

Mapping Small Scale Fisheries (MAP-SSF)

FINAL REPORT - EEA/BHR/24/001

**Assessing small-scale fishing activity and pressure on
Europe's marine ecosystems**

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Submitted by: Fundación AZTI – AZTI Fundación, as group co-leader of the consortium: IPMA (co-leader), CNR-IRBIM, IEO, the University of St Andrews, and the Universitat Politècnica de Catalunya (UPC)

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Client	European Environment Agency (EEA)	
Client's contact person	Natacha Carvalho	EEA
Project Team	Arcas Sen, Esther	IEO
	Ferrà Vega, Carmen	CNR - IRBIM
	Gaspar, Miguel	IPMA
	Grati, Fabio	CNR - IRBIM
	Lattanzi, Pamela	CNR - IRBIM
	Marsaglia, Luca	GFW
	Mugerza, Estanis	AZTI
	Punzón, Antonio	IEO
	Rodríguez-Gutiérrez, Jose	IEO
	Russo, Tommaso	CNR - IRBIM
	Tassetti, Anna Nora	CNR - IRBIM
Project Coordinators	Mateo, María	AZTI
	Rufino, Marta	IPMA
Report reviewed by external advisors	Mendo, Tania	University of St Andrews
	Mujal-Colilles, Anna	UPC-BarcelonaTech

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Abbreviations

AER	Annual Economic Report
AIS	Automatic Identification System
CFAR	constant false alarm rate
CFP	Common Fisheries Policy
CS	Case study
DCF	Data Collection Framework
DFMR	Department of Fisheries and Marine Research (Cyprus)
EEA	European Environment Agency
ESA	European Space Agency
EUFR	EU Fleet Register
EMFAF	European Maritime, Fisheries and Aquaculture Fund
GAM	Generalised Additive Model
GES	Good Environmental Status
GFW	Global Fishing Watch
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSA	Geographical Subareas
KDE	Kernel Density Estimation
LOA	Length overall
LSF	large-scale fisheries
ML	Machine learning
MASAF	Ministry of Agriculture, Food Sovereignty and Forests (Italy)
MOFI	Mobile Observer Fishing Information
MPA	Marine Protected Areas
MPN	Multilayer perceptron network
MS	Member States
MSE	mean squared error
nm	nautical miles
OFR	Other fishing region
PGP	Passive gear
SAR	synthetic aperture radar
SSCF	small-scale coastal fisheries
SSF	Small scale fisheries
STECF	Scientific, Technical and Economic Committee for Fisheries
TMR	Technical Measures Regulation
VMS	Vessel Monitoring System
WBS	Work breakdown structure
WP	Work package

Gear types

DRB	Dredges
FPO	Pots and traps
GNS	Gillnets
GTR	Trammel nets
LHP	Handlines
LLS	Set longlines
OTB	Trawls
PS	Purse seiners

Executive summary

The **MAP-SSF project** set out to improve the understanding of small-scale fisheries (SSF) in Europe by mapping their spatial and temporal activity and assessing their social and ecological pressures, with a forward-looking perspective on the implementation of EU Regulation (EU) 2023/2842 (Control Regulation). Four Work Packages (WP) were designed to pursue the main goal of the project:

WP1 COLLECTED extensive data and methodologies essential for understanding SSF activity. A dedicated questionnaire was developed to capture the diversity and complexity of SSF practices throughout Europe. It covered six main topic areas: SSF definitions, legislation, spatial use, landings and reporting, tracking systems, and existing information. Nineteen case studies from various regions in Europe completed this questionnaire, providing a diverse overview of SSF practices, classifications, and fishing methods. The collected data facilitated the identification of key patterns in gear utilization, sales channels, and catch composition. Multispecies fisheries emerged as a notable feature of SSF, demonstrating adaptability to various habitats, including shallow coastal zones, estuarine and benthic environments, and pelagic areas. Challenges such as limitations in gear functionality, including restrictions on gear quantity (number of pots, nets or hooks), dimensions (mesh size or gear length) and constructions, spatial conflicts, and management deficiencies were identified, offering crucial insights for improving policy frameworks and enhancing monitoring mechanisms. Comprehensive bibliographic and project references were also compiled to support future research and governance efforts focused on SSF.

WP2 DEVELOPED a standardized methodology to collect, process and integrate data from multiple sources, and assess SSF activity and fishing pressure. Building on data collected in WP1, WP2 enhanced the understanding of where and how SSF operate, quantifies fishing effort and pressure, and evaluates their role within the broader Blue Economy. This approach integrates participatory mapping, high-resolution spatial data from vessel tracking systems and remote sensing (vessel detections from Sentinel-2 imagery). Neural network models were applied to predict spatial fishing effort based on environmental and fleet-related data, producing accurate spatial layers of fishing activity that complement existing layers. Reproducible R pipelines were developed to support standardized data processing and analysis across four case studies: Notebook 1 integrates diverse data sources (i.e., participatory mapping, tracking, registries, Sentinel-2) to map SSF fishing effort, while Notebook 2 implements a neural network model (Multilayer Perceptron Network, MPN) to predict the spatial distribution of SSF effort. This work resulted in the creation of spatial layers depicting SSF fishing effort and the calculation of relevant fishing pressure indicators, allowing for analysis in relation to other marine sectors and users identified for each case study. Mapping outputs were also used to identify hotspots of fishing activity and potential spatial overlaps with other maritime uses. Specific examples from the Basque Country (Spain) and the Marche region (Italy) illustrate how SSF activity intersects with other sectors such as aquaculture, tourism, energy infrastructure, and conservation areas. These insights inform spatial planning and stakeholder engagement, promoting better representation of SSF in Blue Economy strategies. In other regions, such as the Iberian coast (Portugal) and Murcia (Spain), preliminary conflict mapping was limited due to data gaps, underscoring the need for further data collection to enable formal impact assessments. These findings reinforce the importance of integrating SSF spatial data into broader Blue Economy strategies and marine governance frameworks.

Building on WP1 and WP2, **WP3 RECOMMENDS** solutions to generate broader recommendations and guidelines for stakeholders. For example, WP3 suggests the combination of data sources, such as high-resolution geospatial data, Sentinel imagery and questionnaires, to incorporate fishers' knowledge and perspectives. The standardized methodology from WP2 is also recommended to obtain comparable results among fisheries and countries, with mandatory on-site real-time data observations to ensure model accuracy. Overall WP3 proposes the implementation of tracking devices in SSF – consistent with EU Regulation (2023/2842), using high temporal resolution and a clear framework to process and analyse the data. A structured framework for data processing and analysis can ensure consistency in scientific assessments and policy applications.

The outputs of MAP-SSF align with the objectives of several EU policy instruments. In the context of the Common Fisheries Policy (CFP), the spatially explicit data generated can support coastal access management, contribute to regionalised governance, and inform advisory processes involving SSF. For the Marine Strategy Framework Directive (MSFD), SSF mapping can contribute to indicators related to seabed integrity (D6), biodiversity (D1), and fishing pressure (D3). Within Maritime Spatial Planning (MSP), georeferenced effort data and gear-specific maps are useful for identifying spatial interactions between SSF and other maritime sectors. The methodologies and tools developed in MAP-SSF offer a replicable and scalable approach for integrating SSF into marine governance.

1 Overview of SSF in the EU and project objectives

Key messages

- Small-scale vessels dominate the EU fleet but remain largely invisible in spatial data and governance frameworks.
- Regulatory inconsistencies and exemptions have created systemic monitoring gaps.
- Data fragmentation undermines robust assessment of fishing pressure and policy effectiveness.
- A broader, harmonised definition is essential for representativeness and comparability.
- MAP-SSF aims to deliver a scalable methodology to integrate SSF into EU marine governance and spatial planning.

1.1 Introduction

SSF represent a significant proportion of the European fishing fleet, accounting for 84 % of vessels (Rufino, 2024) and providing direct employment to around 100,000 people. These fisheries operate predominantly in coastal areas, often with vessels under 12 meters in length overall (LOA), although definitions vary across EU policy instruments. SSF play a crucial role in sustaining coastal communities, contributing to food security, cultural heritage, and local economies. Despite their importance, SSF remain underrepresented in data collection and spatial planning, due to, for example, fragmented operations and limited tracking systems. The current project addresses these gaps by evaluating methodologies to better represent SSF-associated fishing pressure and improve the visibility of this sector in marine governance frameworks.

1.2 Small scale fisheries in numbers

SSF comprise over 50,000 active vessels across the EU and are typically characterised by low engine power, limited onboard technology and high regional fragmentation. Despite representing the majority of the European fleet, they contribute only around 7% of total landings by weight and 6% by value (STECF, 2023).

Using EU Fleet Register (EUFR) data, Rufino (2024) explores the structure and spatial distribution of the EU SSF fleet, which represents 84 % of the total EU fishing fleet. The analysis reveals an uneven distribution of SSF across Member States (MS), with countries such as Greece, Italy, and Spain showing particularly high numbers of vessels under 12 meters LOA. The results highlight the structural dominance of SSF in the EU fleet and the need for harmonised, high-resolution data to support their integration into fisheries management, spatial planning, and sustainability assessments.

1.3 Policy context

The EU regulatory framework concerning SSF includes several key instruments that address sustainability, control, data collection, and financial support:

- **Common Fisheries Policy (CFP)**: provides the overarching principles for sustainable resource use and fleet management (not SSF-specific). This includes the allocation of **fishing opportunities** (e.g. catch limits and effort quotas), which indirectly impact SSF access to shared stocks, particularly in multispecies and mixed fisheries.

- **Technical Measures Regulation (TMR) (EU 2019/1241)**: defines gear specifications, minimum conservation reference sizes, closed areas, and seasonal restrictions. These measures directly affect SSF, which typically operate with passive gears in sensitive coastal habitats.
- **Control Regulation (EU 2023/2842)**: introduces mandatory tracking systems for all vessels, including SSF, to be implemented within five years.
- **Data Collection Framework (DCF)**: legally mandates the collection of biological and socio-economic data for all active vessels. However, due to operational constraints, SSF data are often collected through ad hoc surveys, resulting in gaps that limit policy evaluation and management.
- **European Maritime, Fisheries and Aquaculture Fund (EMFAF)**: provides targeted financial support for SSF, including funding for sustainability initiatives, innovation, data improvement, and socio-economic resilience in coastal communities.

1.4 Small scale fisheries definitions

The definition of SSF in the EU varies across policy instruments, scientific literature, and data collection frameworks. Terms such as SSF and small-scale coastal fisheries (SSCF) are often used interchangeably, despite referring to overlapping but distinct fleet segments depending on the regulatory context.

Under the EMFAF, SSCF is defined as vessels less than 12 meters LOA operating exclusively with passive gears. This definition is also adopted in the Scientific, Technical and Economic Committee for Fisheries (STECF) Annual Economic Report (AER) and in STECF assessments of fleet capacity versus fishing opportunities.

In contrast, other legislative instruments such as the CFP, the TMR, and the Control Regulation (EU) 2023/2842 apply different thresholds and criteria. For example, vessels up to 15 meters LOA may be exempt from certain obligations, such as electronic logbooks, vessel tracking systems (VMS), and catch reporting. These exemptions, while administratively justified, have contributed to a systematic lack of data on the operations, catches, and socio-economic characteristics of the SSF segment.

Although the DCF legally mandates the collection of biological and socio-economic data for all active vessels, in practice, data on SSF are often collected through ad hoc surveys due to the operational and logistical challenges of monitoring this highly fragmented and diverse fleet. This results in data gaps that hinder robust policy evaluation, impact assessment, and the design of tailored management measures for the SSF sector.

Given that the definition of SSF in the EU varies across policy instruments, we **adopted a broader working definition** to better align with the objectives of this study. Our definition includes **all passive gear vessels under 15 m LOA and vessels under 12m LOA using active gears**.

This approach was chosen to ensure a more comprehensive dataset, allowing us to capture a wider range of fishing practices and vessel types, as reflected in different country-specific definitions of SSF across the EU. By expanding the scope, we aim to improve the representativeness of the data used in our study, ultimately enhancing the robustness and accuracy of the model developed.

1.5 Data sources

Several official EU data sources provide information on SSF, each with different levels of detail, coverage and relevance. Table 1.1 summarises the main characteristics of these sources:

Table 1.1 Data sources of EU SSF

Data Source	Type of information	SSF Coverage	Limitations
DCF	Biological and socio-economic data from national sampling programs	Includes SSF, but often collected via ad hoc surveys due to operational constraints	Coverage and consistency vary across MS
Fleet Data Information (FDI)	Harmonised fleet-level data: vessel characteristics, gear types, activity status	Covers ~70,000 SSF vessels registered in the EU	Limited socio-economic detail; gear use may be inconsistently reported
STECF AER	Economic indicators: employment, income, profitability	SSF contribute ~7 % of landings by weight and ~6 % by value ~100,000 jobs linked to SSF	SSF data often aggregated; limited resolution for regional or gear-specific analysis
EU Fleet Register	Official registry of all EU fishing vessels: LOA, gear type, flag state	Identifies SSF vessels based on size and gear type	No operational or socio-economic data; gear classification may not reflect actual practices

1.6 Project objectives

Despite the structural importance of SSF in the EU fleet, their activity remains poorly represented in official datasets and spatial planning tools. The lack of harmonised definitions, limited tracking systems, and fragmented data collection methods hinders the assessment of fishing pressure, fleet dynamics, and interactions with other maritime sectors. These gaps compromise the effectiveness of policy evaluation and management strategies.

The MAP-SSF project was designed to address these limitations by developing methodologies that improve the spatial and quantitative representation of SSF across European waters.

The specific objectives of the project were to:

1. summarise applicable legislation and assembling data from other projects to define SSF areas.
2. map SSF activity using spatialised, semi-quantitative questionnaires.
3. assess data from remote devices to estimate distribution patterns and fishing effort indicators.
4. apply modelling approaches to analyse SSF fishing effort and fleet structure.
5. explore new methods, such as remote sensing data, to map the fishing footprint of SSF in the EU.
assess SSF overlaps and potential areas of conflict with other fleet segments and other Blue Economy sectors.

2 WP1 COLLECT - Data and knowledge gathering on SSF

Key messages

- A structured questionnaire and multi-source review covered 20 case studies across 17 countries, compiling legal, spatial, operational, and socio-economic information on SSF.
- Divergent national definitions and segmentation criteria reduce comparability and challenge EU-wide assessment of SSF fleets and fishing effort.
- Most SSF fleets are not systematically tracked. Even where AIS is installed, active transmission is often low, limiting reliable spatial effort estimation.
- SSF typically operate close to shore, in shallow waters, and use multiple gear types per trip, making effort estimation and regulatory classification complex.
- Incomplete monitoring, weak documentation of gear use and by-catch, social data gaps, and fragmented policy frameworks constrain effective management and integration of SSF into marine governance.

2.1 Introduction

The main goal of WP1 was to collect comprehensive data on small-scale fisheries by developing a questionnaire that addressed various aspects such as legislation, spatial use, landings and logbook reporting, and tracking systems. A multi-targeted approach was applied to access data from: (i) legislation reviews, (ii) project outputs, (iii) trackers, and (iv) grey literature. This data collection strategy enabled the characterisation of SSF operational modes and the estimation of associated fishing pressure. Furthermore, the analysis allowed for the identification of gaps in both existing and planned regulatory and policy frameworks, as well as deficiencies in the quality and spatial coverage of SSF data across European waters (Figure 2.1).

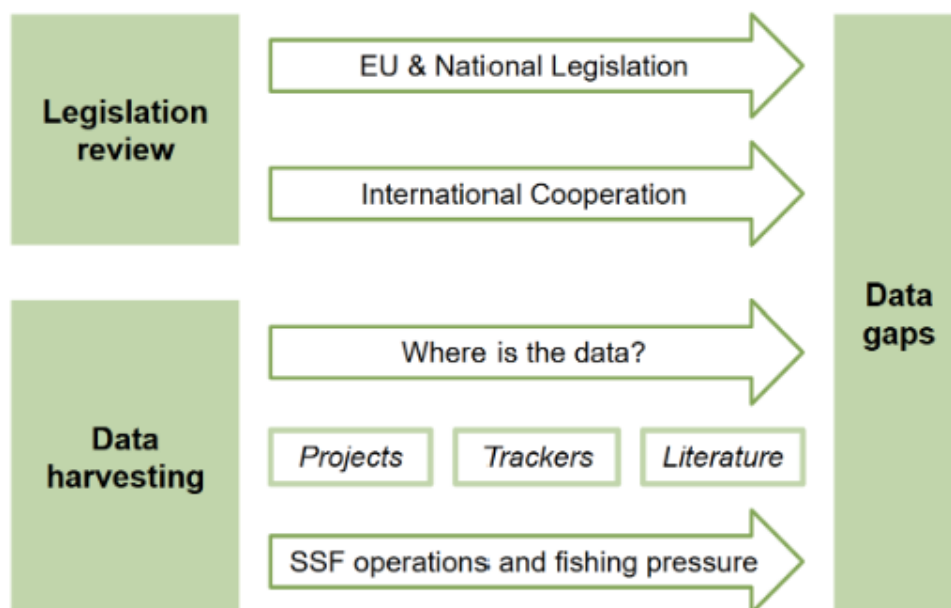


Figure 2.1 Schematic overview of WP1

2.2 Questionnaire on Small Scale Fisheries (SSF)

The methodology and development of the SSF questionnaire are described in detail in ANNEX 1a Methodological description. The questionnaire prioritised maximising the number of closed, obligatory (i.e., predefined option) questions to facilitate the analysis and permit a better quantification of the results (Ranganathan and Caduff, 2023). A limited number of open, non-obligatory (facultative) questions were included to provide additional insights into specific topics (92% of obligatory questions were closed; 64% of all questions were closed; 36% of questions were non-obligatory, of which 86% were open).

The final questionnaire developed was composed of six main sections (ANNEX 1b Questionnaire structure):

1. Definition of SSF – 12 questions
2. Legislation – 9 questions
3. Spatial use – 5 questions
4. Landings and logbooks reporting – 3 questions
5. Tracking systems – 5 questions
6. Previous information on SSF – 5 questions

Although the questionnaire was initially proposed to be completed only for six case studies in four countries, efforts were made to broaden its scope and acquire comprehensive data across Europe. It was therefore sent to 49 contact points assembled by the group, working in SSF-related fields, covering 23 coastal countries (EU Member States as well as other European or neighbouring countries, e.g. Türkiye, Albania, Iceland, Montenegro and Norway) (Figure 2.2).

Some contacts provided relevant information directly by email (ANNEX 1c. Additional relevant information by country), although the majority completed the questionnaire (Albania, Estonia, Iceland, Germany, Greece, Croatia, Malta, Poland, and Romania). **In total, the analysis was based on these responses, plus five case studies, resulting in 19 final completed questionnaires.** This extensive network of contacts is highly relevant for future studies related to SSF.

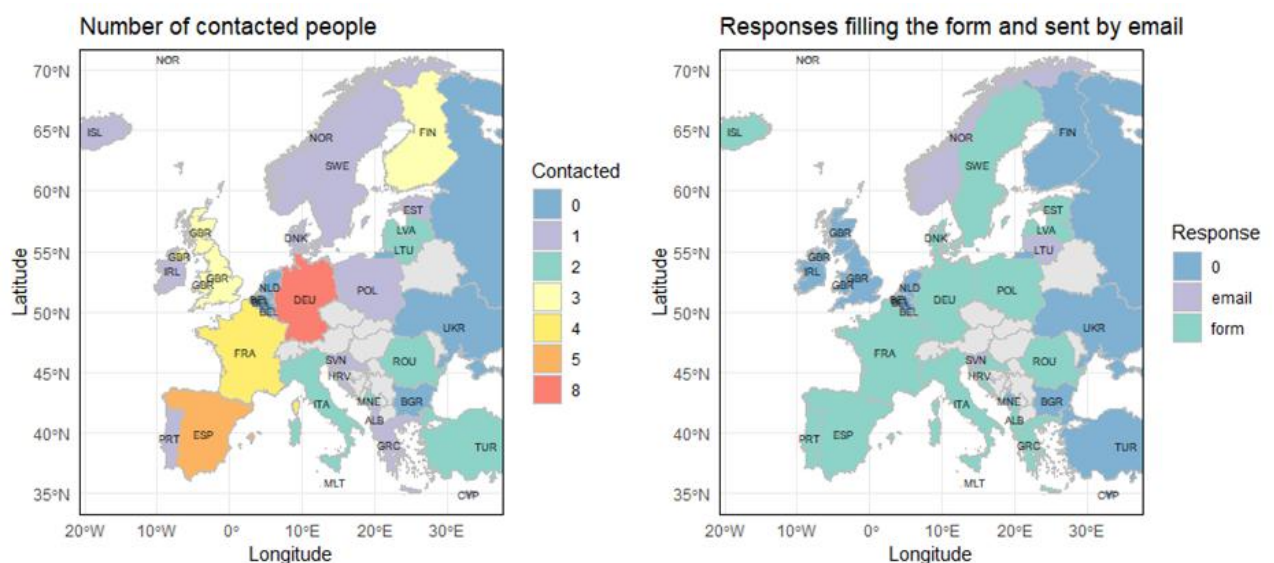


Figure 2.2 Map showing the number of people contacted (left) and number of responses received (right) by country

Overall, twenty case studies from 17 countries were documented through the questionnaire: Albania, Croatia, Cyprus, Denmark, Estonia, France (Bay of Biscay), Germany (North Sea and Baltic

Additional information was provided by email (summarised ANNEX 1c. Additional relevant information by country), for Albania, Cyprus, Finland, Germany, Lithuania, Malta, Norway, Poland, Sicily, Sweden and Türkiye.

The responses covered most EU marine basins, namely the Iberian Atlantic coast, Atlantic Iceland, the Bay of Biscay (Spain and France), the Mediterranean Sea and Adriatic Sea, the North Sea, the Baltic Sea, and the Black Sea (Figure 2.3).



Figure Notes: Main EU marine management basins referenced in this report, derived from the spatial overlay of Exclusive Economic Zones (EEZs) with ICES Statistical Areas and FAO Geographical Subareas (GSAs). Note that boundary inconsistencies exist between GSA 6 and GSA 7.

2.3 Results of the SSF Questionnaire (Deliverable 1.1)

2.3.1 SSF definition and segmentation

While the EU has no official definition for small-scale fisheries (SSF), it defines small-scale coastal fisheries (SSCF) as fishing vessels with an overall length of less than 12 metres and not using towed gear. However, in many countries and regions, local definitions exist that differ from the EU definition. This is highly relevant because official fleet data may therefore be based on different groups of vessels, raising issues regarding comparability across countries. For simplification, the respondents' information has been summarised in Table 2.1.

In Spain, SSF are classified under "Minor Gear," mainly vessels under 15 m, although sometimes larger vessels are included. Iceland lacks a formal legal definition, though approximately 15 m LOA is used in practice. Portugal distinguishes between a local fleet (<9 m) and a coastal fleet (<12 m), each with specific jurisdictional criteria. In Greece, SSF include vessels under 12 m, combined with additional operational criteria. Malta considers vessels under 10 m, reflecting the predominance of small vessels in its fleet. Sweden has no formal definition, but reporting rules create two segments: <10 m (or <8 m for Baltic cod fisheries) and ≥10 m (or ≥8 m in the Baltic). Denmark applies different thresholds depending on the regulatory context: <12 m for position data, <10 m for North Sea logbook requirements, and <8 m in the Baltic Sea. Latvia uses the <12 m threshold but also includes certain small vessels operating with towed gears. Finland applies a <12 m threshold, with an additional sub-segment of vessels <8 m. Germany generally maintains the 12 m threshold, although new segmentation schemes have been proposed (Sulanke et al., 2025).

In contrast, France, Italy, Croatia, Estonia, Romania, Poland, Albania, Lithuania, and several other countries follow the official EU definition of vessels under 12 m and not using towed gear.

The number of SSF vessels (considering all vessels below 12 m LOA — SSF12) can be retrieved from the open database of the EU Fleet Register (EUFR), which lists the characteristics of all vessels operating in the EU and the UK (185,364 records downloaded in March 2025). Although this database provides very important information for most stakeholders working in this field, three main issues arise when using it to characterise SSF fishing effort.

1. **There is no information on the marine basin in which the vessel operates.** This is particularly problematic for countries with fleets operating in multiple basins. For example, Germany has vessels operating in both the North Sea and the Baltic Sea, while France and Spain operate in both the Mediterranean and Atlantic basins (including the Bay of Biscay and, in the case of France, the North Sea). In such cases, it is difficult to associate vessels with specific basins and, consequently, to estimate basin-level fishing effort.
2. **SSF vessels in many countries (as detailed below) may operate with several different gear types.** Although the EUFR indicates the main and subsidiary gears registered for each vessel, it does not specify which gears are actually used in practice or their relative frequency of use.
3. **There is no reliable information on the operational status of tracking devices.** For example, although many vessels may have AIS installed, it is not always activated, meaning that the system may not be operational (as detailed below). Furthermore, no information is provided on the presence of General Packet Radio Service (GPRS) systems in vessels within this database.

The present questionnaire aims to disentangle these components to improve the estimation of fishing effort. Otherwise, further details on these aspects can be retrieved from specific publications, as indicated in the References section of the questionnaire responses. The results from the responses regarding the number of vessels operating by basin are summarised in Figure 2.4, Figure 2.5 and Table 2.2, and are detailed below.

Table 2.1 Summary of EU SSF definitions by country

Country	SSF Definition / Segmentation	Notes
Spain	Special class “ <i>Minor Gear</i> ”; mostly < 15m, but can include > 15m	Specific regional categories
Iceland	No legal definition; for proceedings, ~15m used	Informal threshold
Portugal	Two segments: Local (< 9m), Coastal (< 12m)	Jurisdiction-specific
Greece	< 12m plus other criteria	More complex than EU rule
Malta	< 10m	Reflects actual fleet composition
Sweden	No legal definition; fleet segmented at < 10m or < 8m (for Baltic cod) vs ≥ 10/8m	Reporting requirements differ (monthly vs daily)
Denmark	Segmentation varies: < 12m (position data), < 10m (logbook, North Sea), < 8m (logbook, Baltic Sea)	Multiple criteria
Latvia	< 12m, but can include small towing gears (e.g., flounder seines)	Gear-based exceptions
Finland	< 12m, with an additional segment < 8m	Dual segmentation
Germany	EU 12m threshold, but recent study proposes new segmentation scheme (Sulanke et al., 2025)	Reform proposal
France	EU official < 12m	—
Italy	EU official < 12m	—
Croatia	EU official < 12m	—
Estonia	EU official < 12m	—
Romania	EU official < 12m	—
Poland	EU official < 12m	—
Albania	EU official < 12m	—
Lithuania	EU official < 12m	—

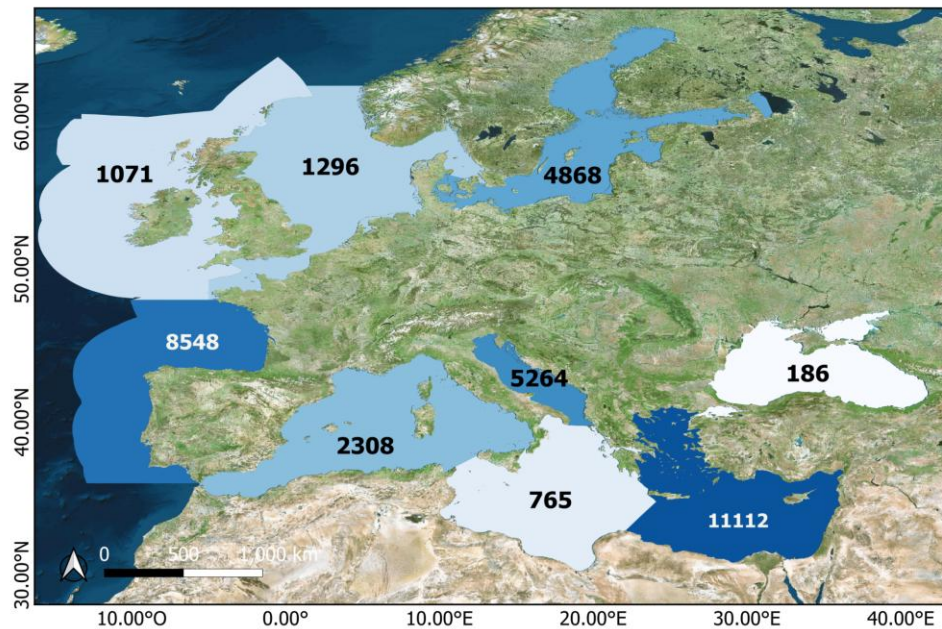


Figure 2.4 Representation of the (minimum) number of vessels by overall basin

Figure Notes: See main text for further details. Data were unavailable for several countries; results should therefore be interpreted with caution.

Table 2.2 Overview of the number of vessels by source and case study

Country/ Region	EUFR ^a	FDI ^b capacity	AER ^c	Official data reports	Form response
Portugal	3045	1406 PG (4495 other)	2753	DGRM	+3000 (2774 (all vessels < 12m, landing > 100kg during 2022 - official landings))
Italy	8855	6307 PG (2144 other)	6307		6307 SSF vessels, thus below 12 m and using polyvalent passive gears (1127 for GSA17) (2023 FDI capacity)
Spain (country wise)	6238	(6476 other)	4099	5463 in 2022 (SGP, 2024)	4567 vessels <12 meters (2022-12-31, Annual Reports of the Fishing Fleet, SGP)). Dredges (1466 vessels) not included
France (Bay of Biscay)	5184	607 PG (4731 other)	3725	Ifremer, 2023	1459 vessels including 1156 SSF in 2023 (Ifremer, 2023)

Table Notes: (a) EUFR, includes all vessels <= 12 m available in 2024, as it is not possible to know for many countries which gears are actually used. This is only country data, and was extracted from the EUFR portal. (b) FDI data was extracted from the 2023 FDI capacity, including segments "VL0006", "VL0008", "VL0010", "VL0612", "VL0812", "VL1012" (i.e. below 12 m), for PGP and others. Data is given by country, from 2022. (c) AER: The numbers provided represent SSCF in the report. Note that it is stated: "within the Other Fishing Region (OFR), French Guiana, Guadeloupe, the Canary Islands, Madeira, Azores, Martinique, la Réunion, and Mayotte were considered. SSCF is determined in Regulation (EU) 2021/1139 of 7 July 2021, i.e. vessels >=12m not using towed gear".

Specifically for the Marche Region (Italy), 312 SSF vessels were listed in 2020 by the NISEA research cooperative (Fisheries and Aquaculture Economic Research) (NISEA, 2022).

In Croatia, 3,231 SSF vessels were reported (compared to 5,806 vessels registered in the EUFR). In Albania, approximately 480 SSF vessels were reported (Albania is not an EU Member State and is therefore not included in the EUFR).

No response was received from Montenegro (also not an EU Member State and therefore not included in the EUFR) or from Slovenia. However, the EUFR reports 116 SSF vessels for Slovenia, and the corresponding fishing area polygon was received.

Based on this information, the EEA assessment area for the Adriatic Sea, which includes Italy (1,576–2,022 vessels, depending on the source/year), Slovenia (116), and Croatia (3,231), should currently account for fewer than approximately 4,923 vessels below 12 m LOA. This number is likely lower in practice, given the overall declining trend in fleet size observed in most countries.

Aegean - Levantine Sea

For the Aegean–Levantine Sea, data are primarily derived from Greece and Cyprus. Greece has the largest SSF fleet in Europe, with approximately 11,000 SSF vessels (**10,682 according to the EUFR**). Combined with the complex coastal topography and numerous islands, this creates significant challenges for estimating spatial fishing effort in the region.

Cyprus reported 740 SSF12 vessels in the questionnaire, compared to 695 vessels registered in the EUFR. However, for a substantial proportion of vessels (approximately 430), fishing activity is highly restricted (Cyprus Department of Fisheries, 2023).

Ionian Sea and the Central Mediterranean Sea

In the Ionian Sea and the Central Mediterranean Sea, the EEA assessment areas include the Italian EEZ (Italian Mediterranean waters in the Eastern Basin, largely south of mainland Italy and Sicily) and Malta.

Malta reported approximately 410 vessels in the questionnaire (possibly referring to vessels <10 m LOA), whereas the EUFR lists 765 SSF12 vessels.

Western Mediterranean Sea

The Western Mediterranean Sea includes the Spanish, Italian, and French Mediterranean coasts. Data for these areas were limited in the questionnaire responses.

In France, $542 + 513 + 167 = 1,222$ SSF12 vessels were reported (Figure 2.3; Ifremer, 2023). In the Spanish Mediterranean, $988 + 98 = 1,086$ vessels under 12 m LOA were reported for 2022 by the Spanish government (SGP, 2024).

Bay of Biscay and Iberian Coast

The Bay of Biscay and Iberian Coast assessment area includes coastal waters of Portugal, Spain, and France. For Portugal, only EUFR vessel numbers were available.

