoring periods	Sampling methods
Water quality	Before installation: July 2019 During installation: September 2019	Water samples collection
Acoustic conditions	Before installation: June 2018 and December 2018	Data acquisition with hydrophones
Marine mammals	Before installation: July 2018 During installation: October 2019	Visual sightings from a vessel and data acquisition with hydrophones installed at site
Seabirds	Before installation: June 2018 and May 2019	Visual records from a vessel

Table 2 – Monitoring components and respective monitoring periods and methods during WFA operation.

Components	Monitoring periods	Sampling methods
Water quality	January 2021 and July 2021	Water samples collection
Noise emitted by the WFA	November 2020 and May 2021	Data acquisition with hydrophones
Plankton	June 2023 to April 2025	Water samples and vertical tows using nets
Nektobenthic invertebrates	June 2023 to April 2025	Bottom otter trawling
Fish	June 2023 to April 2025	Bottom otter trawling
Octopus	Junho 2023 to April 2025	Fixed sets of shelter-pots
Marine mammals	September 2020 to July 2022	Visual sightings from a vessel and data acquisition with hydrophones installed at site
Platforms colonization	September 2021, 2022 and 2023	Sample collection by scraping within quadrats
Bats	September to December 2021 January to December 2022	Acoustic records from collected with ultrasonic sensors installed in one of the WFA platforms
Seabirds	November 2020 to June 2023	Visual records and data from radar installed in one of the platforms

Figure 3 exemplifies the locations of the data recording points for monitored components. Each map includes control areas and impact areas. Defining control areas is part of the monitoring protocol for any

environmental data set, providing a reference or baseline to compare the effects of the factors under investigation – in this case, the effects of the presence of the WFA park.

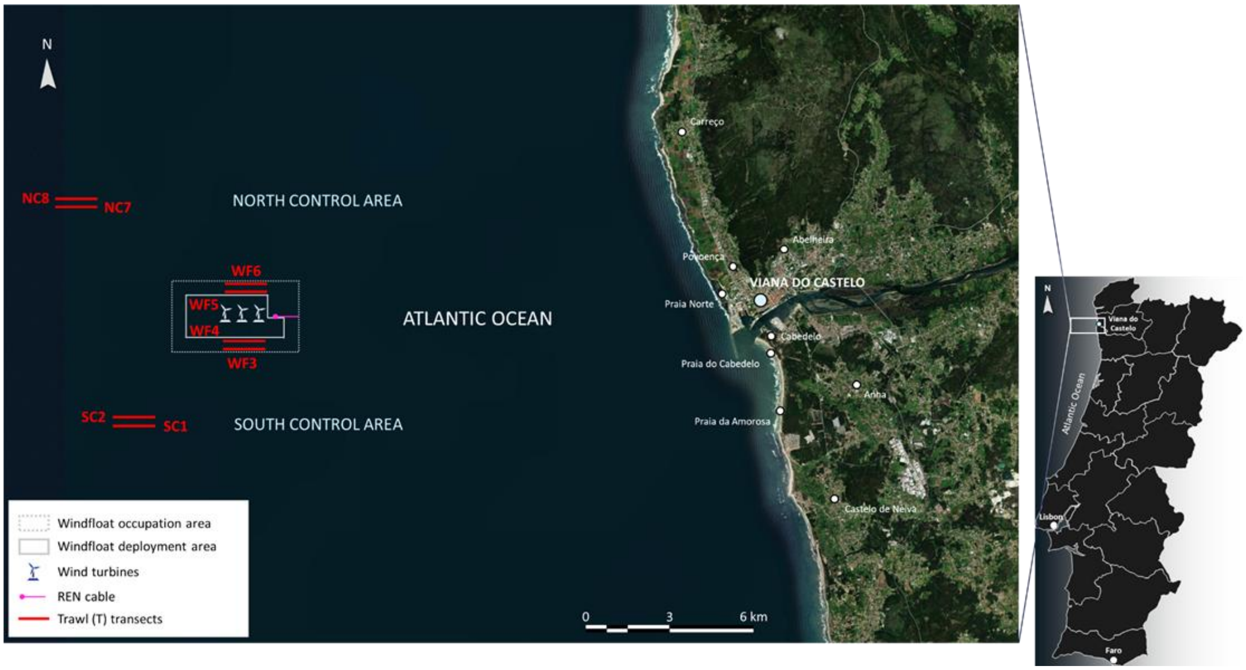


Figure 3 – Sampling locations for fish and marine nektobenthic invertebrates (collected using bottom otter trawling nets during experimental fishing activities).

Data collection was carried out using vessels and specialized equipment appropriate to each type of monitoring, either transported to the site or installed directly at the wind farm (for example, hydrophones for acoustic monitoring of noise/vibrations generated by the operation of the platforms, and for acoustic data acquisitions of vocalizations – such as whistles and click trains – emitted by dolphins and other marine mammals). In total, it was estimated that these monitoring activities corresponded to approximately 100 days of fieldwork by specialized technicians at sea.

Following the collection of data and samples, they were processed, in some cases in laboratories (e.g., counting, measuring, weighing, species identification), and using digital tools to support their recording and handling for subsequent analysis, interpretation and reporting (**Figure 4**).

To interpret the information, statistical tests were applied whenever possible to evaluate differences between data collected before and after the WFA became operational. The interpretation of these results was documented in component-specific reports and subsequently integrated into a final report assessing the project's effects on biodiversity, which forms the basis of this Non-Technical Summary.

