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IMPACT OF ARTIFICIAL REEFS ON FISHING COMMUNITIES:
THE LAGOS BAY CASE

UNIVERSIDADE DO ALGARVE

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Master's in Marine and Coastal Systems

Work performed under the supervision of:
Francisco Leitão
Jorge Ramos

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Declaração de autoria do trabalho

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída**.**

Statement of authorship

I declare to be the author of this work, which is original and unpublished. Authors and works consulted are duly cited in the text and included in the reference list.

Joana Patrícia Pestana da Costa

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Abstract

Coastal zones are highly productive areas that sustain biodiversity and provide essential ecosystem services for human communities. However, they are increasingly threatened by overfishing and habitat degradation, creating a need for management tools that balance ecological sustainability with socioeconomic needs. Artificial reefs (ARs) have been deployed worldwide to enhance fisheries, restore habitats, and support coastal communities, but they also play an extensive role in establishing coastal resilience and offering new livelihood opportunities. This study investigates whether the Alvor artificial reef, deployed 25 years ago off southern Portugal, continues to serve as a fishing enhancement tool for surrounding fishing communities. A mixed-methods approach was applied, combining Automatic Identification System (AIS) data from coastal vessels with semi-structured questionnaire-based interviews (SSQBI) from local small-scale fishers. AIS data provided spatial and temporal records of fishing activity across the AR and two control areas, while interviews offered insights into perceptions, practices, and challenges associated with the AR, ensuring that both observed behaviour and reported knowledge were considered. The results indicate that the Alvor AR still attracts fishing activity, though patterns change across fleet segments. Coastal vessels continue to operate around the reef, suggesting that it remains valuable as a fishing ground for larger-scale operations. In contrast, local fishers report minimal use, citing practical challenges such as ghost fishing and gear entanglement risk, which for small-scale operations can mean significant economic loss. These findings reveal opposing benefits of the AR, shaped by fleet characteristics and perceptions. Study limitations include the restricted coverage of AIS, the small interview sample, and the absence of seasonal analysis due to limited data. Despite these restrictions, the combination of spatial tracking and fisher perceptions offered complementary insights into the AR's use. The study concludes that the Alvor AR continues to support fishing activity, though unevenly across fleets. It highlights the importance of periodic reassessment, smaller-scale monitoring, and fisher engagement to ensure that artificial reefs deliver on their intended socioeconomic and ecological objectives.

Keywords: Fishing vessels, Fisher perceptions, Automatic identification system (AIS), Semi-structured questionnaire-based interviews (SSQBI), Fisheries management, Socioeconomic impacts.

Resumo

As zonas costeiras são dos ecossistemas mais produtivos do planeta, suportam tanto uma grande biodiversidade como as comunidades humanas que vivem nestas áreas. Estas zonas proporcionam habitats essenciais à vida marinha enquanto sustentam a vida das comunidades piscatórias. Mesmo assim, estas zonas estão constantemente sobre várias pressões resultantes de atividades humanas, alterações climáticas e o aumento da procura por recursos marinhos. A sobrepesca, destruição de habitats e competição por espaço costeiro fazem com que seja importante explorar ferramentas que possam contribuir para a sustentabilidade ecológica e o bem estar socioeconómico.

Estas ferramentas podem ser, por exemplo, recifes artificiais (RAs). Ao colocar estruturas tridimensionais no fundo do mar, os RAs imitam as características dos recifes naturais, atraem organismos marinhos e criam oportunidades de pesca. A instalação de RAs tem uma longa história e continua, nos dias de hoje, a ter aplicações desde conservação, a gestão da pesca e turismo. Explorar a eficácia a longo prazo destas estruturas é essencial, para determinar se elas conseguem realmente suportar a pesca e as comunidades costeiras.

O recife artificial de Alvor foi colocado no fundo da Baía de Lagos, no sul de Portugal, entre 2000 e 2001, e 25 anos depois da sua instalação surge uma oportunidade de estudar se as estruturas continuam a manter as funções para as quais foram criadas. O principal objetivo deste estudo foi avaliar se o recife artificial continua a servir como uma ferramenta de apoio à pesca. Ao examinar este estudo de caso, este estudo procurou contribuir para um melhor conhecimento de como os recifes artificiais se comportam passadas décadas e o que isto significa para o desenvolvimento e gestão das pescas.

Foi utilizada uma metodologia complementar que combinou dados quantitativos de monitorização satélite de embarcações costeiras e dados qualitativos de entrevistas com pescadores locais. O primeiro método envolveu a análise de dados provenientes do Sistema de Identificação Automático (AIS), emitidos pelos barcos costeiros que operam na área da Baía de Lagos. Estes dados contêm informação sobre a atividade das embarcações, como a posição, velocidade, data e hora e conseguem ser utilizados para extrair a atividade de pesca no recife artificial e áreas de controlo adjacentes.

Uma vez que só embarcações maiores de 15 metros são obrigadas a ter um dispositivo AIS a bordo, um segundo método foi utilizado para recolher mais informações relativamente à frota local. O segundo método envolveu a realização de entrevistas baseadas num questionário semiestruturado (SSQBI) direcionado aos pescadores locais de Lagos e Alvor. As entrevistas refletiram as perceções dos pescadores em relação ao RA, nomeadamente na utilização da área recifal e na utilidade das estruturas.

A combinação destas duas metodologias permitiu um melhor enquadramento de como as diferentes frotas de pesca interagem com o recife. Os resultados mostraram um contraste entre as frotas costeira e local. Os dados de satélite revelaram que o RA são áreas de pesca para os barcos costeiros, com registos de atividade maiores junto ao recife do que nas áreas de controlo. Estas embarcações parecem incorporar os RA na sua estratégia de pesca. Em contraste, as entrevistas com os pescadores locais indicaram que atualmente existe pouco interesse em pescar no RA. A maior parte dos inqueridos descreveu que existem muitas artes de pesca abandonadas a cobrir o recife, que resulta em menos peixe, maior dificuldade a pescar e a potencial perda das próprias redes por emaranhamento. Esta diferença de resultados mostra como a mesma estrutura consegue ter papéis diferentes consoante o tipo de frota (i.e., costeira versus local), artes de pesca e perceções.

O que acima está sintetizado indica que o recife artificial de Alvor continua a desempenhar importantes funções de apoio à pesca, mas o seu papel não é uniforme na frota toda. Para as embarcações costeiras os RA são zonas de pesca recorrentes. No entanto, para as embarcações locais o RA já não é considerado tão relevante de acordo com os inquéritos. Esta divisão realça a importância de considerar os resultados sociais assim como os ecológicos, quando se avalia o sucesso de ao longo do tempo. De fato, os dados parecem indicar que o desempenho do recife artificial de Alvor alterou-se com o tempo e varia entre setores da pesca (local, costeiro). Por consequência, é essencial realizar reavaliações periódicas, e com maior esforço amostragem, para garantir que os recifes continuam a desempenhar as funções de acordo com os seus objetivos iniciais, quer sejam estes ecológicos, socioeconómicos ou ambos.

A combinação dos dois métodos foi essencial, uma vez que cada método individualmente só teria mostrado uma perspetiva parcial da frota pesqueira. A monitorização espacial das embarcações destacou onde e quando os barcos estavam ativamente a pescar, enquanto as entrevistas explicaram as perceções relacionadas com as decisões do dia a dia da pesca. Em conjunto, estas duas abordagens revelaram os padrões de uso, garantindo uma compreensão mais completa do papel do recife atualmente.

No entanto, as limitações do estudo devem ser reconhecidas. O conjunto de dados AIS era pequeno e de duração limitada, o que impediu a identificação de padrões sazonais. Também excluiu embarcações menores (frota local), criando uma lacuna nos dados que as entrevistas tentam a preencher. O esforço de amostragem das entrevistas foi pequeno e a área de estudo limitada, o que significa que perspetivas mais abrangentes podem não ter sido recolhidas. Apesar destas limitações, o estudo trouxe informações relevantes sobre o uso e a perceção do recife após 25 anos, sobretudo tendo em conta a ausência de outros trabalhos de monitorização posteriores à instalação do RA de Alvor.

Os resultados também têm implicações importantes para a gestão. As abordagens na gestão devem ter em conta estas diferenças, e assegurar que a colocação dos recifes corresponde às necessidades e realidades das comunidades piscatórias, assim como se prolongam no tempo. A contribuição dos RAs para a sustentabilidade depende não só do seu desempenho ecológico, mas também da maneira como as comunidades interagem com eles. De forma a garantir que os recifes proporcionam benefícios a longo prazo, é preciso integrar uma monitorização ecológica e socioeconómica nos planos de gestão.

Estudos futuros deverão procurar recolher padrões de utilização dos recifes a longo prazo e em maior escala, assim como alargar a área de ação das entrevistas para incluir mais pescadores e desta forma, adquirir uma visão mais ampla das perspetivas da comunidade.

Palavras-chave: Embarcações de pesca, perceções de pescadores, sistema de identificação automático (AIS), entrevistas semiestruturadas baseadas num questionário (SSQBI), gestão da pesca, impactos socioeconómicos

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Abbreviation List

AR	Artificial reef
AIS	Automatic Identification System
BRUV	Baited Remote Underwater Video
CTRL1	Control 1
CTRL2	Control 2
DGRM	Directorate General for Natural Resources, Safety and Maritime Services (*Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos*)
EC	European Commission
EEZ	Exclusive Economic Zones
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning Systems
INE	Statistics Portugal (*Instituto Nacional de Estatística*)
IPMA	Portuguese Institute for the Sea and Atmosphere (*Instituto Português do Mar e da Atmosfera*)
KDE	Kernel Density Estimation
LEK	Local ecological knowledge
LOA	Length overall
LPUE	Landings per unit effort
MBES	Multibeam echosounders
MMSI	Maritime Mobile Service Identity
ROV	Remotely Operated Vehicles
SSQBI	Semi-structured questionnaire-based interviews
UVC	Underwater Visual Census

VHF	Very High Frequency
VRSA	Vila Real de Santo António

1. INTRODUCTION

1.1. Portuguese Fisheries

Portugal has always been connected to the ocean, historian Pliny the Elder first reported marine life in the Iberian Peninsula in the 1st century AC (Borja et al., 2013). The Portuguese have one of the highest consumptions of fishery and aquaculture products, at 568,435 tonnes (54.5 kg per capita) in 2022, of which only 165,801 tonnes come from the total catches by the national fleet (INE, 2022; EC, 2024). What drives this high fish consumption pattern in the Portuguese, according to Almeida et al., (2015), is closely related to Portugal's geography, marine living resources, fisheries, social forces and politics.

Firstly, despite being a small country, Portugal mainland has an extensive coastline of 943 km and one of the largest Exclusive Economic Zones (EEZ) in Europe, covering around 1.7 million km^2 when including the Madeira and Azores archipelagos (Cardoso et al., 2019). The country is located in a biogeographic transition zone between temperate and subtropical waters, where several marine species reach the limits of their distribution (Gamito et al., 2016). This diversity is improved by the coast's hydrographical variability, by having a cooler northern region influenced by upwelling and freshwater inputs, and a warmer southern region shaped by Mediterranean conditions, supporting high marine biodiversity (Cardoso et al., 2019).