In Spain, official records report $3,547 + 323 = 3,870$ SSF12 vessels in the North Atlantic region (SGP, 2024). Notably, in addition to northern Spain, there is a smaller southern area near the Portuguese border — the Gulf of Cádiz — which is also officially included in the North Atlantic region (supra-región de Atlántico y Noroeste). In France, $970 + 314 + 189 + 205 = 1,678$ vessels were reported as operating in 2023 (Figure 2.6; Ifremer, 2023).

Overall, this assessment area is estimated to include approximately 8,548 SSF12 vessels (3,000 Portugal [EUFR estimate] + 3,870 Spain + 1,678 France).

Celtic Sea

Very limited information was available for the Celtic Sea. French data for this area are reported together with the Bay of Biscay (within Bretagne), making it difficult to disentangle basin-specific figures. No response was received from Ireland; however, the EUFR reports 1,701 SSF12 vessels for Ireland.

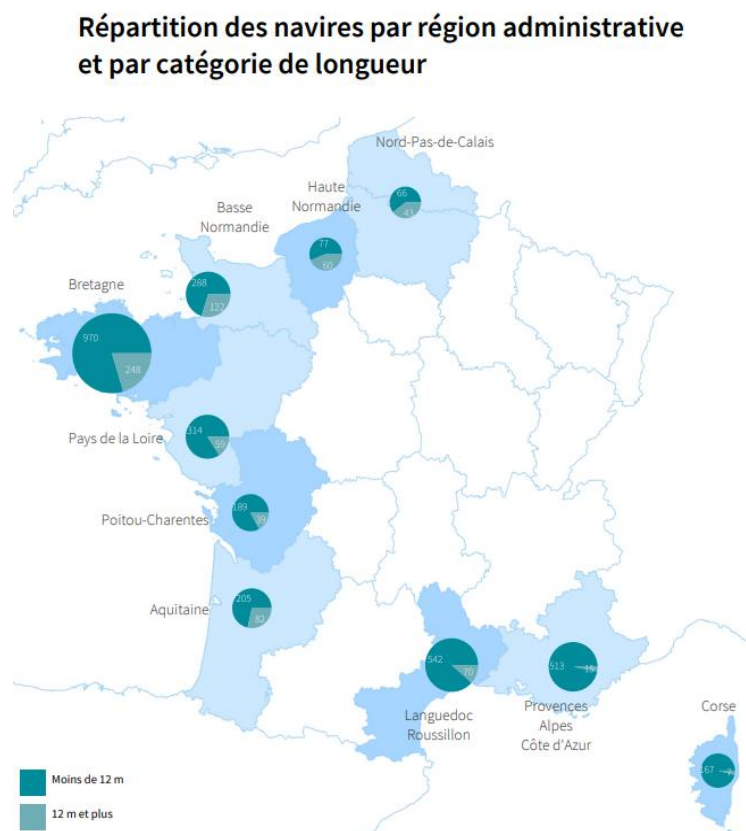


Figure 2.6 Distribution of SSF segments along the French coast

Source: Ifremer, 2023

North Sea

In the Greater North Sea (including the Kattegat and the English Channel) assessment area, Germany reported no SSF12 vessels operating with passive gears, whereas gillnetters operate in Dutch waters (particularly near the Belgian border), as well as potters (e.g., around the island of Helgoland). The EUFR registers 345 SSF12 vessels for the Netherlands.

Belgium has no registered SSF12 vessels. France, across the three regions included in this EEA assessment area, reports $66 + 77 + 288 = 431$ SSF12 vessels. Denmark reports 520 vessels operating in the North Sea.

Based on available data, this assessment area includes at least 1,296 SSF12 vessels (345 Netherlands + 431 France + 520 Denmark), in addition to vessels operating in Swedish waters, for which consolidated figures were not available.

Baltic Sea

The Baltic Sea assessment area includes several countries, most of which have significant SSF fisheries. In Germany, the entire SSF12 fleet is assumed to operate in the Baltic Sea, as noted above. This

corresponds to 860 SSF12 vessels reported in a recent publication (Sulanke et al., 2025), which is consistent with the 867 vessels registered in the EUFR.

Denmark reports 320 vessels operating in the Baltic Sea. Poland has 582 SSF12 vessels registered in the EUFR. Estonia reported 1,290 vessels (MoRAA, 2024), compared to 2,032 vessels listed in the EUFR.

Information was received by email from Lithuania (89 vessels) and Finland. In Finland, the figure provided (Figure 2.7) shows 897 vessels <8 m and 221 vessels between 8–12 m, totalling 1,108 vessels recorded for 2023 (compared to 3,203 vessels in the EUFR).

Latvia reported 619 SSF12 vessels, whereas the EUFR lists 121 vessels.

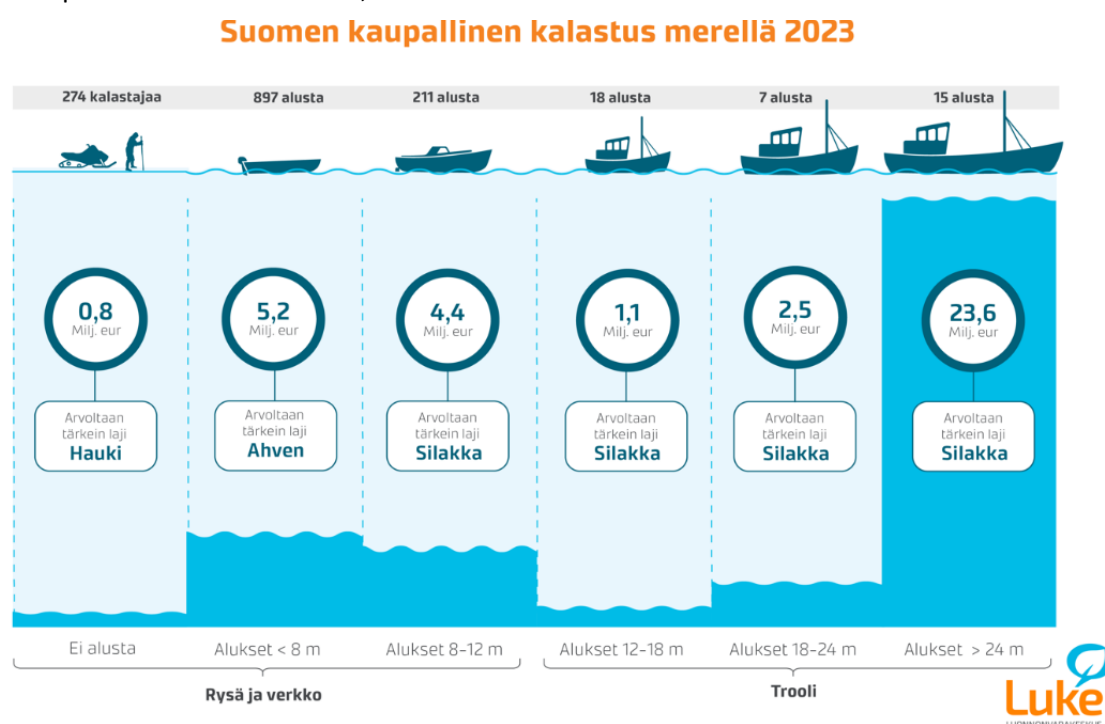


Figure 2.7 Official figure explaining the fleet segmentation in Finland

Figure Notes: Headline in English: The Finnish commercial fishery at sea in 2023. Translations: kalastajaa = fishers; alusta = vessels; alukset = vessels; Arvoltaan tärkein laji = the most important species in commercial value; hauki = northern pike; ahven = European perch; silakka = Baltic herring; rysä ja verkko = trap net and gillnet; trooli = trawl.

The comparison between EUFR data and national figures reveals substantial discrepancies in several Baltic Sea countries, in some cases exceeding a factor of two or more. For example, Estonia reports 1,290 SSF12 vessels compared to 2,032 vessels listed in the EUFR, while Finland reports 1,108 vessels compared to 3,203 in the EUFR. Conversely, Latvia reports 619 vessels, whereas the EUFR lists only 121. These differences likely reflect variations in national segmentation criteria, reporting years, fleet activity status (registered versus active vessels), and gear classifications. They highlight the limitations of relying exclusively on EUFR data for basin-level assessments. Without harmonised definitions and consistent criteria for identifying active SSF vessels, uncertainty remains in estimating fleet size and associated fishing effort in the Baltic Sea.

Nevertheless, in most questionnaire responses, the EUFR remains the official reference and is widely used in scientific publications and policy analyses. Despite its limitations at finer spatial or operational scales, it provides a consistent and valuable approximation of national fleet structures across large geographic areas and multiple basins.

2.3.2 Gears and target species

In terms of gear use, across all case studies, gillnets (GNS) and trammel nets (GTR) are the most commonly used gears by SSF12 vessels, followed by set longlines (LLS) and pots and traps (FPO) (Figure 2.8).

In 14 out of 20 case studies (74%), vessels are reported to operate with two or more gear types during the same fishing trip, **making it difficult to disentangle gear-specific effort and frequency of use**. Furthermore, the official EC definition — which considers only passive gears — complicates the identification and classification of SSF vessels, as gear use is often variable and multi-specific, as noted above.

A simplified definition of small-scale fisheries based solely on vessel length (i.e., <12 m LOA), rather than on gear type, would facilitate data processing, harmonisation, and comparability across countries.

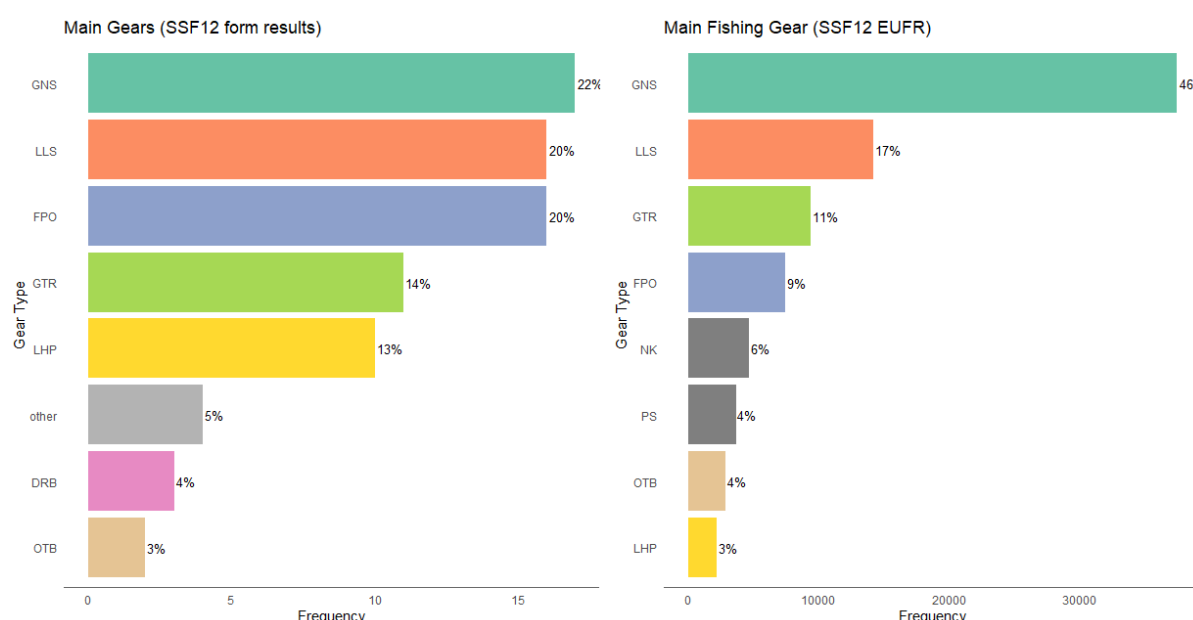


Figure 2.8 Frequency distribution of main gear types based on questionnaire responses (left) and the official EU Fleet Register data (right) on active vessels

Figure Notes: GNS: Gillnets, GTR: Trammel nets, LLS: set longlines, FPO: Pots and Traps, DRB: Dredges, LHP: Handlines, OTB: Trawls, and Other are all remaining and NK means gear not specified.

Fifty-four different taxa were reported in the questionnaire responses as the most important catches in terms of quantity and value. Among these, the most frequently cited species in terms of catch volume were hake (*Merluccius merluccius*), octopus (*Octopus vulgaris*), mackerel (*Scomber* spp.), herring (*Clupea harengus*), cod (*Gadus morhua*), red mullet (*Mullus* spp.), garfish (*Belone belone*), cockle (*Cerastoderma edule*), conger eel (*Conger conger*), and European seabass (*Dicentrarchus labrax*).

In terms of economic value, the most important species were European seabass (*Dicentrarchus labrax*), European hake (*Merluccius merluccius*), common octopus (*Octopus vulgaris*), common sole (*Solea solea*), European eel (*Anguilla anguilla*), European lobster (*Homarus gammarus*), red porgy (*Pagrus pagrus*), common cuttlefish (*Sepia officinalis*), and herring (*Clupea harengus*).

As expected, the diversity of species targeted is considerable, reflecting the wide range of habitats exploited, including benthic invertebrate communities, demersal species, small pelagic species, and larger pelagic resources. The multispecies nature of SSF12 fisheries constitutes a key structural

characteristic, demonstrating their flexibility and capacity to adapt fishing practices to locally available resources across diverse environments, thereby enabling the exploitation of a broad portfolio of species.

2.3.3 Sales and market channels

The majority of SSF12 vessels report selling their catches through harbours or directly to other vessels (**94% of responses**), restaurants (**89%**), and fish markets (**89%**). Additional sales channels were also identified, including taverns, hotels, exports, and direct sales to consumers (Figure 2.9).

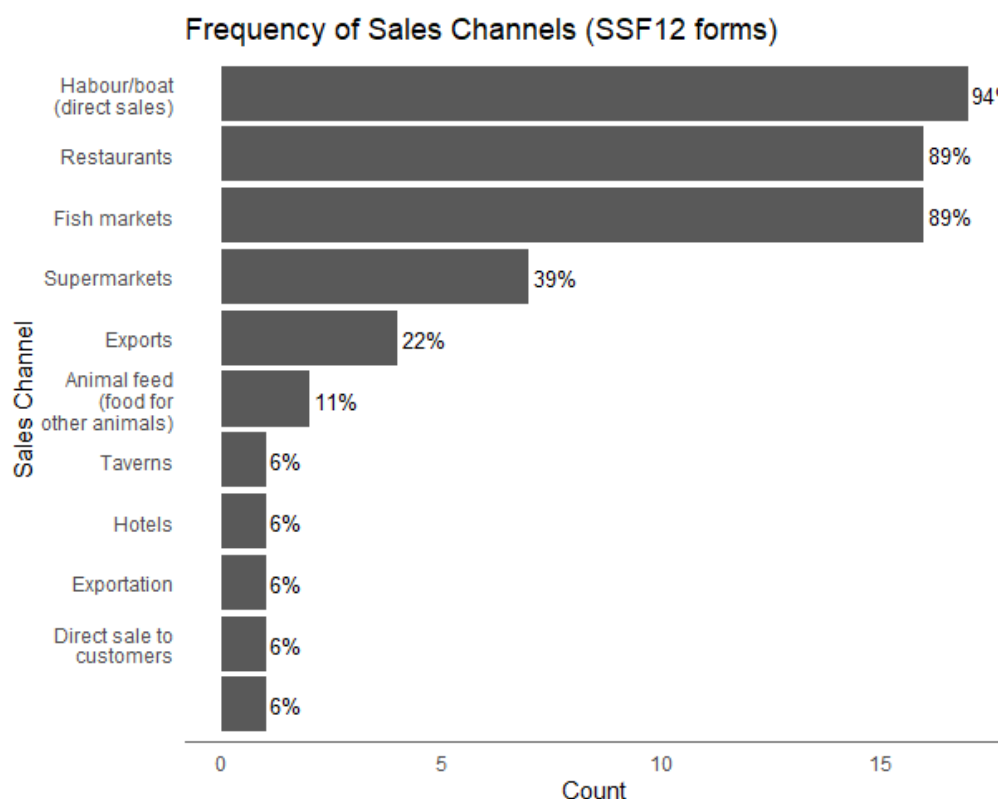


Figure 2.9 Frequency distribution of main sales channels for SSF12 vessels based on questionnaire responses

2.3.4 Social and cultural aspects

Employment

Although information on the social dimensions of SSF is limited in most cases, expert responses indicate that in 13 cases (68%), vessels typically operate with 1–2 persons on board, while 4 responses (21%) reported 1–4 persons, and one response indicated 3–4 persons per vessel.

If these figures were extrapolated to the entire EUFR SSF12 fleet (53,460 active vessels below 12 m LOA), and assuming 1–4 crew members per vessel, this would correspond to an estimated 53,460 to 213,840 persons directly engaged on board in SSF activities across the EU.

However, according to the latest STECF report (STECF, 2024), the EU small-scale coastal fleet totalled 40,083 active vessels in 2022, employing 59,694 fishers. This implies that SSCF represented 76% of the active fleet and 53% of total crew employment.

It should be noted that the EUFR-based estimate presented above includes all vessels below 12 m LOA, potentially including vessels using active gears and operating under multiple licences in some

countries. In contrast, the STECF figures follow the stricter SSCF definition applied under EU regulatory frameworks, which may explain part of the discrepancy.

Regarding additional persons involved in SSF-related activities (e.g., family members or employees), limited information was available. In the six case studies where data were provided, experts estimated an additional 1–2 persons per vessel indirectly involved in the activity.

Traditional practices and cultural significance

Eight case studies reported the presence of specific traditional SSF fisheries, while nine indicated none. Examples include fisheries targeting eel juveniles in the Basque Country; the pot-and-trap fishery for the gastropod *Tritia mutabilis* in the Marche Region; fisheries for transparent goby (*Aphia minuta*) and small tunas (*Sarda sarda*, *Euthynnus alletteratus*) in the Murcia region; the use of “boxes” (a type of pot) targeting *Octopus vulgaris* on the island of Thasos (Greece); static gears such as fyke nets (traditionally used in freshwater systems) in Estonia; and a specialised round goby fishery in Latvia. In Cyprus, catches currently include a high proportion of non-indigenous species.

These examples illustrate the strong cultural embeddedness and regional specificity of SSF practices across Europe. **Approximately half of the case studies highlighted fisheries with distinct traditional or heritage value, underscoring the socio-cultural importance of SSF beyond their economic contribution.**

2.3.5 Legislation and management tools

Temporal and spatial closures

In most cases, both spatial and temporal closures were applicable. In some countries, such as Sweden, these measures were applied across all gear types.

Financial instruments

In 14 cases (72%), SSF reported benefiting from fuel subsidies, primarily in the form of fuel tax exemptions. However, the structure and eligibility criteria of these subsidies are highly country-specific.

In 56% of cases, SSF also benefited from additional targeted subsidies beyond fuel support. These included compensation payments for temporary cessation of fishing activities (e.g., seasonal closures or biological rest periods, as reported in France and the Basque Country); measures supporting innovation, sustainable fishing practices, income diversification, and environmental performance; support for sustainable resource management and aquaculture development; investment in local fish markets, value-added processing, and fisheries-related tourism initiatives (e.g., in Italy, funded by regional councils and local authorities); restoration of traditional fishing vessels and engine power reduction schemes (Malta); establishment of Fisheries Local Action Groups (Germany, through EMFAF); and compensation for fisheries-related damage caused by seals (Germany and Latvia) or dolphins (Cyprus).

Additional instruments include the Brexit Adjustment Reserve (compensation for quota losses due to Brexit) and revenue redistribution from offshore wind farm area auctions (Germany), earmarked for fisheries infrastructure development. Several countries also reported compensation mechanisms linked to the economic impacts of the war in Ukraine.

Further details are provided in the questionnaire responses, many of which contained comprehensive information.

It would be important in **future analyses to assess the actual uptake, accessibility, and effectiveness of these subsidies, particularly in small, family-based fisheries where administrative capacity and literacy levels may limit access to funding mechanisms.** A key policy question remains whether these financial instruments adequately respond to the structural needs of the sector and contribute to its

long-term viability. In particular, what measures would enhance the attractiveness of SSF for younger generations?

Gear restrictions

In 79% of the cases (15 responses), SSF are subject to gear-related restrictions as part of additional management measures. These restrictions include limits on the number of pots, nets, or hooks; mesh size requirements; gear length limitations; caps on the number of permits issued annually; allocation based on historical rights (e.g., in Estonia); and technical specifications related to gear construction.

In terms of management intensity, gillnets (GNS) were reported as the gear type most frequently subject to restrictions, followed by set longlines (LLS), trammel nets (GTR), and trawls (OTB) (Figure 2.10).

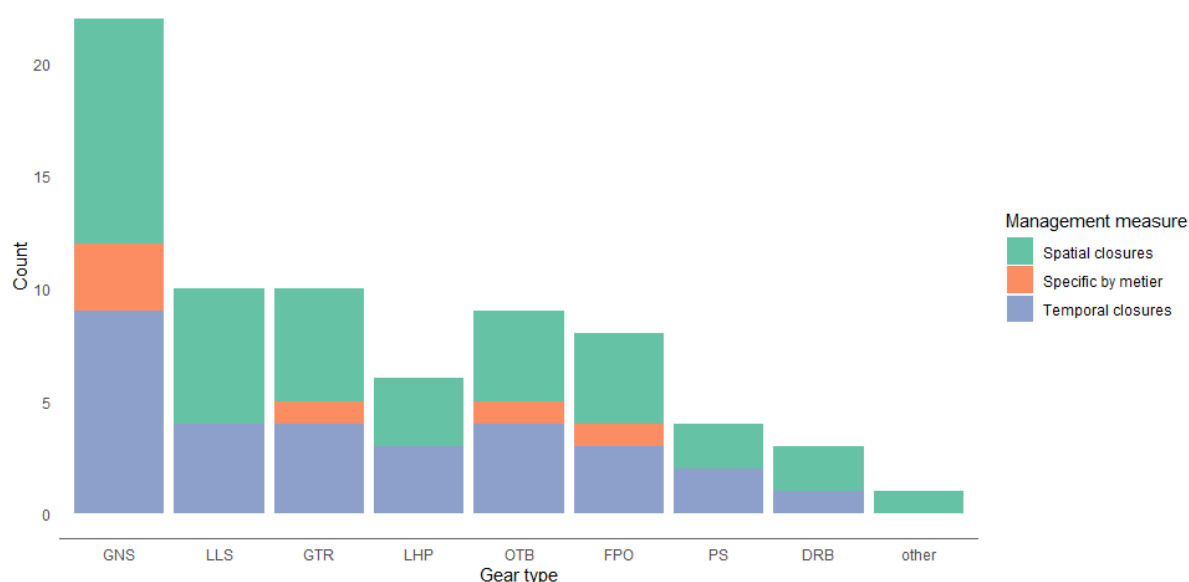


Figure 2.10 Main types of management measures applied by gear type

Figure Notes: for gear types - GNS: Gillnets, LLS: Set longlines, GTR: Trammel nets, LHP: Handlines, FPO: Pots and Traps, PS: Purse Seiners and DRB: Dredges.

Co-management

In most case studies, some form of co-management between fishers and decision-makers is reported.

In Portugal, co-management is being implemented for the octopus fishery in the Algarve, involving WWF and other organisations, including IPMA. In Croatia, the FishMPABlue2 project — which aims to improve the management and effectiveness of Marine Protected Areas (MPAs) through enhanced cooperation with local small-scale professional fishers — has been implemented in several MPAs, including the Telašćica MPA. Additionally, the “Transforming Small-Scale Fisheries in the Mediterranean” project seeks to reduce the ecological footprint of SSF, improve fish stocks, and create socio-economic opportunities for local communities. This initiative has established co-management systems in several Mediterranean countries, including Croatia (WWF Adria).

In Greece, co-management arrangements are reported for Amorgos Island. In Spain, many SSF fisheries are organised into associations known as *cofradías* — public law corporations that collaborate with political and scientific administrations to manage and represent the interests of the fisheries sector. In the Marche Region (Italy), the *Commissione consultiva locale per la pesca* functions as a consultative body that can be considered a “light” form of co-management.

In Estonia, management measures are discussed with fishers, and while agreements are not legally binding, decisions are generally reached through consensus. In contrast, Romania and Malta reported no formal co-management systems currently in place.

For Spain, a detailed overview of regional SSF management systems is provided in Florido et al. (2020, in Spanish).

2.3.6 Spatial use and conflicts

SSF fishing grounds

In the majority of case studies (74%, 14 responses), SSF do not operate within formally designated fishing grounds but rather within preferred depth ranges. In six case studies, fishing activity predominantly occurs at depths <50 m (Estonia, Romania, Cyprus, Denmark, and Latvia); in three cases, below 100 m (Sweden, Croatia, and Greece); and in one case below 200 m (Iceland). In Albania and Malta, SSF12 vessels are reported to operate across all depth ranges.

In Spain, the main industrial fishing activity is carried out by bottom trawlers. Since minimum depth requirements apply to bottom trawling — 100 m in the North Atlantic and 50 m in the Mediterranean and Gulf of Cádiz (except in the Canary Islands, where trawling is not permitted) — SSF predominantly operate in shallower waters closer to the coast.

Overall, across most case studies, SSF12 vessels primarily operate between the coastline and depths of approximately 50–100 m.

With regard to distance from the coast, responses were more variable than expected. Preferred fishing grounds ranged from 0.5 nautical miles (nm) up to 25 nm offshore. Specifically: Estonia (<0.5 nm), Romania (<3 nm), Sweden and Norway (<4 nm, within the 12 nm coastal zone), Finland (<12 nm), Croatia (<15 nm), Malta (<25 nm), and Latvia (a few kilometres from shore). Six respondents did not provide information on this aspect. In Lithuania, coastal waters were defined as extending up to 20 metres from the shoreline.

Encouragingly, several countries reported the availability of spatial polygons (i.e., georeferenced boundaries of SSF operating areas). Portugal, the Basque Country, the Marche Region, Murcia, and Iceland already possess such spatial data. Estonia, Malta, Romania, and Latvia indicated that polygons could be provided to the EEA. Sweden, Cyprus, and Croatia reported that these areas could be delineated interactively if required. Only Greece, Poland, and Albania indicated that no such spatial information was available. Notably, Iceland, Slovenia, and Malta have already submitted shapefiles to the MAP-SSF group.

Spatial conflicts

According to expert responses, the most significant conflicts affecting SSF12 occur between SSF vessels themselves, followed by conflicts with large-scale fisheries (LSF) and with Marine Protected Areas (MPAs) or no-take zones (Figure 2.11). The least significant conflicts were reported to involve oil platforms, aquaculture installations, and offshore wind farms, although each of these was considered relevant in at least one case study.

Additional conflicts identified include interactions with marine recreational fisheries, leisure boating, non-EU fishing vessels, and tourism activities. In Croatia, experts highlighted the negative impacts of coastal pollution and extensive shoreline modification, including artificial beach creation through gravel deposition, port construction, breakwaters, pontoons, concrete waterfronts, promenades, beach replenishment, and land reclamation in river estuaries. These cumulative infrastructural interventions were reported to have substantial adverse effects on SSF operations.

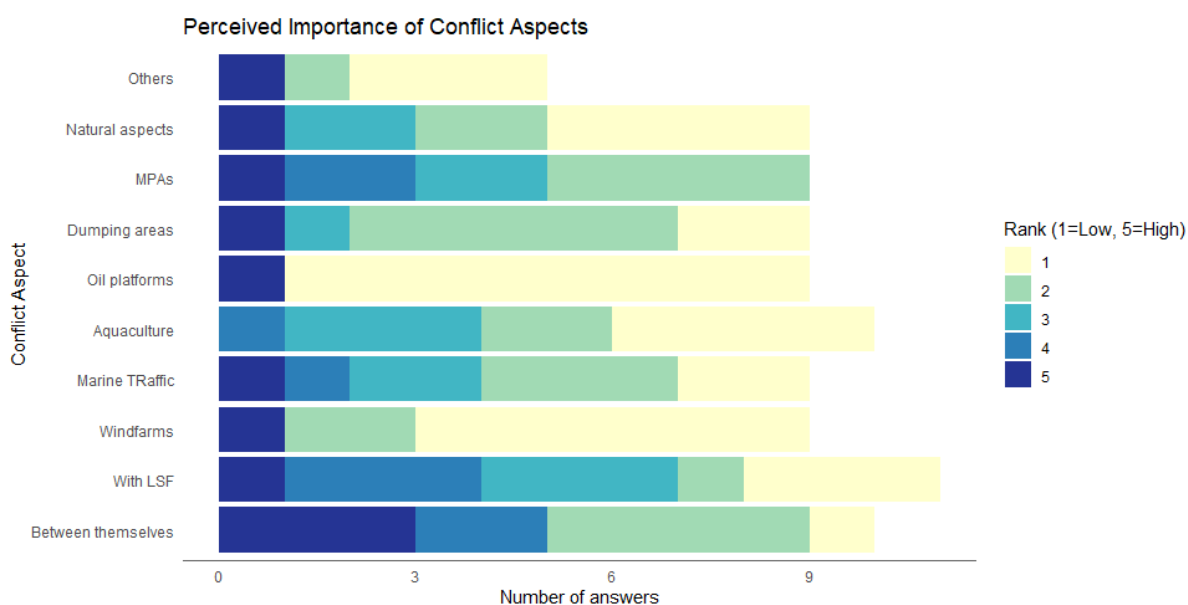


Figure 2.11 Ranked importance of potential conflicts for SSF12

2.3.7 Landings and logbooks reporting

In almost all case studies, fisheries, including SSF12, are required to report catches. Exceptions were identified in Albania, where SSF catches are not reported, and in Malta and Greece, where reporting obligations apply only to certain fisheries. In the Adriatic (Marche Region), catches are reported only for vessels larger than 10 m LOA, in accordance with Regulation (EC) No 1967/2006.

Monitoring information on SSF12 is obtained through several mechanisms: official logbooks (13 responses, 76%), scientific sampling at fish auctions (12 responses, 71%), on-board observers (9 responses, 53%), and electronic monitoring systems, for example tracking systems with video components (7 responses, 44%) (Figure 2.12).

In France, additional information for vessels below 10 m LOA is collected through monthly fishing declarations. In Iceland, monitoring is based on the official weighing of landings at designated landing sites.

Regarding logbook requirements, these generally apply to vessels between 10 and 12 m LOA within the SSF segment and are primarily maintained in electronic format. In Italy, vessels between 10 and 12 m LOA may choose between paper and electronic logbooks, whereas vessels larger than 12 m LOA are required to use electronic logbooks.

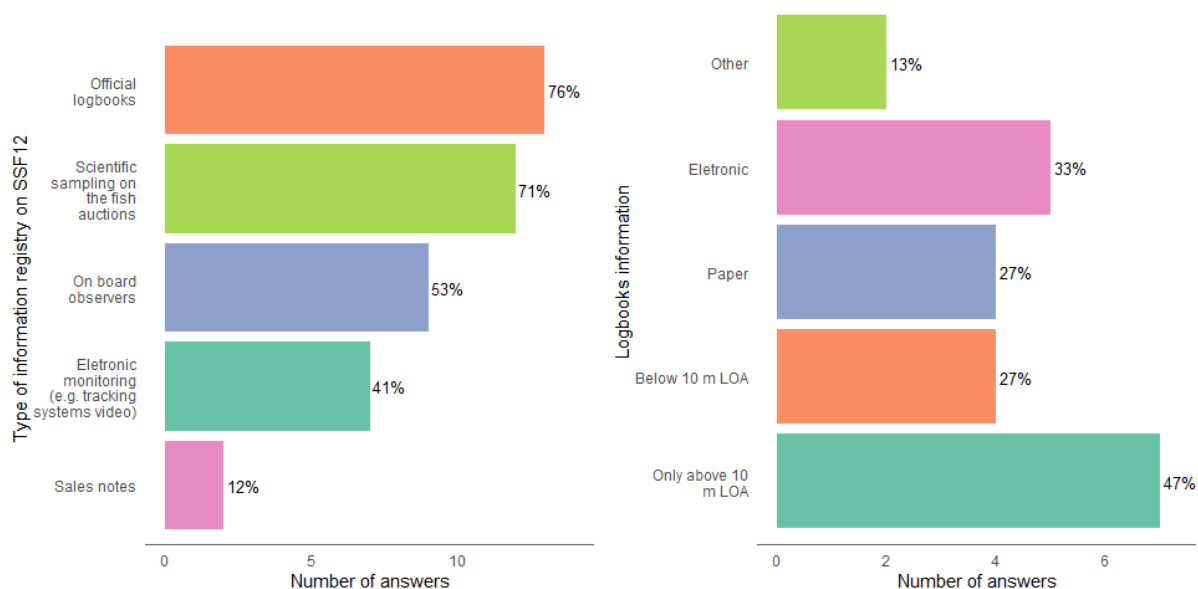


Figure 2.12 Methods used to obtain landings data (left) and type of logbooks (right)

Figure Notes: Figures show the percentage number of responses obtained in each category.

2.3.8 Tracking systems

Type of tracking system and rules

Out of 17 responses, in 7 cases no tracking system was in place for any SSF12 vessels. In the Basque Country (Spain), the Bay of Biscay (France), and Denmark, all fisheries are tracked, either on a voluntary or mandatory basis (Figure 2.13). In Malta, Iceland, and some regions of Spain (Andalucía and Catalunya), tracking is mandatory for all fisheries. In Portugal, Latvia, and Greece, four or fewer fisheries are tracked, and in Romania only one fishery is monitored. Overall, the majority of SSF12 fleets are currently not subject to systematic tracking (Table 2.3).