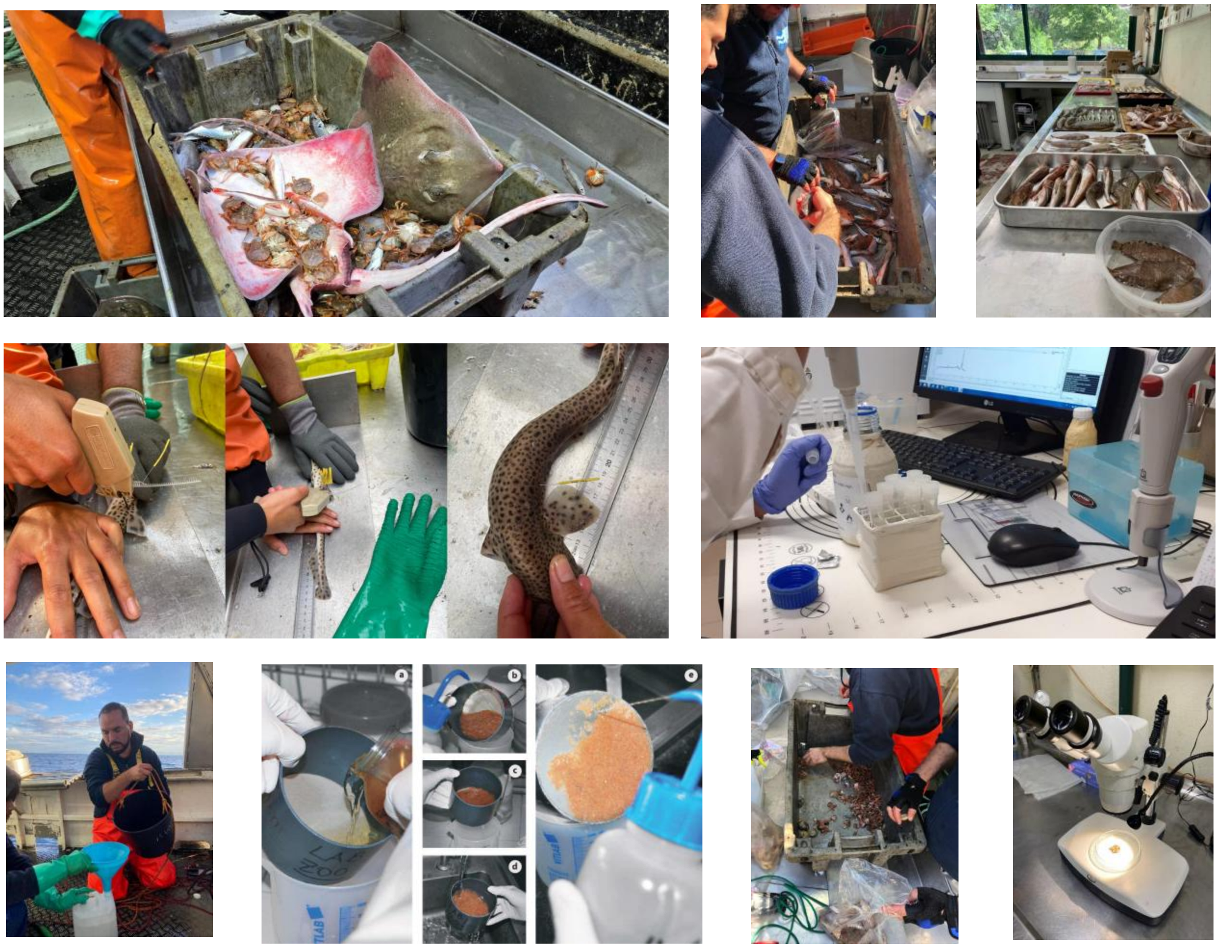


Figure 4 – Images illustrating the collection of fish samples and their subsequent processing in the laboratory, including individual organisms' measurement, species identification, and counting.

WHAT ARE THE MAIN RESULTS OF THE ENVIRONMENTAL STUDIES?

PLANKTON

The Plankton group comprises the organisms that live suspended in the water column and are transported passively by currents, meaning they lack sufficient swimming ability to counteract water movement. This group is fundamental to aquatic ecosystems, as it forms the base of the marine food web and contributes to processes such as primary production and the nutrient cycle.

Plankton is divided into two main groups: phytoplankton and zooplankton, which were analysed separately in this study. Phytoplankton consists of microscopic aquatic organisms that perform photosynthesis (e.g., microalgae and certain bacteria, such as cyanobacteria). Zooplankton, in turn, consists of microscopic aquatic animals that feed on phytoplankton and other planktonic organisms, as well as suspended organic matter (e.g., fish larvae and insect larvae) (**Figure 5**).

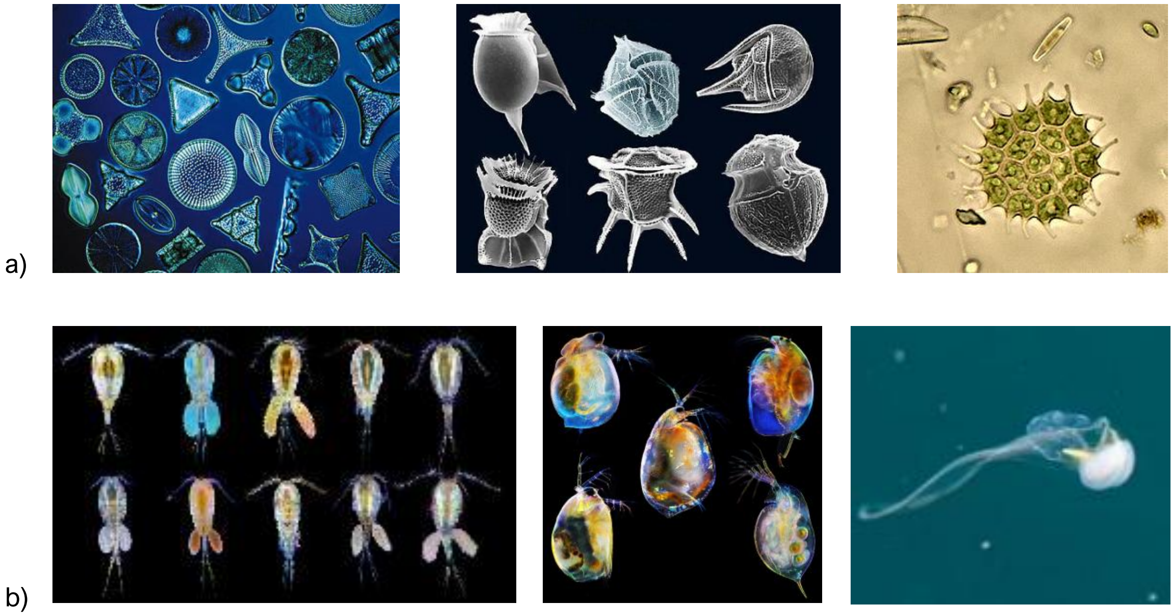


Figure 5 – Microscopic images of species of a) phytoplankton and b) zooplankton.

Phytoplankton abundance in the WFA area and its adjacent zone falls within the typical range for this group of species in this type of marine habitat. Abundance is higher in summer and autumn, and there are no significant differences in species abundance or composition between the area occupied by the WFA and the surroundings (control area). The presence of the wind farm does not appear to affect the growth, abundance, or species composition of these marine organisms in the study area. Interannual variations in growth and species composition are primarily driven by environmental conditions associated with seasonal changes (**Figure 6**).

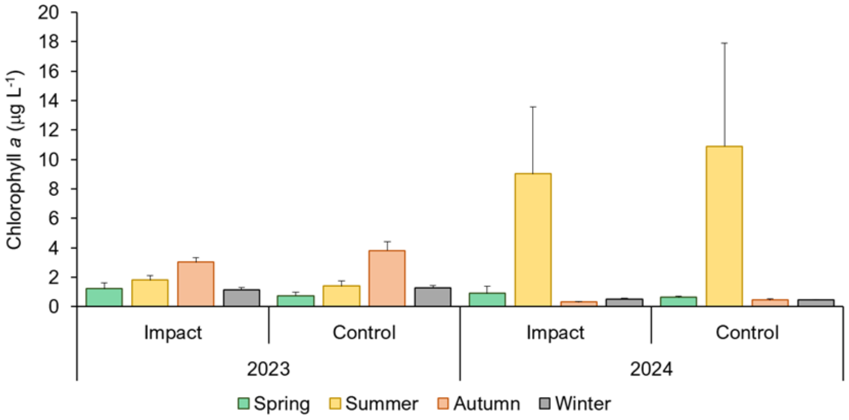


Figure 6 – Variation in phytoplankton abundance between the control area and the impact area (WFA).