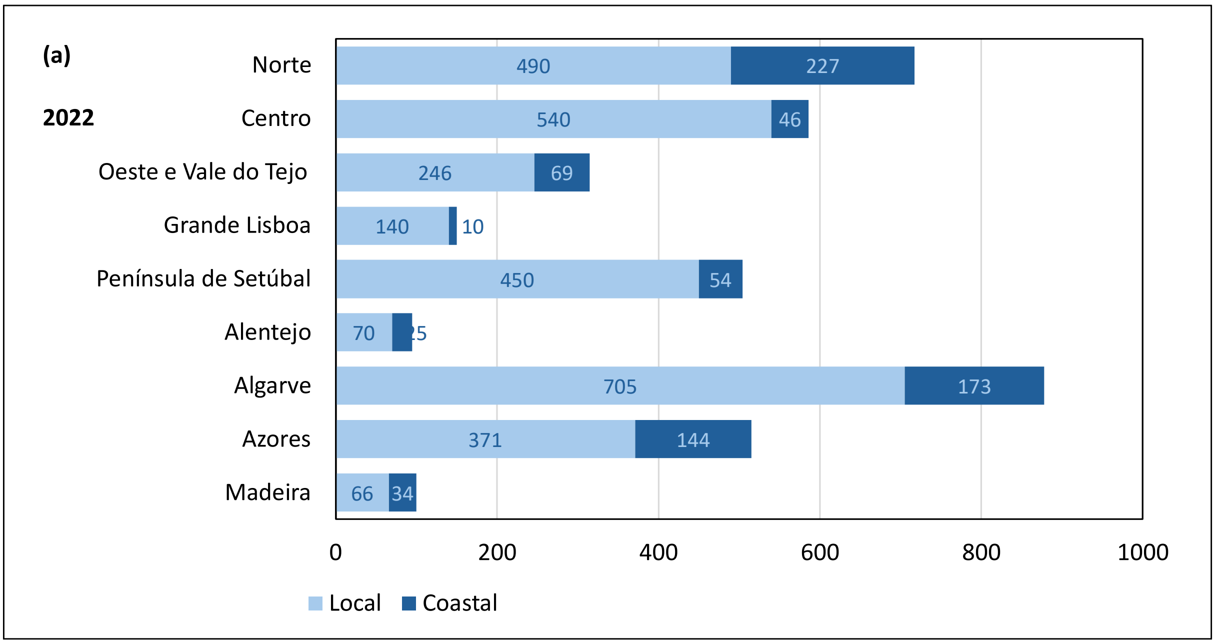
Worldwide, over 600 million people depend directly on fisheries and aquaculture for food security and their livelihoods (FAO, 2024), and Portugal is no exception. As a coastal country, the nation's fisheries sector has a great socioeconomic importance, particularly for rural and coastal communities where employment alternatives are often limited (Pita, 2014). These communities rely not only on fishing activities, but also on wider ocean-related sectors such as tourism and fish processing.

Seafood consumption has been a dominant element of Portuguese culture and food heritage, supported by favourable marine conditions and high coastal productivity. For example, cod (*Gadus morhua*), while no longer fished in significant quantities by the national fleet, remains the most consumed fish species in the country, accounting for nearly 40% of total fish imports (Monteiro and Noronha, 2020). In addition to cod, a wide variety of species are part of traditional Portuguese cuisine, including small pelagic fish such as sardines and mackerel, demersal species, cephalopods like octopus, cuttlefish, and squid, as well as a range of shellfish such as clams and mussels.

1.1.1. *Portuguese Fleet*

According to Portuguese legislation (Decreto-Lei n.º 73/2020), the fishing fleet is often categorized based on vessel size and activity range into local, coastal and offshore. Local, sometimes referred to as small-scale or artisanal, vessels have a length overall (LOA) of up to 9 meters and are limited to operating within the jurisdictional area of their local port authority and adjacent areas. These vessels are only allowed to go up to 6 nautical miles from the coast if they are equipped with VHF radio, or 3 miles without it. Coastal vessels range from 9 to 33 meters in overall length, have an autonomy based on the activity area of the vessel and can operate beyond local waters. Finally, the offshore fleet is made of larger vessels that can operate beyond 12 nautical miles from the coast, often remaining at sea for 15 days or more.

In 2023, a total of 3,728 fishing vessels were registered in Portugal, 147 less vessels compared to 2022 (INE, 2022; INE, 2023). The fleet (Figure 1.1) is mainly composed of local vessels, particularly focused in the Algarve and Centro regions. Local vessels are more predominant in the Norte and Algarve regions. Although offshore vessels are part of the classification, they represent a small component of the fleet, with 15 vessels licensed both in 2022 and 2023.



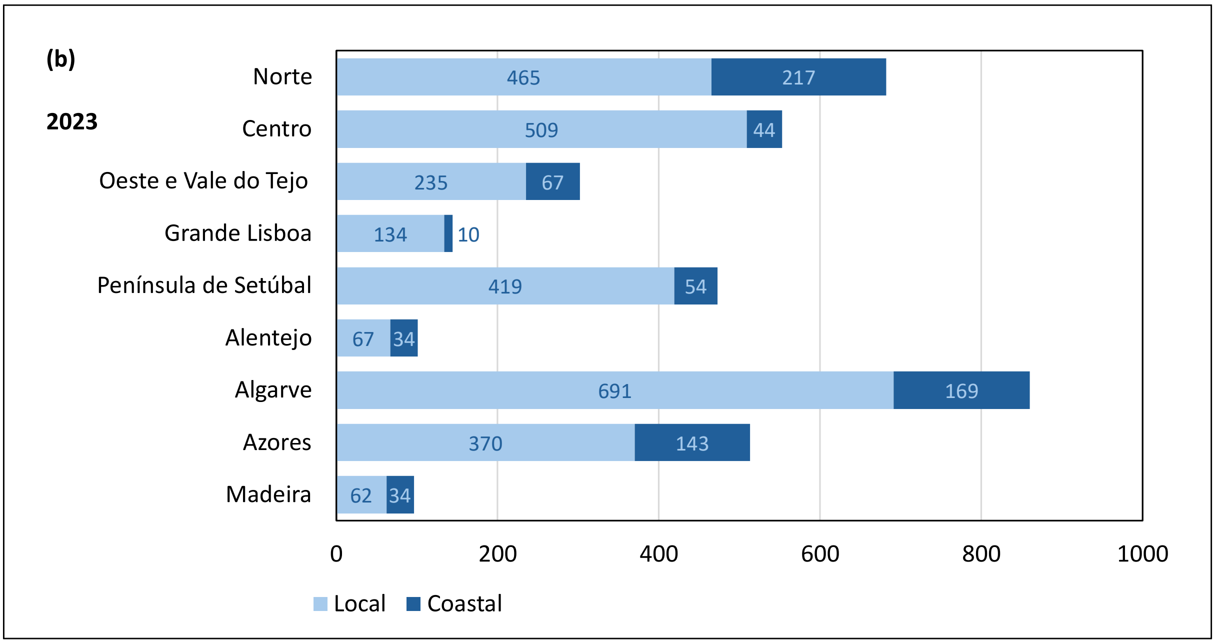


Figure 1.1 Distribution of licensed fishing vessels in Portuguese regions (Norte, Centro, Oeste e Vale do Tejo, Grande Lisboa, Península de Setúbal, Alentejo, Algarve and the archipelagos of Azores and Madeira), classified by vessel length (Local: <10 m; Coastal: 10-40 m) for (a) 2022 and (b) 2023. Data source: INE (2022, 2023).

The Portuguese fishing fleet can also be classified based on the type of gear employed. Most vessels belong to the multigear (or polyvalent) segment, meaning they are equipped with two or more types of gear that they can alternate, without needing major changes in the vessel and its equipment. This segment includes all local fishing vessels and most coastal vessels, except those that operate exclusively with trawl or purse seine gear. Multigear vessels typically operate with passive gears such as hooks and lines (including longlines), nets (such as trammel and gillnets), and cages (including pots and traps), often targeting several species throughout the year.

Hooks and lines involve the use of natural or artificial bait attached to hooks, which are fixed to lines. A longline is a specific type of hook and line system where baited hooks are spaced along a single, extended mainline that can be either anchored or stay drifting, depending on the target species, and fishing depth. Net fishing includes nets such as gillnets with single or double panels of mesh that entangle the fish by the gills and trammel nets, which consist of two outer large meshed panels and one smaller meshed panel in between to trap the fish by entangling their bodies. Traps are cage-like devices made to capture fish or crustaceans (or octopuses caught by pots) that enter and cannot escape. In the Algarve, commonly used traps include *alcatruzes* (clay, vase-shaped pots mainly used to capture octopus), *covos* (small metal traps with a top entry), *armadilhas* (larger metal traps used for fish and cuttlefish) and *murejonas* (circular doughnut-shaped wire traps with one funnel-shaped entry at the top) (Erzini et al., 2008).

Alongside the multigear fleet, there is also the trawling segment that operates using cone-shaped nets towed through the water or along the seabed, held open by side wings. Lastly, the purse seine fleet uses a wide and tall net that envelops the shoal and closes like a purse in the bottom, often operating closer to shore, when compared to trawlers.

Portugal has a total of 163 fish landing ports, of which 33 are located in the Algarve region and are distributed along the five main ports of Lagos, Portimão, Olhão, Tavira and Vila Real de Santo António (VRSA). Data from 2022 and 2023 on licensed fishing vessels (Figure 1.2) confirms the dominance of polyvalent gear types, in particular hooks and lines, followed by nets then traps.

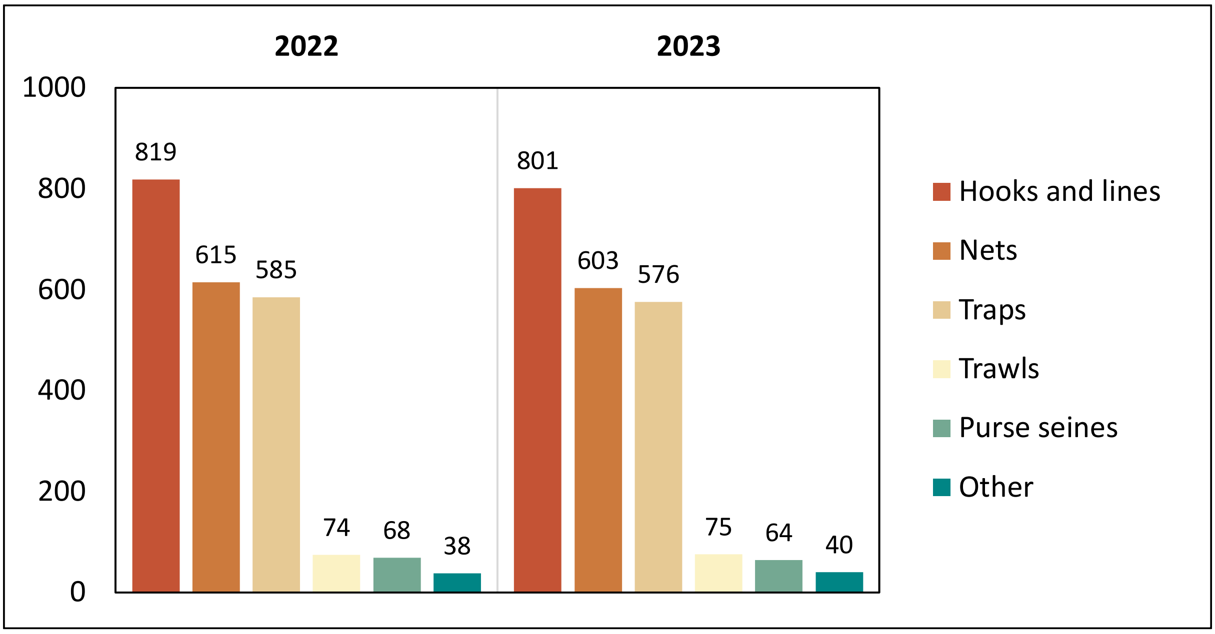


Figure 1.2 Distribution of licensed fishing vessels in the Algarve region by fishing gear (hooks and lines, nets, traps, trawls, purse seines and other), for 2022 and 2023. Note: vessels may have more than one fishing gear license. Data source: INE (2022, 2023).

1.1.2. *Portuguese Fisheries Management*

According to the Food and Agriculture Organization (FAO), the percentage of marine fish stocks exploited at unsustainable levels has increased, from 10% in 1974 to 37.7% in 2021

(FAO, 2024). In Portugal, fisheries management is coordinated under the Ministry of Agriculture and Fisheries and implemented by several entities: the Directorate General for Natural Resources, Safety and Maritime Services (DGRM), which oversees enforcement, licensing, and data reporting; the Portuguese Institute for the Sea and Atmosphere (IPMA), which proposes technical conservation measures; and DOCAPESCA, responsible for the first sale of fish and for supporting fishing ports. Additionally, the Azores and Madeira regions have autonomous jurisdiction over local fisheries (Pita and Gaspar, 2020).

Despite these governance structures and the application of management measures such as quotas, minimum mesh sizes, seasonal and biological closures, and marine protected areas, certain fish stocks remain overexploited (Leitão, 2015). In Portugal, the increasing consumption and declining catches mean national fisheries production only fulfils about one-third of market demand, therefore imports increase to fill this gap, particularly for key species such as cod and sardine, adding to the deficit in fish products (Monteiro and Noronha, 2020). To help address these differences and reduce pressure on wild stocks, enhancement strategies can be considered, including aquaculture-based enhancement (e.g., restocking and sea ranching) and habitat-based approaches (e.g., habitat restoration and the installation of artificial structures) (Lorenzen et al., 2013; Baggett et al., 2015; Kitada, 2020).

1.2. Artificial Reefs

Artificial reefs are human-made structures that are deployed often in sandy bottoms to create a habitat (Seaman, 2007) in marine, brackish or freshwaters (Cavallaro and Schumann, 2024). They can be introduced on purpose as is the case of concrete modules and a purposely sunk ship or they can be unintentional such as oil and gas infrastructures (Guerin et al., 2007).