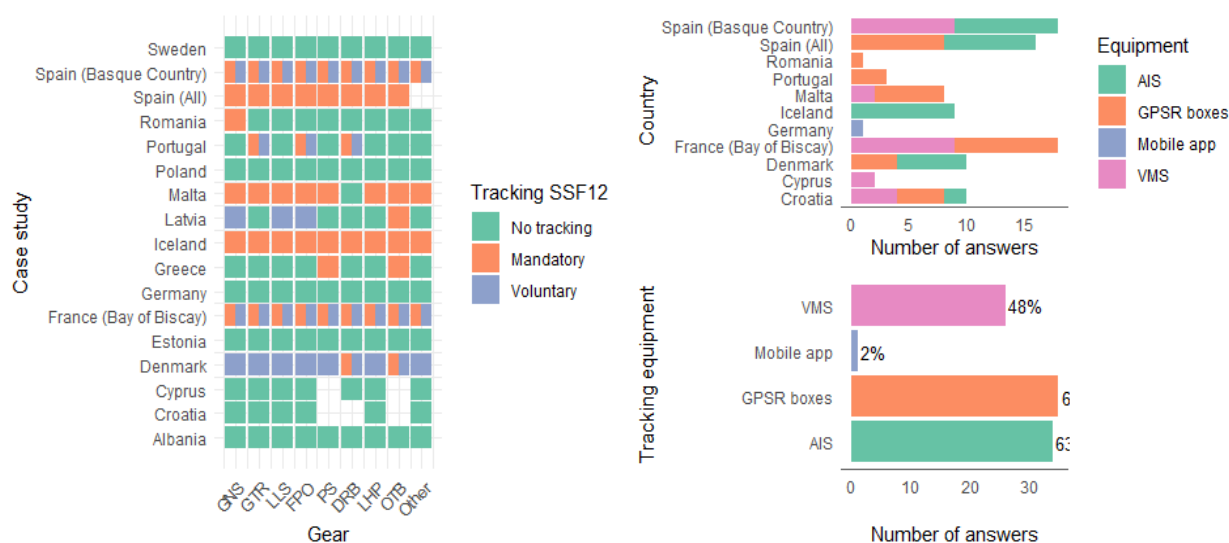


Figure 2.13 Type of tracking equipment (VMS, AIS, GPRS, Mobile app) and respective rules (voluntary/mandatory/no tracking)

In terms of tracking devices, most systems rely on some form of GPRS unit installed on board (61%). This is likely due to lower costs and greater control over data access. In most cases, the equipment has been developed by local companies (personal communication, e.g., Portugal, Spain, France).

In 59% of cases, SSF12 vessels are tracked using AIS systems, including in Croatia, Denmark, Iceland, and the Basque Country (Spain). However, in the latter two cases, SSF were defined as vessels ≥ 15 m LOA. AIS is mandatory for vessels above 15 m LOA, while smaller vessels may install it voluntarily, primarily for safety reasons.

The number of vessels reported in the EUFR as equipped with AIS is considerably higher than the number of vessels actively transmitting AIS signals (see Table 2.6). For example, in the Basque Country, 60% of the fleet had AIS installed since 2017, either on a mandatory or voluntary basis. However, by 2024, only about 7% of these vessels were providing consistent and reliable AIS data, as many operators had begun switching off the devices for various reasons.

VMS devices are mandatory for the industrial fleet and currently constitute the main source of effort information. VMS is also used in the Bay of Biscay (France) and in the Basque Country (Spain) for most fleets. In Croatia, VMS is applied to certain segments, including LLS, PS, DRB, and OTB, and in Malta for OTB.

Mobile Observer Fishing Information (MOFI) systems have been used to monitor gillnet (GNS) fisheries in the Baltic Sea (Germany), although only for a limited period. Similar systems have also been implemented in Scotland and the Marche Region. In Portugal, MOFI-type systems have been developed, although not specifically for vessel tracking purposes.

Table 2.3 Number of vessels tracked by country.

Country	N. vessels tracked	N. vessels SSF
Portugal	151	+3000
France (Bay of Biscay)	164	1156
Italy (Manche Region)	40	312
Spain	1200	1200
Romania	70	90
Malta	100%	410
Iceland	100%	915
Sweden	20	498
Denmark	135	840

Further details about the tracking systems discussed by survey respondents can be found in Table 2.4.

Table 2.4 Details of tracking systems installed on SSF vessels by country.

country	q37
Croatia	AIS (Automatic Identification System) is mandatory for all fishing vessels longer than 15 meters (Mostly OTP and PS which are not included in SSF) while VMS (Vessel Monitoring System) and GPRS are mandatory for all fishing vessels longer than 12 meters. So some SSF vessels have such equipment.
France (Bay of Biscay)	VMS becoming mandatory for vessels operating gillnets. Currently on a voluntary basis for camera equipment associated to geolocation devices (bycatch assessment project)
Germany	There was a mobile App in place (MOFI) that piloted small vessel tracking, but its has not been implemented since then: https://doi.org/10.1016/j.ocecoaman.2022.106186
Iceland	Safety at sea, helicopter in air if ais signal off for +30 minutes if no conventional contact method (radio, phone, nearby vessels contact) has already failed
Italy (Adriatic Sea, Marche Region)	Tracking systems (GPS devices) installed onboard of vessels in research pilot projects
Latvia	As far as I know, vessels >10 m provide tracking information on a mandatory basis. This system is mandatory for the bigger vessels operating outside coastal waters.
Romania	all SSF boats authorized to catch turbot must have a functional monitoring system
Spain (All)	Tracking GPSR devices installed in regions as Andalucia, Murcia, Islas Baleareas, Cantabria and Asturias. Major fleet concentrated in Galicia, where not devices installed.
Spain (Basque Country)	VMS in some vessels above 12m as mandatory and for the rest of the vessels below 15m, AIS B and some specific tablets designed by AZTI for these vessels was installed voluntary bases
Spain (Murcia)	GPSR tracking devices installed in Murcia but no possibility to access data. No devices installed in Alicante. Potfishery targeting live labrids (for salmon aquaculture) do report fishing event positions. Also a monthly average fishing position is self reported by all SSF fishermen in the "monthly journal" system. Some vessels have AIS and it is required in parts of Kattegat due to N2000 areas. This covers all vessels, regardless of size. Some bycatch experiment have videossystems on some passive gear vessels (both daily / monthly reporting.)
Sweeden	

Number of tracked vessels

The differences among responses regarding the number of SSF12 vessels being tracked indicate significant gaps and inconsistencies in available information for this fleet segment (Table 2.5).

In Malta and Iceland, all vessels are tracked on a mandatory basis, primarily using GPRS and AIS systems, respectively, with a temporal resolution of approximately 10 minutes. In Latvia, at least two vessels were reported as being tracked, and in Croatia only a very small number.

In Sweden, 20 vessels were reported as tracked. In Italy, 40 vessels were tracked, mainly in the Sicilian Egadi Islands MPA and along the coast of the Marche Region. In Romania, 60 to 70 vessels were monitored, with a temporal resolution of 15 minutes. In Spain, 120 vessels were tracked in Murcia, while approximately 1,200 vessels were reported as tracked at national level.

In Denmark, 131 vessels had at least one trip tracked during 2024. In Portugal, approximately 151 vessels were tracked. In France, 164 vessels were monitored out of 1,156 vessels operating in the Bay of Biscay area.

Overall, apart from Malta and Iceland, no country reported comprehensive tracking coverage of its SSF fleet. In most cases, tracking applies only to specific fleet segments or limited portions of the fleet.

Where tracking systems are implemented, the temporal resolution generally appears adequate for SSF effort estimation, typically ranging from 30 seconds to 4 minutes (ICES, 2023).

Table 2.5 Summary information of the details on the tracking systems across case studies.

Country	Rules	Equipment	gear
Albania	No tracking	-	GNS,GTR,LLS,FPO,PS,DRB,LHP,OTB,Other
Croatia	-	AIS,GPSR boxes,VMS	GNS,GTR,LLS,FPO,LHP,Other
Cyprus	-	VMS	GNS,GTR,LLS,FPO,DRB,LHP,Other
Denmark	Mandatory,Voluntary	AIS,GPSR boxes	
Estonia	No tracking	-	GNS,GTR,LLS,FPO,PS,DRB,LHP,OTB,Other
France (Bay of Biscay)	Mandatory,Voluntary	GPSR boxes,VMS	
Germany	-	Mobile app	GNS,GTR,LLS,FPO,PS,DRB,LHP,OTB,Other
Greece	Mandatory,No tracking	-	GNS,GTR,LLS,FPO,DRB,LHP,Other
Iceland	Mandatory	AIS	
Latvia	Mandatory,No tracking,Voluntary	-	GTR,PS,DRB,LHP,Other
Malta	-	GPSR boxes,VMS	DRB
Poland	No tracking	-	GNS,GTR,LLS,FPO,PS,DRB,LHP,OTB,Other
Portugal	-	GPSR boxes	GNS,LLS,PS,LHP,OTB,Other
Romania	-	GPSR boxes	GTR,LLS,FPO,PS,DRB,LHP,OTB,Other
Spain (All)	Mandatory	AIS,GPSR boxes	
Spain (Basque Country)	Mandatory,Voluntary	AIS,VMS	
Sweden	No tracking	-	GNS,GTR,LLS,FPO,PS,DRB,LHP,OTB,Other

Temporal resolution of tracking systems

Regarding the preferred temporal resolution, most experts indicated that tracking systems for SSF should operate at a scale of seconds to a few minutes.

Experts from Iceland suggested that the temporal resolution, or ping rate, should be less than 1 minute. Sweden proposed 5 to 10 seconds, Denmark and Poland suggested 1 minute, and Croatia proposed 2 minutes.

Higher intervals were suggested by Malta at 10 minutes, Cyprus at 10 to 15 minutes, and Germany (Baltic Sea) at 15 minutes. In Albania, intervals of several hours were considered acceptable.

In Denmark, different systems are used. AIS operates with variable intervals, ranging from 1 to 60 minutes, depending on configuration and vessel behaviour. For vessels equipped with BlackBox systems, the interval between pings is 10 seconds.

2.3.9 Previous information on SSF

Experts provided detailed information on previous projects related to SSF, particularly in Portugal, Spain, France, Italy, Croatia, Estonia, and Latvia. Several case studies also included extensive bibliographic references that may support future research and policy development.

In Portugal, several projects have contributed to the study of SSF, including PRESPO, MONTEREAL, and MOPPA. These initiatives addressed topics such as the environmental impacts of dredge fisheries and the socio-economic conditions of coastal fishing communities.

In Spain (Basque Country), the Interreg project CabFishMan has contributed to the analysis and management of SSF. This EU-funded initiative developed tools and recommendations to support the integration of artisanal fisheries into broader marine management frameworks. In France (Bay of Biscay), participation in CabFishMan also contributed to improved knowledge of SSF, including the development of indicators and guidance related to sustainability.

In Croatia, multiple national and international projects have addressed SSF, including ArtFishMed, NurseFish, Adri.SmArtFish, and LIFE ARTINA. These initiatives have covered environmental, ecological, and socio-economic aspects of small-scale fisheries.

In Estonia, information on SSF is primarily available through reports under the EU Data Collection Framework and the national Fisheries Yearbook, which document artisanal fisheries activity at national level. In Latvia, projects such as LIFE REEF have examined marine protected habitats, with implications for the spatial management of SSF.

In Cyprus, internal studies and reports produced by the Department of Fisheries and Marine Research focus significantly on SSF, reflecting its relevance within the national fisheries sector.

The reports and bibliographic references associated with these projects provide a substantial body of information that can support future analyses.

Regarding scientific literature, Portugal has produced more than 100 research articles addressing ecological, biological, and socio-economic aspects of SSF. In France (Bay of Biscay), additional references stem from ICES Working Groups and workshops, including WKSSGEO, WKSSFGE02, and WGCATCH, which address stock assessment and fleet dynamics.

In Croatia, extensive national bibliography documents research on ecological impacts, socio-economic resilience, and habitat interactions related to artisanal fisheries. In Estonia and Latvia, national fisheries yearbooks serve as structured repositories of long-term information on small-scale fisheries, supporting data continuity for management purposes.

2.3.10 Challenges, gaps and recommendations

Across the EU, experts identified several country-specific gaps in SSF governance that hinder effective management and long-term sustainability.

In southern countries such as Portugal, Spain (Basque Country and national level), Italy, and Greece, key issues include limited spatial and temporal resolution of fishing activity data, fragmented monitoring systems, and unclear legal definitions. These gaps restrict the integration of SSF into stock assessments and management plans, limit access to financial and institutional support mechanisms, and create uncertainty regarding rights and obligations. Spain and Greece reported persistent data gaps and legal ambiguities, while in Italy fishers indicated insufficient recognition within regulatory frameworks.

In northern and eastern EU regions, including France, Croatia, Estonia, Romania, Malta, Germany, Denmark, and Latvia, reported challenges include incomplete vessel tracking, insufficient gear reporting, weak market structures, and limited consideration of social dimensions. Malta reported the absence of mandatory logbook reporting for parts of the fleet, which constrains accurate estimation of fishing pressure. Estonia and Romania noted tensions between regulatory requirements and operational feasibility. Germany emphasised the need for improved understanding of the cultural and social roles of SSF, while Denmark and Latvia highlighted gaps in tracking and documentation systems. These differences reflect diverse national contexts but point to a common need for improved data consistency, clearer policy frameworks, and targeted support measures for SSF across Europe.

Regarding missing elements in SSF governance, experts recommended the development or strengthening of dedicated monitoring programmes, improved estimation of fishing effort, systematic reporting of gear dimensions and soaking time, and better documentation of by-catch and other operational data. Additional recommendations included clearer application of existing legislation, improved fisher education and capacity-building, clarification of professional fisher status, strengthened control and supervision mechanisms, regulation of marine recreational fisheries, mandatory logbook reporting where absent, and expanded research on social and cultural dimensions of SSF. Further details are available in the full questionnaire responses.

Experts also identified structural challenges affecting SSF across Europe. In southern countries such as Portugal, Spain, Italy, and Greece, these include the adaptation of EU-level regulations to artisanal contexts, declining landings, competition with recreational and industrial fleets, and limited organisational cohesion within the sector. Reduced profitability and demographic ageing were frequently cited as constraints on long-term viability. Limited representation in policy processes and restricted access to fishing grounds and markets further affect these fisheries.

In northern and eastern Europe, environmental and structural pressures were highlighted. Countries including Croatia, Estonia, Sweden, Denmark, Latvia, and Cyprus reported impacts from marine predators, invasive species, stock depletion, and environmental changes such as hypoxia and warming waters. Spatial constraints linked to marine protected areas and marine spatial planning were also reported, particularly where SSF activities are insufficiently considered in planning processes. Rising operational costs, limited value chains, and weak organisational structures were identified as additional factors affecting economic resilience and sectoral representation.

Main challenges for SSF across Europe

Croatia: Environmental degradation, competition, high costs, and weak supply chains.

Cyprus: Invasive species, shifting ecosystems, and spatial access conflicts.

Denmark: Ecological instability from warming and hypoxia.

Estonia: Rising seal and cormorant populations threaten viability.

France (Bay of Biscay): Economic sustainability threatened by resource decline.

Greece: Sector shrinkage, aging workforce, and youth disengagement.

Italy (Marche Region): Decreasing landings and growing competition with recreational/industrial fisheries.

Latvia: New MPAs risk excluding SSF.

Malta: Limited access to productive coastal fishing grounds.

Portugal: Difficulty adapting EU control regulations to artisanal realities.

Romania: Need for stronger SSF organizations to access markets and policy making.

Spain (Basque Country): Logistical and political barriers to SSF integration in marine spatial planning.

Spain (country level): Fragmented SSF representation undermines policy influence.

Sweden: Stock depletion and industrial competition.

Eighty percent of the case studies would be available for a follow up quick interview.

2.4 Datasets (Deliverable 1.2)

This deliverable presents aggregated datasets on fishing effort and related indicators of fishing pressure. Aggregation was applied to ensure data confidentiality. These datasets are available in the attribute tables of the spatial layers (shapefiles) provided under the WP2 deliverable on effort mapping. Annex 2 lists and describes all input datasets used in the main case studies of the project. Further details on data processing and integration are provided in the WP2 section.

In addition, a comparison was conducted to assess the currency and reliability of vessel information reported in the EU Fleet Register (EUFR). For example, many vessels are officially reported as equipped with AIS; however, in practice, these systems may not be active. This can be illustrated by comparing the number of vessels listed in the EUFR as having AIS installed with the number of vessels for which AIS signals are recorded (Table 2.6).

For instance, in Spain, 3,595 vessels are registered as having AIS installed, but Global Fishing Watch records AIS transmissions for only 293 vessels, corresponding to 4.7% of the reported total. Similar discrepancies were observed in France and Portugal, as well as in Romania.

Table 2.6 Summary of the number of vessels reported in each segment, within the EUFR.

Country	N	LSF	SSF	SSF9	per.SSF	SSF.VMS	per.SSF.VMS	SSF.AIS	per.SSF.AIS	SSF.ton	SSF.AIS.GFW	per.SSF.AIS.GFW
GRC	11401	719	10682	9529	93.694	1488	13.93	115	1.08	22722.69	-	-
ITA	12277	3422	8855	7274	72.127	4	0.05	594	6.71	18327.79	27	0.30
ESP	8461	2223	6238	5061	73.727	59	0.95	3595	57.63	14696.14	293	4.70
HRV	6195	362	5833	5384	94.157	292	5.01	111	1.90	11169.89	24	0.41
FRA	5957	773	5184	3720	87.024	675	13.02	3735	72.05	23402.19	656	12.65
FIN	3257	54	3203	2914	98.342	0	0.00	17	0.53	7175.19	-	-
PRT	3541	496	3045	2674	85.993	39	1.28	1570	51.56	8173.48	62	2.04
EST	2067	33	2034	1917	98.403	0	0.00	0	0.00	2335.85	-	-
IRL	1944	243	1701	1229	87.500	1	0.06	0	0.00	6074.68	-	-
DNK	1768	287	1481	1227	83.767	5	0.34	4	0.27	4338.47	2	0.14
DEU	1084	217	867	754	79.982	1	0.12	8	0.92	2225.00	8	0.92
SWE	917	123	794	540	86.587	8	1.01	154	19.40	3631.90	159	20.03
MLT	821	56	765	683	93.179	45	5.88	1	0.13	1982.14	-	-
CYP	736	41	695	585	94.429	1	0.14	0	0.00	1671.08	-	-
POL	783	148	635	462	81.098	3	0.47	76	11.97	2875.19	64	10.08
GBR	1089	472	617	326	56.657	-	-	0	0.00	4120.90	-	-
NLD	763	418	345	256	45.216	0	0.00	50	14.49	898.00	45	13.04
LVA	167	46	121	115	72.455	0	0.00	0	0.00	168.28	-	-
SVN	131	15	116	102	88.550	8	6.90	2	1.72	295.07	-	-
BGR	106	10	96	91	90.566	8	8.33	2	2.08	167.40	1	1.04
LTU	108	19	89	79	82.407	1	1.12	0	0.00	201.04	-	-
ROU	78	14	64	40	82.051	0	0.00	63	98.44	227.66	-	-
BEL	60	60	0	0	0.000	0	-	0	-	0.00	-	-

Table Note: The column SSF.AIS indicates the number of vessels officially reported as equipped with an AIS device. The column SSF.AIS.GFW indicates, among those vessels, how many are actively transmitting AIS signals and therefore have records available in the Global Fishing Watch database. **N** represents the total number of vessels in each segment, including both LSF and SSF. **SSF** indicates the number of vessels below 9 m LOA. **Per.SSF** represents the percentage of vessels within the SSF segment. **SSF.VMS** indicates the number of SSF vessels equipped with a VMS system. **SSF.AIS** indicates the number of SSF vessels with AIS installed. **SSF.ton** represents the total gross tonnage (GT) of vessels within the fleet segment.

3 WP2 DEVELOP - Defining and evaluating small-scale fisheries activity and fishing pressure

Key messages

- A multi-method framework was developed and applied across four case studies. The framework integrated participatory mapping, vessel tracking data, remote sensing, and machine learning to generate spatial layers of SSF fishing effort.
- Questionnaire-based data collection enabled the identification of core fishing grounds in the Murcia and Marche regions. Fishers mapped gear-specific areas and seasonal patterns, allowing spatial characterisation and estimation of effort indicators despite limited tracking coverage.
- Three case studies (Basque Country, Marche Region, and Iberian Coast) had access to high-resolution spatial data from GPS or AIS systems. This supported gear-specific effort estimation and consistent spatial aggregation across grid cells.
- The use of Sentinel-2 satellite imagery was limited and varied across regions, nonetheless, Sentinel-2 remains a cost-effective remote sensing tool whose relevance for SSF monitoring could be strengthened through improved detection algorithms and calibration.
- Neural network models successfully predicted spatial fishing effort. In the Marche Region case study, strong model performance for gillnet fisheries demonstrated the capacity of machine learning approaches to estimate SSF activity using environmental and fleet-related variables.
- Fishing hotspots and spatial overlaps with other maritime uses were identified, particularly in the Basque Country and Marche Region. These results provide spatially explicit inputs for marine spatial planning and stakeholder processes

Case Study	Main SSF spatial conflicts	Impact assessment
Iberian coast (Portugal)	- Recreational fisheries - Dumping zones - Wrecks - Shellfish farming - MPAs - Pleasure boating	- No formal impact assessment conducted: missing data - Further data collection is required to enable conflict mapping and analysis
Basque Country (Cantabrian Sea)	- Other fishing fleets - Recreational fishing - Maritime traffic - Aquaculture - Marine energy platform - Offshore wind farm - Gas storage platform - Natura 2000 sites	Spatial impact assessments conducted by AZTI: - Bluefin tuna farming was relocated to reduce spatial conflict - Local Getis-Ord Gi analysis identified SSF Gross Value Added (GVA) hotspots overlapping with Jaizkibel-Capbreton Marine Area - Fishing effort in Capbreton canyons showing gear-specific spatial segregation driven by species traits, operational needs, and fishing regulations
Murcia (Mediterranean Sea)	- Aquaculture - Recreational fishing - Maritime traffic - MPAs - Artificial reefs - Dumping zones	- No formal impact assessment conducted: missing data - Further data collection is required to enable conflict mapping and analysis
Marche region (Adriatic Sea)	- Other fishing fleets - Mussel farming - Recreational fisheries - Offshore oil and gas platforms - Dumping zones - MPAs	- GIS-based spatial interaction analysis conducted using the SEAGRID tool - The analysis quantified spatial conflicts and synergies between SSF and other maritime uses, identifying depth and fleet pressure as key drivers of conflict - Cumulative interaction scores were mapped across 1 km² grid cells, revealing areas of high spatial pressure on SSF

3.1 Introduction

WP2 developed a comprehensive framework for mapping SSF activity to support sustainable marine management and policymaking. Building on the data collected in WP1, each case study defined its methodological approach according to data availability.

Where questionnaire-based information was available, a participatory mapping approach was applied (Lattanzi et al., 2024). In cases where high-resolution geospatial data were available, modelling techniques were implemented and adapted to the specific fishery context (Mendo et al., 2024; Rufino et al., 2023; Russo et al., 2019). In addition, radar sensing methods using synthetic aperture radar (SAR) satellite imagery enabled the automatic detection and classification of vessels through machine learning (ML) techniques (Paolo et al., 2024; Snapir et al., 2019).

The combined application of these approaches improved the identification of spatial fishing patterns, enhanced the quantification of fishing effort, and supported the assessment of SSF within the broader Blue Economy context (Figure 3.1).

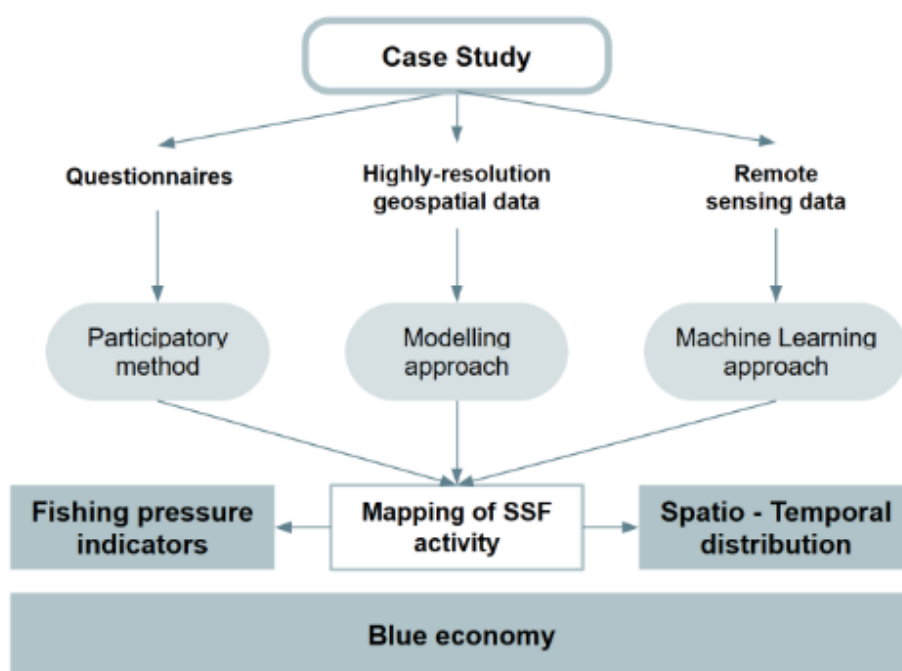


Figure 3.1 Schematic overview of WP2.

WP2 was structured into three main tasks:

- TASK 2.1- Analyse the spatial and temporal distribution of SSF activity. A standardised approach was designed to collect, process, and integrate data from multiple sources. This involved evaluating diverse data sources, including participatory mapping, remote sensing, and vessel tracking.
- TASK 2.2- Develop SSF fishing effort spatial layers and fishing pressure indicators. The methodology defined in Task 2.1 was applied across four case studies, leading to the generation of spatial layers of SSF fishing effort and the calculation of fishing pressure indicators.

- **TASK 3.3- Assess SSF activity within the Blue Economy.** SSF activity was analysed in relation to other marine users and sectors. Mapping results were used to identify hotspots of fishing activity and potential overlaps with other maritime uses (e.g., aquaculture, tourism, artificial reefs). These insights contributed to informed spatial planning and stakeholder engagement, ensuring SSF are better represented in Blue Economy strategies.

3.2 TASK 2.1 - Analyse the spatial distribution of SSF activity: Common Methodology and Notebook

A standardised methodology was developed to collect, process, and integrate data from multiple sources, ensuring a consistent approach for mapping SSF activity. As part of this work, two dedicated notebooks were created to provide: (a) guidance on combining different data sources; and (b) a neural network model (Multilayer Perceptron Network, MPN) to predict the spatial distribution of SSF fishing effort based on environmental and fleet-related variables.

MPNs are a core deep learning architecture capable of capturing complex nonlinear relationships. They have been widely applied in fisheries science, including time series modelling and resource forecasting (Yáñez et al., 2010), identification of fishing set positions from VMS data (Joo et al., 2011; Russo et al., 2011), detection of fishing gear types (Kim et al., 2020; Marzuki et al., 2018), coastal engineering applications, and modelling of landing profiles (Russo et al., 2016).

To implement the methodology, a set of baseline spatial and tabular resources is required (Figure 3.2):

Fleet information:

- Fleet register listing all vessels registered in the study area, including associated gear types.
- Fishing capacity data describing fleet structure, including the number of vessels per port and per gear type.

Geographical data:

- Case study area polygon representing the potential operational range of SSF, defined based on local knowledge and operational constraints.
- Grid layer derived from the case study area polygon to spatially aggregate fishing effort.
- Harbour locations identifying SSF landing sites.
- Land polygon distinguishing terrestrial areas in spatial analyses.
- Seabed substrate and bottom depth data describing environmental characteristics relevant to fishing activity.

Fishing activity data:

- SSF questionnaire data to map self-reported activity, where available.
- Fishing activity tracking data (e.g., VMS, GPS, and/or AIS), used to reconstruct vessel movements and estimate spatial fishing effort.
- Remote sensing data providing independent detections of vessel presence, including vessels operating without tracking devices (e.g., Sentinel-2 vessel detections).

Sentinel data:

Sentinel-2 vessel detections are derived from 10 m resolution electro-optical imagery acquired by the European Space Agency ESA's Sentinel-2 mission, using a deep-learning model developed by Global Fishing Watch. Sentinel-2 imagery was selected because it is freely accessible through the Copernicus Open Access Hub.

Compared to Sentinel-1 synthetic aperture radar imagery at 20 m resolution, Sentinel-2 enables the detection of smaller vessels irrespective of hull material—unlike SAR, which struggles with non-metallic vessels such as those made of wood or fiberglass. Additionally, Sentinel-2 captures vessel wakes, enhancing the detectability of moving vessels and enabling inference of their speed and heading. Sentinel-2 also offers broader ocean coverage and, unlike the constant false alarm rate (CFAR) method used with Sentinel-1, its neural network–based detection does not exclude near-shore areas, making it effective in densely trafficked coastal zones.

Overall, Sentinel-2 imagery allows us to detect approximately three times more vessels and a wider variety of vessel types and sizes. Limitations include cloud cover, poor sun angles, and low-light conditions. Sentinel-2 detections are matched with AIS data using the same methodology applied in the Global Fishing Watch Sentinel-1 dataset. This methodology is deeply reported in Paolo et al., (2024).

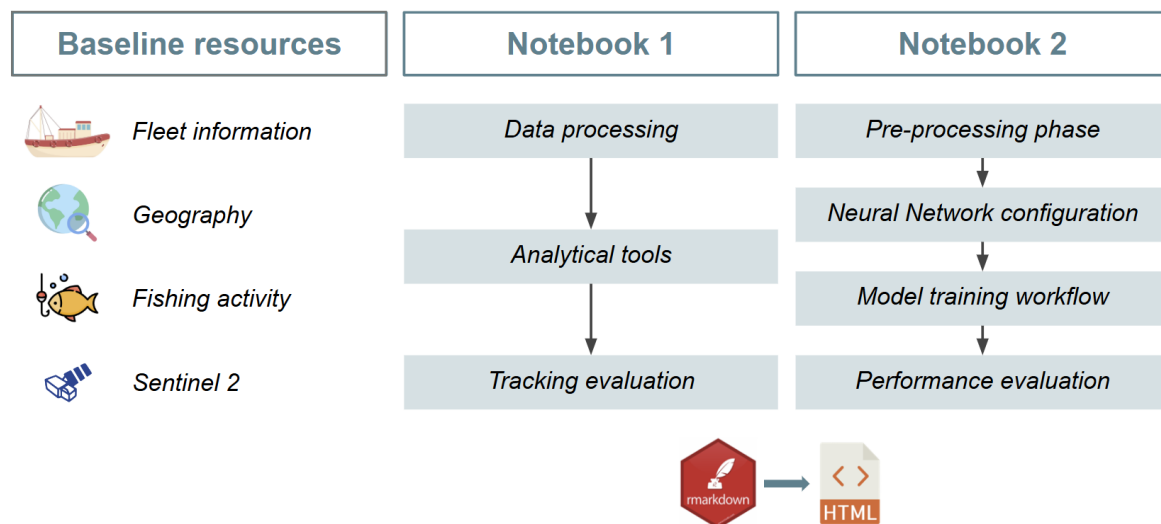


Figure 3.2 Standardised workflow integrating multiple data sources via two dedicated R notebooks to map SSF activity

Figure Notes: Further details and links to Notebooks can be found in Annexes 5 to 8.

3.2.1 Notebook 1

A repeatable R pipeline (Notebook 1) is developed to guide the integration of multiple data sources - including participatory mapping, tracking devices, vessel registries, and remote-sensing imagery (i.e., Sentinel-2 satellite) - and generate maps of SSF fishing effort for each case study. Notebook 1 is organized into 4 sections: Overview, Loading resources, Processing questionnaire data, Assessing the coverage of different tracking instruments (Figure 3.2).

After loading the required data, the processing of the data collected through the questionnaires includes:

1. Cropping the dataset to the predefined study area to focus the analysis on the relevant region.
2. Converting the spatial data into a non-spatial format to facilitate further manipulation.
3. Reshaping the data into a long format to standardize the fishing effort across different métiers, defined as “a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern” (Regulation EC/199/2008).
4. Recoding métier classifications to group similar fishing practices and improve interpretability.
5. Filtering out irrelevant categories, such as unknown or non-fishing activities.

6. Aggregating fishing effort data by métier and grid cell to obtain a spatially resolved measure of fishing intensity.
7. Merging the processed data with the spatial dataset, ensuring that fishing effort is correctly attributed to the grid.