Regarding zooplankton, there are no differences in species abundance or diversity between the WFA area and its surrounding zone, although species diversity seems to be higher in spring and winter. Similarly to phytoplankton, the presence of the wind farm does not appear to affect the growth, abundance, or species composition of this group of marine organisms in the area. Annual variations in growth and species composition are primarily driven by environmental conditions associated with seasonal changes (**Figure 7**).

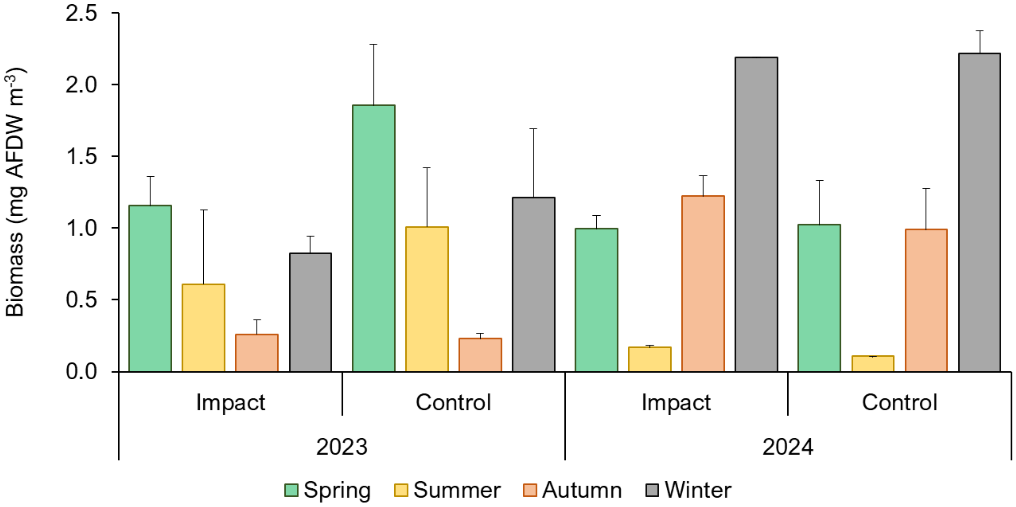
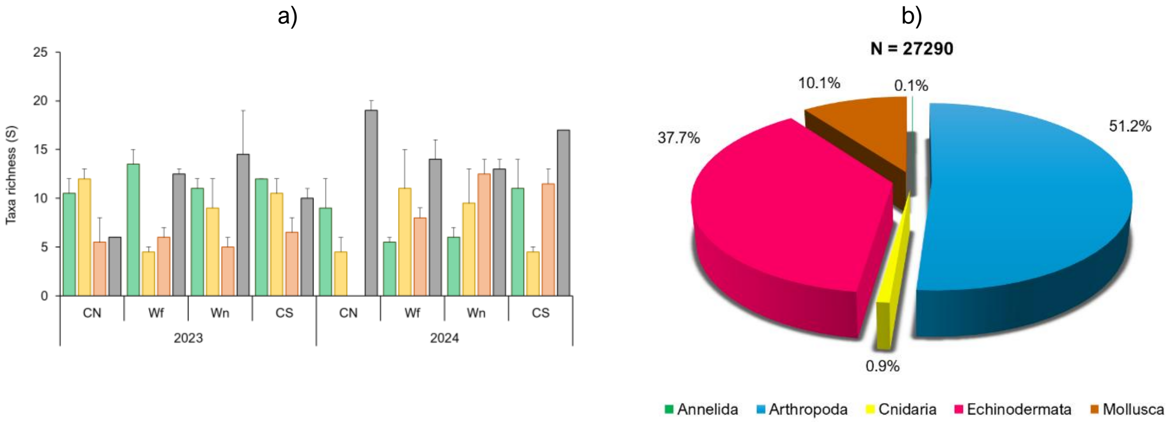


Figure 7 – Variation in zooplankton biomass between the control area and the impact area (WFA).

NEKTOBENTHIC INVERTEBRATES

A total of 75 species were recorded, with an overall biomass of approximately 365 kg over the two years of sampling. Arthropods (e.g., crabs) and echinoderms (e.g., starfish) accounted for more than half of the total abundance and biomass. The most abundant species included the Henslow's-swimming-crab, the sea-urchin sea-potato, the hermit crab, the common squid, and the blue-mussel. A clear trend of higher species richness (diversity) was observed in winter, with lower values in summer and autumn, and diversity was generally higher in the southern control area (**Figure 8**).


a)

b)

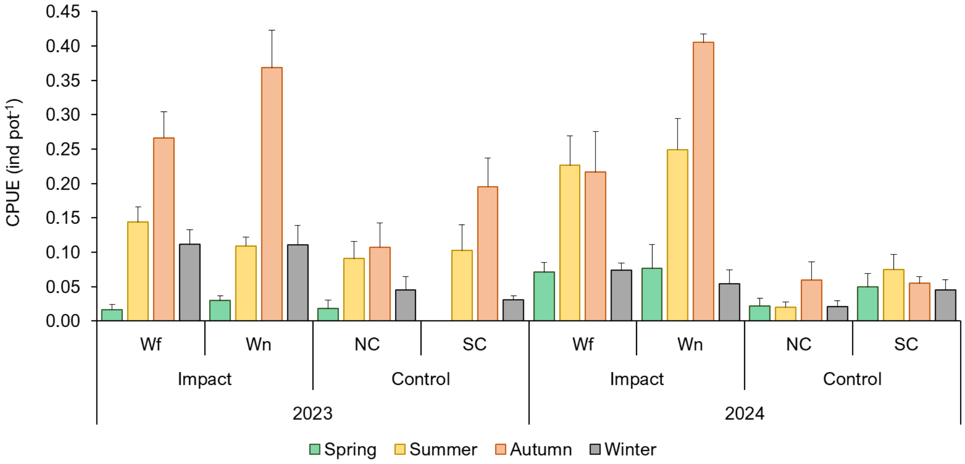
c)

Henslow's-swimming-crab Sea-potato Hermit-crab

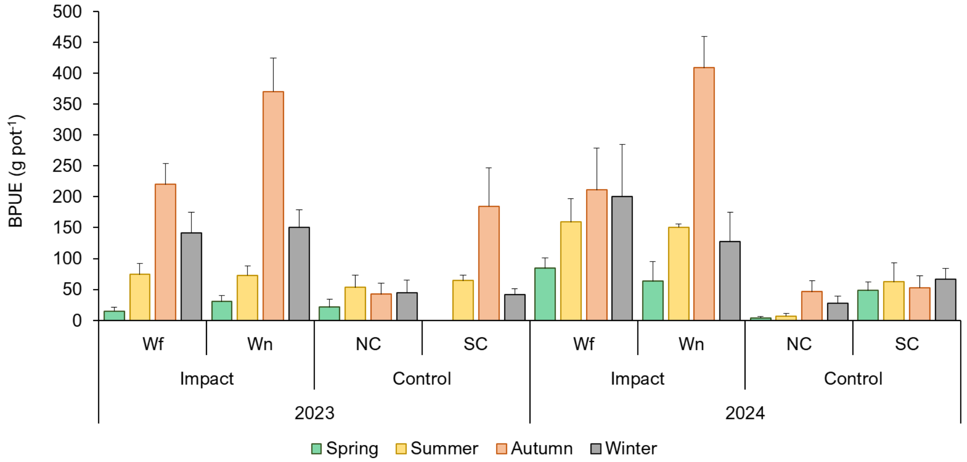
Common-squid Blue-mussel

Figure 8 – Invertebrate species in the study area: a) seasonal and spatial variation of invertebrates species richness in impact (Wf, Wn) and control (NC, SC) areas during 2023 and 2024; b) numerical importance of the main species groups; c) most abundant species recorded (control area and impact area).