The deliberate creation of human-made environments by submerging structures has been a practice since a very long time in places like Africa and South America (Lima et al., 2019). However, the first records of artificial reefs being used by humans come from Japan dating back to the 17^{th} century (Lee et al., 2018). Early records describe a warrior who created a fishing area by submerging stones and other records mention fishers sinking bamboo structures to form fishing grounds (Thierry, 1988; Lee et al., 2018; Lima et al., 2019). In 1916, Japan began using abandoned naval ships as artificial reefs, and by 1952, a structured plan was implemented to establish concrete reef blocks to support commercial fishing efforts (Lee et al., 2018).

The AR concept also appeared in the USA, with the earliest reported use of such structures dating back to the 1880s, when anglers deployed large huts off the coast of South Carolina to create fishing reefs (Lee et al., 2018). In the 1930s, vessels were intentionally sunk for recreational fishing purposes off New Jersey's coast. In the 1960s, the United States' innovations in artificial reefs began to spread globally (Lima et al., 2019). In Europe, this concept was implemented in the second half of the 20th century and many countries have been deploying artificial reefs since then (Fabi et al., 2011).

1.2.1. ***Factors Influencing Artificial Reef Deployment***

The main factors to consider when designing and deploying artificial reefs begin with their intended purpose, which then leads to other aspects, including shape, material choice, depth, and substrate selection (Vivier et al., 2021). Artificial reefs are deployed mainly due to three reasons: to enhance/restore biodiversity, to increase commercial fishing yields and recreational issues, that attract anglers and divers (Folpp et al., 2020; Özgül and Lök, 2022). Other reasons why ARs are deployed, include coastal protection and research (López et al., 2016; Higgins et al., 2022).

Artificial reefs enhance biodiversity and fisheries by providing hard substrates that support fish biota and increase species abundance (Glarou et al., 2020). They also play a role in coastal protection by dissipating wave energy, reducing shoreline erosion, and aiding coral population recovery (Ghiasian et al., 2021). From a socioeconomic perspective and based on their location, these structures attract tourists seeking unique diving experiences with features such as sunken ships and monuments, boosting local economies, and supporting new business opportunities (Bideci and Cater, 2019). Additionally, research-purposed artificial reefs can highlight the impact of AR materials on biofilm bacterial communities, which are crucial for coral larval settlement and the success of reef restoration efforts (Sajid et al., 2024). The following section highlights some of the main factors that directly or indirectly influence artificial reefs' deployment, from design to socioeconomic factors to consider when creating and deploying these structures (Figure 1.3).

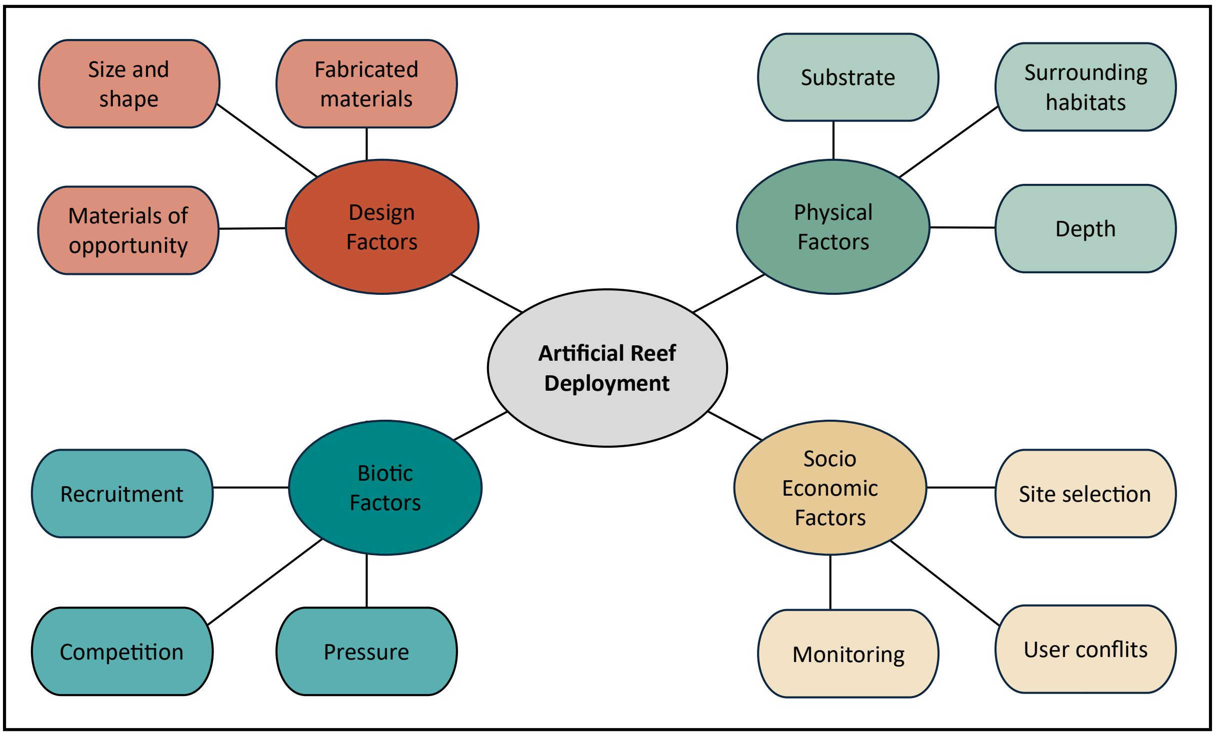


Figure 1.3 Conceptual diagram summarizing the main factors inflencing artificial reef deployment, including design, physical, biotic and socioeconomic factors.

Design Factors – The materials used in artificial reef building can be categorized into fabricated materials (purpose-built structures) and materials of opportunity (repurposed existing structures). Concrete is the most widely used fabricated material for artificial reefs worldwide (Lemoine et al., 2019; Hylkema et al., 2021) due to its durability, weight, and versatility. It can be molded into various shapes like cubes, blocks, balls, tubes, grids, and pyramids (Lima et al., 2019). Its high rate of organism fixation makes it ideal for habitat restoration, fisheries enhancement, and coastal protection (Vivier et al., 2021). Concrete continues to be optimized for a better ecological performance (Potet et al., 2021). Steel cages and plastic materials are less common but can also be combined with other materials for more stability (Saharuddin et al., 2012; Christie et al., 2019). These structures act as nursery grounds and make complex structures that also attract divers (Mercader et al., 2017; Tynyakov et al., 2017).

Materials of opportunity, such as decommissioned ships, oil platforms, and coastal protection structures, can be repurposed as artificial reefs. While accidental shipwrecks can pose navigational risks (Lima et al., 2019), purposely sank vessels undergo preparation to ensure they are free of harmful materials and safe for divers (Bideci and Carter, 2019). Since these ARs can attract a high number of species, they are also popular among recreational fishers

(Consoli et al., 2015). Decommissioned oil platforms also show high rates of fish production (Claisse et al., 2014) as do offshore wind and wave energy structures (Langhamer, 2012). Infrastructure such as breakwaters and ports can also develop communities of marine organisms, evolving into ARs (Burt et al., 2011). Certain coastal protection structures are even designed to simultaneously function as habitats for reef species (Silva et al., 2016).

In addition to the materials used, the size and shape of artificial reefs influence fish abundance and community composition (Hackradt et al., 2011) affecting ecological and socioeconomic outcomes. Larger reefs, such as sunken ships and decommissioned oil rigs, provide high structural complexity, which is often linked to greater fish abundance (Bulger et al., 2019; Lemoine et al., 2019). In contrast, smaller reefs may be harder for fish to detect and impose physical limits on the number of fish they can support (Blount et al., 2021).

In general, materials used in artificial reef construction must be inert, durable, and provide a suitable substrate for marine life by creating vertical and structural complexity. They should not pose entanglement risks to marine life, must offer refuge, comply with permitting requirements, maximize cost-effectiveness, and be free of harmful substances, pollutants, floating debris, or conditions that cause turbidity (Lindberg and Seaman, 2011).

Physical Factors – The site selection of artificial reefs, including depth and substrate, is essential to ensuring their effectiveness and alignment with their purpose. Factors such as other habitats in proximity (e.g. coral reefs, seagrass beds and other hardbottom communities), structure and substrate stability, hydrodynamic conditions and accessibility for users (i.e. proximity to main ports/marinas) must be considered to guarantee the artificial reef's longevity and minimize displacement as these factors vary based on the depth and the nature of the seabed (Fabi et al., 2011; Lindberg and Seaman, 2011; Komyakova et al., 2019).

For example, reefs designed for fisheries enhancement are often placed at depths of 20–30 meters where they provide ideal conditions for fish populations while remaining accessible to fishers using small or medium-sized vessels (Ramos et al., 2021). On the other hand, reefs intended for dive tourism or research are located in shallower waters, typically under 15 meters, to provide accessibility for divers and reduce costs associated with sampling equipment in scientific diving (Ramm et al., 2021). These considerations have socioeconomic implications, as closeness to main fishing grounds or popular tourist areas directly influences the reef's benefits for the local community (Mousavi et al., 2015).

Most artificial reefs are deployed on sandy substrates to add habitat complexity to otherwise featureless areas (Ramm et al., 2021). Sandy bottoms are also characterized by their low productivity, and the establishment of new feeding areas (i.e., ARs) enhances trophic efficiency in these regions, resulting in an increase in fish biomass (Leitão, 2013).

Biotic Factors – Other factors such as recruitment, competition, predation, and biotic pressure influence how artificial reef communities develop and function. The growth of foundational species like canopy algae may be suppressed on artificial reefs due to both consumptive and non-consumptive biotic disturbances, which can reduce overall habitat quality (Ferrario et al., 2016). Recruitment patterns also vary spatially and temporally, with species-specific preferences for reef type and location influencing community composition over time (Komyakova and Swearer, 2019). In addition, trophic interactions such as predator–prey dynamics are increasingly recognized as important in determining the ecological success of artificial structures (Leitão et al., 2008a). Together, these biotic processes play a critical role in shaping reef function and must be integrated together with physical and structural considerations to ensure that restoration, enhancement, or fisheries goals are met.

Socioeconomic Factors – To minimize potential conflicts among the artificial reef's intended users, it is essential to involve local stakeholders, such as fishers' organizations, in the site selection process. Sayer and Wilding (2002) highlighted that fishers may have different concerns depending on their fishing method. For example, static-gear fishers may worry that AR could attract additional fishing effort targeting existing wild stocks, while towed-gear fishers might fear displacement from their traditional fishing grounds.

Each location has unique characteristics that demand a custom-made approach, making reef design, site selection, and ongoing monitoring essential. These elements ensure that the artificial reef meets its intended goals, whether contributing to biodiversity, enhancing fisheries or generating tourism.

1.2.2. ***Monitoring Artificial Reef Use***

Monitoring artificial reef structures is essential to confirm they meet pre-deployment goals and adapt effectively to their original purposes (Becker et al., 2020; Vivier et al., 2021). To assess AR effectiveness, the selection of monitoring techniques requires a combination of complementary methods tailored to the artificial reef goals (Vivier et al., 2021).

Biological Monitoring – Observational methods, such as underwater visual census (UVC), underwater photography, Remotely Operated Vehicles (ROVs), Baited Remote Underwater Video (BRUVs), and hydroacoustic techniques, are used to study fish assemblages and reef colonization (Lima et al., 2019). Among these, UVC is most used in shallow waters and lower-income regions due to its simplicity and cost-effectiveness, whereas higher-income countries often choose advanced technologies like ROVs and BRUVs to improve precision and scalability (Ramm et al., 2021).

More invasive techniques, such as direct organism collection, core sampling for infauna, and bongo nets for plankton, are employed in certain contexts but carry environmental risks, including habitat disruption, which requires careful planning and extended intervals between sampling (Lima et al., 2019). Advanced tools like multibeam echosounders (MBES) combined with 3D visualization, as demonstrated by Tassetti et al. (2015), provide detailed metrics on seafloor alterations and sampling assemblages inhabiting the reef, offering a general view of AR performance. Overall, monitoring approaches must align with project resources and objectives, integrating biodiversity assessments, SCUBA-based surveys, and ecological structural monitoring to provide comprehensive evaluations (Vivier et al., 2021).