Notebook 1 also provides tools for exploring and analysing SSF fishing effort data, with a focus on gear-specific patterns. Key analytical components include:

- Exploration of fishing effort distribution by gear: Kernel Density Estimates (KDEs) are used to provide smoothed distributions of fishing effort for each gear type, revealing trends, peaks, and variability in gear-specific activity.
- Identification of core fishing grounds: a quantile-based approach identifies core fishing grounds for each gear, defined as clusters of grid cells where fishing days exceed a defined threshold.
- Effort quantification in core areas: total fishing effort is computed within the identified core grounds, providing a benchmark for comparing tracking data and calibrating the subsequent predictive model.

The next phase of the analysis uses the core fishing grounds identified through questionnaire data in WP1 as a benchmark to evaluate the effectiveness of vessel tracking systems in detecting and representing SSF activity. The objective is to evaluate both spatial and temporal coverage provided by each tracking source and assess how effectively they capture actual SSF fishing patterns.

Vessel detections from Sentinel-2 satellite imagery are categorized into: (i) detections matched with AIS data, and (ii) unmatched detections. To further validate these classifications and enhance the detection of untracked or partially tracked SSF operations, VMS and GPS data are also integrated. The ultimate objective is to train a ML model capable of characterizing unmatched detections, thereby supporting the automated identification of SSF activity from satellite imagery. This analytical phase lays the groundwork for the neural network-based modelling presented in Notebook 2, where predictive tools are developed to estimate the spatial distribution of SSF effort using both observed activity and environmental data layers.

3.2.2 Notebook 2

Notebook 2 presents a second reproducible R workflow to implement a MPN for modelling and predicting the spatial distribution of fishing effort in SSF. The approach is inspired by Russo et al. (2019), who applied artificial neural networks to predict trawling activity using environmental and fleet data. The workflow aims to train a neural network capable of capturing complex relationships between SSF fishing activity and a range of spatial-temporal predictors. Notebook 2 is structured into 5 sections: Short introduction, Loading resources, Preprocessing, Artificial Neural Network (ANN) and Results (Figure 3.2).

After loading the required data, the pre-processing phase prepares and joins spatial and environmental variables to a reference grid, producing the input dataset for the model. The pre-processing includes:

- Calculating the distance of each grid cell each harbour;
- Extracting the depth at each grid cell;
- Assigning seabed substrate information to each grid cell;
- Identifying the corresponding gear type for the Sentinel-2 data.

Each cell in the final spatial grid is thus characterized by fishing effort, distance from the cell centroid to each point, sea depth, seabed substrate type, the Sentinel-2 detections. In the subsequent step, the MPN is configured by defining the following components:

- Input layer, that receives the features of the dataset, specifying both the input variables and the output variable. The output variable consists of aggregated fishing effort data, which can be derived either from SSF questionnaires or from tracking devices, depending on data availability and coverage in the case study area;
- One or more hidden layers where the input data is processed through interconnected artificial neurons using non-linear activation functions (e.g., ReLU or sigmoid) to capture complex relationships between predictors and the target variable. Each connection between neurons has an associated weight, which is adjusted during training using algorithms like backpropagation to minimize prediction errors.
- Output layer, that produces the final prediction, representing the modelled fishing effort or corresponding classification output

Later the following actions are carried out:

- Normalization of input data: The input variables (excluding the cell ID column) are normalized using range standardization to ensure comparability across features.
- Dataset partitioning: The dataset is randomly split into training (60%), validation (20%), and test (20%) sets. This process is repeated five times with randomly extracted datasets to increase robustness of the prediction.
- Model definition and training: the network is initialized with one hidden layer and trained on each training set using a sigmoid activation function and gradient descent optimization with momentum.
- Model evaluation: After training, predictions are generated on the test set for each iteration and observed versus predicted effort values are stored.
- Result compilation: All prediction results are compiled into a single data frame for further analysis of the model's performance across different iterations.

The performance of the trained MPN is evaluated by conducting the following analysis steps:

- Training performance: The mean squared error (MSE) trends during the training processes are extracted for both the training and validation sets for all five training iterations. These errors are combined into a single data frame and visualized using line plots to assess model convergence and potential overfitting across epochs and iterations.
- Model evaluation: To reduce noise and improve the reliability of performance assessment, predicted and observed effort values from the test datasets are first averaged by cell ID across iterations. A linear regression is then fitted to evaluate the relationship between the aggregated predicted and observed values. Model performance is quantified using the adjusted R^2 and p-value from this regression.
- A scatter plot comparing observed and predicted values is generated, to visually evaluate the agreement between model outputs and true values.
- Sensitivity analysis: To assess how each input variable influences the model's predictions, the trained MPN is tested with controlled perturbations ($\pm 10\%$ to $\pm 50\%$) applied to each input in the test dataset. For each perturbation, the model re-predicts effort, and the MSE is computed and averaged across all models. These MSE values indicate the sensitivity of the model to each input, and a bar plot visualizes the results.
- Classification evaluation: A confusion matrix is generated to assess the predictive power of the MPN on the test dataset, where effort values are classified into Low, Medium, or High levels. The Cohen's Kappa index is used to evaluate the agreement between predicted and observed classifications.

Finally, the final output is constituted by maps portraying the observed vs. predicted fishing effort for the considered area.

3.3 TASK 2.2 - Develop SSF fishing effort spatial layers and fishing pressure indicators: Case Studies

Case studies are presented along with related outcomes from Notebook 1 and Notebook 2. Additionally, Annex 2 lists and describes all the input layers used in each case study. Figure 3.3 summarises the most relevant information for each case study, including the number of vessels, LOA range, type of data used (time interval for high-resolution spatial data), and study year.

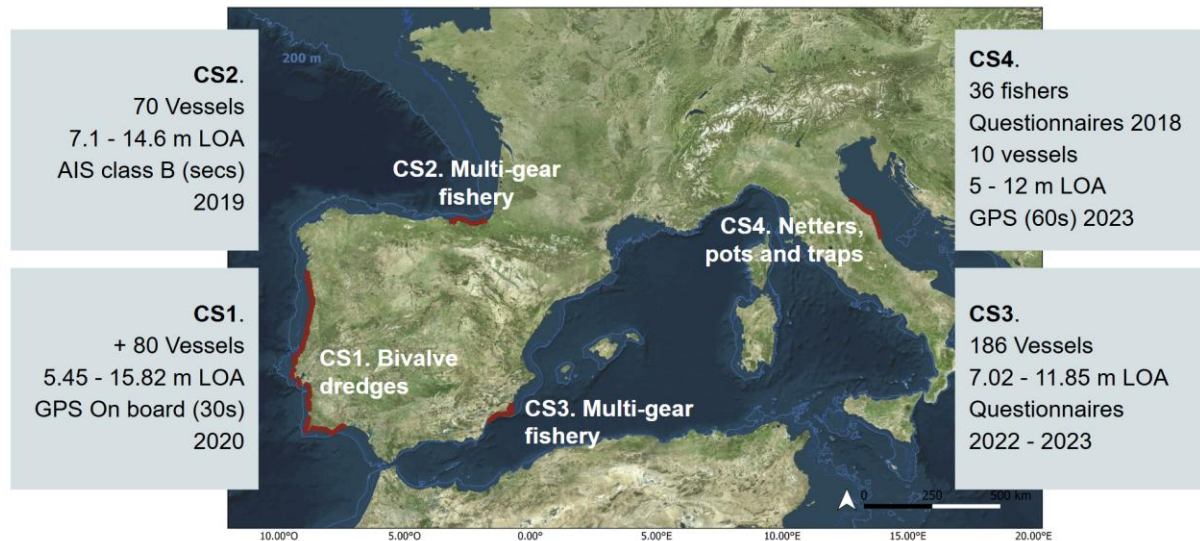


Figure 3.3 Case study locations and summary information

Maps with the fishing activity of each case study were generated through the exploration and modelling processes carried out in the different notebooks. These maps represent the main outputs of this task and provide a spatial overview of SSF activity. To highlight these results, Table 3.1 summarises the fishing effort estimated for each case study. It includes the reference data used, the study year, and the fishing effort estimated (indicating the unit of measure). All results are disaggregated by gear type. Although these indicators are not directly comparable across case studies due to methodological and contextual differences, we can observe that gillnets, trammel nets, and pots and traps show significant activity in all regions, except in Portugal, where dredges are the only target gear.

Table 3.1 Summary of fishing effort across case studies

	DRB	FPO	GNS	GTR	LHM	LLS	LTL
CS1. Bivalve dredges Iberian Coast (Portugal): Observed total fishing days (2020 - GPS)	13879						
CS2. Basque Country Region (Spain): Observed total fishing days (2019 - AIS)			4240		1248	1156	1286
CS3. Murcia (Spain): Total number of vessels (2002 - 2023, questionnaires)		1545	6793	8874		2361	
CS4. Marche Region (Italy): Number of fishing operations (2018, questionnaires)		600896	53512	92268			
CS4. Marche Region (Italy): Total soaking hours (2023, GPS)		24981	3795.2	2836.8		427.4	

Table Notes: Summary of fishing effort across case studies are disaggregated by gear type and expressed in different units according to reference data and processing methods. DRB: dredges, FPO: pots and traps, GNS: gillnets, GTR: trammel nets, LHM: handlines, LLS: set longlines, LTL: trolling.

3.3.1 CS1 Bivalve dredges Iberian Coast

Datasets

An important fishery targeting thirteen species of coastal bivalves operates along the Portuguese mainland coast, with three main fishing grounds located in the northwest, southwest, and south. The fishery uses bivalve dredges and involves more than 80 vessels, with LOA ranging from 5.45 to 15.82m. Official landings between 2018 and 2020 ranged from 2,100 to 2,700 tonnes annually.

In southern Portugal, the fishery operates at depths between 3 and 15 m, while in the northwest it extends to depths of up to 34 m. This case study focuses on fleet activity during the year 2020.

The entire fleet was tracked using on-board GPS units (ROBOT enterprise), providing positional data at 30-second intervals. Data were additionally examined for the northwest region, where some vessels exceed 15m LOA and are therefore equipped with AIS. This dataset is referred to as “Matosinhos_Nazare.”

The GPS positional data were implemented and collected as part of the MONTEREAL project “Real-time monitoring of bivalve dredge fisheries”, funded by the 712 Fisheries Operational Programme (MAR 2020) and co-financed by the European Maritime and 713 Fisheries Fund (EMFF 2014–2020) project, and currently, under MOPPA program "Small scale fisheries and harvest monitoring program" funded by the Fisheries Operational Programme (MAR-014.7.2-FEAMPA-0005).

Data were processed following the procedure described in Rufino et al. (2023) and Samarão et al. (2025), using a database of 183 validated boat trips. based on a database of 183 validated fishing trips.

Final outputs were spatially aggregated onto a 500 × 500 m grid, as detailed in the referenced publications.

For this case study, notebooks 1 and 2 were merged and results presented together, to facilitate the interpretation.

Results (Annex 3)

Within the study area corresponding to the bivalve fishing grounds, very few positional records were available from the AIS Global Fishing Watch database. In contrast, clear spatial patterns were observed using the high-resolution GPS data (Figure 3.4).

The Sentinel dataset provided 4,997 vessel detections associated with an MMSI and 10,973 detections without an MMSI.

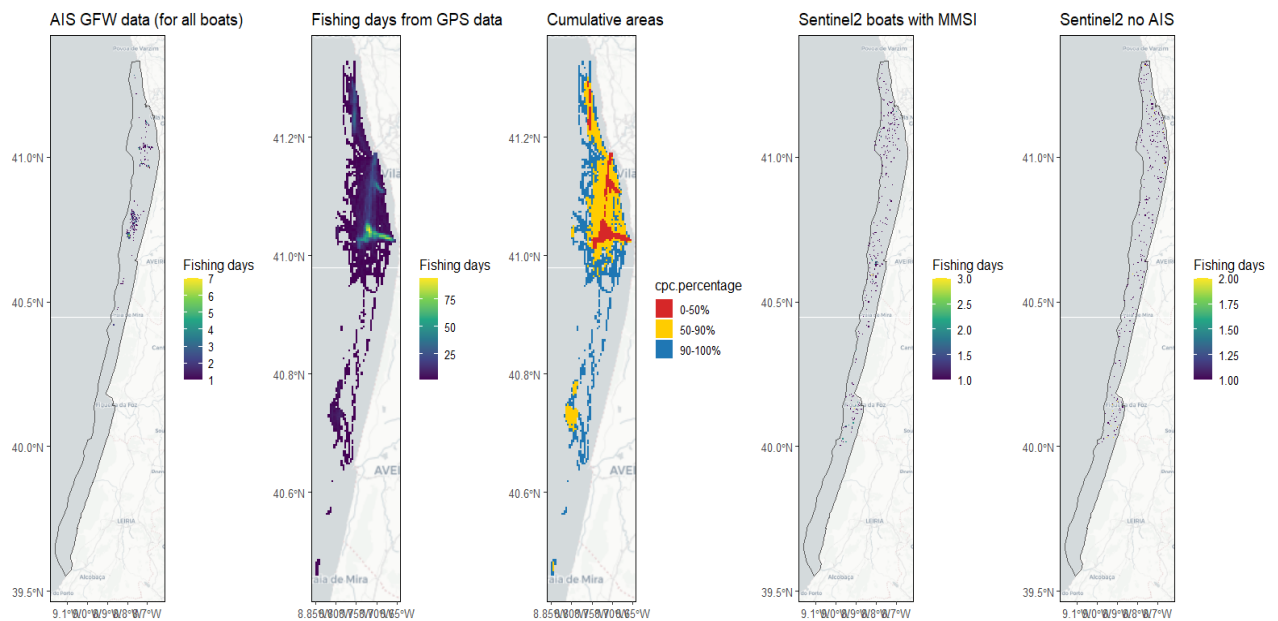


Figure 3.4 Estimated fishing effort within bivalve fishing grounds

Figure Notes: AIS-based effort estimates are derived from the GFW database; fishing days are calculated from GPS devices installed on bivalve dredge vessels.

All datasets were subsequently integrated to test the neural network model. For this analysis, five fishing harbours were considered: Nazaré, Figueira da Foz, Aveiro, Matosinhos, and Póvoa do Varzim.

A summary of the number of data points available for each harbour is presented in Figure 3.5.

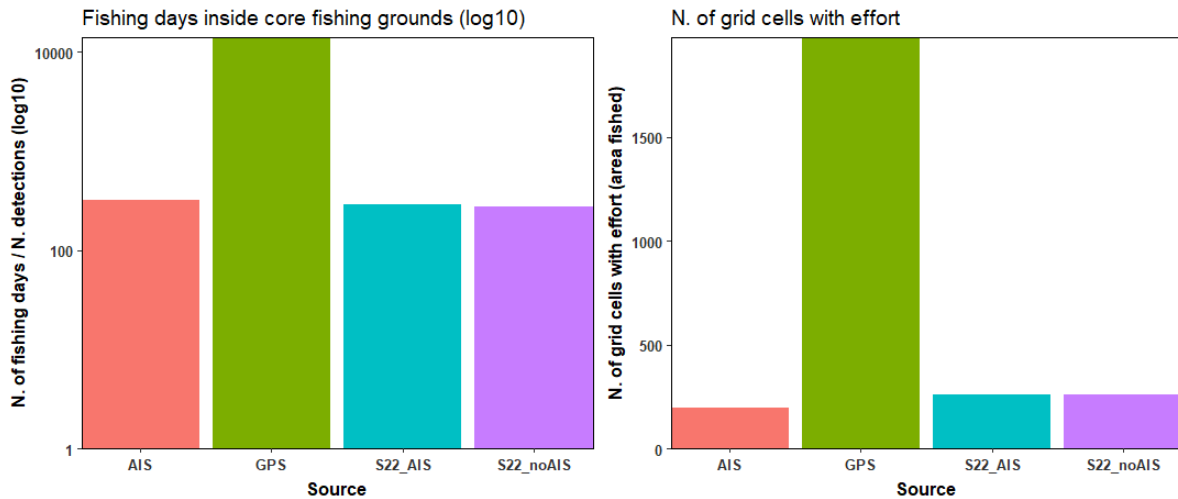


Figure 3.5 Number of data points (left) and number of grid cells with recorded fishing effort (right) by source

Despite the relatively low number of Sentinel-2 detections, this variable was still clearly important for the Neural Network Model, although sediment type was the most important variable (muddy-sandy). The results of the predicted effort show a strong resemblance with the overall pattern, regardless of the reduced R2 obtained (27%) (Figure 3.6).

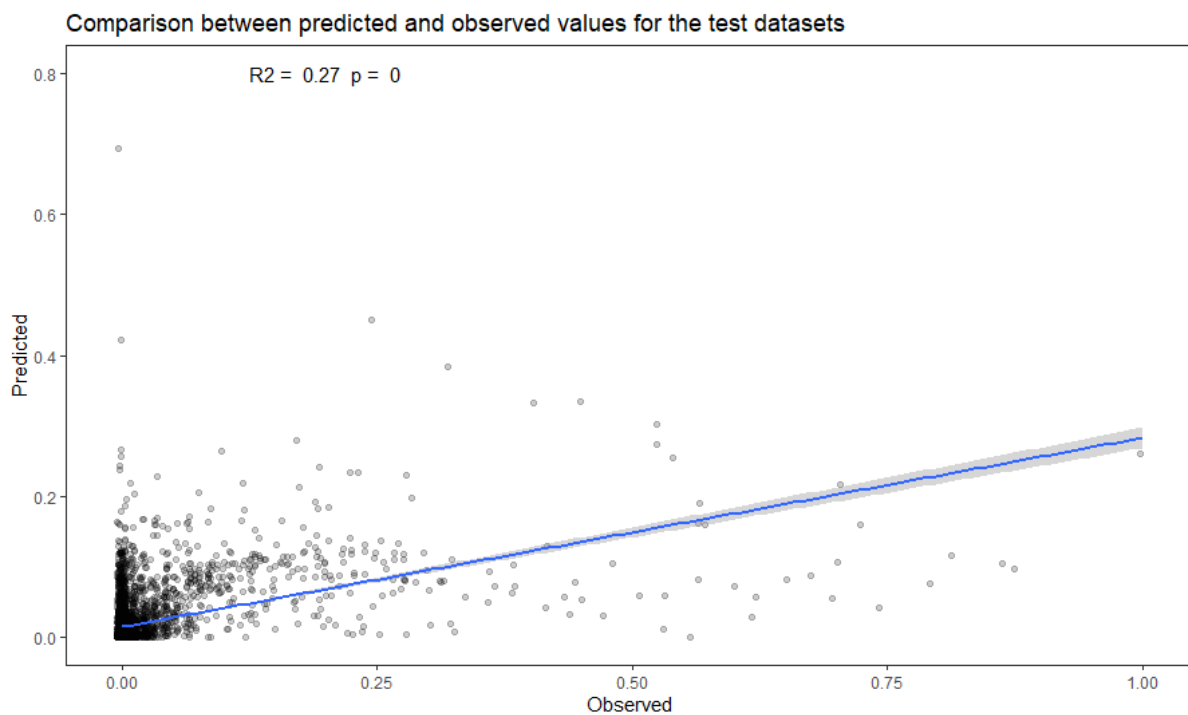


Figure 3.6 Comparison of predicted and observed values for the test dataset (DRB)

Figure Notes: The model shows a reduced fit with $R^2 = 0.27$, but still a highly significant relationship ($p < 0.001$), indicating a good predictive performance.

The sensitivity analysis, investigating how variations in input variables affect the model's predictive performance (measured using the Mean Squared Error - MSE), states that *muddy_sediment*, *weighted_fleet* (a distance-weighted index that estimates the potential fishing pressure in each grid cell by accounting for the number of vessels using gillnets in nearby harbours - calculated as the

weighted average number of vessels, where closer harbours contribute more than distant ones) and detections by Sentinel-2 appear to be the most influential factors, as even small changes in their values lead to larger changes in the model's predicted fishing effort (Figure 3.7).

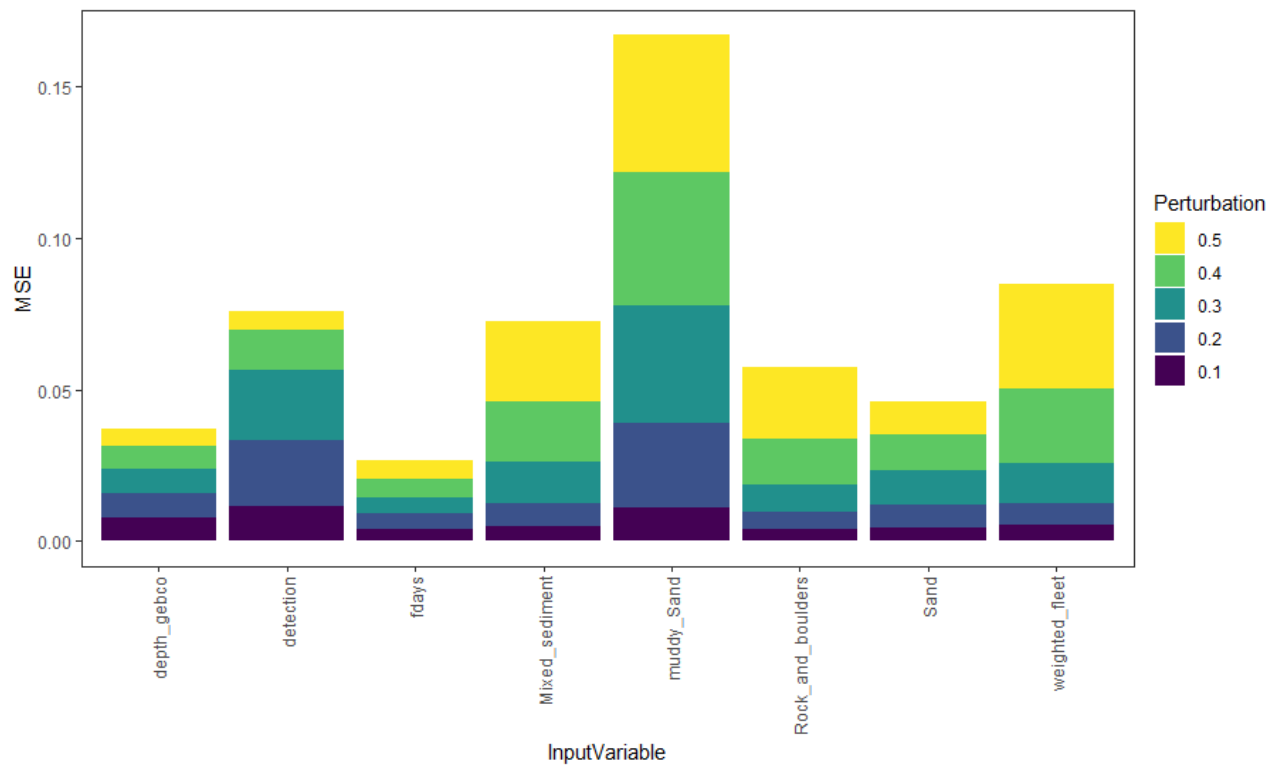


Figure 3.7 Sensitivity analysis showing the effect of input perturbations (± 0.1 to ± 0.5) on model prediction error (MSE)

Figure Notes: Larger bars indicate input variables that significantly affect model performance when altered, highlighting their importance in the predictive model; fdays variable identifies fishing effort estimated from Sentinel2 detections matching AIS, while detection represents Sentinel2 unmatched detections.

The final output (Figure 3.8) is extremely useful to spatially visualize and compare the observed (actual) with the predicted fishing effort by the MPN model. It is noteworthy that there is a great deal of similarity on the overall patterns between the two maps, because of the good predictive power of the model, able to successfully capture its spatial pattern and intensity.

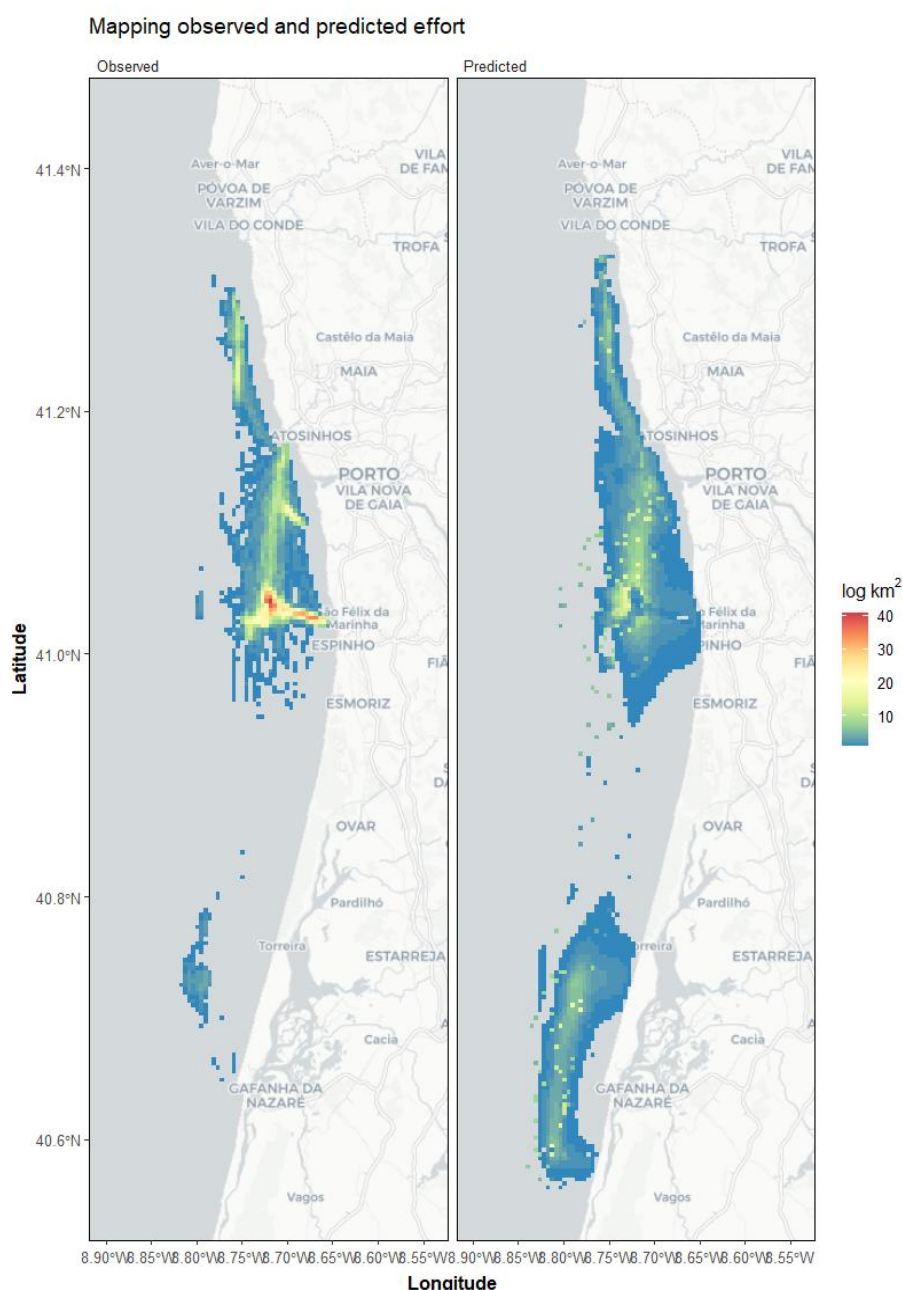


Figure 3.8 Predicted and observed fishing effort for Portuguese bivalve dredge vessels

Figure Notes: Right panel shows fishing effort (measured in number of fishing days, log transformed) predicted by the Neural Network model (MPN). Left panel shows the observed effort from Portuguese bivalve dredges data. Only observations with effort > 0 day are displayed

3.3.2 CS2 Basque Country Region (Cantabrian Sea)

Introduction

The Basque small-scale fleet comprises a group of 70 vessels, most of which are included in the Spanish census of 'Minor Arts'. However, other vessels from different censuses are also included, provided they have an overall length of less than 15 meters. These vessels are based in ports along the Basque coast and operate close to them. These vessels usually carry one to three crew members and change the fishing gear they use throughout the year. The diversity of fishing gear and target species is related to the geomorphological complexity and heterogeneity of the seafloor (Galparsoro et al., 2024). The

most common fishing gears are: i) nets (gillnets and trammel nets) and ii) hand lines, which are used very close to the coast. iii) Longlines operate in three distinct outer-water areas (Bermeo on the Biscay coast, Pasaia on the Gipuzkoa coast, and at the limit of the outer waters off the Gipuzkoa coast). iv) Trolling mainly takes place in oceanic waters during July and August, targeting Albacore tuna (*Thunnus alalunga*) (Iriondo et al., 2023).

Due to the legal impossibility of forcing fishing vessels under 12 m LOA to have VMS installed (EC No 1224/2009), the Basque Government initiated a voluntary installation programme of AIS class B on Basque vessels under 15 m LOA in 2015. The programme aimed to enhance safety and enable the Fisheries Department to monitor fishing zones and effort. About 40% of the Basque SSF fleet, defined by vessels with LOA < 15 meters, has been tracked through these voluntary devices.

Datasets

Datasets used in the Basque Country case study are listed/described in Annex 2.

SSF Spatial Data

The reference data for this case study are the AIS Class B data for 2019, as this is the most complete year of data. The AIS records were processed following the workflow of Mendo et al., 2024. The fishing gear used in AIS Class B data refers to the information reported in logbooks and/or sale notes by combining both data sources through vessels and dates. Once vessel activity is classified as fishing or not-fishing based on speed, the soak time is estimated as a proxy of fishing effort. Finally, the soak time is aggregated per fishing gear within grid cells, which are defined by 0.01 X 0.01 degrees.

To include spatial data from more vessels, VMS data were used, selecting only those fishing gears identified in the Basque SSF fleet. The fishing gear used in VMS data refers to the information reported in logbooks by combining both data sources through vessels and dates. From this dataset, only 28 vessels are under 15 m LOA, which are the only ones selected for analysis so that they can be compared with the AIS class B data. The method used to estimate soak time and perform spatial aggregation is the same as that applied to AIS class B data.

Results (Annex 4)

Results obtained from the methodology allow us to combine different spatial data sources and observe significant fishing activity in our study area (Figure 3.9). Using AIS class B data as the reference for the Basque SSF fleet, we observe that the VMS data contains records that we are not identifying in the reference dataset, while the GFW AIS data has lower spatial coverage. Regarding the Sentinel-2 data (AIS matched), only 1233 records have an associated MMSI (compared to 3851 records without an associated MMSI).

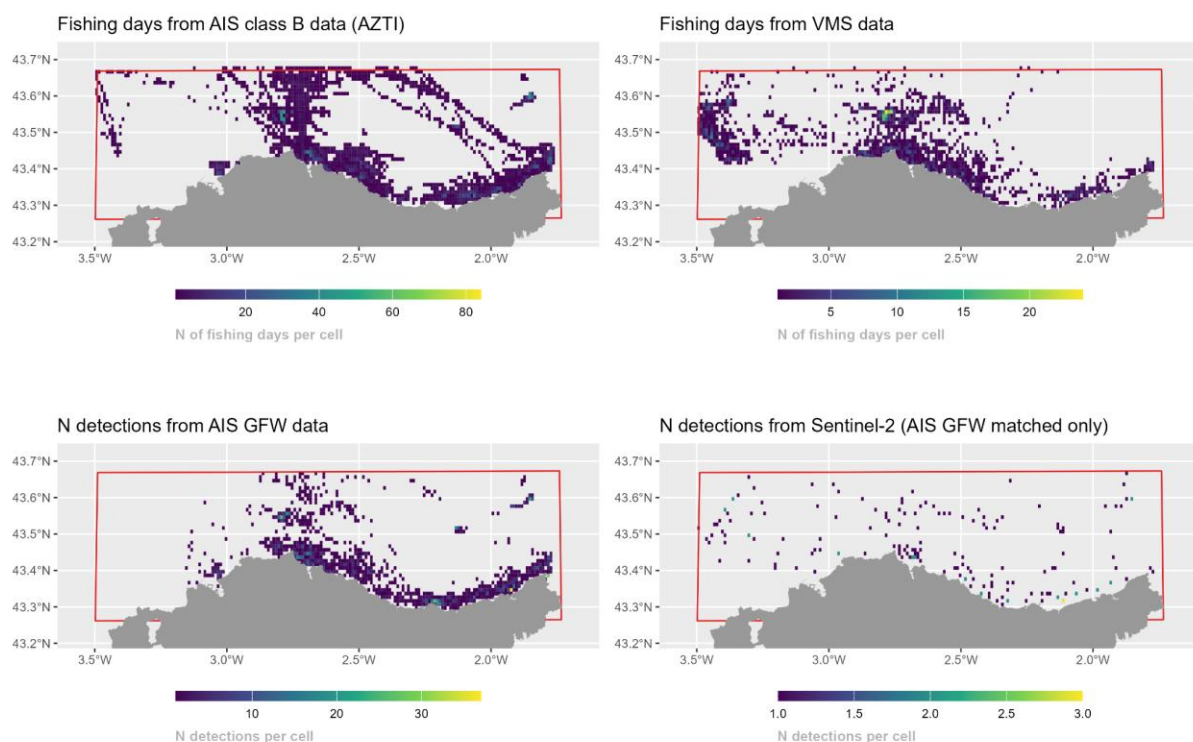


Figure 3.9 Total fishing effort estimated from the different data sources used in the case study

Figure Notes: Fishing effort is expressed either as fishing days or as vessel detections, depending on the data source (VMS or AIS)

Fishing activity by data source or instrument can be disaggregated by fishing gear (Figure 3.10, results shown on a logarithmic scale). Here, we observe that the different data sources detect the activity of all fishing gears (note: all data sources have been previously linked to logbook and/or sales notes to better identify the fishing gear). AIS class B data shows a higher number of records across all fishing gears, except for longliners, where VMS data provides greater coverage.