A total of 674 common octopuses were captured, with an overall biomass of approximately 640 kg. Captures were notably lower in spring and winter, suggesting a possible seasonal influence on the species' behaviour and availability, a trend that was observed in both monitored areas (impact and control). Catch numbers were higher in the WFA area, regardless of the distance from the wind turbines. Biomass showed strong seasonal variation, with higher values in autumn and winter and minima in spring, reflecting greater individual growth and/or the availability of adult octopuses later in the year. Biomass was also higher in the WFA area, regardless of distance to the turbines, and larger individuals were mostly captured near the WFA platforms (**Figure 9**).



a)



b)

Figure 9 – Seasonal and spatial variation in octopus population in impact (Wf, Wn) and control (NC, SC) areas during 2023 and 2024: a) Catch per unit effort (CPUE; individuals ha^{-1}) and b) Biomass per unit effort (BPUE; g ha^{-1}).

FISH

A total of 4,971 fish, representing 52 species, were captured. Species sensitive to electromagnetic fields, such as the lesser-spotted-dogfish, were recorded, with this species showing higher abundance in the WFA area. According to the IUCN Red List of Threatened Species, two of the recorded species – the blonde-skate and the thornback-skate – are classified as “Near Threatened”. Among the most abundant are the species shown in **Figure 10**.

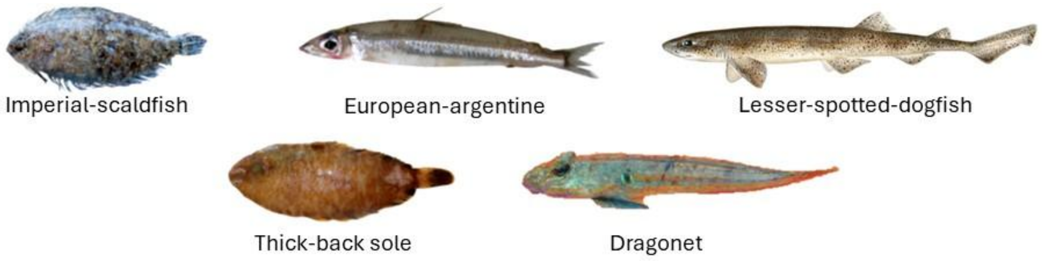


Figure 10 – Most abundant fish species in the study area.

The number of species showed a tendency to be higher in winter and autumn, with peaks in diversity during the colder seasons. In contrast, lower diversity was observed in spring and summer. Statistically significant differences were identified both among seasons and between sampled areas, with the highest values recorded in the impact area (WFA). Biomass also varied significantly among sampling locations, with consistently higher values observed in the area occupied by the WFA (**Figure 11**).

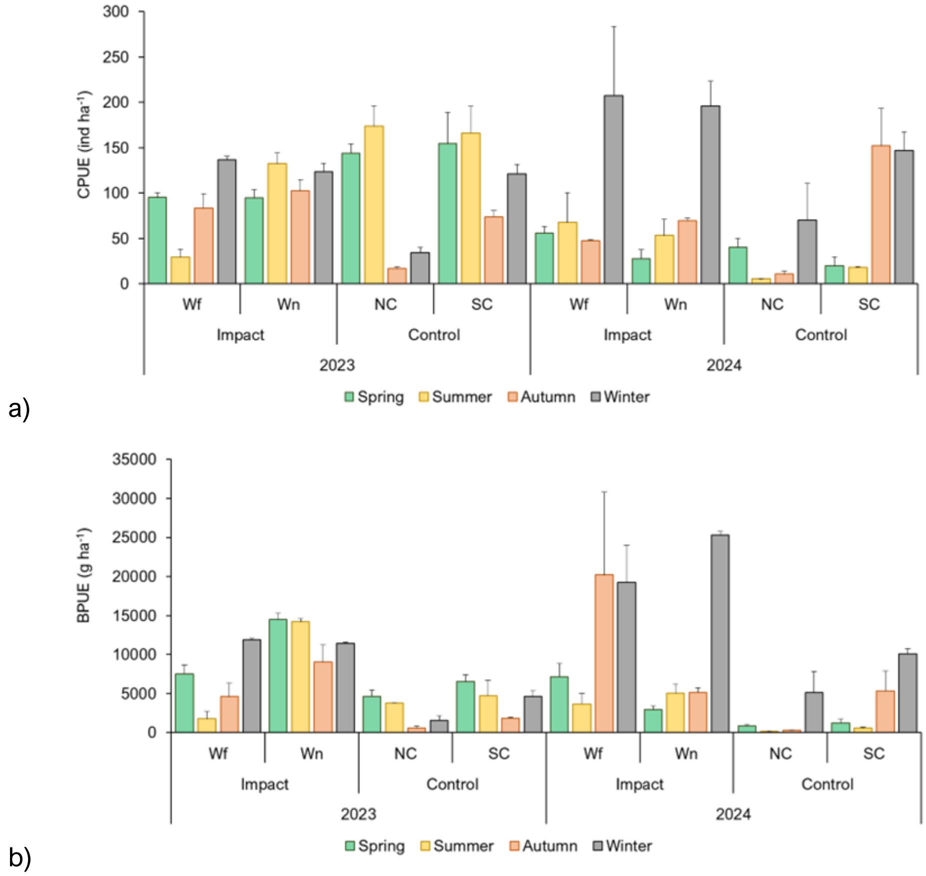


Figure 11 – Seasonal and spatial variation in fish community in impact (Wf, Wn) and control (NC, SC) areas during 2023 and 2024: a) Catch per unit effort (CPUE; individuals ha^{-1}) and b) Biomass per unit effort (BPUE; g ha^{-1}).

MARINE GROWTH ON PLATFORMS

The most abundant species currently colonizing the WFA platforms are kelp (large brown algae) and barnacles (**Figure 12**), although in previous monitoring years it was dominated by blue mussels and sea stars. Two species of anemones were also detected and, together, accounted for more than 35% of the total abundance. A high density of arthropod invertebrates was also recorded, a result that is consistent with findings from other studies on artificial floating structures (e.g., buoys). Their dominance on artificial structures is likely driven by a combination of high colonization capacity, structural refuge availability, and relatively reduced or heterogeneous predation pressure (artificial vertical structures may limit access by benthic predators compared to natural rocky reefs or soft-bottom habitats). In terms of flora, the number of species decreased over the sampling period. Nevertheless, kelp remains by far the dominant species, despite a substantial decline in its biomass in 2023.