Socioeconomic Monitoring – Socioeconomic methodologies for studying the effectiveness and usefulness of artificial reefs include semi-structured interviews with stakeholders, which are the most common approach due to their simplicity, reproducibility, and ability to capture diverse perspectives (Lima et al., 2019). However, interviews can be prone to informant bias (Tessier et al., 2015), making it necessary to combine them with complementary methods such as questionnaires for large-scale data collection and Likert scales for converting qualitative insights into measurable data (Kirkbride-Smith et al., 2013; Ramos et al., 2019). Monitoring boats equipped with GPS and other transponders can offer indirect ways to analyse fishing and diving patterns of use around ARs (Ramos et al., 2024).

Despite these tools, gaps remain in understanding fishers' perceptions and insights, which can contribute to conflicts between AR projects and fishing communities. For example, a study on the AR systems in the French Catalan coast using UVC and fishing surveys showed no significant differences in landings per unit effort (LPUE) compared to other fishing grounds and suggested the consideration of demersal fish populations to evaluate AR impact on artisanal fisheries (Koeck et al., 2011). Similarly, in Malaysia, interviews and questionnaires to artisanal fishers revealed the overlapping use of multiple fishing gears at AR sites which led to conflicts among fishers, highlighting the need for fisheries agencies to provide sustainable fisheries management to local fishing communities (Islam et al., 2014).

Additionally, insights on the local ecological knowledge (LEK) from artisanal fishers on Brazil's southeast coast revealed artificial reefs' ecological functions, such as providing reproduction sites and attracting species (Lima et al., 2018). These findings together suggest that AR projects must integrate ecological research, social considerations, and inclusive management to address conflicts and enhance their effectiveness.

1.2.3. *The Alvor Artificial Reef*

In the Algarve region, the deployment of artificial reefs began in 1990, aiming to enhance small-scale fisheries and protect juvenile fish migrating from estuarine-lagoon areas (Monteiro and Santos, 2000). Two pilot cubic concrete reef systems were sunk off Faro and Olhão, a project proposed by the Portuguese Institute for Sea and Atmosphere (former IPIMAR, now IPMA) and implemented by the Algarve Regional Centre (CRIPSul, at the time) targeting fisheries enhancement (Monteiro and Santos, 2000). Early monitoring studies revealed promising results for fishing communities and at ecological level (Santos and Monteiro, 1997; Santos and Monteiro, 1998) which encouraged the expansion of the project.

The larger-scale project was implemented afterwards in two phases: from 1998 to 2001 and from 2002 to 2003 (Roa-Ureta et al., 2019). This extended the artificial reef complex to cover 43 km^2, expanding the Faro reef and establishing new reefs along the Algarve coast, including Cacela, Tavira, Vilamoura, Oura, and Alvor (from east to west). The modules were deployed at depths of 16–40 meters to mitigate the absence of rocky substrates, such as sandy and muddy bottoms. Those are also areas adjacent to highly productive estuarine and lagoon systems (Ria Formosa, Ria de Alvor and Guadiana Estuary), where the ARs can function as corridors that connect these habitats to coastal waters (Santos et al., 2011).

As part of the Algarve artificial reef expansion project, the Alvor artificial reef (Figure 1.4) was implemented between 2000 and 2001 (Fonseca et al., 2007). It followed the project's design, consisting of both small cubic modules (2.7 m^3) and larger octagonal modules (174 m^3) made of concrete. These structures were strategically deployed in lines, with the smaller units placed closer to the shore in shallower waters (~20 m depth) and the larger units further offshore (~35 m depth).

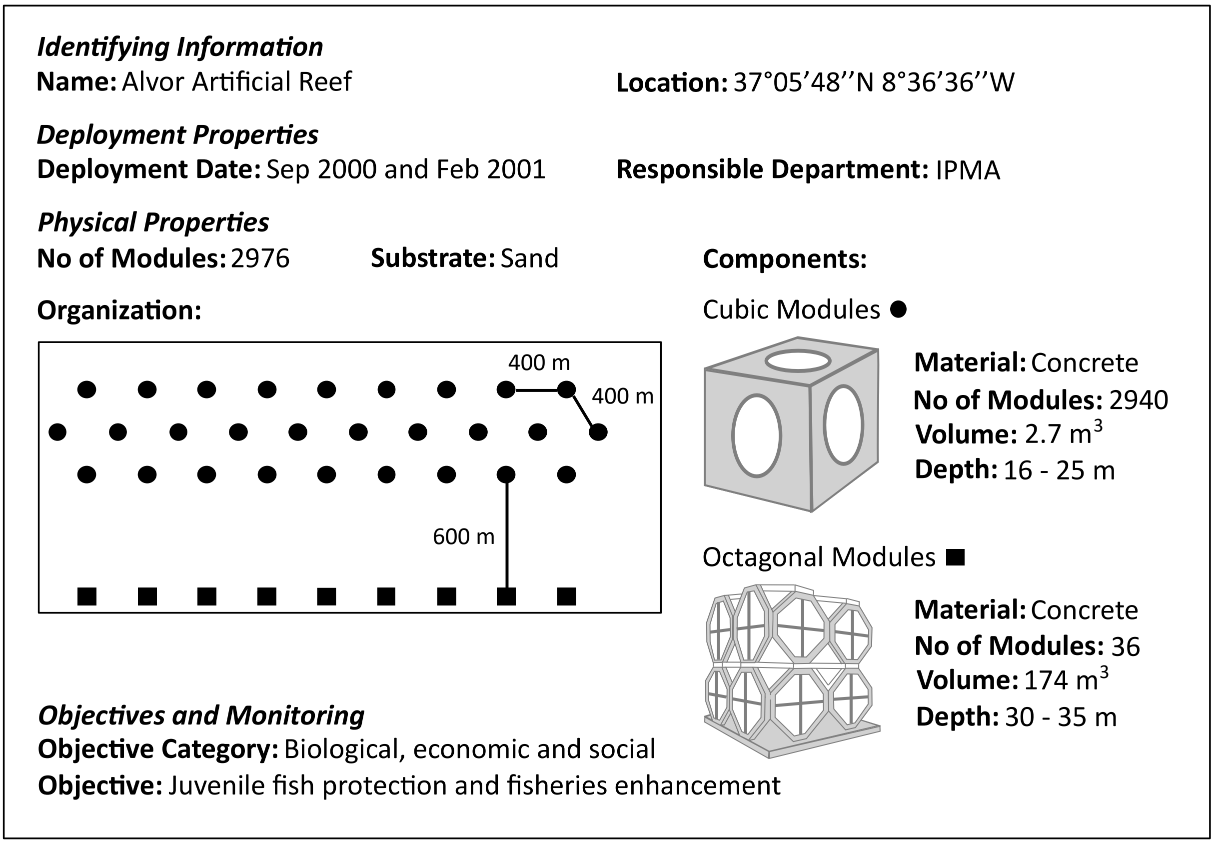


Figure 1.4 Alvor artificial reef essential attributes, adapted from Santos et al., (2011) and J. Silva's illustrations.

Early studies of the Alvor AR revealed a fast colonization. Within nine months of deployment, benthic communities had widely covered the reef's surfaces, with algal species distinct from those observed at the Faro AR. This difference was likely due to the reef's closeness to rocky cliffs and higher water turbidity (Fonseca et al., 2007). Additionally, the reef showed usefulness for local fisheries two years after deployment. A comparative study with the other AR sites in the Algarve complex found that the Alvor AR provided the best fishing efficiency in terms of return of capital (Ramos et al., 2005).

1.3. Research Objectives

Artificial reef research has traditionally concentrated on their socioeconomic benefits, including fisheries enhancement and ecological services, such as habitat restoration (Seaman, 2007; Becker et al., 2018). However, over time, socioeconomic research has increased with advancements in AR technology (Lee et al., 2018). In the Algarve artificial reef project, initial studies addressed the colonization processes (Boaventura et al., 2006), biogeochemical processes and nutrient cycling (Falcão et al. 2007), followed by research on predator-prey dynamics (Leitão et al., 2008a), fish assemblages (Leitão et al., 2008b) and productivity (Moura et al., 2011).

Socioeconomic studies have mainly addressed patterns of use (Ramos et al., 2006; Ramos and Santos, 2015) and stakeholder perceptions (Ramos et al., 2007; Ramos et al., 2011) of the Algarve artificial reefs. These studies have been centred on the Faro-Ancão and Vilamoura AR, reflecting the larger scale of these reefs and the significance of the Faro, regional capital, and Vilamoura areas. In contrast, research on Alvor AR has been limited. A study has investigated the substrate colonization by benthic communities (Fonseca et al., 2007) and another assessed the AR's efficiency through fishers' logbooks (Ramos et al., 2005), both within two years after deployment. This highlights the need for further exploration of the potential long-term socioeconomic benefits of Alvor AR, particularly in relation to local fishing communities.

The main objective of this study is to assess the socioeconomic impact of the Alvor artificial reef on the fishing community surrounding it, 25 years after its deployment. Specifically, it aims to determine whether the artificial reef continues to serve as a fishing enhancement tool for the communities. By analysing this case, this study intends to offer valuable insights into the long-term role of artificial reefs and their potential as sustainable tools for coastal fishing communities.

2. METHODOLOGY

2.1. Study Area

The main difference between each of the seven artificial reefs of the Algarve AR complex is their location. The Alvor AR was established off Lagos Bay, Portugal's largest bay, which extends from Lagos to Portimão. This region is characterized by a diverse landscape of rocky cliffs, sandy beaches, the Ria de Alvor coastal lagoon system, and the Arade River estuary. The seabed of Lagos Bay, shaped by limestone erosion along the Algarve coastline (Fraga, 2013), is characterized by sand, muddy sand and mixed sediment that are well-suited for artificial reef placement (Figure 2.1). The Alvor AR was placed in a sandy and relatively shallow section of the bay, between the 20- and 30-meter bathymetry lines. The Lagos and Portimão fishing ports, located on either side of Lagos Bay, along with the smaller fishing port in Alvor, were the primary communities expected to benefit from the artificial reef.

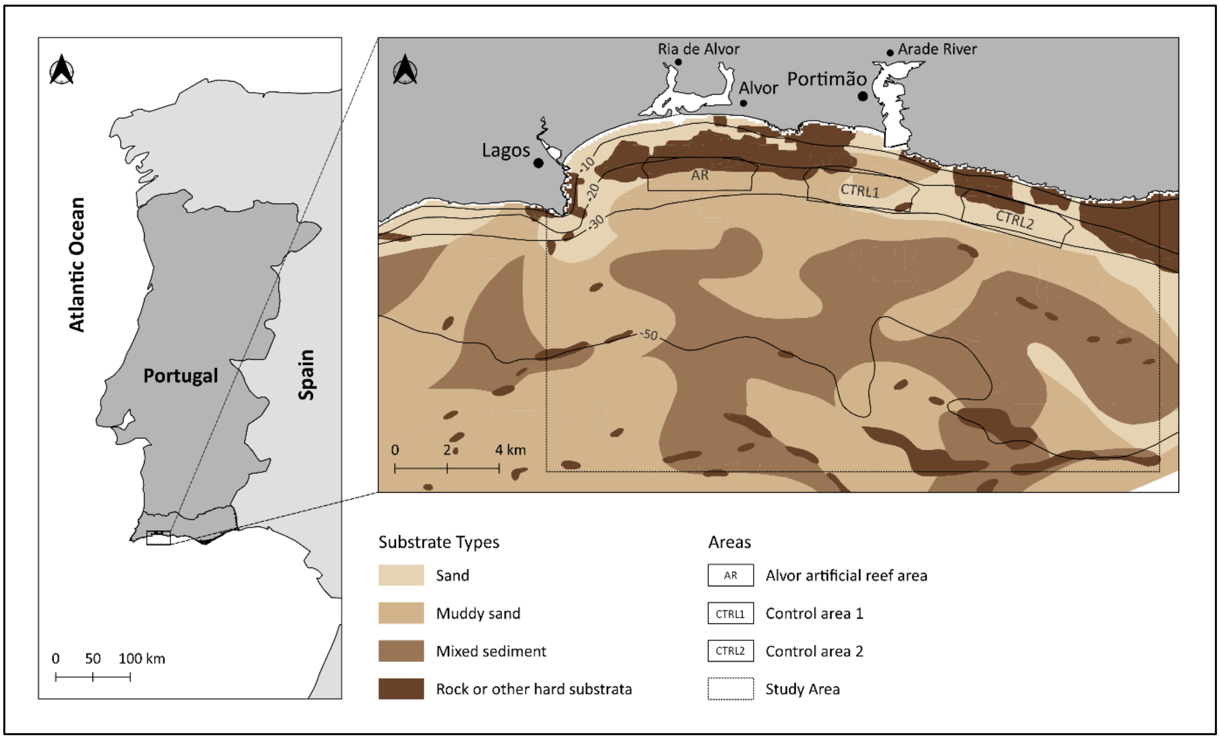


Figure 2.1 Map of Lagos Bay study area (southern Portugal), showing the Alvor artificial reef (AR), two control areas (CTRL1 and CTRL2), substrate types (sand, muddy sand, mixed sediment, rock or other hard substrata), bathymetric contours and nearby fishing communities (Lagos, Alvor and Portimão). Data sources: EMODnet substrate layers (2019) and local AR shapefiles.