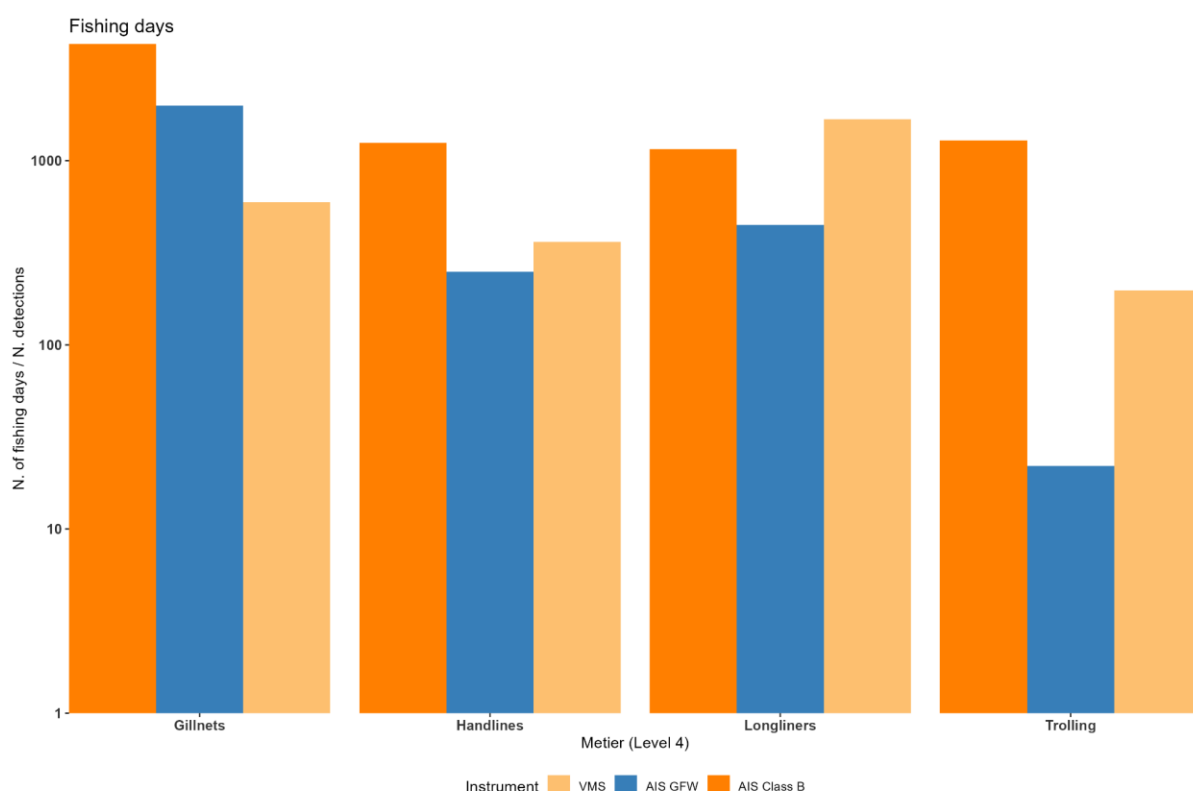


Figure 3.10 Fishing effort recorded by gear type and monitoring instrument (2019)

Figure Notes: Fishing effort is expressed either as fishing days or as vessel detections, depending on the data source (VMS or AIS)

In this case study, two different AIS data sources have been used. In Figure 3.11 we observe the activity recorded in each of them by fishing gear. The AIS class B data collected by antennas from the Basque government shows greater spatial coverage of the SSF fleet's effort. Furthermore, the GFW AIS data seems to contain errors in the identification of the fishing gear, as it relies on the main gear type registered in the EUFR to assign fishing activity to vessels. This approach does not account for the dynamic nature of the multi-specific fishing fleet, where vessels often switch gear types throughout the year depending on the target species and season. These gear changes are typically only recorded in fisheries-dependent data, not in static data (EUFR). In the case of the Basque SSF fleet, for example, vessels may operate with handlines during the spring (March to April) to fish for Atlantic mackerel (*Scomber scombrus*), and switch to trolling gear during the summer months (June to August) to target Albacore tuna (*Thunnus alalunga*). As a result, the spatial patterns derived from GFW AIS data are less accurate and less representative of actual fishing activity compared to the reference dataset (AIS class B).

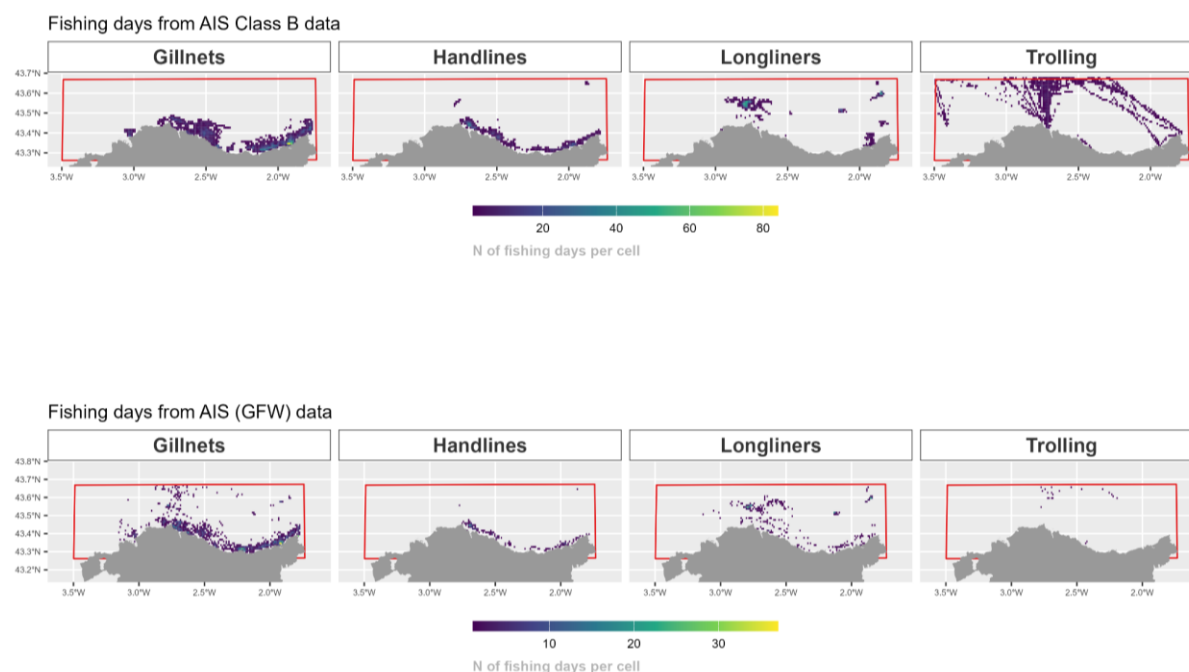


Figure 3.11 Estimated fishing effort by gear type across data sources for the Basque Country case study

Figure Notes: Fishing effort is expressed as the number of fishing days. The top panel uses Basque Government AIS Class B data as the reference dataset for the case study; the bottom panel is based on AIS data from Global Fishing Watch (GFW).

3.3.3 CS3 Murcia

Introduction

This case study aims to contribute to the project's objectives by exploring and developing the potential of questionnaires as a tool to enhance knowledge and understanding of the spatial distribution and dynamics of small-scale fisheries.

The case focuses on the small-scale fishing fleet operating along the coastal areas of Murcia and Alicante, on the southeastern coast of Spain. The fleet consists of 186 vessels, distributed across 9 fishing ports, and primarily uses passive gears such as trammel nets (GTR), gillnets (GNS), pots and traps (FPO), set longlines (LLS), and handlines (LHP). This diverse gear usage reflects the multi-species and seasonal nature of the activity.

The main target species include a mix of demersal and pelagic resources, such as red mullets (*Mullus spp.*), greater amberjack (*Seriola dumerili*), common octopus (*Octopus vulgaris*), Atlantic bonito (*Sarda sarda*), common dentex (*Dentex dentex*), scorpionfish (*Scorpaena scrofa*), common cuttlefish (*Sepia officinalis*), and gilthead seabream (*Sparus aurata*).

A key challenge in analysing the activity of this fleet is the lack of spatial data, as vessel tracking systems (VMS, AIS) are not mandatory for small-scale vessels. Although GPSR devices have been installed in the Region of Murcia, data access remains restricted, and no tracking devices are in place in Alicante.

To overcome this limitation and gain insight into SSF operations, we relied on structured questionnaires specifically designed to gather detailed information on fleet behaviour. These surveys covered various aspects such as gear and métier types, timing and frequency of use, species caught, and fishing grounds by gear type. This methodology has enabled a more comprehensive

understanding of the spatial and operational dynamics of small-scale fisheries in the region, despite the absence of positioning data.

Datasets

The primary data source in this case study consists of questionnaires conducted with fishers across the different ports in the study area (Figure 3.12). These questionnaires represent the key distinguishing feature of this case study within the project. It is, therefore, essential to clearly describe the methodology used and the spatial and temporal coverage of the questionnaires.

For the case study of Murcia, a survey was carried out among the small-scale fishing fleet in all the ports of Murcia and four ports of Alicante, obtaining almost 70% of the fleet surveyed. The survey is addressed to fishers, skippers and ship owners and designed to collect information on the characteristics of the vessels (Table 3.2), their fishing activity and gear (Figure 3.13) main species, the spatial-temporal distribution of their activity and some socioeconomic metrics (e.g., number of skippers by vessel, etc.).

For the spatial distribution, the methodology involved interviewing the fishers with a map where they draw their fishing areas (fishing grounds) for each metier, considering the depths, distances to the coast and different reference points, both at sea and on the coast. This methodology allows for the incorporation of the temporal dimension through indicating in which months of the year they used each type of metier and the main species caught.

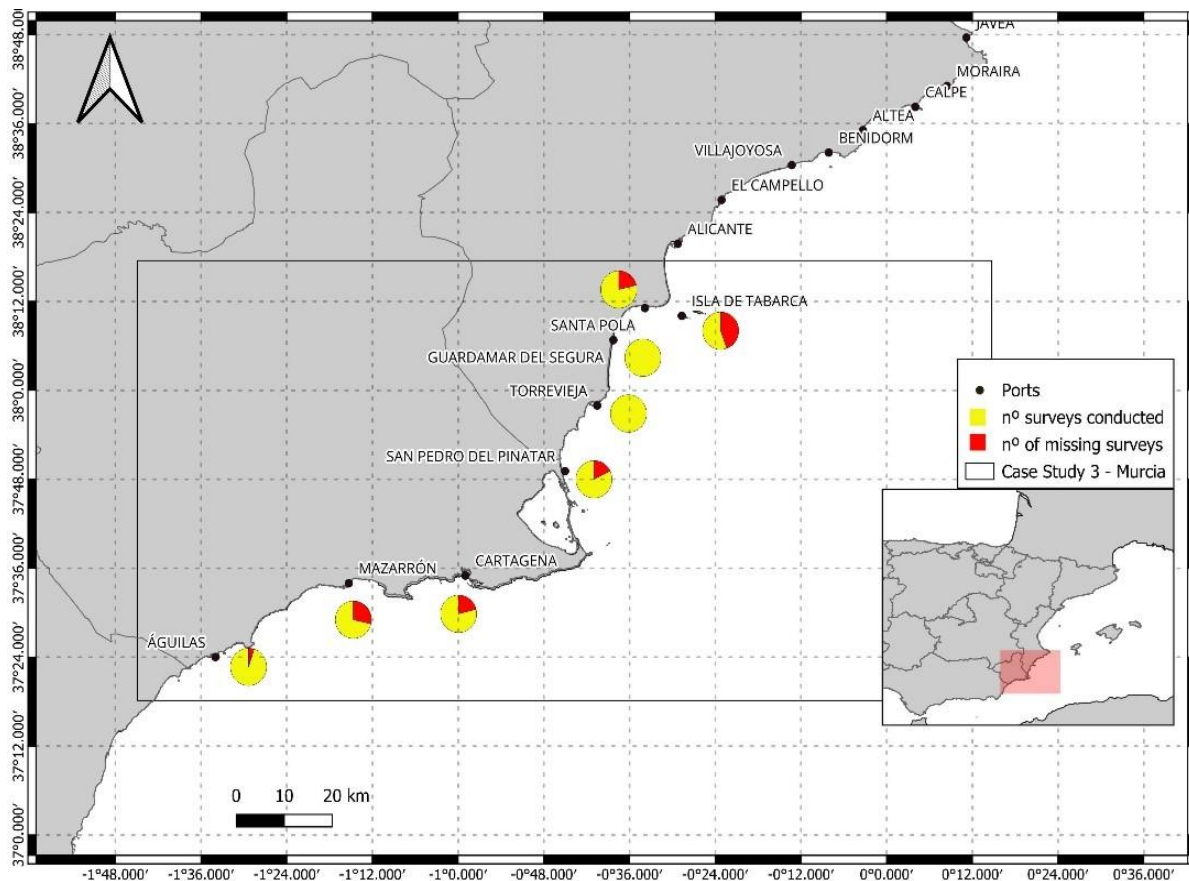


Figure 3.12 Survey coverage of the fleet by port within the study area (percentage of vessels covered)

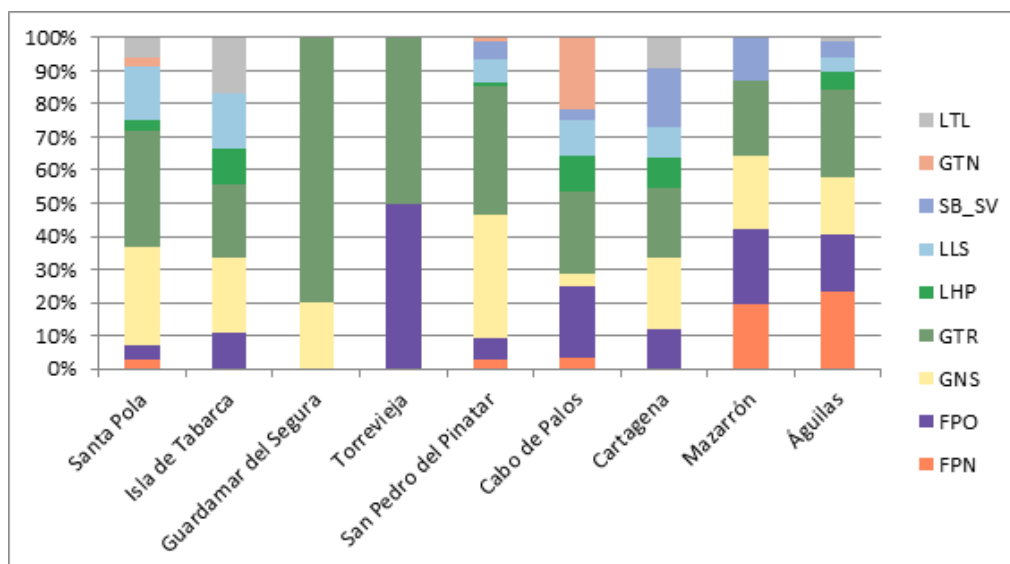


Figure 3.13 Percentage of gears used by port within the study area

Table 3.2 Characterisation of the small-scale fishing fleet by port and survey coverage

Ports	Total vessels	Surveyed vessels	% Surveyed	Age	Length	Power (kw)	Tonnage
Águilas	20	19	95	44 ±17.84	7.65 ±1	31.81 ±8.91	2.09 ±0.73
Cartagena	27	15	55.6	34 ±6.67	7.02 ±2.20	30±39.48	1.5 ±2.50
Guardamar del Segura	6	5	83.3	34 ±15.02	10.30 ±1.56	50±10.73	6.94 ±2.19
Isla de Tabarca	9	5	55.6	28.5 ±8.06	8.85 ±1.96	51±29.20	3.98 ±1.48
Mazarrón	14	10	71.4	33 ±11.9	9.13 ±1.78	47±36.15	3.52 ±1.84
San Pedro del Pinatar	39	28	71.8	32 ±8082	8.85 ±1.20	44±20.83	3.15 ±1.59
Santa Pola	45	26	57.8	32 ±10.89	8.75 ±1.41	45±26.59	4 ±1.52
Torrevieja	1	1	100	26±0	11.85±0	75±0	8.96 ±0

The fishing effort layer was developed based on the information gathered through these questionnaires. The spatial distribution of the fishing activity collected in the surveys was digitised using the QGIS software, obtaining a layer with a standard grid (c-squares). Although the information was collected based on métiers, it was finally decided to group it by gear to facilitate the development of the methodology and further allow the comparisons with other sources within the MAP-SFF project.

To obtain the fishing effort in the number of vessels, the number of vessels for each c-square of the grid was aggregated according to the gear used, resulting in a layer of effort by gear, in which the most frequent fishing grounds can be observed. This layer has been the input for the analysis in the subsequent Notebook 1 analysis for CS3.

Results (Annex 5)

The results are presented and analysed in Notebook 1. However, it is worth highlighting some important aspects to consider when comparing these results with the spatial distribution of fishing activity from other sources.

The way questionnaire data has been collected—identifying fishing areas where fishers report operating throughout the year—allows for the identification of fishing grounds and core fishing areas in a similar way to other sources such as GPS, AIS, or Sentinel-2 data. However, it should be noted that

questionnaires do not capture precise fishing effort in terms of number of trips or fishing days. Therefore, some comparisons in the Notebook 1 analysis have been adjusted to enable a proper, or at least a more suitable, alignment of outputs across different data sources.

In this case study, the questionnaires provide significantly more information—both in terms of the number of vessels and spatial coverage—than the AIS and Sentinel-2 datasets. Even though no filter was applied to vessel length in the Sentinel-2 dataset, the available information remains limited. Some gears, such as pots, show no records at all in the Sentinel-2 dataset, indicating that no vessel detections associated with these gear types were captured by the satellite imagery. Others, like trammel nets, are underrepresented, suggesting that although some detections exist, their spatial and numerical coverage is significantly lower than what is reported in the questionnaire data. Part of this discrepancy—particularly regarding gear information—may stem from how data is recorded in the EUFR. However, the overall number of vessels, regardless of gear type, appears low in this area, reflecting limited activity being captured by AIS and Sentinel-2.

3.3.4 CS4 Marche Region (Adriatic Sea)

Introduction

In Italy, SSF typically operate within 3 nm of the coast, despite licenses allowing activity up to 20 nm offshore. This is largely due to the nearshore trawling ban, which leaves the coastal zone more accessible to SSF. SSF vessels may go farther offshore mainly during summer seasonal closures that affect LSF, such as those using otter and beam trawls. These closures are intended to support the conservation of demersal fish stocks and the sustainable exploitation of marine resources, especially during biologically sensitive periods such as spawning and recruitment, and are determined annually by the Italian Ministry of Agriculture, Food Sovereignty and Forests (MASAF), with specific provisions varying across maritime compartments defined by the Ministry of Infrastructure and Transport.

In the Marche Region, three maritime compartments fall under the jurisdiction of distinct harbour authorities - Pesaro, Ancona, and San Benedetto del Tronto (listed from north to south). In 2023, which is the reference year for the GPS data analysed in this study, fishing closures were implemented from July 29 to September 9 in the Pesaro and Ancona compartments, and from August 19 to September 24 in the San Benedetto del Tronto compartment. Within the study area, SSF vessels typically operate up to 6 nm from the coast. In the Central Adriatic Sea (GSA17), Italian SSF mainly employ passive gears such as gillnets (GNS), trammel nets (GTR), pots and traps (FPO), and occasionally set longlines (LLS). The choice of gear depends on target species, market demand, and season, which in turn influences both the timing and location of fishing activities. These gears are deployed and retrieved after variable soaking periods, depending on environmental and operational conditions. Their use is subject to specific regulations that set technical and quantitative limits to control overall fishing effort (Tasseti et al. 2022).

Datasets

Datasets used in the Marche Region case study are listed/described in Annex 3Annex 3.

SSF Spatial Data

Baseline spatial data for SSF in the Marche Region is sourced from Grati et al. (2022), who developed a participatory mapping method across eight Mediterranean countries (Italy, Slovenia, Croatia, Montenegro, Albania, Tunisia, Malta, Libya) and eight GSAs (17, 18, 12, 13, 14, 15, 16, 21). In GSA17, 36 trusted fishers were interviewed to map fishing grounds by gear and target species, using 1×1 nm grids. Fishing effort for 2018 was estimated based on the number of operations per métier, as follows:

$$O_{m,i} = N_{Fm,i} \times O_{Wm,i} \times 4 \times M$$

where, $O_{m,i}$ is the total number of fishing operations carried out annually in cell i by one or more fishers with métier m ; $N_{Fm,i}$ is the total number of fishers exploiting the cell i with one métier m ; $O_{Wm,i}$ is the

average number of fishing operations carried out weekly by one fisher; and M is the number of months a year when the métier was used. Cross-check validation was conducted at two levels to ensure data reliability: (i) national-level review of landing site data to detect inconsistencies and exclude unreliable interviews; (ii) field validation through direct observation during fishing trips to ground-truth reported information. This near-census approach was favoured over sample-based alternatives (Lattanzi et al., 2023) for its comprehensiveness. Related spatial data are not yet publicly available but will soon be released.

The GPS data used in this case study were collected from 10 SSF vessels based at Ancona harbour. These vessels were equipped with tracking devices under the Strategic ARGOS project, part of the Interreg Italy–Croatia Cross-Border Cooperation (CBC) Programme. Data were recorded at 60-second intervals. Details on the system architecture and data acquisition methodology are available in Tassetti et al. (2022). The GPS data were processed to identify individual fishing trips, classify vessel activity as fishing or non-fishing, assign gear types, and estimate soak time as a proxy for effort. Results were spatially aggregated using the same grid employed in the participatory mapping.

Results

Notebook 1 (Annex 6)

Questionnaire data was used as a starting point for mapping fishing areas. The fishing effort distribution calculated using Kernel Density Estimation (KDE), measured as fishing operations (paired setting-hauling events for each set gear), can be observed in Figure 3.14. For all the three listed gears - pots, trammel nets and gillnets - right-skewed curves can be noticed, indicating that they have mostly a low number of fishing operations (peaking around 3-5). The long tails indicate a few cases characterized by many operations, especially for gillnets, where a possible bimodal distribution can be outlined. In each panel, the vertical red line corresponds to the 10th percentile, meaning that 10% of the fishing operation values for that gear type fall to the left of this line.

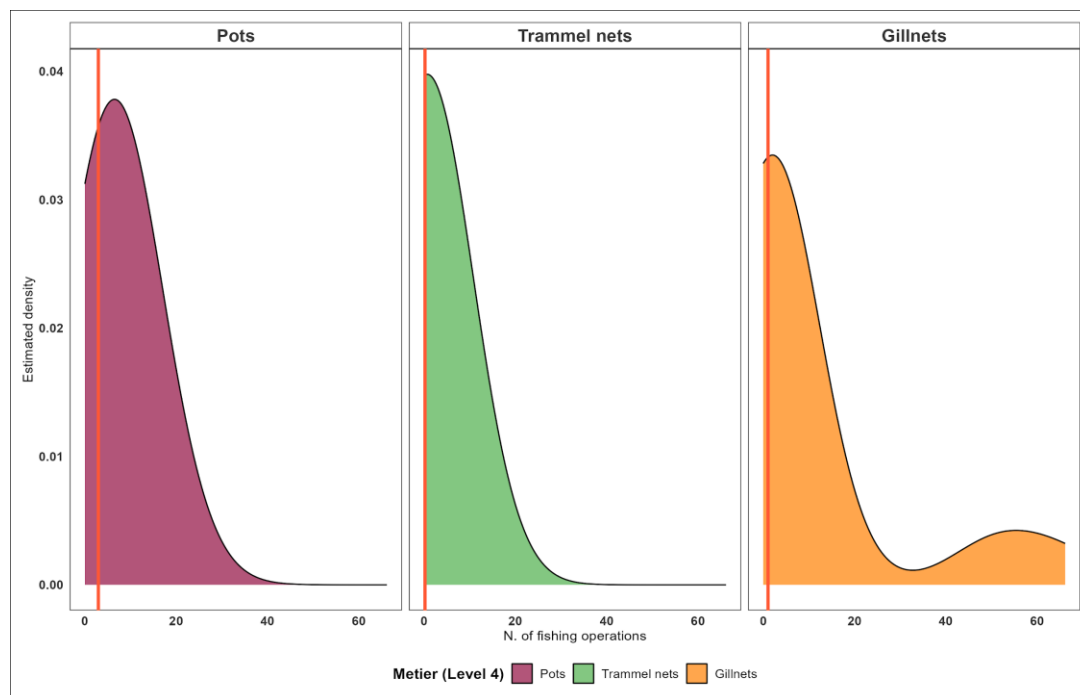


Figure 3.14 Distribution of fishing effort by main gear type identified in the SSF questionnaires for the Marche Region (measured as number of fishing operations)

Core fishing grounds were then identified, as cells where the top 90% of operations occurred (where fishing is most concentrated and recurrent), based on the previously generated gear-specific effort distributions (

Figure 3.15). Consequently, marginal fishing grounds are defined as the areas where the number of fishing operations is equal to or below the 10th percentile of the fishing effort distribution for each gear type. These areas account for the lowest 10% of fishing activity (occasional or peripheral use).

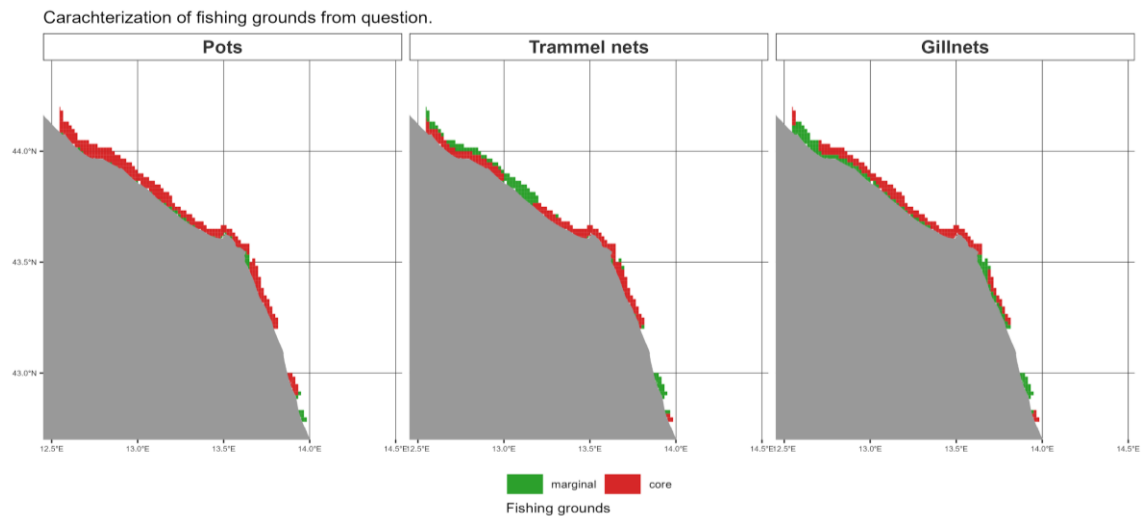


Figure 3.15 Spatial distribution of core (main) and marginal (less used) fishing areas by gear type

Finally, a bar chart illustrates the summed fishing effort inside core fishing grounds, broken down by gear type and by data source/instrument used to record the effort (Figure 3.16). A logarithmic scale is used to account for the wide range in effort across different data sources and gear types. Beyond the “Unknown” category, AIS and VMS data represent a small fraction of the total recorded effort, indicating limited coverage or applicability in detecting small-scale fishing activities.

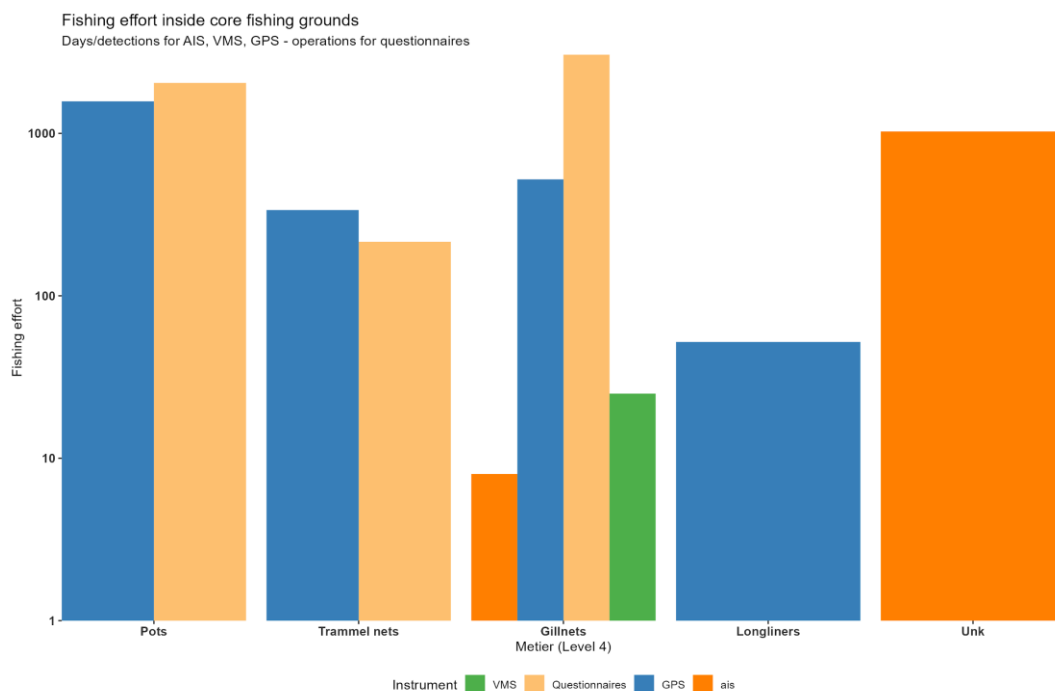


Figure 3.16 Fishing effort within core fishing grounds by gear type and monitoring instrument

Figure Notes: Fishing effort is expressed as fishing days or vessel detections for AIS, VMS, and GPS data, and as reported number of fishing operations for questionnaire data.

Notebook 2 (Annex 7)

Concerning gillnets, a scatter plot comparing predicted (from the MPN model) vs observed values of SSF fishing effort for the test set is shown in Figure 3.17. The $R^2 = 0.87$ indicates a strong linear relationship between those values, meaning that 87% of the variance in the observed values is explained by the model's predictions. This consideration is also linked by the very low p-value, confirming that the regression slope is statistically significant (significant linear association between observed and predicted values). It generalizes well to the test data, capturing the underlying pattern.

The sensitivity analysis, investigating how variations in input variables affect the model's predictive performance (measured using the Mean Squared Error - MSE), states that *depth_gebco* (bathymetry) and *weighted_fleet* (a distance-weighted index that estimates the potential fishing pressure in each grid cell by accounting for the number of vessels using gillnets in nearby harbours - calculated as the weighted average number of vessels, where closer harbours contribute more than distant ones) appear to be the most influential factors, as even small changes in their values lead to larger changes in the model's predicted fishing effort (Figure 3.18).

The final output (Figure 3.19) is extremely useful to spatially visualize and compare the observed (actual) with the predicted fishing effort for gillnets (GNS) by the MPN model. It is noteworthy that there is a great deal of similarity between the two maps, because of the good predictive power of the model, able to successfully capture its spatial pattern and intensity.