Kelp (large brown algae) Barnacles

Figure 12 – Images of the most abundant species growing on the WFA platforms.

The average thickness of biological growth on the platforms increased from 2021 to 2022, reaching approximately 1.5 cm, and then decreased to about one third of that value (around 0.5 cm) in 2023. In 2023, 17 fewer fauna species and one additional flora species were recorded compared to 2022. An apparent consistency in flora species and a reduction in fauna species to levels like those observed in 2021 were registered. This pattern is likely a consequence of ecological succession during the colonization process, which gradually converges towards a more homogeneous community structure.

The presence of seven non-native species was recorded: four algae species and three fauna species, some of which (particularly algae) are listed among the most invasive species worldwide. However, the surface coverage of these species on the platforms is generally low (<10%), except for the brown alga Wakame, whose coverage has increased over the last two monitoring years. Continued monitoring of its growth is therefore necessary, with eradication measures to be considered if required. Overall, the non-native community developing on the WFA platforms is like that found in comparable natural habitats, such as coastal rocky environments (**Table 3**).

Table 3 – Coverage percentage (%) of exotic (non-native) species detected on the WFA platforms. Bryozoans: aquatic invertebrates that form colonies of organisms of the same species, mostly marine. (1) List of aquatic exotic species of the Iberian Peninsula (Invasaqua project, 2020): https://lifeinvasaqua.com/wp-content/uploads/2021/04/TR1_Invasaqua_PORT_PDF_interact.pdf; (2) EASIN - European Alien Species Information Network: https://easin.jrc.ec.europa.eu/spexplorer/search.

Species	Group	2021	2022	2023
Dead-man's-fingers (*Codium fragile fragile*) (1)	Algae	-	-	1
Oyster-thief or bladder-weed (*Colpomenia peregrina*) (1)	Algae	0,001	-	-
Devil's-tongue-weed (*Grateloupia turuturu*) (2)	Algae	-	-	13
Wakame (*Undaria pinnatifida*) (1)	Algae	-	8,8	24
Tufty-buff (*Tricellaria inopinata*) (1)	Bryozoan	0,3	0,02	-
Red-ripple-bryozoan (*Watersipora subatra*) (2)	Bryozoan	0,2	0,2	0,01
Sexton's-mud-shrimp (*Monocorophium sextonae*) (2)	Crustacean	0,2	-	-

MARINE MAMMALS

Five marine mammal species were recorded: common-dolphin, bottlenose-dolphin, harbour-porpoise, killer-whale, and minke-whale (**Figure 13** and **Figure 14**). The minke-whale is classified as "Vulnerable," while both the harbour-porpoise and the killer-whale are listed as "Critically Endangered" in terms of the IUCN categories for threatened species. The common-dolphin was the most frequently observed species, with its density peaking in autumn. No significant differences were detected between the WFA and adjacent areas regarding sighting results. Swimming was the most frequently observed behaviour, suggesting the area is primarily used as a transit zone.

Common-dolphin Minke-whale Harbour-porpoise

Bottlenose-dolphin Killer-whale

Figure 13 – Images of the main marine mammal species sighted in the study area.

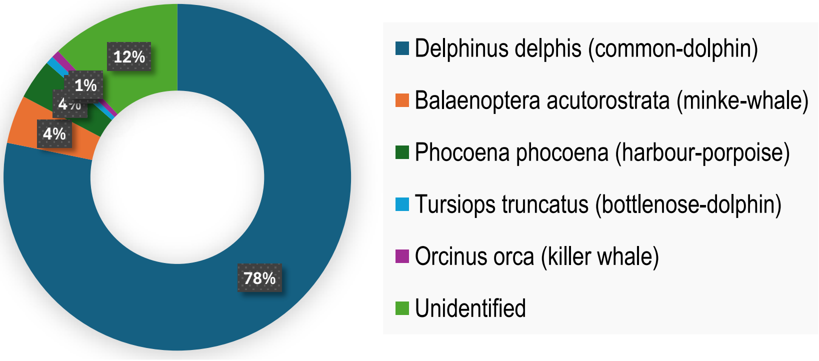


Figure 14 – Sightings percentage per species in the study area.

The results from hydrophone monitoring are consistent with those obtained through onboard vessel observations (sightings), showing a higher number of common-dolphins compared to harbour-porpoises. Hydrophone data also confirm that common dolphins are more frequently present during the autumn months (September, October, and November), when water temperatures are higher. In general, the number of marine mammals increased during the operational phase of the WFA project; however, for harbour-porpoises, numbers were higher in areas adjacent to the WFA, outside the project's influence. Other marine mammals, including common dolphins, appear to prefer the WFA area, as acoustic recordings indicate higher levels of activity within this area.

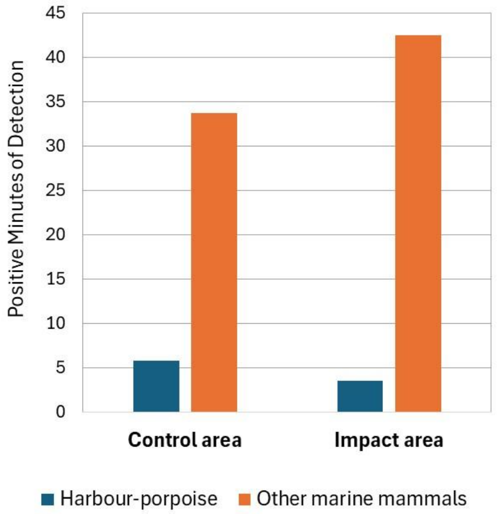


Figure 15 – Results of marine mammal presence (harbour-porpoises and other) in the study area according to data records from hydrophones.

BATS

Three species classified as "Least Concern" in terms of IUCN conservation status categories were detected (**Figure 16**). These species are long-distance migrants, characterized by fast flight at high altitudes, and have been associated with higher collision mortality rates at onshore wind farms. However, the number of records is considered very low, corresponding to sporadic activity within the WFA area and linked to the migration period. The WFA turbines may act as visual landmarks in the seascape but do not appear to be used as shelter.


Leisler's-bat European-free-tailed bat Greater-noctule bat

Figure 16 – Main bat species detected in the study area (WFA).

SEABIRDS

A total of 33 bird species were recorded in the study area, comprising 17 species prior to installation and 31 species during the operational phase of the WFA. Among the most abundant species, the Balearic-shearwater and the razorbill present the highest conservation concern, being classified as “Critically Endangered”. These species typically fly at low altitudes and are therefore not considered to be at significant risk of collision with turbine blades.

Species with lower abundance but with conservation status ranging from “Endangered” to “Near Threatened” were also recorded. Although species richness remains comparable between the WFA footprint and adjacent areas, overall seabird abundance was consistently higher within the WFA area, with this difference being more pronounced during the operational phase (**Figure 17**).