2.2. Approach to the Case Study

This study focused on two distinct but complementary sources of data to assess whether the Alvor artificial reef continues to be used as a fishing ground, 25 years after its deployment. Although both the coastal and local fleets operate within the enclosed bay of Lagos, their characteristics and technological capabilities differ. A visual representation of this methodological approach is illustrated in a Venn diagram (Figure 2.2).

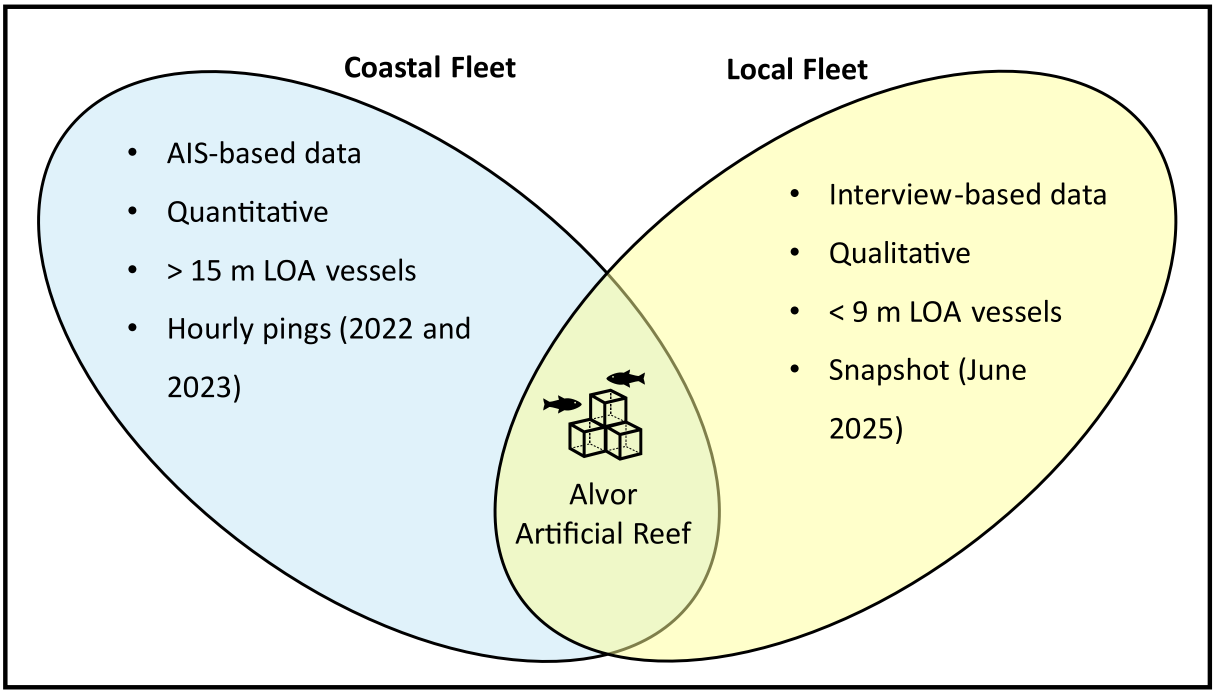


Figure 2.2 Venn diagram illustrating the combination of two methodological approaches for assessing the Alvor artificial reef use: AIS-based vessel tracking (coastal fleet) and interview-based data collection (local fleet). Note: vessels with a length overall (LOA) between 9 m and 15 m are not legally required to have an AIS transponder onboard.

Coastal fishing vessels over 15 meters in length are obligated by European regulations (EU Dir 2011/15/EU) to be equipped with Automatic Identification System (AIS) transponders, which transmit the vessel's position and other relevant data. This geopositioned information allows the spatial analysis of fishing activity and behaviour around the AR, providing a quantitative overview of the coastal fleet activity.

In contrast, local vessels fishing in the same area are under 9 meters in length and not required to carry transponding equipment, making their activity untraceable through AIS-based tracking. In order to address this data gap and include the perspectives of the local fleet, semi-structured questionnaire-based interviews (SSQBI) were conducted with fishers from the nearby communities. This qualitative method allowed the collection of perceptions related to artificial reef use and relevance.

2.3. Coastal Fleet (AIS-Based Data)

The Automatic Identification System is a tracking system onboard vessels, which broadcasts information through VHF (Very High Frequency) and GPS (Global Positioning Systems) technology. Vessels emit AIS messages that can be received by other vessels, by ground stations and by satellites (Zhang et al., 2017). These emitted signals are also called pings, i.e. points in time and space, include dynamic data, such as the vessel's position (given by the longitude and latitude) and speed, as well as static data entered by the vessel's pilot, such as the Maritime Mobile Service Identity (MMSI) number, vessel type and dimensions.

Numerous studies on fishing management refer to this type of spatial and temporal data as essential to help understand the dynamics of fishing activities and develop models to detect and identify fishing behaviour (De Souza et al., 2016; Cappa et al., 2024; Chinacalle-Martínez et al., 2024). The following sub-sections cover the workflow that went into assessing the use of the Alvor artificial reef by coastal fishing vessels. For a detailed breakdown of the data processing and spatial analysis, please refer to Annex 1 and 2.

2.3.1. *Data Collection*

Geopositioned data provided by MarineTraffic, a vessel-tracking website (MT, n.d.), was used in order to track fishing vessels in time and space. This study used hourly AIS pings, starting from a total of 67,304 pings, obtained from both satellite and Lagos AIS terrestrial station (Figure 2.3), during the spring and summer months (April, May, and June) and autumn and winter months (October, November, and December) for the years 2022 and 2023.

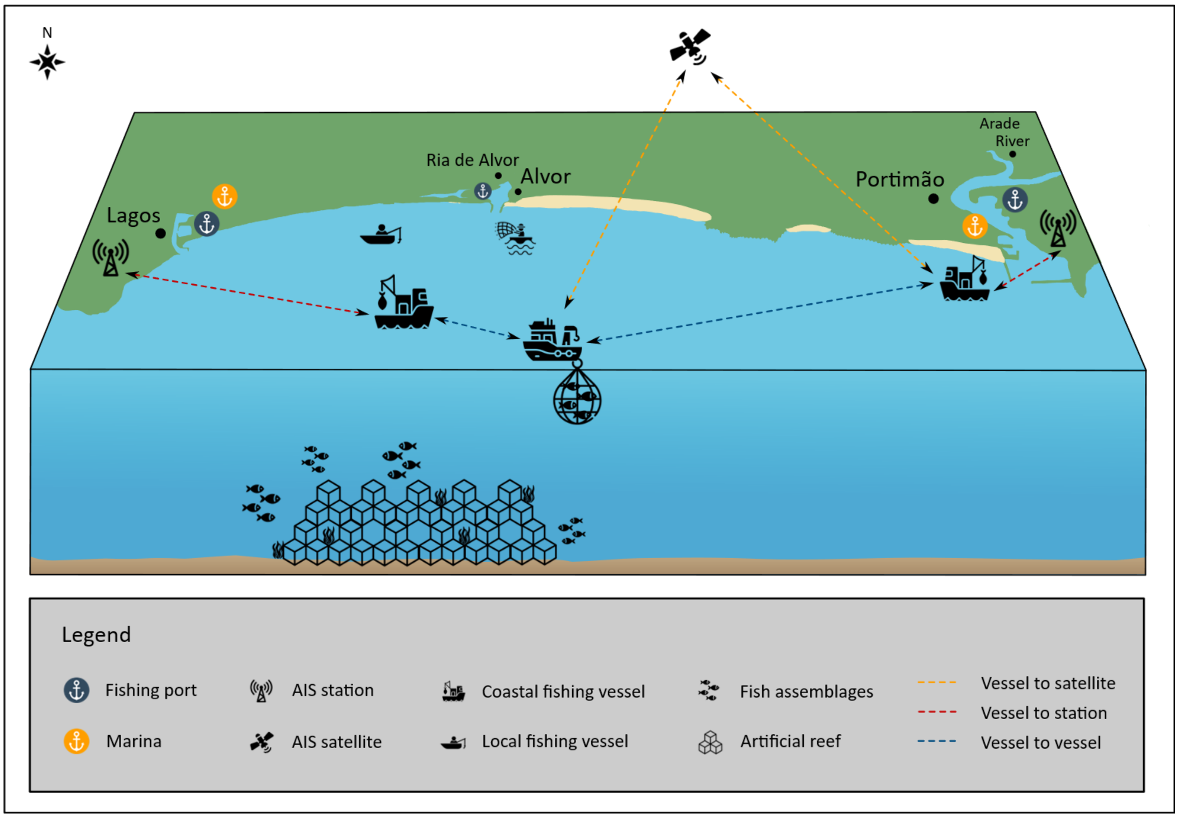


Figure 2.3 Diagram showing AIS information exchange among fishing vessels, terrestrial stations, satellites and local communities in the Lagos Bay area. Developed with Inkscape (2023).

2.3.2. *Spatial and Statistical Analysis*

The original dataset contained static parameters, such as vessel MMSI and name, and dynamic parameters, including speed, position (latitude and longitude), and timestamp. The open-source GIS software, QGIS version 3.22 (QGIS Development Team, 2021), was used for spatial computations. In order to define the study area, the dataset was imported into QGIS along with shapefile layers, including Alvor AR polygons, the Algarve region, bathymetry lines, and substrate types from EMODnet (EMODnet, 2019).

Three areas were defined (Figure 2.1): the Alvor artificial reef (AR) area of influence and two control areas of equal size and shape (CTRL1 and CTRL2). The first control area covered sand and muddy sand substrate while the second covered sand a partially rocky substrate. The control areas were placed eastward of the AR, approximately 1.8 km apart, between the 20–30 m bathymetry lines. The study area extended south to approximately the 50 m bathymetry line, and the vessel record dataset was clipped, using QGIS geoprocessing tools, before further processing.

To filter the dataset, AIS data was cleaned using Fleet Register (European Commission, n.d.), a database containing the registrations of all the fishing vessels that use an EU country flag, which provided vessel and fishing gear information, allowing the removal of research and recreational vessels. Fleet Register was also used to extract the vessels' registration port. Vessel behaviour was categorized as drifting or navigating, based on speeds lower or higher than 5 knots, respectively (Gloaguen et al., 2016; Ramos et al., 2024). With this, vessels moving above 5 knots (i.e. exhibiting navigating behaviour) were removed to leave only fishing-related data.

Finally, Kernel Density Estimation (KDE) analysis in QGIS was used to identify areas of higher fishing activity, providing a spatial representation of fishing effort. A radius of 500 meters was set and KDE values represented concentration of fishing activity per kilometre square.

Regarding statistical analysis R version 4.3.2 (R Core Team, 2023) was used. The significance level was set at 0.01. Descriptive statistics were initially used to explore the distribution of vessel records by area (AR, CTRL1 and CTRL2) and by fishing gear (seine, trawl and multigear). Since there was a low occurrence of trawl and multigear types, the rest of the analysis focused on fishing activity independently of gear. The same was applied to seasonality. Through boxplots, outliers were identified in KDE values and two extreme outliers were removed. Since the KDE variable had a skewed distribution, normality was assessed using the Shapiro-Wilk test. Due to the fact that the KDE values did not meet the assumption of normality, a non-parametric Kruskal-Wallis test was used to assess whether there were statistically significant differences in fishing activity among the three areas. To identify which specific pairs of areas differed significantly, pairwise Wilcoxon rank-sum tests with Bonferroni correction were applied afterwards.

2.4. Local Fleet (Interview-Based Data)

Semi-structured questionnaire-based interviews are a flexible method of data collection that combines pre-planned questions with open-ended conversation (Runeson and Höst, 2009). Unlike fully structured interviews, SSQBI allow the natural progression of conversation while ensuring all key topics are covered (Runeson and Höst, 2009). This method is suitable for descriptive and explanatory cases by collecting real-time data and analysing hidden data within the situation (Naz et al., 2022). This type of interview has been used to gather qualitative and quantitative insights from fishers in previous studies (Leite and Gasalla, 2013; Young et al., 2016), in contrast to more formal approaches such as surveys and interviews scheduled by external researchers (Hind, 2015). The following sub-sections detail the process of interview data collection and analysis.