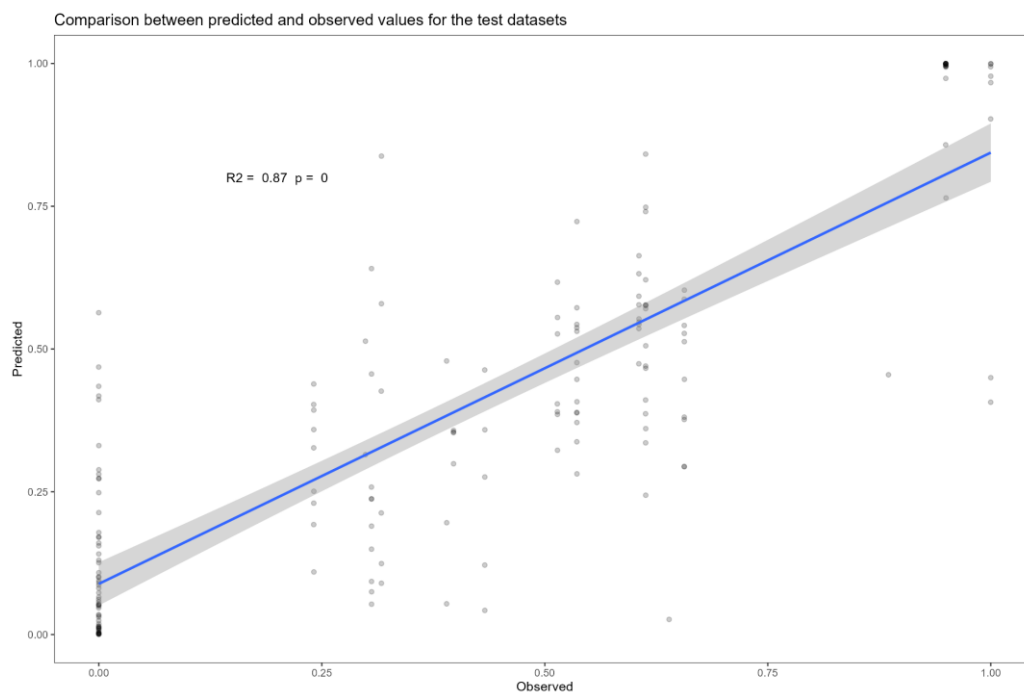


Figure 3.17 Comparison of predicted and observed values for the gillnets (GNS) test dataset

Figure Notes: The model shows a strong fit with $R^2 = 0.87$ and a highly significant relationship ($p < 0.001$), indicating accurate predictive performance.

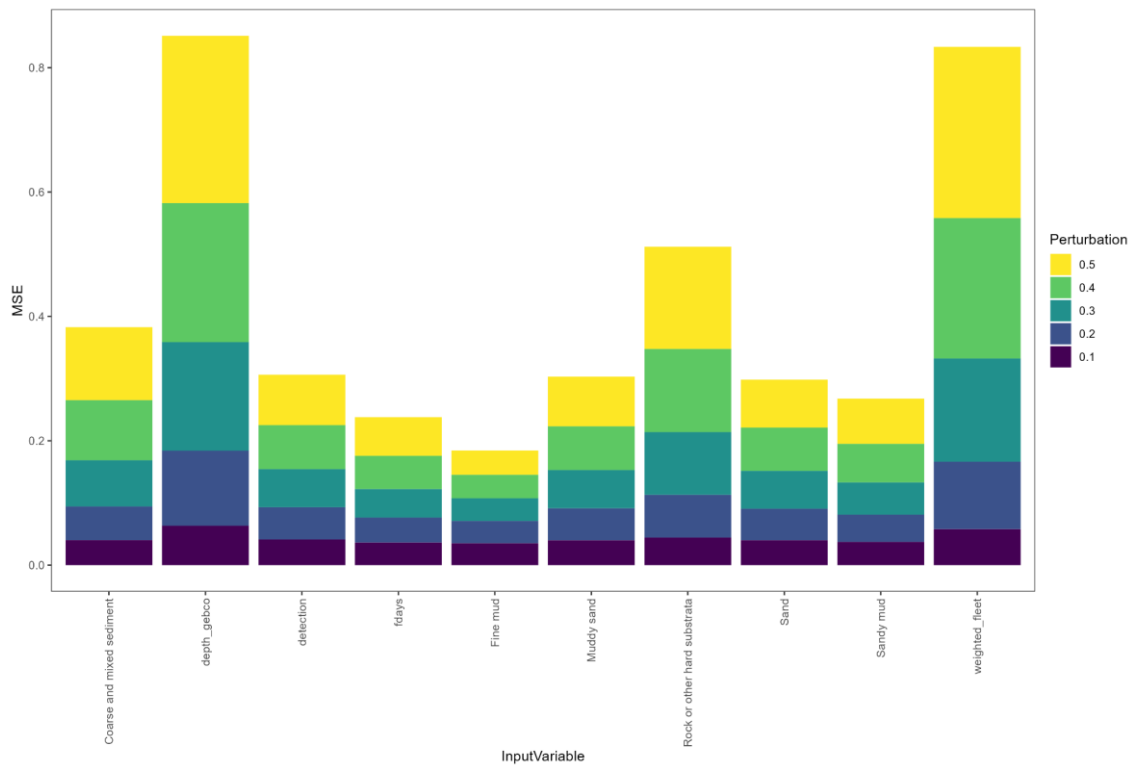


Figure 3.18 Sensitivity analysis showing the effect of input perturbations (± 0.1 to ± 0.5) on model prediction error (MSE) for gillnets (GNS)

Figure Notes: Larger bars indicate input variables that significantly affect model performance when altered, highlighting their importance in the predictive model. fdays variable identifies fishing effort estimated from Sentinel-2 detections matching AIS, while detection represents Sentinel-2 unmatched detections.

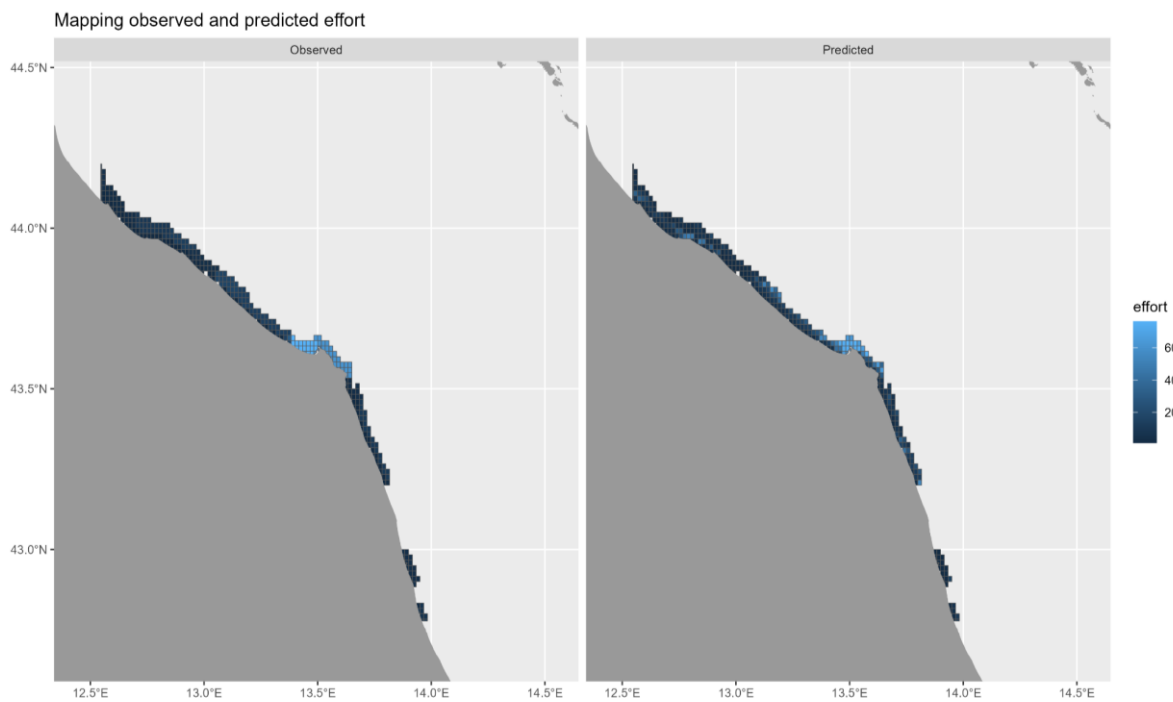


Figure 3.19 Final output comparing observed (left) and predicted (right) fishing effort for gillnets (GNS) generated by the MPN model

3.4 TASK 2.3 - Assess SSF Activity Within the Blue Economy

SSF faces spatial and operational constraints due to overlapping and often competing marine uses across all case studies. Table 3.3 lists the different maritime uses identified as potential competitors for the space, indicating for each case study whether they have an impact on SSF activities. SSF activity in all case studies reports spatial competition with other maritime uses, particularly recreational fishing, dumping areas, and shellfish aquaculture. In contrast, none of them report interactions with algae production or military areas, suggesting negligible impact from these uses. A more detailed breakdown of these interactions is provided in Annex 8.

Table 3.3 Overview of maritime uses potentially competing with SSF activities across case studies

Sub-category	Factor	Portugal	Basque Country	Murcia	Marche region
Fisheries	Trawling	N	Y*	Y	Y
	Purse seiners		Y		
	Longliners		Y		
	Dredges	Y	N	N	Y
	Recreational fishing	Y	Y	Y	Y
Barriers and wrecks	Artificial reefs	N	Y	N	Y
	Breakwater barriers	N	N	N	Y
	Wrecks	Y	N	N	N
Dumping areas		Y	Y	Y	Y
Energy	Gas/Oil Platforms	N	Y	N	Y
	Pipelines	N	Y	N	Y
	Windfarms	N	Y	N	N
	Marine Energy Platform		Y		
Aquaculture	Shellfish	Y	Y	Y	Y
	Marine Finfish		Y	Y	N
	Algae production	N	N	N	N
Maritime traffic	Pleasure boating	Y	Y	Y	Y
	Shipping routes	N	Y	Y	Y
Military areas		N	N	N	N
Management measures	MPAs	Y	Y	Y	N
	Fishing bans (e.g., FRA)		Y	Y	Y
	Area closures	N	Y		Y

3.4.1 CS1 Bivalve dredges Iberian Coast

In terms of the main spatial conflicts for SSF in Portugal, most of the spatial layers are not yet available (like, recreational fisheries, dumping areas and wrecks - these last ones being less important). The spatial conflicts identified for which it might be possible to get the spatial information were the shellfish aquaculture farms, MPAs and pleasure boating. Thus, to properly map the SSF conflicts, some extra work is required to acquire this missing data.

3.4.2 CS2 Basque Country Region (Cantabrian Sea)

In recent years, the Basque SSF fleet has encountered new interactions with emerging blue economy sectors that are settling in coastal waters. AZTI has assessed whether these interactions are perceived as spatial competition, quantifying their impact on the Basque SSF fleet.

Traditionally, the SSF fleet has been limited by the presence of other fishing fleets, such as **demersal bottom pair trawlers, purse seiners, and longliners**. These modalities operate in some of the same areas as the SSF, especially during peak seasons. Although there are regulations to restrict the use of different fishing gear (for example in SSF, gillnets and trammel nets within 10 to 12 nautical miles from the coast in Gipuzkoa and Bizkaia, respectively), these measures do not always prevent overlap of activities. **Marine recreational fishing** can also occur in the same inshore waters, though its impact is difficult to quantify due to the lack of spatial and temporal data. **Maritime traffic**, including recreational and commercial vessels, also crosses coastal zones, with its impact on the SSF yet to be evaluated.

Other emerging sectors of the blue economy, such as **aquaculture** (particularly the mussel farming and bluefin tuna (*Thunnus thynnus*) farming in submersible cages), the **BiMEP marine energy platform**, and the Basque Country's first **offshore wind farm**, introduce new restrictions on access and navigation. The **gas platform** used for underground storage is surrounded by exclusion zones of 500 meters, limiting the space available for SSF. However, AZTI, as a referent technology centre in the Basque Country, has conducted various impact studies on these sectors. In some cases (for instance, the bluefin tuna farming), they have been spatially relocated to minimize their impact on Basque SSF.

On the other hand, some **artificial structures**, such as those promoted by the PiE-REEF project, are valued by fishers because they attract commercial species and can increase catches.

Finally, two new **Sites of Community Importance** (SCI) under the Natura 2000 network have been designated: i) the Jaizkibel-Capbreton Marine Area (ESZZ12005) covering approximately 1,500 km², it stretches from the cliffs of Igeldo to the Capbreton trench, reaching depths of up to 2,000 meters. This area is ecologically significant for its pelagic biodiversity, including bottlenose dolphins (*Tursiops truncatus*), marine reefs, and submerged caves. And ii) the Capbreton Submarine Canyons (ESZZ12006), recently proposed and accepted within the INTEMARES framework, represent a deep-sea ecosystem of high ecological value. Although it is still unclear whether these areas will be closed to SSF fishing, various studies have been conducted to determine the spatial overlap of these zones with SSF fishing activities. The economic hotspots for SSF within the Jaizkibel-Capbreton Marine Area were identified using the Local Getis-Ord Gi tool to detect significant Gross Value Added (GVA) (Figure 3.20, Larrinaga, 2024). Gillnets (GNS) and set longlines (LLS) revealed significant areas, especially near the continental slope and Capbreton canyon. Rodríguez-Basalo et al. (2024) assessed the fishing effort in the Capbreton Submarine Canyons, focusing exclusively on fishing techniques that interact with the seabed (such as longlines and gillnets in small-scale fisheries) and impact benthic habitats. The findings reveal a clear spatial segregation of fishing gears, influenced by: (i) the biological traits of target species, (ii) the operational requirements of each method, and (iii) fishing regulations, particularly relevant for deep-sea fishing.

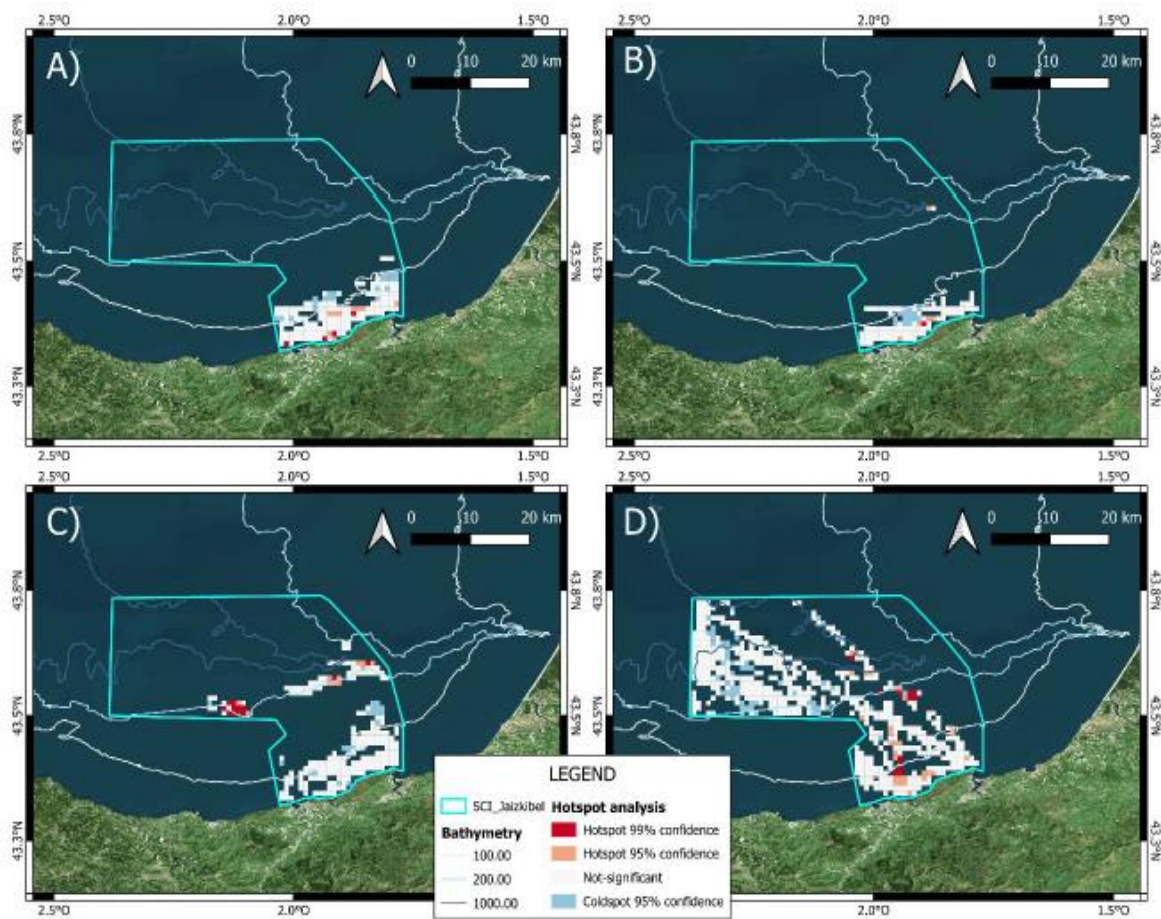


Figure 3.20 Gross Value Added (GVA) hotspots and coldspots within the Jaizkibel-Capbreton SCI area for selected Basque SSF gears

Figure Notes: Red areas indicate GVA hotspots and blue areas indicate coldspots within the Jaizkibel–Capbreton Site of Community Importance (SCI). Results refer to the Basque small-scale fleet segments identified as most affected, operating with (a) gillnets, (b) hand lines, (c) longlines, and (d) trolling

3.4.3 CS3 Murcia

Small-scale fisheries in the regions of Murcia and Alicante operate primarily in shallow coastal waters. A key regulatory factor shaping spatial interactions is the prohibition of **bottom trawling** in areas less than 50 meters deep. This has created a de facto spatial refuge for small-scale fishing vessels, protecting them from direct competition with trawlers in most of their fishing grounds. Furthermore, **artificial reefs** have been installed in the area specifically to deter bottom trawling. Because their exact locations are unknown, the negative impact on small-scale fisheries can be considerable, especially at the beginning of its installation, when nets snag on reefs; however, they can also provide indirect benefits by improving local biodiversity.

Other marine activities interacting with SSF in the region include aquaculture, recreational fishing, maritime traffic, and marine conservation measures. The coast is characterized by significant **aquaculture** development, especially marine finfish farming and tuna fattening operations. These installations, while spatially extensive, are generally located offshore or in designated areas, and their interference with SSF is localized and mostly manageable. **Marine recreational fishing** overlaps spatially with artisanal fishing in coastal waters, especially in summer, but its impact remains difficult to quantify due to the lack of reliable spatial and temporal data.

Marine traffic, including both commercial and leisure vessels, is an ongoing concern for SSF operations, particularly during the summer tourism season when pleasure boating intensifies along the coast. While **shipping routes** do not directly compete for fishing grounds, they do pose navigational and safety challenges to small-scale fishers.

The region also includes several **marine protected areas** (MPAs) that impose specific restrictions on SSF. Notably, the Cabo Tiñoso, Cabo de Palos-Islas Hormigas, and Tabarca Island Marine Reserves restrict access for fishing vessels to varying degrees. In addition, the area encompasses multiple Sites of Community Importance (SCI) and one Special Area of Conservation (SAC), which may further constrain fishing activities in the future depending on management plans and conservation objectives.

Other spatial uses include uncontrolled **dumping zones** (e.g., Cala Reona in Murcia and Cabo Huertas in Alicante), whose impact on artisanal fishing is unquantified but raises environmental concerns. Elements that do not currently create spatial conflicts include **shipwrecks**, which are often considered beneficial by local fishers as fish aggregation sites, and **coastal breakwaters**, which are too shallow to interfere with SSF operations. **Military zones** near the Cartagena naval base lie in deeper waters and are not in direct interaction with SSF activity.

Importantly, in the area, regional governments have already taken steps to integrate SSF into a broader Blue Economy strategy. The Maritime Strategy of the Region of Murcia (2024–2030) aligns with the EU’s European Maritime Fisheries and Aquaculture Fund (EMFAF), promoting sustainable fisheries and innovative blue growth. Key measures include the centralization of fish auctions, marketing campaigns to promote local seafood, support for producer organizations, and programs for mentoring, training, and valorising artisanal fishing practices. Additionally, improved coordination among stakeholders and enhanced maritime surveillance aim to reduce illegal fishing and support fairer spatial management.

In this context, while SSF in Murcia and Alicante benefit from certain spatial protections, they continue to face pressure from overlapping marine uses. Future efforts to enhance coexistence should prioritize integrated marine spatial planning and active stakeholder involvement to ensure the sustainable development of both traditional and emerging blue economy sectors.

3.4.4 CS4 Marche Region (Adriatic Sea)

In the Marche Region, SSF operations are mainly limited by the presence of other fishing fleets, notably trawlers and dredgers. According to Regulation EC/1967/2006, **bottom trawling** is prohibited within 3 nautical miles of the coast or in waters shallower than 50 m across the Mediterranean. Thus, when SSF vessels operate beyond this limit—such as during seasonal closures for large-scale fisheries in summer—they risk losing their set gears due to trawler activity. **Hydraulic dredgers**, primarily targeting clams, pose a particularly significant conflict, as they operate in many of the same areas used by SSF. The only spatial restriction for dredgers under EC Regulation 1967/2006 (Article 13, point 2) is a 0.3 nautical mile buffer from the coastline. Additional rules may be applied by the local maritime compartments (e.g., departure/return times, non-fishing days). **Marine recreational fishing** also creates tension with SSF, but its full impact is difficult to assess due to the lack of spatial, temporal, and quantitative data. Moreover, illegal fishing undermines fish stocks, complicates fisheries management, and places lawful small-scale fishers at a disadvantage. **Aquaculture**, particularly mussel farming within 3 nautical miles of the coast, is another competing use. These installations often overlap with traditional SSF grounds. Fishers frequently report incidents of plastic mussel nets, especially after storm surges, becoming entangled in their gear (based on questionnaire data). Conversely, some offshore structures — such as **artificial reefs, breakwaters, wrecks, and platforms** — are viewed positively by fishers, as they tend to attract commercial species and boost catches and income (Frehse et al., 2025). However, **offshore oil and gas installations** are surrounded by a 500 m safety exclusion zone, as required by the Petroleum Act 1987, where fishing activities are strictly prohibited.

In this context, decision support tools can play a key role in evaluating and managing these spatial interactions, promoting more equitable and sustainable marine resource use. An example is given for CS4, where interactions, conflicts and synergies are analysed and mapped by means of a GIS-based spatial interaction analysis tool, SEAGRID (SEA GeoReference Interactions Database). Originally developed as GRID within the COEXIST (Stelzenmüller et al., 2013) and ECOAST (Grati et al., 2019) projects, the platform has evolved into the SEAGRID webGIS application through subsequent international projects which expanded the scope of the tool by incorporating environmental and socio-economic considerations, with the overarching goal of supporting scenario-based stakeholder assessments (Bergh et al., 2023). SEAGRID is available online at <http://seagrid.irbim.cnr.it/> and is accessible free of charge upon request (login and password required).

Among the co-existing human activities identified as useful for CS4 (see Annex 8), only those with available spatial data are included in the SEAGRID analysis. These are listed in Table 3.4.

Table 3.4 Sea use layers available and used in SEAGRID CS4.

Sub-category	Factor	Layer name	Acronym
Fisheries	Trawling	Bottom Otter Trawl	OTB
	Dredges	Hydraulic dredge	DRB
	Small scale fisheries	Small scale fisheries	SSF
Barriers and reef	Artificial reefs	Artificial reefs	AR
Sediment handling	Dumping	Dumping areas	DUMP
Energy	Gas/Oil Platforms	500m around platforms	AC2
	Pipelines	Pipelines (b:300m)	PIPE
Aquaculture	Shellfish	mussel farms	FARM
Maritime traffic	Shipping routes	Shipping routes	SR
Management measure	Fishing ban	3 nm	FB 1
		Restricted areas: fishing and anchoring prohibited	FB 2
	Area closure	Prohibited areas - no unauthorized entry	AC1
		500m around platforms	AC2
	Exclusive aquaculture areas	Areas devoted to aquaculture	AQUA

Table Notes: see Annex 8 for more details

SEAGRID is employed to assess the coexistence of different marine uses. This involves calculating spatial interaction scores, generating an interaction matrix, and producing corresponding spatial maps. Interactions between marine uses are identified as either negative (conflicts) or positive (synergies), based on expert judgment or established management rules and regulations. A standardized set of criteria is used to define and quantify these interactions for representation within the interaction matrix. Each marine activity is characterized using five traits, following the COEXIST methodology (Stelzenmüller et al., 2013a): (i) Vertical Scale (VS), (ii) Spatial Scale (SS), (iii) Time Scale (TS), (iii) Mobility (M) and (iv) Location.

Based on these traits, SEAGRID applies predefined rules to compute interaction scores for each pair of activities (e.g., pipelines and bottom trawling). The scores, which reflect the degree of spatial

conflict or synergy, range from –6 to +6, where: –6 indicates mutual exclusivity (strong conflict), 0 indicates no interaction, +6 indicates full synergy. When more than two human uses co-occurred within a single 1 km² grid cell, SEAGRID computes the total score as the sum of all pairwise interaction scores. These cumulative values are then used to generate categorized spatial maps of the CS4, illustrating the intensity and distribution of interactions across the area. The following rules are applied sequentially to determine the level of potential spatial and temporal conflict or synergy between pairs of marine uses. Each rule corresponds to a mathematical condition that reflects how traits such as vertical overlap, mobility, time scale, and spatial scale influence interactions:

- Rule 1: If the VS of the two activities differed, and neither affected the entire water column, the interaction score was set to 0 (i.e., no spatial overlap).
- Rule 2: If both activities were mobile, the interaction score was calculated as the minimum value of their TS plus the minimum of their SS.
- Rule 3: If neither Rule 1 nor Rule 2 applied, the interaction score was assigned as the maximum value of TS plus the maximum value of SS.

Trait values are assigned based on expert judgment. In specific cases—such as when particular management measures or contextual knowledge warranted a deviation—experts override the calculated score to reflect more accurate or locally relevant conditions.

SEAGRID quantifies interactions between each pair of marine uses occurring within the same 1 km² cell (spatial interaction matrix in Figure 3.21, left) and visualizes the results in a thematic map of the entire CS4 (Figure 3.21, right), where each cell displays the cumulative interaction score based on all overlapping uses. Yellow cells signify no interaction, green cells signify synergies, while red cells signify conflicts.

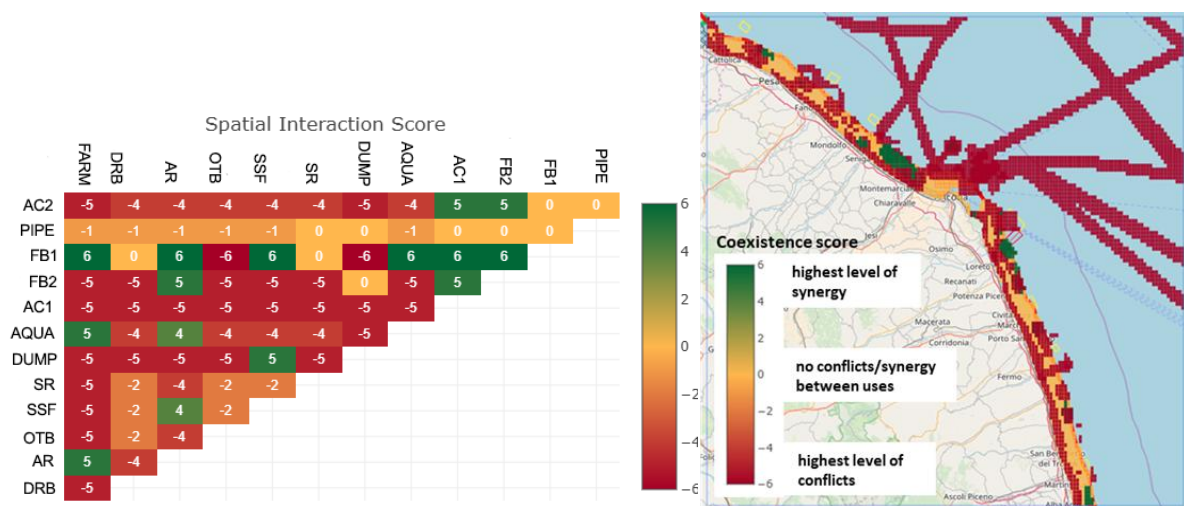


Figure 3.21 SEAGRID matrix (left) of spatial interactions between all pairs of specified marine uses

Figure Notes: Yellow denotes no interaction, green signifies synergies, while red signifies conflicts between two activities. Numbers reflect the strength of each conflict/synergy, ranging from +6 to –6, while 0 indicates no spatial overlap or spatial co-existence without any conflict/synergy. Right: SEAGRID map visualizing the location of conflicts/synergies, expressed as spatial interaction scores per grid cell. Each cell's score is the sum of interaction values for all relevant pairs of marine uses.

3.4.5 Future research needs

A key step towards effectively integrating SSF into the Blue Economy is to address the spatial and operational interactions between SSF and other emerging maritime sectors, such as aquaculture, coastal tourism, marine energy, MPAs, and maritime transport.

Although the project has identified potential conflicts across all case studies, the lack of detailed and up-to-date spatial data for all uses significantly limits the ability to accurately assess the impact of these activities on SSF. Therefore, future research should focus on:

- Expanding the collection of geospatial data on coexisting marine uses, particularly in coastal zones where SSF activity is most concentrated.
- Developing analytical tools to model and visualise interactions between SSF and other sectors, such as the SEAGRID system applied in the Marche region case study.
- Establishing standardised methodologies to assess conflicts and synergies, incorporating ecological, socio-economic, and operational criteria.
- Integrating fishers' perspectives in the validation of maps and models, ensuring that local knowledge complements technical datasets.

In summary, future research should aim to improve the quality, coverage, and resolution of data, while developing integrated approaches that support more equitable and sustainable marine spatial planning for SSF.

4 WP3 RECOMMEND - Recommendations and Guidelines

Key messages

- **Combining diverse methodologies** allows **robust and adaptable SSF mapping** across heterogeneous fleet structures and fishing practices, ensuring comprehensive analyses beyond individual case studies.
- **Case studies demonstrate the value of mixed data sources:** insights from the four case studies show that combining spatial questionnaires, tracking data, and modelling improves the accuracy of fishing effort estimates, identifies spatial conflicts, and supports marine spatial planning tailored to SSF realities.
- **Current limitations in data coverage and resolution affect SSF mapping accuracy:** highly-resolved spatial data provide reliable effort estimates in cases with sufficient fleet coverage and high temporal resolution. Remote sensing offers broader spatial coverage where tracking data are unavailable, but its effectiveness is constrained by resolution and weather conditions. Gear variability and the static nature of the EUFR further limit the precision of fishing effort estimation.
- **Mapping SSF activity supports the implementation of EU fisheries policies by providing spatially explicit data for management, control, and planning:** the methodologies developed support the implementation of the Common Fisheries Policy, the Marine Strategy Framework Directive, and Maritime Spatial Planning by providing georeferenced effort data, gear-specific mapping, and standardized tools on SSF activity.
- **High-frequency tracking is essential for reliable SSF effort estimation:** Low temporal resolution in tracking systems leads to underestimation of fishing effort and misclassification of activity. A ping rate of less than one minute is recommended to ensure accurate spatial modelling and compliance with future EU control requirements (Rufino et al., 2025).

4.1 Introduction

The main goal of WP3 was to summarize and synthesize all the key findings to generate recommendations and guidelines for estimating areas used by SSF and identify key data gaps and propose solutions.

A synthesis of relevant findings from WP2 and case studies is developed to provide clear recommendations for estimating SSF distribution and inferring fishing effort in European waters. Concrete recommendations address the identification of gaps and propose solutions. Some recommendations are done to support EU regulations, specifically in relation to EU fisheries control regulation (Regulation (EU) 2023/2842).

4.2 Deliverable 3.1 Key Points

Efforts are underway to estimate the fishing footprint and improve the spatial distribution knowledge of SSF in European waters using innovative methods and the best available data. Defining the necessary data and ensuring its correct use for sustainable fisheries management is critical. Data scarcity remains a major challenge for these small-scale fleets, particularly regarding the precise spatial effort. Technical barriers include low coverage of high-resolution tracking devices and difficulties in inferring the gear of the trips in a context of a small-scale activity that have a heterogeneous behaviour and carry out activities shorter in time compared to industrial fleets, and thus, more complex to model.

To overcome these challenges, the project integrates multiple data sources and methodologies, leveraging both statistical models and ML techniques to infer spatial distribution.

Expanding tracking devices such as GPS to obtain high-temporal resolution data is key to enhancing SSF monitoring. Additionally, improving remote sensing techniques with higher-resolution imagery, such as Sentinel-1, Sentinel-2 or daily Planet imagery, will help refine spatial assessments.

A relevant lesson from this project is the need to strengthen collaboration with fishers to enhance data collection, validation, and result interpretation, as experience is something algorithms can't replace. Their involvement will ensure more accurate and actionable insights for better SSF management and sustainability.

4.2.1 Combined methodologies to address multiverse scenarios

The project integrates multiple methodologies to effectively handle the diversity of fleets and fishing practices, ensuring adaptable and comprehensive analyses.

1. **Diversity of small-scale fleets** in European waters:
 - o There is significant diversity across fleets, but lots of similar issues are faced across them. The approach combining sources and methodologies seems to be adequate to integrate this heterogeneity, providing a comprehensive perspective on SSF activity.
2. **Methodological and collaborative approach:**
 - o The project combines diverse methodologies and promotes strong collaboration among experts. This ensures the analyses are robust, comprehensive, and enriched by diverse expertise, making the approach adaptable beyond individual case studies.

4.2.2 Key findings & Case study insights

Sources for SSF Fishing Effort

- Different methods are being explored to infer SSF fishing effort using readily available data from different sources.
- Based on the results of the case studies a comprehensive SWOT¹ analysis for each of them has been conducted during WP2, evaluating their strengths, weaknesses, opportunities, and threats to gain a deeper understanding of their potential and challenges.