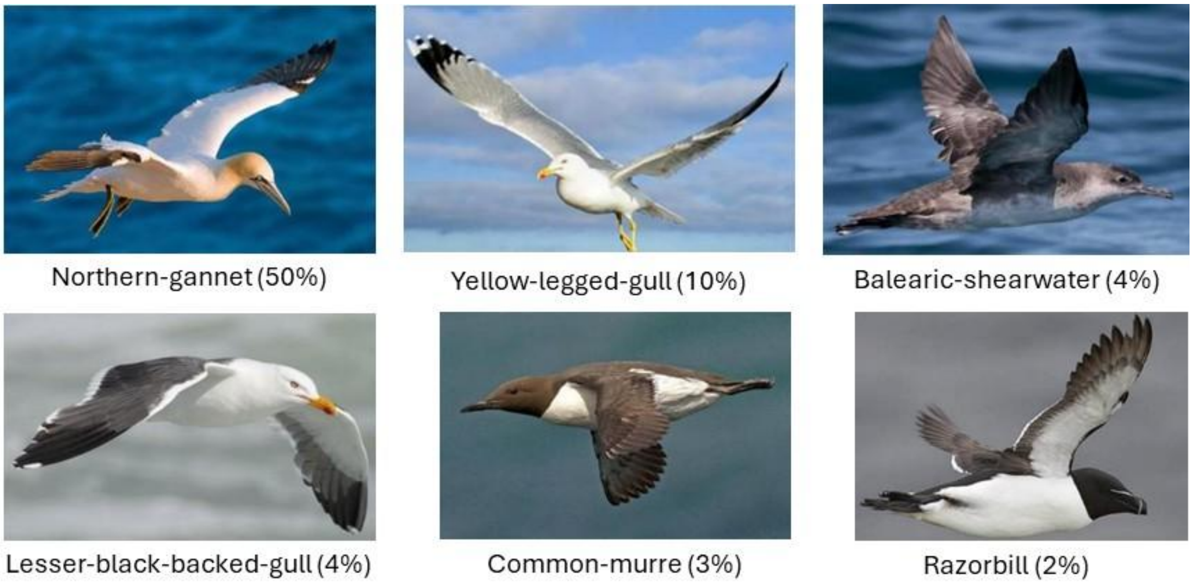

Northern-gannet (50%)
Yellow-legged-gull (10%)
Balearic-shearwater (4%)
Lesser-black-backed-gull (4%)
Common-murre (3%)
Razorbill (2%)

Figure 17 – Most abundant seabird species and their abundance percentage in the study area.

Bird detections were higher during the winter months (January to March), followed by the autumn period (September to December), indicating the predominance of wintering and migratory species in the area. During daylight hours, bird activity during the winter period (December to February) and the pre-breeding migration period (March to May) was highest around the middle of the daytime period; in summer, activity levels were higher during the early morning and late afternoon. Most species were observed in flight, followed by birds at rest, with a smaller proportion of individuals recorded while foraging. During the pre-breeding migration, movements were predominantly northward, whereas during the post-breeding migration, movements were predominantly southward (**Figure 18**).

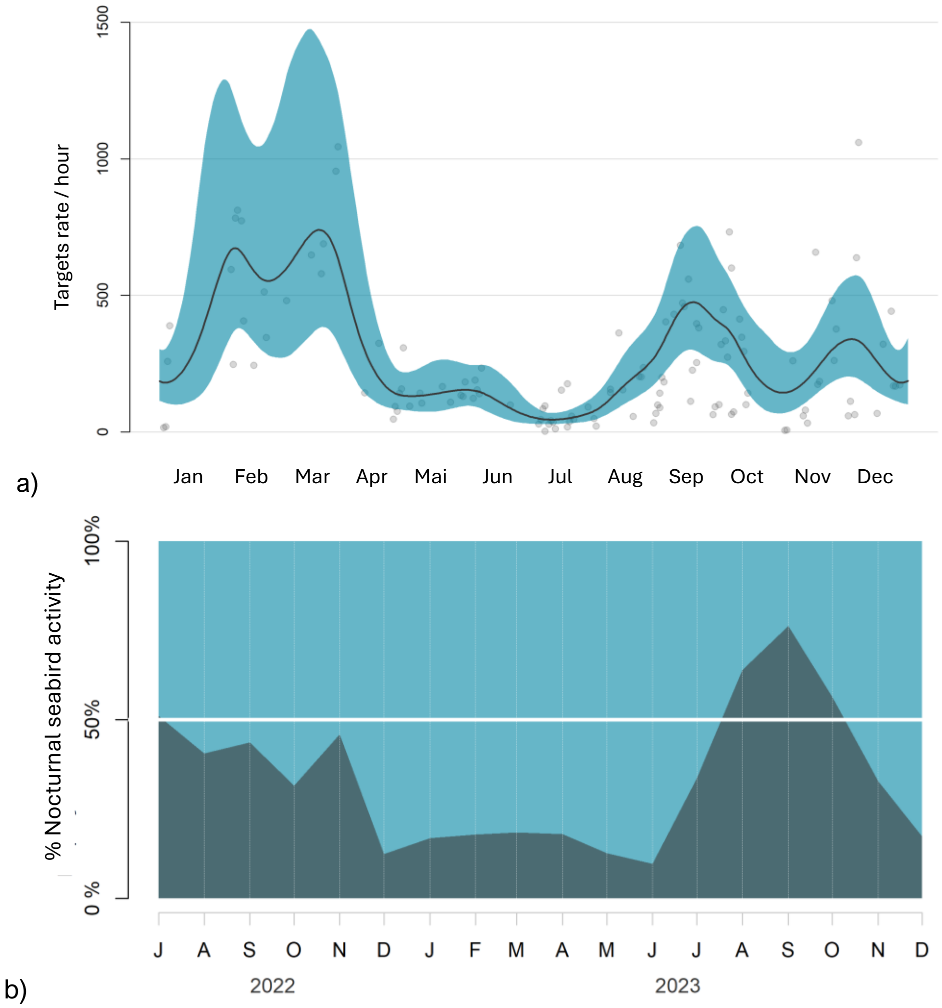


Figure 18 – a) Number of seabirds (targets) detected and b) annual distribution of nocturnal seabird activity recorded by radar.

The results of the collision risk model applied to the WFA indicate six bird species flying at heights associated with a high risk of collision with turbine blades. High abundance combined with flight altitude makes the northern-gannet, the yellow-legged-gull and the lesser-black-backed-gull the species most susceptible to turbine blade collisions. Mortality estimates derived from the applied collision model indicate that large gull species (yellow-legged-gull, lesser black-backed-gull and other large gull species) are expected to be the most affected group, followed by the northern-gannet.