2.4.1. *Interview Process*

The interviews were conducted with small-scale fishers based in the communities of Alvor and Lagos in June 2025. Fishers were approached informally at the local fishing harbours, all separately. The initial goal was to also include participants from Portimão, but no eligible fishers were available to participate during the research period, as no captains nor crew of local vessels were found. A total of six interviews were successfully conducted, five in Alvor and one in Lagos.

A snowball sampling technique (Ramires et al., 2015) was used, starting with one found fisher and expanding to other nearby fishers. Interviews lasted 15 to 20 minutes, depending on the fishers' availability, and were conducted in informal settings such as near the docks and vessels. The semi-structured questionnaire (Annexes 3 and 4) offered a guide, allowing fishers to speak freely about their fishing practices, perceptions of the AR and challenges.

Interviews were carried out in Portuguese, audio-recorded, transcribed verbatim and translated to English for analysis. Field notes were also taken to gather the context and details not covered in the recordings. The main steps of this process are summarized in a simple diagram (Figure 2.4).

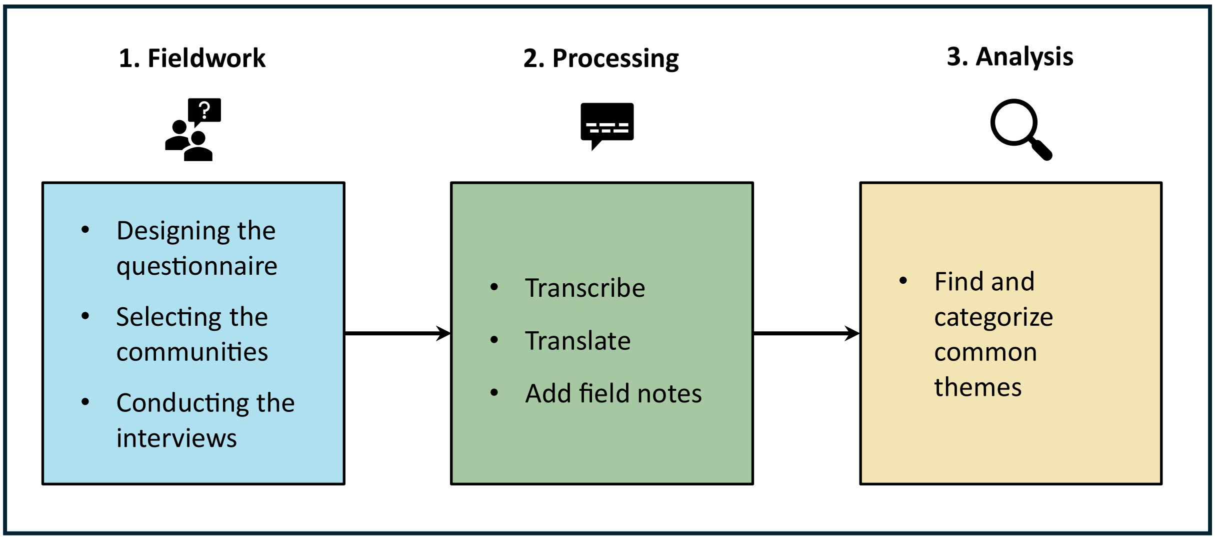


Figure 2.4 Workflow of the semi-structured questionnaire-based interviews (SSQBI), from designing the questionnaire to transcription, translation and thematic analysis.

2.4.2. *Brief Qualitative Analysis*

Due to the low sample size (n = 6) and exploratory nature of the study, the resulting data were analysed qualitatively using thematic analysis, a method used to identify recurring patterns in qualitative data (Lochmiller, 2021), in this case, related to the Alvor artificial reef's use. Although the number of interviews was limited, qualitative research does not necessarily require large samples, since sample size is contextual and depends on the underlying research paradigm (Boddy, 2016). Reflexive thematic analysis, for example, is not tied to a minimum sample size, but is supported by the depth and quality of insights it extracts related to the research (Wutich et al., 2024). The analysis started with familiarity with the transcripts to ensure no information was lost, common themes, as well as the main questions from the questionnaire were answered. Field notes were also relevant sources of information. These themes were transferred to an Excel table for readability and to organise it into broader themes: who, how, where, when, AR use, perceived AR usefulness, comments and suggestions.

3. RESULTS

3.1. Coastal Fleet (AIS-Based Data)

Starting from 7,283 AIS pings recorded within the defined study area of Lagos Bay, the dataset was filtered by vessel type and activity. After removing research and recreational vessels and keeping only pings associated with drifting vessels, the dataset included 1,390 pings corresponding to fishing activity (Figure 3.1).

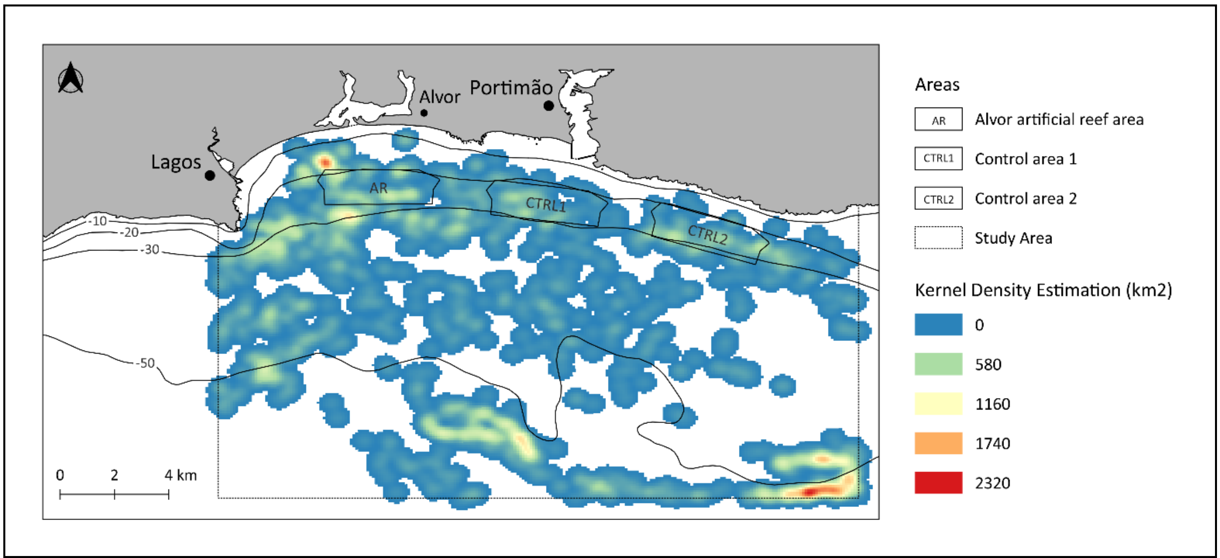


Figure 3.1 Kernel Density Estimation (KDE) of fishing vessels (in pings per km^2) in Lagos Bay from 1390 AIS pings during the same six-month periods in 2022 and 2023. Includes AR, CTRL1 and CTRL2 boundaries, bathymetric contours, and nearby fishing communities.

The Kernel Density Estimation map revealed that fishing activity was not evenly distributed across the study area. The highest concentration of activity occurred between the 20–30 meter bathymetry lines, particularly adjacent to the Alvor artificial reef area (AR) next to Ria de Alvor and southeast next to the 50-meter bathymetry line. Two additional hotspots, with KDE values above 1740 pings/km^2, were observed beyond the 50-meter bathymetry in the southeast part of the study area.

Regarding the three defined polygon areas, the Alvor artificial reef, Control 1 and Control 2, a total of 177 pings were used for the analysis. They involved mainly seiner vessels (n = 9), followed by trawlers (n = 3) and multigear (n = 1) (Table 3.1). Their respective registration ports extended across the Algarve and had LOA between 16.10 and 27.26 meters. The records spanned across the three areas with 71 pings in the artificial reef (AR), 49 pings in the first control area (CTRL1) and 57 pings in the second control area (CTRL2).

Table 3.1 Summary of data for 13 recorded fishing vessels including their type, registration port, length overall (LOA) in meters and their number of AIS pings within the three polygon areas (AR, CTRL1, CTRL2). Vessel codes: S = seiner, T = trawler, M = multigear; ordered by total pings in descending order.

Vessel Code	Vessel Type	Registration Port	LOA (m)	AIS Pings			
				AR	CTRL1	CTRL2	Total
S1	Seiner	Quarteira	19.68	28	3	4	35
S2	Seiner	Quarteira	18.30	12	12	10	34
S3	Seiner	Portimão	19.00	16	12	5	33
S4	Seiner	Portimão	20.87	13	7	5	25
S5	Seiner	VRSA	22.62	0	4	11	15
S6	Seiner	Faro	22.30	0	2	8	10
S7	Seiner	Olhão	23.00	0	1	9	10
S8	Seiner	Faro	16.10	0	0	5	5
S9	Seiner	Sagres	23.00	2	2	0	4
T1	Trawler	Portimão	27.26	0	2	0	2
M1	Multigear	Vila do Conde	21.18	0	2	0	2
T2	Trawler	Olhão	18.50	0	1	0	1
T3	Trawler	VRSA	18.80	0	1	0	1

The Kernel Density Estimation values showed a non-normal distribution as indicated by the Shapiro-Wilk test ($p > 0.02$). Summary statistics indicated a higher median KDE in the artificial reef (559), followed by the Control 2 (434) and Control 1 (378) areas (Figure 3.2). The Kruskal-Wallis test (Table 3.2) detected that there were differences in KDE values between the areas and the Wilcoxon tests indicated that there was a significant difference between the AR and Control 1, while the differences between the two control areas were almost none.

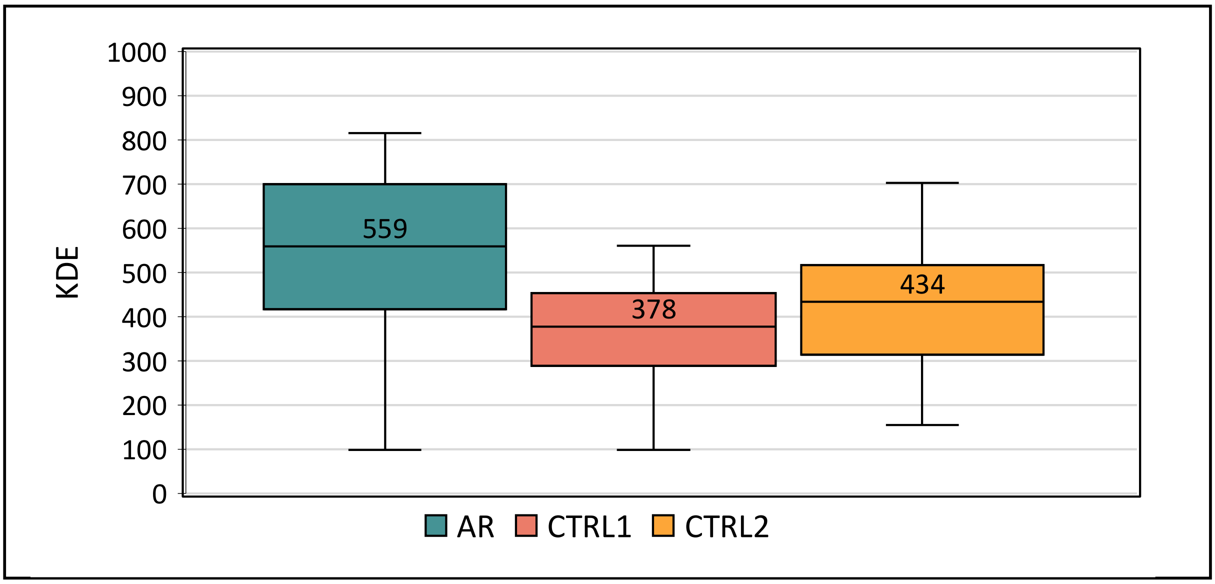


Figure 3.2 Boxplots of KDE-derived fishing activity (pings per km²) for AR, CTRL1, and CTRL2 after removal of two extreme outliers. Sample sizes: AR (n = 71), CTRL1 (n = 49), CTRL2 (n = 57).

Table 3.2 Pairwise Wilcoxon rank-sum test results comparing KDE-derived fishing activity among the three areas (Artificial Reef, Control 1, Control 2), with *p*-values and significance levels. Sample sizes: Artificial Reef (n = 71), Control 1 (n = 49), Control 2 (n = 57).