¹ The SWOT analysis is originally presented in the WP2 section of the MAP-SFF Report. It is reproduced here to ensure the standalone nature of Deliverable 3.1, which is intended for use in various contexts (e.g., websites, social media, dissemination materials).

- **S2 REMOTE SENSING DATA:**

STRENGTHS • EU-funded satellites provide open data to scientists and companies. • Algorithms for detection and classification are developed and open-sourced. • Resolution (10 m for S2). • Useful to validate other data sources.	WEAKNESSES • Long time between transmissions (5 days for S2). • Local time (10:30a.m., for S2). • Clouds. • Confidentiality problems increase the higher the resolution of the satellite images. • Legal rules not adapted to this data, no final position from the European Data Protection Board. • Detected targets need validation. • Few detections in some CS (Portugal, North Spain, Murcia).
OPPORTUNITIES • Deep learning algorithms will allow huge amounts of data to be processed. • Computing power keeps getting cheaper.	THREATS • Fisheries control could be illegal using this data due to confidentiality issues. • Private companies are offering products similar to those developed for fisheries control to anyone with the money. • Computing capacity.

- **QUESTIONNAIRES:**

STRENGTHS • Cost-effectiveness. • Fill quantitative and spatial data gaps, in absence of other methods. • Useful to validate other data sources. • Available ways to increase data quality (Marche region and Murcia, e.g. census method and high coverage of the questionnaires).	WEAKNESSES • Not measurable reliability due to personal biases (fishers may report inaccurate information or lie due to mistrust). • Lack of formal documentation or standardized methodologies. • Time consuming to reach the right coverage and to repeat it (How many times shall they be repeated?).
OPPORTUNITIES • Enhances scientific research with experiential knowledge. • Connections to local fisheries. • Involves fishers in co-management and MSP (good answers/participation in most CS, Fishers are motivated to support the process).	THREATS • Potential resistance from policymakers and scientists who prioritize quantitative data. • Potential resistance from fishers who are stressed with more requests.

- **HIGHLY-RESOLVED GEOSPATIAL DATA:**

STRENGTHS ● Precise fishing grounds. ● Algorithms for analysis available. ● Useful to validate other data sources.	WEAKNESSES ● Coverage, still no authority enforcing use. ● Need of high-quality validation data (e.g., gear in use). ● Need to validate precise fishing activity (start/end fishing). Validation is time and personnel demanding (onboard observers, etc.).
OPPORTUNITIES ● Full traceability. ● Computing power keeps getting cheaper. ● Regulatory framework making data available within a short time. ● Fishers can have prove of their activity.	THREATS ● Confidentiality issues from data protection laws could impair its use for fisheries science if this is not addressed in the new fisheries control framework. ● Fishers would be reluctant to abide by stricter control measures. ● Highly-resolved data demands for computing power

- Some key findings can be highlighted from this SWOT analysis:

1. Highly resolved geospatial data (as GPS and AIS based tracking systems) for which it highlighted its ability to provide the most precise spatial estimates and well based algorithms for analysis available.
2. Remote sensing data (Sentinel2) which stands for being open data that can be used to validate other sources. There is a potential to overcome current limitations in relation to aspects such as weather conditions and resolution.
3. Spatial questionnaires for fishers have proven to effectively detect fishing grounds and to provide large amount of information complementary to tracking and remoting devices to enrich spatial knowledge. Two different approaches tested, both successfully. Ensuring adequate coverage of spatial questionnaires improves data reliability.

- Combining sources improves results. It should be noted that, in some cases, the effectiveness of certain sources depends on the availability or support of others. For example, a low GPS/AIS coverage for a fleet affects the capacity to match detections with Sentinel-2 data; or the ability to have better gear estimation and catches depends on the quality of logbooks data.

Methodologies

- Vessel detections were derived from electro-optical imagery at 10-m resolution from the ESA's Sentinel-2 mission using a **deep-learning model** GFW developed. The detections were matched with AIS data using the same method for the GFW published Sentinel-1 dataset described in Paolo et al. 2024.
- **ML methods** were explored to predict the location of the fishing grounds and distribution of effort, i.e., a Multilayer Perceptron Network, a type of Artificial Neural Network, (Russo et al. 2019). After spatially organising the data on fleet distribution per port, and system topology

(including sea depth and sea bottom substrates), the model will be trained to predict the spatial distribution of SSF fishing effort. The case study in the Adriatic sea was used to develop the model and the data provided in the questionnaires published by Grati et al. (2022) will be used to inform the model and capture the relationships between fishing grounds distribution and fleet capacity. In parallel, classical statistical models (i.e. Generalised additive model, GAM) will be used to fit an explicit model linking the spatial allocation of fishing effort for SSF and the main topological features.

- Comparing different modelling approaches, **statistical** and **ML**, for each step improves methodological robustness.
- **Include spatial components** —i.e. the ability to georeference available data such as vessel detections, fleet distribution, and environmental variables— in these models to improve accuracy and applicability.
- A standardized methodology should be used to estimate fishing effort, adapting to the available information in each case study.

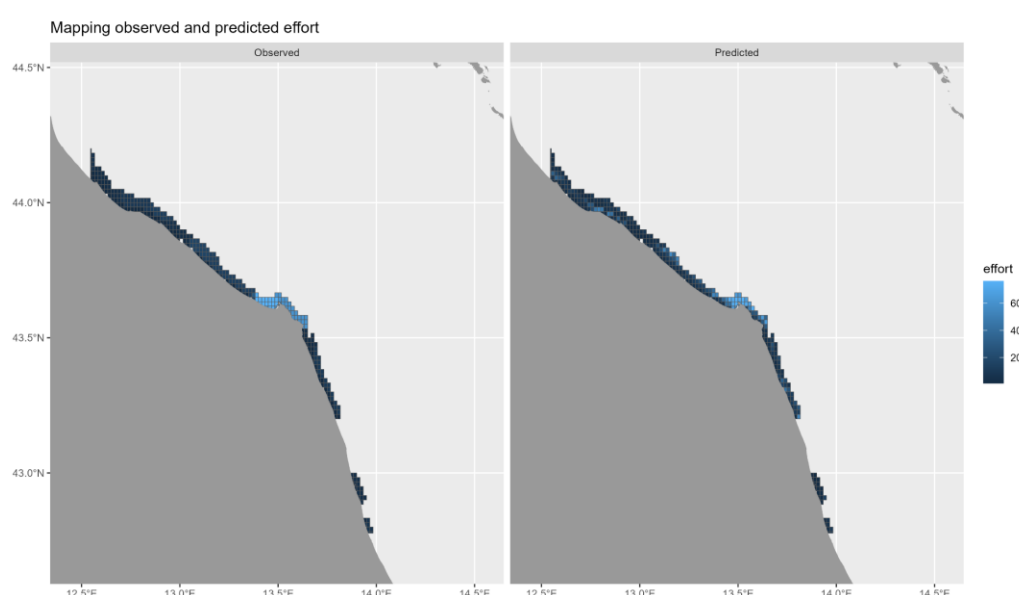


Figure 4.1: Observed and predicted gillnet (GNS) fishing effort in the Marche Region (CS4)

Figure Notes: The left panel shows observed fishing effort, while the right panel presents effort predicted by the previously described MPN model. The spatial similarity between the two maps indicates strong model performance in capturing the distribution and relative intensity of gillnet fishing effort.

Reproducibility & Scalability

The method combining different sources of information is **easy to follow and replicate** beyond the current case studies. A common procedure (notebook) could help address **SSF activity** in different areas.

Two R-based notebooks were developed to map and model small-scale fishing effort across case study areas.

Notebook 1 provides a reproducible pipeline for integrating data from participatory mapping, tracking devices, vessel registries, and Sentinel-2 satellite imagery. Questionnaire data are cleaned, standardized by métier, and spatially aggregated by grid cell. Analytical steps include **KDEs** to explore effort distributions by gear, **quantile-based identification of core fishing grounds**, and effort quantification within those areas. These results are used as a benchmark to evaluate the spatial and

temporal coverage of vessel tracking systems, including AIS, GPS, and VMS. Sentinel-2 detections are categorized as matched/unmatched and serve as input for training detection algorithms.

Notebook 2 develops a **MPN** to predict fishing effort using spatial/environmental variables (e.g., distance to ports, depth, substrate type). The model is trained and validated through repeated random partitioning and performance evaluated using regression, error metrics, and a confusion matrix for classified effort levels. Sensitivity analysis quantifies the influence of each input. Outputs include effort prediction maps and model diagnostics to support SSF monitoring and management.

Notebooks (such as Jupyter Notebooks or RMarkdown) improve:

1. Method **reproducibility**, documenting the code and allowing visualizations and explanations in a single file. Also help maintain a clear record of analyses.
2. Facilitate **sharing** as notebooks are portable files that can be easily shared, and others can run them without having to rebuild the entire analysis from scratch. Also, they can be hosted on platforms like **GitHub** or **RPubs** to enable collaboration.

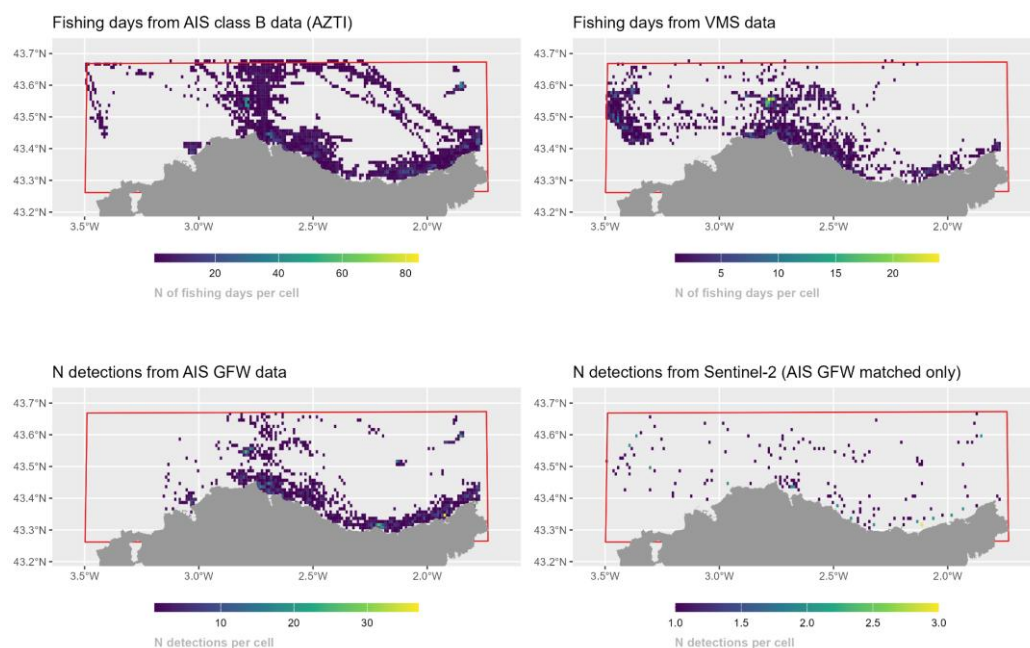


Figure 4.2 Spatial distribution of small-scale fisheries (SSF) based on multiple monitoring sources (AIS Class B, VMS, GFW AIS, and Sentinel-2) for the Basque Country Region (CS2)

Validation

- On-site real-time data observations are crucial for validation.

Fishers participation

- **Fishers' knowledge** should be integrated to improve maps and spatial assessments.
- Maps require **validation with fishers**, as many estimates rely on indirect data.

4.2.3 Gaps and Challenges

Data availability and Coverage

- **Limited data** on **SSF** remains a key issue. For GPS and AIS the issues mostly rely on the current coverage as they are not yet mandatory for all SSF vessels in the EU.

- GPS provide good effort estimates for specific cases where coverage of the fleet is good and when they provide high resolution data (<3-5 min/ping)
- **Remote sensing data** (Sentinel-2 optical imagery, 10-meter spatial resolution) were tested along with other sources, proving to be useful although also showing some limitations that need to be addressed. We opted for optical Sentinel-2, a pair of satellites (Sentinel-2A and 2B) operated by the ESA. Together, they provide global coverage every 5 days, with more frequent revisits at higher latitudes. Sentinel-2 offers free and open-access data, making it a cost-effective solution for large-scale monitoring. It delivers imagery at multiple spatial resolutions: 10 meters for visible and near-infrared bands, 20 meters for red edge and short-wave infrared, and 60 meters for atmospheric correction bands.

The long interval between satellite transmissions, combined with the fact that optimal records are affected by weather conditions (e.g. cloud cover) limits the capacity of remote sensing to fully capture the SSF activity. Nevertheless, this approach is needed and further work on remote data can enhance its potential. This methodology enables the detection and geolocation of vessel activity in contexts where high-resolution geospatial data are unavailable or incomplete, thereby addressing critical data gaps and allowing for broader spatial coverage in monitoring efforts. Case studies have shown that some of the GFW decision rules, designed to infer fishing activity, may not be applicable to SSF, as they were developed for larger fishing fleets.

Regarding resolution, the current data resolution (less than 15-meter spatial resolution) is inadequate for SSF. Despite these limitations, Marche Region CS has demonstrated promising results, highlighting the method's potential for further development.

Technical and Methodological Challenges

- Identifying **gear type** is difficult:
 - Especially for vessels using **multiple gears in one trip**.
 - Also, a challenge for vessels changing frequently the gear along the different days as they don't always register those gear changes in fishery-dependent data (such as logbooks).
- **Predicting fishing grounds** is challenging when focusing on **only one type of gear** as the fishing gear in many cases is not possible to identify.
- **EU Fleet Register (EUFR)** consists of a static list of fishing vessels, which provides general information but has no limitations when used to infer fishing effort. Declared main fishing gear is not always specific or accurate, and **gear changes** during operations and along days are not registered in the EUFR. This allows a general picture but not precise enough by gear type. These dynamic aspects of gear use are not captured in the EUFR, which prevents a precise understanding of fishing behaviour by gear type. This particularly affects trammel nets (GTR), which is highly relevant in SSF. In the EUFR all GTR activity is stated under gillnets (GNS).
- Many **data layers** are required for **MPN models**, adding complexity.

Spatiotemporal considerations

- **Temporal variability**, such as seasonal shifts in target species, variable trip duration, and changes in fishing effort depending on weather conditions or market demand, in SSF operations makes data collection and modelling more complex.
- **Spatial questionnaires** do not incorporate seasonality at this stage.

4.2.4 Solutions and scientific work forward

1. Collaboration & Fisher involvement:

- Improve **collaboration with fishers** in using tracking devices.
- Utilize **fisher's expert knowledge** to validate and enhance data on their activity.

- Consider finding a balance to avoid survey fatigue.

2. Technological & Data Improvements:

- Optical satellite imagery captures visible light and sometimes infrared, making it highly valuable for monitoring vessels at sea, particularly on clear, cloud-free day.

For more detailed analysis, future work could deal with:

- higher-resolution optical imagery—around 3 meters—from commercial providers like Planet Labs, which allows finer identification of vessel features. And explore the potential of Sentinel-1 data for improved resolution.
- Adapt **GFW algorithms** to better reflect SSF behaviours (e.g., accounting for shorter fishing events, such as 5-minute durations).

3. Spatial questionnaires:

- Develop **spatial questionnaires** based on WP2 experience to improve and standardize data collection.
- Incorporate **seasonality** in spatial questionnaires for more accurate data.
Define the frequency of spatial questionnaires that are necessary for reliable data updates. This must be balanced to ensure data consistency, keep a cost-benefit approach, maintain good collaboration and avoid survey fatigue (that can lead to lower response rates, incomplete answers, or less thoughtful responses, thus resulting in decreased data quality).
- Use **gear information from landings** to better determine the primary fishing gear of each vessel.

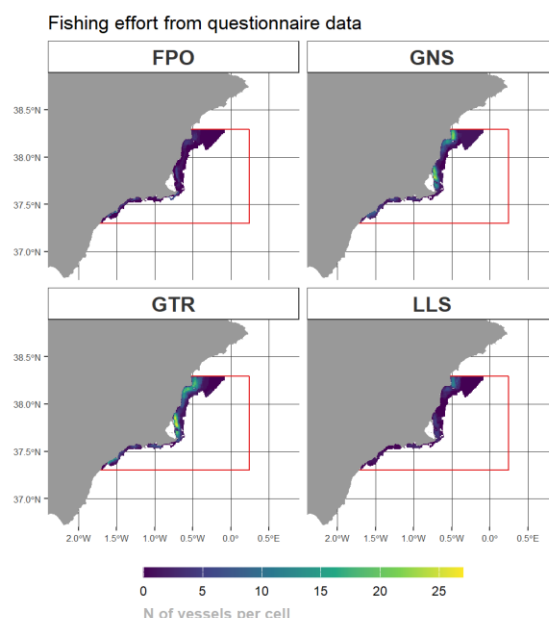


Figure 4.3 SSF spatial distribution for the four main gears based on questionnaire data from fishers at ports for the Murcia Region (CS3)

4. Optimization of sampling effort estimation:

- Need to optimize sampling strategies for fishing effort estimation. Include the determination of optimal sampling size for fishing effort estimation in cases where full fleet coverage is not possible.

- Develop a framework to estimate fishing effort using available data with minimal sampling, making it applicable beyond the EU.

5. **Multidisciplinary Approach:**

- Secure a larger project with a multidisciplinary team combining expertise from different fields relevant to SSF research.
- Increase research scope with a multidisciplinary approach and broader funding.

6. **Open Data & Transparency:**

- Open data (anonymized) or a shared common network can enhance collaboration and reliability.

7. **Common Definition for SSF:**

- There's a need for a common definition of SSF to align methods, instruments, and data. Standardizing the definition of SSF is relevant for consistent methods and data usage.

4.2.5 *Policy and management recommendations*

Implications for EU Fisheries Policy and Regulatory Frameworks

The main objective of this study is to enhance knowledge of SSF, with a particular focus on mapping their activity. This section identifies and synthesizes how the results of this study contribute to the implementation of the Common Fisheries Policy and other EU instruments —such as Regulations, Directives, and strategic frameworks relevant to SSF— many of which were introduced in the overview of EU legislation at the beginning of this report:

Common Fisheries Policy (CFP):

The Common Fisheries Policy (CFP) is a set of rules for managing European fishing fleets and conserving fish stocks. It was designed to manage a shared resource, thus giving all European fishing fleets equal access to EU waters and fishing grounds, allowing fishers to compete on a fair basis.

Within the CFP, there are different sections that refer to artisanal fisheries, which include SSF. Among other things, it mentions the specific recognition and support for these fisheries. It is acknowledged that this type of fishing is fundamental for many coastal communities, both for its economic value and for its role in social and cultural cohesion.

It is also mentioned that these fisheries should be given preference regarding the access to coastal areas, where Member States (MS) may restrict access to coastal waters (up to 12 nm) to vessels that traditionally operate in those areas, which directly benefits artisanal and small-scale fleets.

The CFP has introduced mechanisms for regionalised governance, which allows fishing communities, including artisanal ones, to participate in decision-making through regional advisory councils. There is a drive for fleets, including artisanal ones, to become more selective and reduce unwanted catches, in line with the landing obligation and the ecosystem-based approach of the CFP.

Knowing where these fisheries operate is essential to address the issues mentioned above. This project has demonstrated how, through various methodologies applied according to the type of data available, it is possible to map SSF activity at different resolutions, both spatially and in terms of the fishing gear used, etc. It also provides tools for identifying the gear used by these fleets, whose polyvalency in terms of the use of fishing gear is a common characteristic.

This knowledge of activity, with maps based on high spatial resolution data, would enable better management of these fisheries, especially if, as mentioned in the CFP, they could have priority within

coastal waters. It also allows for the assessment of the importance of these fisheries, based on the effort they make within each Member State and regionally.

Governance is an essential point when it comes to managing fishing activity. As mentioned in a previous section, the CFP contributes to ensuring that fishing communities, including artisanal fisheries and SSF, have a voice within the regional advisory councils. For this to happen, it is crucial that the SSF has sufficient information about its activity to defend its interests. The SSF sector has always faced more difficulties in these Advisory Councils, in defending its interests, due to various factors, one of which is the limitation in knowledge of its activity. This may be partly because these fleets have been exempted or subject to lesser requirements (compared to LSF) regarding the official reporting of information related to their activity (e.g. catch data in logbooks, effort data at high resolution level by VMS, etc.).

This project, through different case studies, provides essential information about the activity of these fisheries, especially in a very visual and easy-to-understand manner, showing how it could be very useful for these fisheries when any management measure needs to be taken.

It should be borne in mind that one of the objectives of the CFP is managing European fishing fleets and conserving fish stocks. As demonstrated in this study, through surveys conducted with experts in these fisheries (with very good regional coverage), it is highlighted as a main characteristic that these are multi-species fisheries. In addition, it should be noted that the target species of these fisheries are species or stocks that have no assessment and whose current conservation status is unknown. This is a very important gap and could have a significant impact on the economic sustainability of these fisheries, if the situation of these species or stocks were negative. It is recommended to improve and increase the specific fisheries sampling programmes focused on these fisheries.

Finally, one of the important points currently being discussed in the possible revision of the CFP is the allocation of fishing opportunities, through Article 17 and based on various criteria (environmental impact, historic catch levels, contribution to the local economy, etc.). As mentioned earlier, it is essential that, based on the criteria to be used for this allocation of fishing opportunities, SSF fisheries have as much information as possible about their activity, and the results obtained in this study contribute to making this a reality.

Marine Strategy Framework Directive (MSFD)

The European Marine Strategy Framework Directive (MSFD) was developed to provide a framework for MS to protect the marine environment more effectively (Directive 2008/56/CE). This is to be done by maintaining biodiversity and providing diverse and dynamic oceans, which are clean and healthy, while allowing the sustainable use of marine resources (EU, 2008). The MSFD is based on an ecosystem approach and will, where necessary and appropriate, draw on existing regulation to achieve coherence between policy areas (e.g. CFP EU, 2013; Habitats Directive CEC, 1992). It came into force in 2008 and aims to allow MSs to take the necessary measures to achieve or maintain Good Environmental Status (GES).

To determine GES, eleven qualitative descriptors of the state of the environment were defined comprising biodiversity, non-indigenous species, commercial fish, foodwebs, eutrophication, seabed integrity, hydrographical conditions, contaminants, food safety, litter, and underwater noise. The most likely interactions between SSF and MSFD are under D1 biodiversity, D3 fish stocks in relation to fishing mortality and population structure, D4 food webs in relation to uncertainty and anthropogenic pressures; and D6 seabed integrity for passive fishing gears. SSF are included inside the term commercial fisheries, but attention should be made to the differences between large-scale and small-scale fisheries and their different impacts.

The results obtained in this project could primarily be used to address indicator D6, concerning seabed integrity for passive fishing gears. It should be noted that the main fishing methods used by these fisheries are also passive gears.

In the study, it was possible to map the activity and fishing effort of these fisheries at different spatial resolutions based on the type of data available. Moreover, the methodologies used are replicable in any region.

Overlaying these maps with existing seabed information maps would allow the impact of SSF on this indicator to be assessed. Furthermore, it should be considered that the main activity of these fisheries happens in the most coastal areas, very close to their home ports. These types of coastal habitats also tend to be very sensitive, important habitats for the juvenile individuals of the main commercial species, and so on.

It has always been assumed that the impact of SSF is less than that of LSF. If this comparison is made at the unit of fishery level, this is usually the case. However, it is very important to bear in mind that SSF represents 84% of the total EU fleet and, as mentioned before, their effort is concentrated in coastal areas. This is why it is essential to have the information provided in this project to address this indicator.

The same exercise of overlaying maps between the fishing activity produced in this study and maps of the distribution of Endangered, Threatened Species, for example could also serve to address indicator D1 and to create risk maps of incidental capture between these species and the SSF, considering the different fishing gears and their spatial distribution.

Maritime Spatial Planning (MSP)

Maritime spatial planning (MSP) was succinctly defined as the “Public process of analysing and allocating spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives”. The European Union policy instrument for MSP is Directive 2014/89/EU which gives the definition as “A framework under the Integrated Maritime Policy to manage human activities at sea & in coastal zones”.

MSP is believed to reduce conflicts, encourage investments, increase coordination between administrations, increase cross-border cooperation between EU countries and protect the marine environment. No explicit reference to SSF is made by MSP (2014/89/EU), but their consideration is implicit under the tourism and fisheries sectors. Their relevance for MSP is particularly relevant in the coastal area. Their reduced mobility makes them extremely dependent on coastal ecosystem resources, and conflicts can arise between SSF, large scale and recreational fishing fleets (and also with other uses of the sea such as renewable energies, dredging, tourism, and even conservation marine areas), because they interact in the same area.

MSP planners require digitized maps of spatial and temporal SSF effort. Maps should be of sufficient temporal and spatial resolution to enable informed decision-making in consideration of coastal and marine habitats and the activity of other marine stakeholders. In making value judgments on use policy, economic maps are critical, particularly where economically significant activity is thought likely to occur. SSF stakeholders need to be engaged to understand what and where they value within their marine environment (e.g. fishing areas, fishing types, target species). There is a general need to understand what conflicts and compatibilities exist, or could arise, with other marine activities.

All MS require provision for a maritime spatial plan covering all marine activities. The objective is to balance stakeholder interests, economics and environmental management of marine resources. Maritime Spatial Planning and associated recommendations and legislation are evolving, but a description of the activities and economics of small-scale fisheries in time and space will be critical to

the maritime spatial planning process. It is important (as specified in the EU directives) for the process to be transparent and stakeholder driven.

The work carried out and the results obtained in this project, along with the methodologies used, are fundamental for addressing this Directive. To develop plans for marine spatial planning, it is essential to know where the activities of the various users of the maritime area take place. In the case of SSF, most of this activity is concentrated in the most coastal zone, and it is foreseeable that the greatest interactions and conflicts with the other users mentioned above will occur in this area.

A very important part of this project focuses on mapping the activity of SSF, considering the effort made and considering the different fishing gears used. Different methodologies have been employed based on the data available and their resolution. These methodologies range from gathering information through questionnaires with the fishing sector itself, making use of their knowledge of their activities, to methods that enable the creation of high spatial resolution maps using high-resolution geospatial information that can be collected via various devices installed on the vessels. The implementation of these methodologies would allow for the development of marine spatial planning specifically in relation to fishing activity, and particularly SSF. Furthermore, the methodologies used are replicable in any region. Having this information available, as can be seen in the case studies described in this project, encourages the active involvement of SSF fishing communities.

Birds and Habitats Directives

The Birds Directive (2009/147/EC) and the Habitats Directive (92/43/EEC) are the cornerstones of European legislation for nature conservation. Both have had a significant impact on SSF, both in terms of opportunities and restrictions.

The Directives require that human activities do not deteriorate habitats or disturb protected species. To assess this, it's essential to know:

- Where SSF operates.
- What fishing gear is used.
- When fishing takes place.
- Which species are targeted.

The ability to increase spatial knowledge of SSF, the gears used and the seasonality of their activity is the main objective of this project, and this is how it supports compliance with these Directives:

1. Avoiding sensitive areas:
 - Helps identify overlaps between fishing zones and protected habitats or species, allowing adjustments to minimize impacts.
2. Designing realistic conservation measures:
 - Spatial data enables tailored restrictions (e.g., seasonal closures or gear limitations) without unfairly excluding SSF.
3. Demonstrating compatibility:
 - SSF can prove its sustainability by showing that its activities do not negatively affect conservation values.
4. Facilitating stakeholder involvement:

- Clear maps and data empower SSF communities to actively participate in Natura 2000 site management.

Marine Action Plan:

The EU Marine Action Plan (*“Action Plan: Protecting and restoring marine ecosystems for sustainable and resilient fisheries”*), adopted in February 2023, aims to reconcile the protection of the marine environment with fishing activity, and directly affects the SSF in several respects.

Among the main priorities of this plan is the recognition of low-impact fisheries. The plan promotes selective and low-impact fishing, which could benefit small-scale fisheries over more aggressive industrial methods. The plan strengthens local stakeholder participation, giving SSF communities a voice in planning and monitoring processes.

Based on this plan, there are challenges that are closely related to SSF: The plan aims to phase out bottom trawling in Marine Protected Areas (MPAs) by 2030, which could affect some SSF practices if not properly differentiated. The increased monitoring and control are also highlighted: It calls for better implementation and monitoring, which may require tracking technologies not always accessible to small vessels.

The project identifies, using various methodologies, how to differentiate the activity of SSF considering their seasonality, the most commercially important species, fishing effort by gear type, etc. This type of information is essential, for example, when it comes to managing potential MPAs that may be implemented in different regions, as it can allow, where possible, the activity of low-impact fleets even within these protected areas.

Another relevant issue highlighted is the need to increase control and monitoring of the different fisheries, including SSF. In this project, through different case studies, various devices adapted for SSF have been identified, which make it possible to collect essential high-resolution data that can improve both monitoring and, where necessary, control of the activity.

- European Ocean Pact

The European Ocean Pact seeks to establish a comprehensive and coordinated approach to protect ocean health, strengthen the sustainable blue economy, improve maritime security, and reinforce international ocean governance.

Concerning SSF, the European Ocean Pact makes explicit reference to these fisheries, among other things, in:

- o Priority Support: The European Commission states that SSF will be a priority.
- o Planned Actions:
 - Publication of a handbook of best practices that MS can use to allocate fishing opportunities more transparently and sustainably.
 - Launch of a dedicated implementation dialogue for this segment.
 - Consideration of establishing a dedicated Advisory Council for artisanal fisheries

This pact also makes explicit reference to the most relevant directives mentioned in this section (MSFD, MSP, Habitats and Bird Directives). Therefore, the impact of the work carried out within this project would be the same as that identified in each of the directives.

Data Collection Framework (DCF):

The Data Collection Framework (DCF) Regulation (EU) 2017/1004 of the European Union is a regulatory and operational system that underpins the collection, management, and use of fisheries and aquaculture data across MS.

This regulation is implemented through:

- o Commission Delegated Decision (EU) 2021/1167: Defines the multiannual Union programme (EU MAP) from 2022 onward.
- o Commission Implementing Decision (EU) 2021/1168: Lists mandatory research surveys and thresholds.
- o Commission Implementing Decision (EU) 2022/39: Sets rules for submitting national work plans and annual reports.

The DCF mandates the collection of:

- o Biological data (e.g. species composition, size, age, sex, maturity, stomach content).
- o Fishing effort and catch data (e.g. number of trips, gear used, discards).
- o Socioeconomic data (e.g. employment, income, fleet structure).
- o Environmental and oceanographic data (e.g. marine litter, bycatch of protected species, top predator censuses).

Data are gathered through:

- o Fishery-dependent sources: Port sampling, onboard observers, logbooks.
- o Fishery-independent sources: Scientific surveys at sea.
- o Electronic monitoring and geospatial data (AIS, VMS) are increasingly integrated.

Within this Regulation, there is no specific section referring to SSF. However, based on various studies (e.g. the fishPi project (Call for proposal MARE/2014/19)), it has been observed that, to date, the information collected through the different national work plans via sampling is highly deficient regarding SSF. This deficiency or limitation in the data affects biological data, socioeconomic data, and environmental and oceanographic data alike. Such limitations hinder the management of these SSF fisheries and continue to represent one of the most significant gaps, as well as one of the greatest challenges.

This project has demonstrated that high-quality data, particularly regarding the fishing effort of this fleet, the gear types used, etc., would allow for better management of these fisheries and enable compliance with the Directives already mentioned in this section. Furthermore, collecting such basic data as the catches made by this fleet, information on incidental catches, etc., would allow for an assessment of the impact of SSF.

It is therefore essential that the sampling carried out under this regulation achieves at least levels comparable to those for LSF. This deficiency is not only present in sampling. Due to the requirements previously imposed on SSF regarding data reporting under the former Control Regulation (e.g. exemptions from carrying a vessel monitoring system, exemptions for reporting catches below certain kilogram thresholds, etc.), knowledge of SSF activity remains limited.

Fisheries Control Regulation:

The EU Fisheries Control Regulation (Regulation (EU) 2023/2842) is likely the most relevant in terms of applying the methodologies developed within this project.

Within this regulation, one of its main objectives—which directly affects SSF—is the mandatory use of geolocation devices and the requirement to report all catches without exception through electronic fishing logbooks. The implementation of these devices will be done gradually, but by 2029, it is expected that all vessels longer than 10 meters will have these devices installed. For boats shorter than 9 meters, each member state will decide how to proceed with implementation, if at all.

The installation of these devices, especially those that will collect all geospatial information about the activities carried out by these vessels, represents a significant quantitative leap. The methodologies and tools developed in this project make it possible, with this high-resolution spatial information, to estimate fishing effort in detail, identify the fishing gears used, possibly identify the lengths of the fishing gears used (e.g., number of nets, hooks), the soak time of passive gears, and more.

Implementation of tracking devices

The installation of tracking devices for all the fleet to enhance SSF monitoring is essential. Estimates from other sources can provide insights on small-scale fishing grounds and effort deployed but can't estimate accurate spatial distribution to meet the needs for fisheries management and spatial marine planning. This data will be acquired with a proper implementation of the new EU regulatory framework.