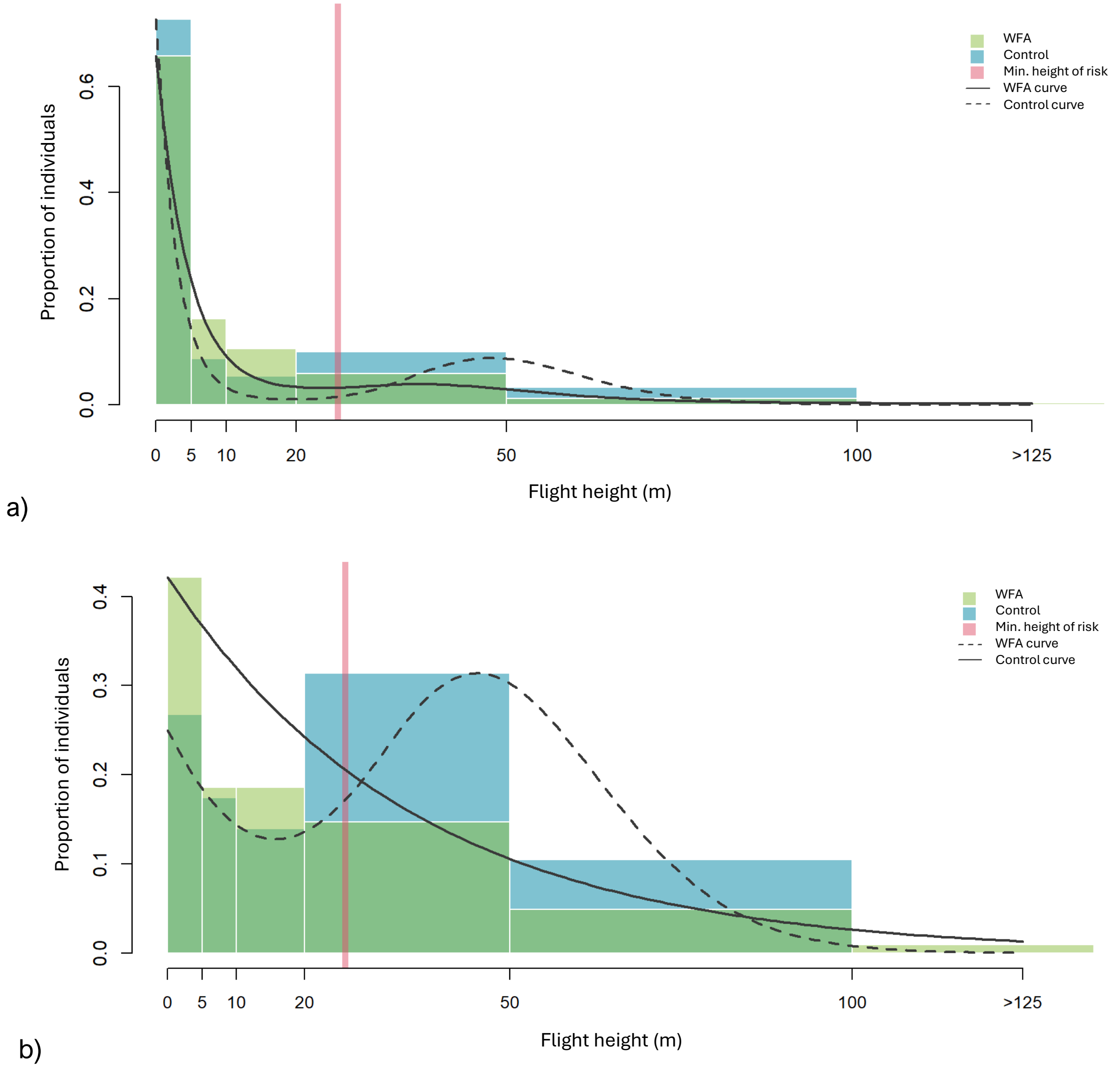


Figure 19 – Results of the collision risk model applied to a) all species and to b) large gulls (species with the highest probability of collision with the wind turbine blades).

WHAT ARE THE MAIN CONCLUSIONS OF THIS STUDY?

The results obtained from the environmental monitoring activities conducted across the biological components are summarized in **Table 4**. The findings indicate that natural seasonal and interannual variations were the primary factors influencing the structure of the observed biological communities, while spatial differences between the WFA area (Impact) and control sites were most pronounced for invertebrates, including octopus, a key commercial species, and for fish assemblages. These results suggest that, although the wind farm has not disrupted overall ecosystem functioning, the restricted fishing zone appears to confer local ecological benefits by providing habitat protection and refuge.

Fish abundance and biomass were consistently higher within the WFA area compared to both control sites. The lack of significant differences between near and far locations from WFA platforms suggests that the observed spatial patterns are primarily attributable to the exclusion of fishing rather than localized aggregation around the platforms.

Some species living near the seabed benefited most from the fishing exclusion, including three commercially important species – the sand sole, the common sole and octopus – as well as the lesser-spotted-dogfish, which was almost exclusively recorded within the wind farm. The concentration of these species within the impact area indicates a strong refuge effect, consistent with observations from other offshore wind farms worldwide. Furthermore, the elevated abundance of predatory species (fish and octopus) within the protected zone (WFA) likely affects local food chain dynamics, exerting top-down control on nektobenthic invertebrates (other than octopus) and helping to maintain ecological balance across food chain levels.

Table 4 – Summary of the results obtained in this study. The indication regarding statistical differences relates to the differences tested between control and impact (WFA) zones. MPD: Minutes of Positive Detections.

Biological groups	Parameters	Control zone	Impact zone (WFA)	Significant difference between zones?	Notes
Phytoplankton	Number of species	73	82	NO	Seasonal effects rather than spatial conditions are driving changes in the communities
	Biomass ($\mu g\ L^{-1}$)	0.51-15.85	0.34-14.25	NO	
Zooplankton	Number of species	~50	~50	NO	
	Density (ind m^{-3})	7-300	6-400	NO	
	Biomass (mg AFDW)	0.1-2.2	0.2-2.2	NO	
Nektobenthic invertebrates	Number of species	42-48	52	-	-
	Abundance (minimum and maximum ind/ha; considering results per season)	112-10,038	89-1404	NO	Variability driven by temporal factors, with strong seasonal cycles and interannual fluctuations
	Biomass (minimum and maximum kg/ha; considering results per season)	0.4-163.4	0.2-9.0	NO	Spatial contrasts episodic and temporally dependent rather than persistent
	Octopus abundance (minimum and maximum ind/ha; considering results per season)	3-38	3-81	YES (higher in WFA)	Significant effects of season and sites on population structure Biomass: seasonal fluctuation stronger in WFA
	Octopus biomass (minimum and maximum; kg/ha; considering results per season)	0.6-35.3	2.6-81.8	YES (higher in WFA)	
Fish	Number of species	23-43	40	YES (differences in fish communities' structure of both sites)	Impact (WFA): heterogeneity in species composition Control: homogenous and stable assemblages
	Abundance (minimum and maximum ind/ha; considering results per season)	10-282	46-373	YES (higher in WFA)	Fish abundance and biomass greater within the WFA area compared to control sites
	Total biomass (minimum and maximum kg/ha; considering results per season)	0.3-19.8	2.7-41.9	YES (higher in WFA)	
Marine mammals	Number of species	5	5	NO	Most abundant species: common dolphin

	Density of common dolphin (ind/km^2)	1.19	1.14	NO	Higher density in autumn and summer
	MPD of porpoise (minutes)	5	3	YES (higher in control)	Higher MPD during autumn
	MPD of other cetaceans (minutes)	41	44	YES (higher in WFA)	
Bats	Number of species	-	6	-	Low bat activity detected from July to November
	Abundance	-	Low	-	
Seabirds	Number of species	17	31	NO	Wintering birds are the most abundant
	Abundance (num ind)	1158	2188	NO	

The consistently higher abundance and biomass of fish and invertebrates within the WFA zone may also generate a spillover effect into adjacent areas, which has been reported to enhance fishery yields by up to 7%[1]. This protective function of wind farms underscores the importance of integrating offshore renewable energy infrastructure into broader marine spatial planning frameworks to support both ecological conservation and sustainable fisheries management.