First Area	**Second Area**	**Wilcoxon *p*-value**	**Significant ($p < 0.01$)**
Artificial Reef	Control 1	0.0000012	Yes
Artificial Reef	Control 2	0.0021	Yes
Control 1	Control 2	0.0490	No

3.2. Local Fleet (Interview-Based Data)

A total of six interviews were conducted with small-scale fishers from the communities of Alvor and Lagos. The thematic analysis of the answers (Table 3.3) revealed shared experiences and perspectives regarding the use of the Alvor artificial reef. While all interviewees reported having fished near the AR at some point, most described its nowadays use as rare, mentioning gear abandonment and ghost fishing as the main limiting factors. Despite these current challenges, all fishers interviewed acknowledged that the reef had been productive in its earlier years, particularly for species such as seabass and seabream. Only one fisher described the AR as consistently useful today, while others expressed concerns about its maintenance and suggested deploying more reefs to reproduce the Alvor AR's initial benefits.

Table 3.3 Brief characterization of six local small-scale fishers based on the qualitative analysis of semi-structured questionnaire-based interviews (SSQBI) and field notes.

Themes	Local Fishers (n = 6)
Who	All interviewees were male, mostly between 40 and 60 years old, with fishing experience from more than 20 years.
How	The most common fishing method was longline, used by five fishers. One fisher from Lagos used nets. All vessels were small local crafts (< 9 meters). Some participants also engaged in parallel activities such as shellfish aquaculture and net repairing.
Where	Fishing occurred mainly within local waters off Alvor and Lagos, not exceeding 10 nautical miles from the home port. All fishers reported having fished in the AR at some point.
When	Fishing was described as a daily activity. One fisher from Lagos reported fishing in the AR frequently in the winter months.

Why	Species caught in and around the reef included seabass, seabream and meagre. These were typically sold locally or to restaurant buyers.
AR use	Five of the six fishers acknowledged using the reef at least occasionally, though most described current use as rare. One fisher from Lagos reported regular use of the AR even today.
Perceived AR usefulness	Four fishers rated the artificial reef as “useless” due to net abandonment and what they perceived as poor or degraded reef conditions. However, most of these also emphasized that the AR had been very productive in the early years, with good catches and less competition. One fisher held a neutral view, and one described the AR as “very useful,” mentioning consistent catches of meagre in it.
Comments and suggestions	General concerns included abandoned gear and insufficient maintenance of the reef. Several described the AR as “blocked by nets” or “dirty.” All fishers suggested that new ARs should be deployed in nearby zones to replicate the earlier benefits observed after the initial deployment of the Alvor AR.

4. DISCUSSION

The Algarve artificial reef project started in the early 1990s to support local fisheries in several communities, with Lagos Bay identified as one of the chosen sites for deployment. The Alvor AR, comprising nearly 3,000 concrete modules, was deployed in two phases between 2000 and 2001 in the same bay. A preliminary study done by Ramos et al., (2005) revealed that local fishers expected the Alvor AR to improve fishing efficiency. However, in the two decades that followed, no further research revisited this reef’s role in the communities. This study addressed that gap by examining the Alvor AR’s contribution 25 years after its deployment.

Coastal fishing activity in the study area gathered in very specific depth ranges, with the most evident concentration between the 20-30 m depths around the Alvor artificial reef and along deeper rocky zones beyond 50 m (Figure 3.1). This pattern is consistent with observations that structurally complex habitats, either natural or artificial, tend to attract more fishing effort because they aggregate target species and improve catch predictability (Baine, 2001; Gardner et al., 2022). In this case, the reef modules provide vertical complexity to otherwise featureless sandy bottoms and shelter that mimic rocky reef conditions, which are known to support higher biomass and species richness than sandy or muddy bottoms (Wang et al., 2015; Lemoine et al., 2019).

The two additional hotspots further offshore (Figure 3.1) suggest that natural features can function in much the same way, creating multiple focal points for fishing activity. Similar interactions between artificial and natural habitats have been reported in other ARs in the Algarve (Ramos et al., 2006; Leitão et al., 2008b), where fishers make use of both areas depending on species availability and season.

The types of vessels detected in these areas suggest that the artificial reef's influence extends beyond one fishing practice. Purse seiners dominated the observed fleet, and four of them returned repeatedly to the AR over the study period (Table 3.1). This recurrence implies a degree of site fidelity, potentially reflecting the reef's reliability as a productive fishing ground. While purse seine vessels are typically associated with pelagic species such as sardine and mackerel (Monteiro, 2017; Feijó et al., 2018), their use of an artificial reef points to additional benefits, such as opportunistic catches of demersal species that may occasionally aggregate around the modules (Leitão et al., 2008b).

Similar patterns have been documented in other places, as Gardner et al. (2022) observed, vessels in the Gulf of Mexico made repeated trips to artificial structures due to their consistent productivity, while Ramos et al. (2006) noted similar patterns of use in the Olhão AR by the local fleet.

The statistical comparisons showed that fishing activity at the AR was significantly higher than in the nearby sandy/muddy habitat (Control 1), once again highlighting the role of habitat complexity in attracting fish assemblages and consequently, fishing activity. The similarity between AR and Control 2 (a mixed sand and rocky area) reenforces earlier findings that artificial reefs can resemble natural rocky reefs (Wang et al., 2015; Lemoine et al., 2019).

The two control areas showed almost non-significant differences in fishing intensity despite their substrate types. This may indicate other spatial or operational factors, such as proximity to port or seasonal targeting priorities, since Control 1 is very close to the Portimão marina/fishing port and Control 2 is located more eastward. However, the consistent position of AR fishing activity above both controls suggests that the reef continues to be a fishing ground for coastal fishers, following the patterns recorded in the Olhão AR's early years (Ramos et al., 2006).

Nevertheless, fishers' perceptions of the Alvor artificial reef highlight a common pattern observed in other AR projects: early optimism followed by a gradual decline in use. Several Alvor fishers recalled that, in the first years after deployment, the AR supported regular catches of seabass and seabream using longlines. However, results regarding species catches aligns with findings in the Algarve, where *Diplodus sargus* (white seabream), a high-value species, dominated longline catches on artificial reefs due to its exploitable biomass (Leitão et al., 2009). Similar early productivity and satisfaction have been reported in other places, with fishers perceiving artificial reefs as available resources that enhanced livelihoods (Ramos et al., 2007; Kantavichai et al., 2019). In the Faro-Ancão AR, *Dicentrarchus labrax* (European seabass) was found to be a transient species, often present in the early stages but not keeping long-term residency (Leitão et al., 2008a), which reflects the Alvor fishers' experiences. Koeck et al., (2011) also highlight the importance of connectivity in demersal fish populations when assessing an AR's influence area. The only Lagos fisher interviewed still uses the reef and described consistent catches of meagre, a large, high-value sciaenid of economic importance to southern Portuguese fleets (Prista et al., 2007). This contrasts with other interviews, resulting in quite different perceptions. These reports suggest that species-specific behaviours and market values can influence the persistence of fishing effort in artificial reef areas, even after the initial abundance has decreased.

However, operational barriers have also weathered the Alvor AR's attraction. Most Alvor fishers stated they no longer fish in the reef because it has become "covered" in lost fishing nets, making it less efficient and more expensive to fish. The Lagos fisher, despite continuing to use the reef, raised the same concern. Situations like these, ghost fishing cumulative impact and gear conflicts, are documented issues in several socioeconomic impact studies in AR fisheries. In Malaysia, the overlapping use of multiple gears in the same fishing location created both social conflict and physical entanglement risks (Islam et al., 2014). Equally, in the Gulf of Gabès, gear loss was often attributed to conflict with other gear types, mainly gillnets and trammel nets, and to obstacles such as wrecks and artificial reefs (Ghaouar et al., 2024). In the Algarve, stakeholders have previously identified the lack of enforcement and management measures as a negative impact, leading to uncontrolled increases in fishing pressure and expensive gear replacement costs (Ramos et al., 2007). Without governance such as gear restrictions or regular removal and cleaning, these operational challenges can turn an initially productive and promising AR into an avoided site.

The change in economic motivations and competition for space may also explain the decline in attractiveness of the Alvor AR. The Ria de Alvor, with an average depth of only 2.3 m, requires dredging to maintain navigation but offers optimal conditions for aquaculture, particularly shellfish farming (Mateus et al., 2016; Picado et al., 2023). Some Alvor fishers reported moving away from fishing in the AR to gain additional income from clam aquaculture within the lagoon. This shift may be related to wider socioeconomic pressures: aquaculture in the Ria is a priority activity within European conservation frameworks, and rising local population density has increased competition for space and resources (Picado et al., 2023). As noted by Ramos et al. (2011), the benefits of artificial reefs are not evenly distributed among stakeholders since certain user groups gain more than others, while some sectors, such as aquaculture, may become more profitable and reliable over time. In these contexts, sustainable engagement with ARs depends not only on ecological performance and maintenance, but also on whether they are comparable, economically and operationally, with alternative livelihoods.

When taken together, the two methodological approaches on the Alvor artificial reef use revealed complementary perspectives on its use. AIS tracking showed limited but persistent activity from the coastal fleet within the AR area, while interviews showed that local vessels had their own distinct patterns of use, shaped by species availability, operational and market value. For example, tracking data highlighted repeated visits by seiners and other gears, while interviews suggested the importance of seabass and seabream for longline small-scale fishers, and the change in fishing effort when the resources declined and fishing in the AR became exhaustive and complicated.

Koeck et al., (2011) and Forero et al., (2017) found that integrating spatial tracking with fisher's knowledge and perceptions revealed dynamics that neither method could express alone. The advantage of this combination of methods also aligns with Chong et al., (2024) call to take into consideration the social-ecological feedback when evaluating artificial reef's performance, as both datasets in this study revealed that perceptions, maintenance, and species availability influenced fishing activity in the AR.

Though, limitations of each method must also be considered to help explain the patterns of use and identify potential bias. For AIS-based data, a key limitation is that only fishing vessels over 15 meters in length are legally required to carry active AIS transponders. While interviews with local fishers, with vessels < 9 m LOA, partially address this gap, coastal vessels between 9 m and 15 m may or may not have AIS onboard, since they are not mandatory. This was verified in the geopositioned dataset, as all vessels recorded in the three areas all had more than 15 meters LOA (Table 3.1), in other words, there could be an underrepresentation of certain segments of the fleet in the dataset. Additionally, despite the legal requirement, AIS transponders can be intentionally switched off, which has been documented in several studies (Mazzarella et al., 2017; Kontopoulos et al., 2020). The volume of AIS records across time was also low (< 200 pings across the three areas) which meant that seasonal variation could not be examined. This is a relevant gap, as previous studies in the Algarve (Leitão et al., 2008b; Ramos and Santos, 2015) have shown that both fish assemblages and fishing effort in the ARs follow seasonal patterns.

Regarding the interview-based data, the small sample size (n = 6) represents only a minor fraction of the local fleet. Besides, five participants were from the same port and similar age group, potentially narrowing the range of perspectives. Practical difficulties during fieldwork limited the range of areas covered while conducting the SSQBI, consequently no local fishers were interviewed in Portimão, as initially planned, possibly because the port is more dedicated to coastal fishing, with vessels spending longer periods at sea. These gaps can reduce representativeness and could lead to location or gear bias in qualitative findings.

The question of whether the Alvor artificial reef still functions as fishing enhancement tool for the communities does not have a direct answer, as its benefits vary across fleets. Geopositioned data indicates that the reef continues to attract fishing activity from the coastal fleet, but this use is irregular. Interview findings suggest that the local fishers have diminished engaging with the AR, with the impediment of losing gears to ghost nets and reduced productivity, whereas larger coastal vessels are better equipped to operate around these obstacles.

This uneven use reflects the evidence that artificial reef benefits are not equally accessible to all user groups and can change over time. To address this, management strategies should consider the roles of fisheries managers and artificial reef managers, as suggested by Chong et al., (2024), with the fishery manager overseeing fish populations and activity while the AR manager focuses on the design and deployment of the structures, ensuring that resources are regulated and habitat enhancement is coordinated.

Minute-resolution, multi-year spatial tracking alongside increased sampling effort in interviews, could help with the detection of temporal patterns such as seasonality, known to influence reef productivity and fish decisions in the Algarve (Leitão et al., 2008b; Ramos and Santos, 2015). Applied research must be integrated, providing the data and analysis needed to guide adaptive management and to link researchers, fishers, and decision makers in a common framework (Santos et al., 2011).

5. CONCLUSION AND FURTHER WORK

The study main aim was to infer on whether the Alvor artificial reef continues to serve as a fishing enhancement tool for the coastal communities, 25 years after its deployment. The findings showed that while the AR still attracts coastal vessels, its impact on the local fleet has become less relevant. By combining AIS data to track observed behaviour with fisher interviews to capture reported knowledge, the study provided a more complete understanding of how different fleet segments interact with the reef, revealing contrasting patterns of use and avoidance.

Altogether, the results indicate that the Alvor AR still maintains some function as a supporting structure to fishing activity, though its advantages are not consistent among the fleets. This highlights how important it is to periodically revisit the performance of artificial reefs, not only in ecological ways but also in relation to their socioeconomic roles, particularly when those were a part of the initial deployment goals.

Suggestions on future work should extend the temporal and spatial scope of data collection, to allow long-term patterns of use to be more clearly identified. High-resolution tracking, ecological monitoring, and deeper engagement with local fishers would provide a more complete insight into how the Alvor AR, and other artificial reefs, impact fishing communities. Comparative studies with other Algarve's artificial reefs (whether designed for fisheries enhancement or recreation) could further explain whether the observed patterns of use are specific to the Alvor AR or a part of a wider trend.

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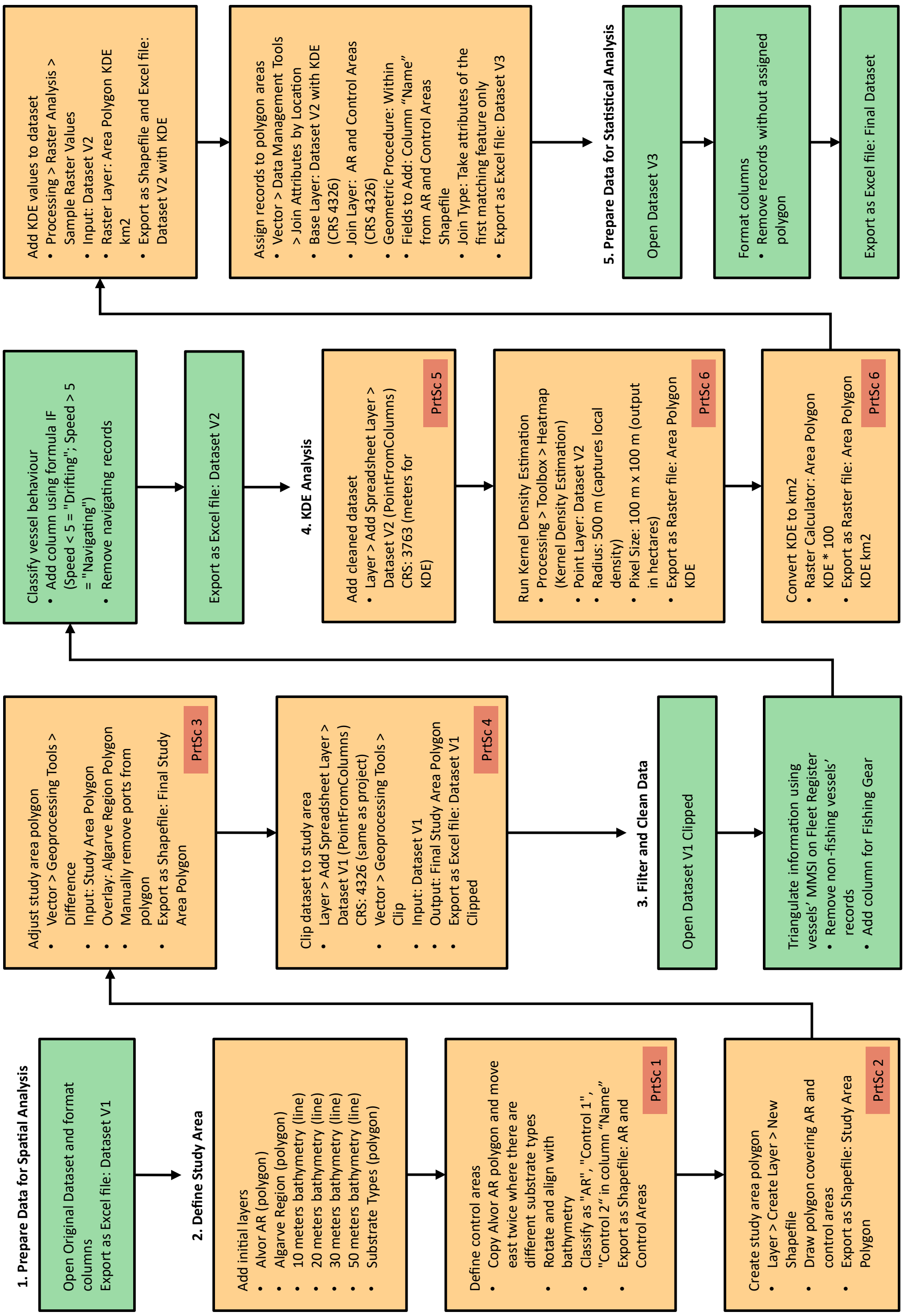
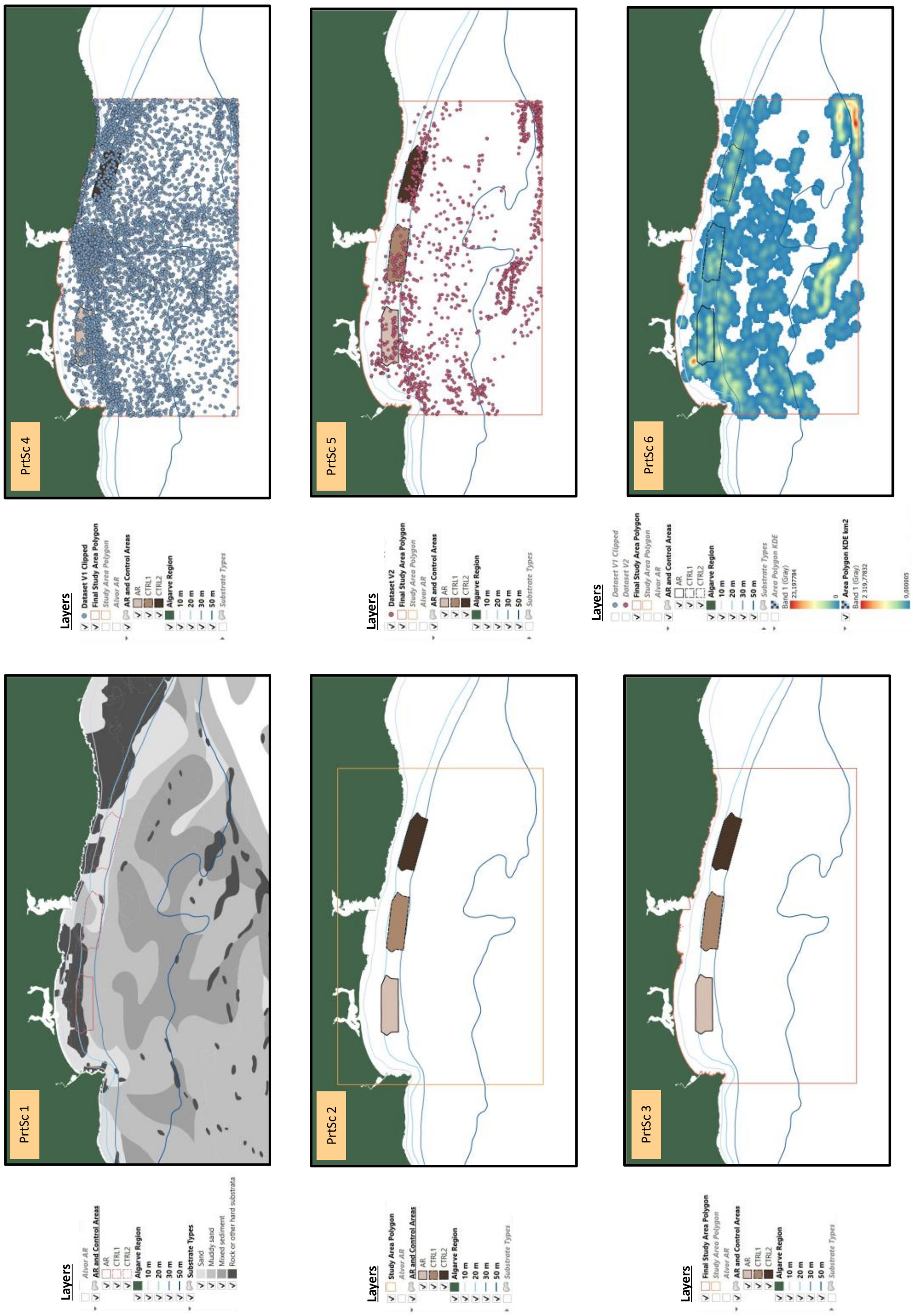
7. ANNEXES

Annex 1. Workflow for AIS-based data processing and spatial analysis. Green boxes indicate steps conducted in Excel (e.g., preparing, filtering, and cleaning data), while orange boxes represent steps conducted in QGIS (e.g., defining the study area and Kernel Density Estimation, KDE, analysis). Dark orange notes in QGIS boxes refer to corresponding screenshots in Annex 2.



Annex 2. Sequential QGIS process screenshots corresponding to the workflow in Annex 1, illustrating each spatial analysis step.



Annex 3. Semi-structured questionnaire form (SSQBI) used to collect qualitative data from local small-scale fishers regarding identification, fishing activity, knowledge and artificial reef (AR) perceptions related to the Alvor AR. In Portuguese.

Questionário Dirigido a Pescadores
Número:

Porto:
Data:

1. Identificação

1.1. Qual é o seu tipo de pesca?
- ☐ Pesca desportiva
- ☐ Pesca local
- ☐ Pesca costeira

1.2. Onde vive?
- ☐ Lagos
- ☐ Alvor
- ☐ Portimão
- ☐ Outro (_________)

1.3. Idade ___

2. Atividade

2.1. Quais são as artes que utiliza?
- ☐ Redes de arrasto
- ☐ Redes de tresmalho
- ☐ Redes de emalhar
- ☐ Palangre
- ☐ Covos/armadilhas
- ☐ Outra (_________)

2.2. Quando é que pesca?

____

2.3. Há quanto tempo pesca?
- ☐ Menos de 1 ano
- ☐ 1 – 4 anos
- ☐ 5 – 10 anos
- ☐ 10 – 20 anos
- ☐ Mais de 20 anos

3. Conhecimento do RA

3.1. Já utilizou o recife artificial de Alvor?
- ☐ Sim
- ☐ Não
- ☐ Não sabe

3.2. Com que frequência o utilizou?
- ☐ Menos de uma vez por mês
- ☐ 1 a 2 vezes por mês
- ☐ Mais de 3 vezes por mês
- ☐ Quase diariamente
- ☐ Não sabe

3.3. Considera que o recife artificial de Alvor é útil para pescadores? Por favor, classifique de 1 a 5, considerando 1 como inútil e 5 como muito útil.
- ☐ 1 – inútil
- ☐ 2 – ligeiramente útil
- ☐ 3 – neutro
- ☐ 4 – útil
- ☐ 5 – muito útil

Annex 4. Semi-structured questionnaire form (SSQBI) used to collect qualitative data from local small-scale fishers regarding identification, fishing activity, knowledge and artificial reef (AR) perceptions related to the Alvor AR. In English.

Questionnaire Directed at Fishers
Number:

Port:
Date:

1. Identification

1.1. What is your type of fishing?
- ☐ Recreational fishing
- ☐ Local fishing
- ☐ Coastal fishing

1.2. Where do you live?
- ☐ Lagos
- ☐ Alvor
- ☐ Portimão
- ☐ Other (__________)

1.3. Age ___

2. Activity

2.1. Which fishing gears do you use?
- ☐ Trawl nets
- ☐ Trammel nets
- ☐ Gillnets
- ☐ Longline
- ☐ Pots/traps
- ☐ Other (__________)

2.2. When do you fish?

____

2.3. How long have you been fishing?
- ☐ Less than 1 year
- ☐ 1 – 4 years
- ☐ 5 – 10 years
- ☐ 10 – 20 years
- ☐ Over 20 years

3. AR Knowledge

3.1. Have you ever used the Alvor artificial reef?
- ☐ Yes
- ☐ No
- ☐ Doesn't know

3.2. How often did you use it?
- ☐ Less than once a month
- ☐ 1 to 2 times a month
- ☐ More than 3 times a month
- ☐ Almost daily
- ☐ Doesn't know

3.3. Do you consider that the artificial reefs are useful for fishers like yourself? Please rate from 1 to 5, considering 1 as not useful and 5 as very useful.
- ☐ 1 – not useful
- ☐ 2 – slightly useful
- ☐ 3 – neutral
- ☐ 4 – useful
- ☐ 5 – very useful