Several studies, primarily conducted in the North Sea, have shown that the introduction of new hard substrates into the marine environment can lead to substantial increases in populations of certain hard-bottom species, such as mussels and barnacles, which are otherwise absent from comparable natural rocky habitats. The most abundant colonizer of offshore structures is the blue-mussel, a filter-feeder that removes large quantities of suspended particles from the water column and provides an important food source for intermediate and top predators, potentially modifying the local food web. The results presented here are consistent with these observations, as mussels were the dominant initial colonizers of the platforms, followed by barnacles. Mussel shells may also create secondary hard substrates that attract the colonisation of other organisms. Continuous deposition of shells on the seafloor alters sediment grain size in areas of accumulation, creating new habitats for species requiring solid attachment points or hard bottoms (e.g., crabs, sea stars). Consequently, offshore artificial structures, such as the WFA platforms, often support communities that are more diverse and abundant than those in surrounding areas, including natural reefs or soft substrates. However, as discussed, this should not automatically be interpreted as an environmental benefit, since these artificial structures may also create ecological imbalances.

Furthermore, the introduction of hard substrates may facilitate the spread of non-native species, using artificial structures as "stepping stones" to disperse over large spatial scales (tens to hundreds of kilometres). Such proliferation can have significant ecological impacts by competing with, preying upon, or displacing native species, potentially leading to economic consequences. However, three years of monitoring marine flora and fauna colonizing the WFA platforms indicate that, although non-native species were recorded, their abundance and biomass remain very low, apart from the algae *wakame*, which increased over the last two years of monitoring. However, no significant deleterious effects of the reef effect on invasive species proliferation have been observed, consistent with recent reviews on offshore wind farm

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[1] According to: Halouani, G. et al., 2020. A spatial food web model to investigate potential spillover effects of a fishery closure in an offshore wind farm. J. Marine Syst. 212: 103434. https://doi.org/10.1016/j.jmarsys.2020.103434

impacts. While the deepwater, offshore location of floating wind farms further reduces the likelihood of such pathways compared to nearshore installations, the potential for invasive species proliferation should (and will) continue to be monitored.

The higher presence of marine mammals (excluding porpoises) within the WFA corresponds with the observed increase in fish abundance and biomass, as greater activity was recorded in the impact area compared to control sites. In contrast, porpoise activity declined in the impact area following project installation, a pattern that may be associated with the presence and operation of the wind farm, as has been documented in other offshore wind farms.

Seabirds are recognized as one of the groups most potentially affected by offshore wind farm operation. The results presented here indicate that the number of seabird species remained relatively consistent between the control and impact areas, as well as across the two project phases (pre-installation and operation), although overall bird abundance was consistently higher within the impact area. This difference was particularly pronounced during the operational phase of the WFA. These conclusions should be interpreted with caution, as a single year of pre-installation sampling may be insufficient to fully represent species composition and abundance in the area.

For seabirds and bats exposed to offshore wind farms, three main effects are generally of interest due to their potential impact on survival and productivity: 1) collision mortality, 2) behavioural responses, including avoidance, displacement, and attraction, and 3) habitat-mediated effects on prey populations, such as changes in habitat and prey resources resulting from the introduction of new hard substrates (i.e., reef effects). No evidence of collision mortality was recorded within the WFA impact zone, although six species were observed flying at heights associated with a high risk of turbine blade collision. Large gulls (yellow-legged gull, lesser black-backed gull, and other gull species) are predicted to be the most affected group, followed by the northern-gannet as the second most at-risk species. None of these species currently holds a conservation status of concern.

Regarding behavioural responses, most seabird species were observed in flight, followed by birds at rest, with a smaller proportion engaged in feeding behaviour. This pattern suggests that the WFA area is likely used primarily as a migratory corridor rather than as a resting or foraging site.

Regarding bats, the low activity recorded in the WFA zone appears to be associated with dispersal and migratory movements, which typically occur in late summer and autumn. It is evident that the bats detected do not use the wind turbines as daytime shelter or foraging sites.

Biodiversity plays a critical role in supporting ecosystem processes and functions that underpin ecosystem services. These services represent the direct and indirect benefits that ecosystems provide to human well-being and quality of life, including provisioning services (e.g., food, fiber, minerals, renewable energy), regulating services (e.g., wastewater treatment, carbon sequestration and storage), cultural services (e.g., recreational and aesthetic benefits), and habitat and supporting services (e.g., life-cycle maintenance and habitat provision).

The ecosystem services (ES) framework is a comprehensive approach designed to capture and define the benefits people derive from nature. In the context of offshore wind farms, the ES approach situates ecological impacts within a societal and economic framework, allowing assessment of which impacts may influence human well-being.

This study supports previous research regarding the contribution of offshore wind farms to ecosystem services, particularly in provisioning, not only renewable energy but also potential food resources that sustain and enhance local biodiversity, while also benefiting commercial fisheries and, ultimately, human populations onshore. On the other hand, the reef effect created by the project also provides food for other top predators, such as seabirds and cetaceans present in the area, representing a positive conservation impact. Nevertheless, to ensure that these benefits translate into a net ecological gain, continuous environmental monitoring and integrated analysis of results would be essential, allowing the project's effects to be tracked over time, positive ecosystem service outcomes to be strengthened and potential negative impacts or ecological imbalances to be identified early and effectively mitigated.

The WFA project appears to influence the local marine ecosystem by affecting the abundance of several groups of species that typically occur in this region of the Portuguese coast.

A general increase in organism abundance was observed within the WFA area, particularly for octopus and fish (including species sensitive to electromagnetic fields), common dolphin, and seabirds.

The WFA project appears to provide shelter and foraging habitat, primarily for octopus and certain fish species.

Some bird species with a high risk of collision with wind turbines were identified, including the northern-gannet and large gulls, although no evidence of turbine collisions was recorded.

Some non-native species were detected in the communities colonizing the platforms, which should continue to be monitored to prevent their proliferation.

The results are consistent with other studies on the role of offshore wind farms in providing food resources, supporting not only local biodiversity but also commercial fisheries, ultimately benefiting human populations.

Figure 20 – Main conclusions of the present study.

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