High resolution data

Polling or temporal frequency is critical. The quality of fishing effort measures decreases with temporal resolution. Low temporal resolution affects several aspects, such as the underestimation of real fishing effort and the ability to accurately detect, classify, and assign fishing operations, among others. Data with low temporal resolution will not be suitable for SSF. High temporal resolution data (with a frequency of less than 1 minute, as recommended by published studies) is required. The new EU Control Regulation (EU 2023/2842) does not specify the frequency, which remains a critical issue (Figure 4.4).

Consequences of low resolution fishing boats tracking data

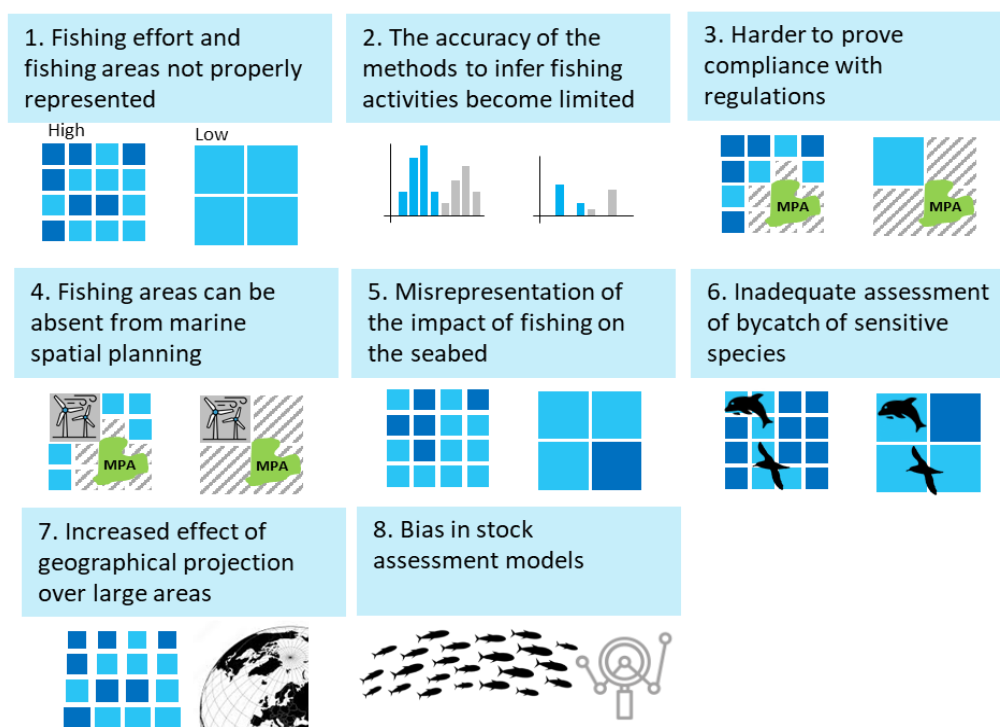


Figure 4.4 Overview of key risks and limitations resulting from low temporal resolution in vessel tracking data (figure from Rufino et al., 2025)

Another goal of this project has been to standardize as much as possible all the tools that have been developed (e.g., data workflows, notebooks, etc.). This standardization would allow these methodologies to be applied to any region, both at the European and global level, once access to this data is available. Furthermore, specific recommendations have been provided on how this spatial information should be collected (e.g., frequency of ping rates) so that it enables all types of analyses with maximum possible resolution and high reliability.

Identification of a structure to channel the mapping work

To effectively manage the vast amount of data involved in mapping SSF activity, a well-defined procedure is needed, one that aligns with current best practices in both scientific and regulatory contexts. This includes fishery-dependent data reported by MS to EFCA on behalf of DG MARE for control purposes (e.g., VMS and logbooks), as well as fishery-independent data (such as AIS) used in scientific analyses.

The ICES Data Calls, such as those coordinated by the Working Group on Spatial Fisheries Data (WGSFD), are designed for scientific purposes and require MS to aggregate and anonymize data before submission, typically following ICES protocols. These calls currently focus on larger fleets, but a similar structure could be adapted for SSF mapping efforts. Establishing a clear framework and workflow would ensure consistency, accuracy, and relevance in the mapping process.

Given the complexity and heterogeneity of SSF data —ranging from vessel tracking to questionnaire-based spatial information— developing robust protocols, functions, and algorithms can handle different types of information efficiently. Scientific projects can play a key role here in designing and refining these tools, providing the technical foundation for effective SSF data processing and analysis.

However, a structured approach to SSF data management must go beyond tool development. It requires continuous oversight, including database maintenance, regular quality control checks, and

monitoring of emerging issues. This should be embedded within a formal institutional framework — ideally involving a dedicated team or unit within a competent authority (e.g., national fisheries institutes, EFCA, or a future SSF data coordination body) to ensure long-term reliability, consistency, and scientific soundness of the mapping process.

4.2.6 Considerations and Future Work

The MAP-SSF methodologies have demonstrated the feasibility of mapping SSF activity, generating spatially explicit, gear-specific, and scalable data to support fisheries management, marine spatial planning, and policy implementation.

SSF information on definition, legislation, spatial use, landings, tracking systems, and existing data has been collected from 19 case studies across Europe, capturing the diversity and complexity of SSF practices.

The combination of different data sources, such as spatial questionnaires, vessel tracking systems, and remote sensing imagery, together with modelling techniques, enabled the generation of spatial layers of SSF fishing effort and pressure indicators in a standardised format that can be applied by other countries using their own data. These outputs revealed fishing hotspots and are particularly relevant for analysing overlaps with other Blue Economy sectors, for which complementary data are required.

The MAP-SSF results, including the identification of key data gaps and proposed solutions, contribute to a better understanding of SSF dynamics and support their integration into fisheries governance and decision-making processes. These findings are especially relevant in the context of increasing human pressures from the expanding Blue Economy, climate change impacts on marine ecosystems, and environmental degradation (e.g. pollution, invasive species, habitat loss).

To address these challenges and close remaining information, policy and implementation gaps, the following actions are proposed:

- **Data Completion and Dissemination (WP1 COLLECT):**
 - o Finalise short interviews to complete data acquisition.
 - o Map areas where fishers indicated they could contribute interactively.
 - o Extend the questionnaire to additional countries and identify regions with missing data.
 - o Align questionnaire results with ICES/GSA areas where applicable.
 - o Disseminate findings through a scientific publication and an infographic for the European Environment Agency (EEA).
- **Methodological Development and Integration (WP2 DEVELOP):**
 - o Present results at relevant scientific and advisory platforms (e.g., GFCM WGSSF, GFCM Subregional Committees, ICES WKSSFGEO).
 - o Test and integrate higher-resolution remote sensing imagery (e.g., PlanetScope Dove, 3 m resolution) and match detections with AIS and tracking data.
 - o Explore SSF behavioural economics and adaptive capacity to better understand decision-making processes and resilience under changing environmental and socio-economic conditions.

- **Strategic Recommendations (WP3 RECOMMEND):**
 - o Promote the use of high-frequency tracking systems (e.g., <1 min ping rate) to improve the accuracy of fishing effort estimation and support compliance with Regulation (EU) 2023/2842.
 - o Encourage the combination of multiple data sources to enhance spatial coverage and reliability, particularly in data-poor regions.
 - o Develop standardised, scalable methodologies for mapping SSF activity, adaptable to different national contexts and data availability.
 - o Integrate SSF spatial data into marine spatial planning and Blue Economy strategies to ensure equitable representation and minimise spatial conflicts.
 - o Establish a coordinated institutional framework for SSF data management, including technical oversight, stakeholder engagement, and long-term sustainability mechanisms.

This integrated approach will strengthen the role of SSF in European marine governance and contribute to more inclusive, adaptive, and sustainable management of coastal resources.

5 WP4 MANAGE - Project Management and Coordination

5.1 Introduction

The main goal of WP4 was to ensure effective coordination among partners to facilitate timely and efficient project implementation. The tasks and objectives of the different WP are outlined in Figure 5.1, providing a comprehensive overview of the project.

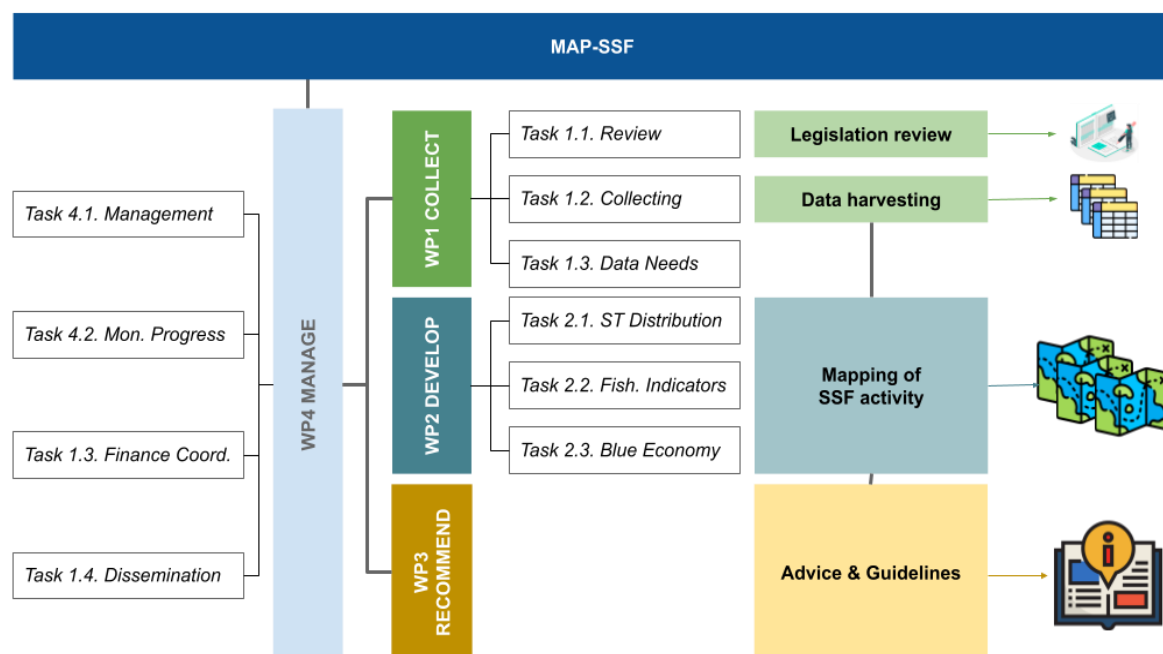


Figure 5.1 Work Breakdown Structure (WBS) for the project, which sets out the main tasks and objectives of each WP and the deliverables to be produced by each of them

The following tables summarise the main information from each WP, as originally outlined in the project proposal and updated throughout its implementation.

Table 5.1 Structure of WP1

WP1	COLLECT			
Leader	Marta Rufino (IPMA, Portugal)			
Participants	Partners and Project Advisory Group (PAG)			
Objective	Provide a complete overview of state-of-the-art research			
Tasks		Deliverables	Draft	Final

1.1	Review applicable legislation	Short Report	23/12/24	13/05/25
1.2	Data harvesting	Datasets	13/05/25	13/05/25
1.3	Data availability and needs			

The results of *Task 1.3* shall be included in the deliverable produced in *Task 1.1*.

Table 5.2 Structure of WP2

WP2	DEVELOP			
Leader	Anna Nora Tasseti and Tommaso Russo (CNR - IRBIM, Italy)			
Participants	4 Case studies and Project Advisory Group (PAG)			
Objective	Mapping the SSF activity of the case studies			
Tasks		Deliverables	Draft	Final
2.1	Analyse the spatial distribution of SSF activity	Maps with the fishing activity of each case study	14/02/25	13/06/25
2.2	Develop SSF fishing effort spatial layers and fishing pressure indicators			
2.3	Assess SSF activity within the blue economy			

Table 5.3 Structure of WP3

WP3	RECOMMEND		
Leader	Jose Rodríguez-Gutiérrez and Daniel Cano (IEO, Spain)		
Participants	WP leaders and Project Advisory Group (PAG)		
Objective	Generate recommendations and guidelines		
Deliverable		Draft	Final
A summary of key points		28/03/25	13/05/25

Table 5.4 Structure of WP4

WP4	MANAGE		
Leader	Maria Mateo (AZTI, Spain)		
Participants	Project partners		
Objective	Ensure that project delivers to the required specification on time and budget		
	Tasks	Deliverables	Deadlines
4.1	Management	Consortium agreement	08/11/24
4.2	Monitoring progress	Inception report	28/10/24
		MoM Meetings with EEA	04/11/24 & 13/05/25
		Workshop	10 - 14/02/25
4.3	Finance coordination	Invoices for payment	13/12/24 & 13/06/25
4.4	Dissemination	Linkedin	February 2025

5.2 Management and Finance Coordination

The contracts were signed by the partners, who then sent the invoices.

5.3 Monitoring progress and Dissemination

The inception report was sent out prior to the inception meeting (04/11/2024). All meeting minutes are available [here](#). The workshop held in Sukarrieta from 10 to 14 February was published on [Linkedin](#).

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7 Annexes

Annex 1 Questionnaire methodology and responses

A1.1 ANNEX 1a Methodological description

During the initial phase of the project, a [questionnaire](#) (A1.2) was developed to collect information on legislation, grey literature and SSF activity data (*Task 1.1* and *1.2* respectively). First, a conceptual framework of the questionnaire was developed, numbering the relevant areas where there was a need to gather information (six sections and introduction):

1. Definition of SSF
2. Legislation
3. Spatial use
4. Landings and logbooks reporting
5. Tracking systems
6. Previous information on SSF

Particular care was taken with the language and wording in the text, to minimize the use of scientific jargon and technical terminology, ensuring that the form remained accessible and easy to complete.

The questionnaire prioritized maximizing the number of closed, obligatory (i.e., predefined-option) questions to facilitate the analysis and permit a better quantification of the results (Ranganathan and Caduff, 2023). Most open not-obligatory questions (facultative) were present; to give new insights on the subjects under work (92% of obligatory questions were closed / 64% of all questions were closed / 36% of questions were non-obligatory (from which 86% were open)). Additionally, experience from previous questionnaires was incorporated, namely by the participation of Cristina Pita and Fábio Grati (who coordinated a major project on SSF in the Mediterranean).

In terms of process, the questionnaire was initially developed by the WP leader and reviewed by all project partners. Afterwards, it was sent to be filled and corrected again in an interactive process. This initial version had 61 questions, distributed along six sections. With the analysis of the respondents, the case studies from WP2, who answered as completely as possible, preliminary data were analysed and presented during the workshop. The questionnaire was filled for the five case-studies proposed: Portugal, Basque country (Spain), Bay of Biscay (France), Adriatic Sea (Marche Region, Italy), Canary Islands initially, but it was then changed to Murcia region (Spain), as a pilot testing, to validate and confirm its reliability.

Pilot testing provided information on the time taken to complete the questionnaire and whether any questions were confusing or misleading and needed to be rephrased. Validity indicates that the questionnaire measures what it claims to measure – this means taking into consideration the limitations that come with any questionnaire-based study. Reliability means that the questionnaire yields consistent responses when administered repeatedly even by different researchers, and any variations in the results are due to actual differences between participants and not because of problems with the interpretation of the questions or their responses (Ranganathan and Caduff, 2023).

The questionnaire was filled for the five case-studies proposed: Portugal, Basque Country (Spain), Bay of Biscay (France), Adriatic Sea (Marche Region, Italy), Canary Islands initially, but it was then changed to Murcia region (Spain), as a pilot testing, to validate and confirm it's reliability.

During the workshop held in Sukarrieta from February 10 to 14 (2025), the participants gathered in groups and discussed each section in detail. Thus, the questionnaire was deeply reformulated by all workshop participants and a new more concise and improved version was produced. The new version has 41 questions, where 22 questions were removed, 19 questions changed, and three new added ones. The final version had 1. Definition of SSF – 12Q, 2. Legislation – 9Q, 3. Spatial use – 5Q, 4. Landings and logbooks reporting – 3Q, 5. Tracking systems – 5Q and 6. Previous information on SSF – 5Q. This version was then sent again to the partners to make the respective changes in their answers (relative to the first version).

Additionally, as an extra task, a list of respondents from other countries in Europe and Turkey was gathered. This list of 49 contact points working on SSF related areas corresponded to 23 coastal countries (EC, but also countries in Europe or contiguous, e.g. Turkey, Albania, Iceland, Montenegro and Norway), were asked to fill the questionnaire after a first email sent (template text made together - email sent by different project participants). Of these, 15 were available to fill it in the future. Some of these contacts have given relevant information directly in the email (summarised in the section below) and the majority of those filled the questionnaire (Albania, Estonia, Iceland, Germany, Greece, Croatia, Malta, Poland and Romania). Thus, the results of the form were done with these, plus the five case-studies, i.e. 19 final answers. Additionally, potentially relevant information gathered from the emails directly (A1.3), along with the contact point name and respective institution can be found in 0 and is mapped in Figure 2.1. This extensive list of contacts is highly relevant for future studies related to SSF.

A1.2 ANNEX 1b Questionnaire structure

Data collection questionnaire on small scale fisheries (SSF):

This questionnaire has the objective to gather qualitative and quantitative data on SSF for each European country/region, that we can use for the EEA call report and possibly, for publication (if the data is good).

The idea is to get data that can be analysed, as much as possible, and avoid more descriptive/qualitative data.

If possible, answer the questions thoroughly, with real data.

- Email
- What is your name?
- How many years you are working on SSF related subjects?
- What institution are you currently working (please add the link besides the name in English)?
- What country/region are you referring to on this questionnaire about SSF? NOTE: if you have information about different regions/countries, please submit one form for each region.

1. Definition of SSF

- Does your country use the EU definition for SSF (i.e., <12m, no towed gear) as a working definition for SSF vessels?
 - Yes
 - No
 - Other: _____
- Are SSF fisheries defined by: length, if yes specify length (answer); by gear type, if yes specify gear type; by engine power, if yes specify threshold? If it is defined in any other way, please specify _____
- Does the definition of SSF vary from region to region or is it applicable country wise?
 - Region
 - Country
 - Other: _____
- Which organization (and person) is responsible for the SSF data collection/management in your country/region? _____
- How many active vessels in your country / region belong to SSF? _____
- Please identify the reference to the data provided in the previous question (if possible)? _____
- Which are the five main gears operated by SSF in your country?
 - GNS (gillnets)
 - GTR (trammel nets)
 - LLS (longlines)
 - FPO (pots and traps)
 - PS (purse seine)

- DRB (dredge)
 - LHP (handlines)
 - OTB (trawls)
 - Other: _____
- Do the SSF boats change gear during the year?
- Yes
 - No
 - Other: _____
- Can the SSF boats operate with two or more gears during the same fishing trip, in your country?
- Yes
 - No
 - Other: _____
- Overall, how many fishers operate in a SSF boat?
- 1-2
 - 3-4
 - 5-6
 - Other: _____
- Besides fishers, who else is involved in the SSF fishery?
- Family members
 - Employees
 - Other: _____
- The catch from the SSF sector can be found at:
- Harbour/boat (direct sales)
 - Animal feed (food for other animals)
 - Exports
 - Fish markets
 - Supermarkets
 - Restaurants
 - Other: _____
- Which are the five main species caught by SSF in your country (in terms of tonnage)?

- Which are the five main species caught by SSF in your country (in terms of value)?

- Do you have special local SSF fisheries (different from other countries)?
- Yes
 - No
 - Other: _____

If you answered yes before, please give examples and describe briefly these fisheries.

2. Legislation

- Is there specific legislation for SSF in your country/region?
 - Yes
 - No
 - Other: _____
- Is the legislation of SSF in your country/region specific by gear, metier or other?
 - Gear
 - Metier (gear-species)
 - Target species
 - Other: _____
- Any of the SSF are subject to fishing quotas in your country?
 - Yes
 - No
 - Other: _____
- If you answered yes before, please identify the species under quota
- Are SSF subject to:

	Temporal closures	Spatial closures	Specific by metier
GNS	☐	☐	☐
GTR	☐	☐	☐
LLS	☐	☐	☐
FPO	☐	☐	☐
PS	☐	☐	☐
DRB	☐	☐	☐
LHP	☐	☐	☐
OTB	☐	☐	☐
Other	☐	☐	☐

- Any of the SSF are subject to size restrictions on the captured resources, e.g. can only catch bivalves larger than 3 cm (please mention details and for which fishery below)?
 - Yes
 - No
 - Other: _____

- Please mention the details of the size restrictions in the previous question here:
- Do any of the SSF have gear restrictions, e.g. can only use 1 pot by m, or 10 m fishing net)?
 - Yes
 - No
 - Other: _____
- Please mention the details of gear restrictions, if answered yes in the previous question
- Do any SSF receive subsidies for the vessel fuel from the government?
 - Yes
 - No
 - Other: _____
- Please mention the details of the subsidies answered in the previous question here:
- Are there other governmental subsidies in SSF (beside fuel)?
 - Yes
 - No
 - Other: _____
- Please mention the details of other governmental subsidies in SSF (besides fuel)

3. Spatial use

- Do the SSF have spatial conflicts for areas fished?
 - Between themselves
 - With recreational fisheries
 - With other stakeholders (please name some)
 - Other:
- Do SSF have spatial areas for their exclusive use?
 - Yes
 - No
 - Other: _____
- If answered yes on the last question, how are these SSF fishing areas defined?
 - Distance to the coast
 - Depth
 - Protected areas (e.g, MPA)
 - Other: _____
- If so, please add the numerical criteria of the previous answer below.
- Do the SSF operate in areas where the LSF also operate?
 - Yes
 - No
 - Other: _____

- Do you have (or can you define in theory) the polygons where you consider that the SSF operate (spatial boundaries)?
 - Yes
 - No
 - Other: _____
- What other ocean activities do you think are competing with SSF fishing areas?
 - Windfarms offshore
 - Artificial reefs
 - Marine Protected Areas
 - Other: _____

What other ocean activities do you think are impacting or affecting the SSF fishing grounds?

4. Landings and logbooks reporting

- Are the SSF obliged to report catches in your country/region?
 - All fisheries
 - Some fisheries
 - Other: _____
- Are the SSF reporting data verified?
 - On board observers
 - Scientific sampling on the fish auctions
 - Official logbooks
 - Electronic monitoring (e.g. tracking systems, video)
 - Other: _____
- Please give further details on the SSF reporting verification that you think might be relevant.
- What information is given in the SSF official reporting?
 - Gear used in the trip
 - Quantity captured
 - Areas operated
 - Species caught
 - Other: _____
- Please give further details on SSF official reporting, that you think might be relevant.

- Do SSF have logbooks in your country?
 - All fisheries
 - Just some fisheries
 - Other: _____
- How are these SSF logbooks?
 - Electronic (app)
 - Paper

- Other: _____
- Please give further details on the SSF logbooks that you think might be relevant.
- What information is given in the SSF logbooks?
 - Gear used in the trip
 - Quantity captured
 - Areas operated
 - Other: _____
- Please give further details on SSF logbooks information that you think might be relevant.

5. Tracking systems

- Do any of the SSF have any kind of tracking system (is yes, click on if it is mandatory or voluntary and which type)?
 - Mandatory
 - Voluntary
 - AIS
 - VMS
 - GPSR (grey boxes, black boxes, green boxes)
 - Mobile app
 - Other: _____
- Which SSF fisheries have tracking systems?
 - GNS (gillnets)
 - GTR (trammel nets)
 - LLS (longlines)
 - FPO (pots and traps)
 - PS (purse seine)
 - DRB (dredge)
 - LHP (handlines)
 - OTB (trawls)
 - Other: _____
- Please mention the details on the tracking systems mentioned in the previous question here:
- How many SSF boats currently (2024) have tracking systems?
- What is the temporal resolution of the SSF tracking systems (please give the information in seconds)?

6. Previous information on SSF

- Please mention projects that studied SSF in your country (add the funding body and years interval, e.g. EU, local funding). If the final report of the project is available, please add the link/reference.
- Please mention other bibliography (previous works) that focus the SSF in your country (when available, please add the DOI)
- What is missing for SSF in your country?
- What are the challenges faced by SSF in your country?

A1.3 ANNEX 1c. Additional relevant information by country

Additional information provided directly by email is available upon request for the following countries.

Albania

Cyprus

Finland

Germany - North Sea

Germany - Baltic

Lithuania

Malta

Norway

Poland

Sicily

Sweden

Turkey

Greece

Annex 2 List and description of datasets used in the case studies

Link to [Shared Excel table \(live document\)](#)

Case studies	CS3			CS4		
Input data	Notebook 1	Notebook 2	Description	Notebook 1	Notebook 2	Description
SSF - Tracking devices	No			Yes	No	Aggregated fishing effort derived from high resolution
SSF - Participatory mapping	Yes		Aggregated fishing effort derived from digitized	Yes	Yes	Aggregated fishing effort derived from digitized
LSF - AIS	Yes		AIS data from GFW	Yes	No	See above
LSF - VMS	No			Yes	No	MASAF? (unit of measure = fishing days)
Remote sensing - Sentinel 2	Yes		data from GFW	Yes	Yes	See above
Bounding box	Yes		Area where SSF can potentially operate, manually	Yes	Yes	Area where SSF can potentially operate, manually
Grid	Yes		A grid standard called 'c-squares' has been used, and	Yes	Yes	The one used for the participatory mapping, with cell
Fishing capacity	No			No	Yes	Calculated from the EU Fleet Register, according to the
Fleet register	Yes		GFCM Fleet Register -	No	Yes	GFCM Fleet Register -
Bathymetry	Yes			No	Yes	See above
Ports	Yes			No	Yes	Polygons manually drawn for the Marche Region
Sea bottom substrates	No			No	Yes	See above

Annex 3 Results from Case Study 1 (Bivalve dredges Iberian Coast)

Combines Notebook 1 and 2 - [HTML document](#) (needs to be downloaded for viewing)

1 Overview
1.0.1 Load resources
2 Assessing the overage of different tracking instruments
3 Automatic Identification System (AIS) Data (Global Fishing Watch)
4 GPS Systems on SSF Vessels (Collected by IPMA)
5 Sentinel-2 Vessel Detections (Global Fishing Watch)
6 Capacity maps using neural networks
7 Maps of predictions

MAP-SSF: Mapping Small Scale Fisheries - Case Study 1 Iberian bivalve dredges

Code ▾

Rufino, M.M., Russo T, Marsaglia L

June 12, 2025

1 Overview

This notebook was elaborated to provide guidance in combining various sources of data during the MAP SSF workshop. In here, we will apply data to case study 1 (CS1), that corresponds to the Iberian Margin, bivalve dredges fishery.

1.0.1 Load resources

Show

[1] 171 6

Show

1 Overview
2 Assessing the overage of different tracking instruments
3 Automatic Identification System (AIS) Data (Global Fishing Watch)
4 GPS Systems on SSF Vessels (Collected by IPMA)
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7 Maps of predictions

2 Assessing the overage of different tracking instruments

In this section, we evaluate the spatial and temporal coverage of various vessel tracking instruments used to monitor fishing activity in the study area. Understanding the strengths and limitations of each data source is essential for assessing their effectiveness in capturing fishing effort, particularly for small-scale fisheries (SSF), which are often underrepresented in traditional tracking datasets. The instruments analyzed include:

- **Vessel Monitoring System (VMS):**
As this is **NOT AVAILABLE FOR PORTUGAL, by the group**, we have considered using AIS from GFW, instead, as an indicator effort from vessels above 15 m (the only that need to have AIS)
- **Automatic Identification System (AIS) Data (Global Fishing Watch):**
 - A global tracking system that provides frequent vessel position updates, enabling real-time monitoring.
 - Effective for large-scale commercial fleets but has **significant gaps** for SSF, as many smaller vessels are not equipped with AIS.
 - Can be used to validate and complement other datasets when cross-referenced with independent vessel detection sources.
- **GPS Systems on SSF Vessels (Collected by IPMA):**
 - High-resolution tracking data collected directly from small-scale fishing vessels.
 - Offers a more detailed view of SSF activity, including nearshore and seasonal fisheries that are often missing from AIS and VMS datasets.
 - Coverage is limited to the subset of vessels equipped with these devices, making representativeness a key consideration.
- **Sentinel-2 Vessel Detections (Global Fishing Watch):**
 - Derived from optical satellite imagery, providing a direct observation of vessel presence on the water.
 - Useful for detecting both AIS-equipped and non-AIS vessels, including those that operate without transponders.
 - Limited by cloud cover, revisit time, and image resolution, which may affect the detection of smaller SSF vessels.

By comparing these different tracking systems, we aim to assess their respective contributions to mapping fishing effort, identify potential biases, and explore how they can be integrated to improve the monitoring of fishing activity, particularly for SSF operations.

- 1 Overview
- 2 Assessing the overage of different tracking instruments
- 3 Automatic Identification System (AIS) Data (Global Fishing Watch)**
- 4 GPS Systems on SSF Vessels (Collected by IPMA)
- 5 Sentinel-2 Vessel Detections (Global Fishing Watch)
- 6 Capacity maps using neural networks
- 7 Maps of predictions

3 Automatic Identification System (AIS) Data (Global Fishing Watch)

Open the data provided by LUCA for AIS in Portugal, and plot the AIS data corresponding to the CFR licenses where we have the GPS trackers, i.e. dredge boats).

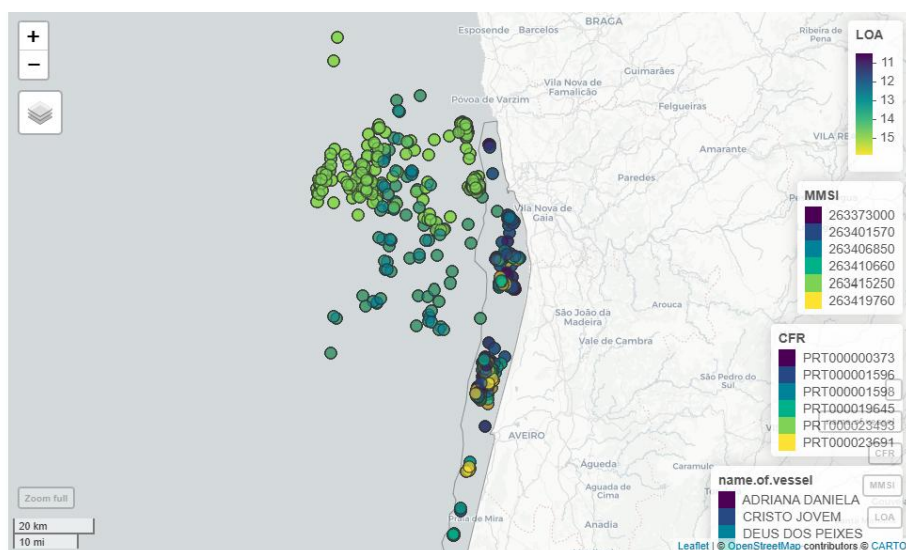
[1] "Number of records"

[1] 49400

Boats operating, with AIS
actively sending data (2020; PT,
bivalve dredge)

CFR	LOA	n
PRT000023691	10.50	89
PRT000019645	13.00	58
PRT000001596	14.00	84
PRT000023493	14.90	249
PRT000000373	15.40	65
PRT000001598	15.82	108
NA	NA	48747

- 1 Overview
- 2 Assessing the overage of different tracking instruments
- 3 Automatic Identification System (AIS) Data (Global Fishing Watch)**
- 4 GPS Systems on SSF Vessels (Collected by IPMA)
- 5 Sentinel-2 Vessel Detections (Global Fishing Watch)
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- 7 Maps of predictions



1 Overview

2 Assessing the overage of different tracking instruments

3 Automatic Identification System (AIS) Data (Global Fishing Watch)

4 GPS Systems on SSF Vessels (Collected by IPMA)

5 Sentinel-2 Vessel Detections (Global Fishing Watch)

6 Capacity maps using neural networks

7 Maps of predictions

fish_area	fdays	n
<fct>	<dbl>	<int>
Matosinhos_Nazare	1	124
Matosinhos_Nazare	2	39
Matosinhos_Nazare	3	23
Matosinhos_Nazare	4	6
Matosinhos_Nazare	5	2
Matosinhos_Nazare	6	2
Matosinhos_Nazare	7	1

7 rows

Show

[1] "How many squares have information inside fishing grounds?"

Show

fish_area	n
<fct>	<int>
Matosinhos_Nazare	197

1 row

1 Overview

2 Assessing the overage of different tracking instruments

3 Automatic Identification System (AIS) Data (Global Fishing Watch)

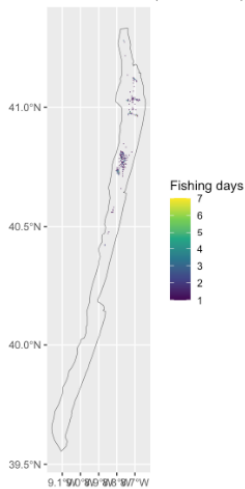
4 GPS Systems on SSF Vessels (Collected by IPMA)

5 Sentinel-2 Vessel Detections (Global Fishing Watch)

6 Capacity maps using neural networks

7 Maps of predictions

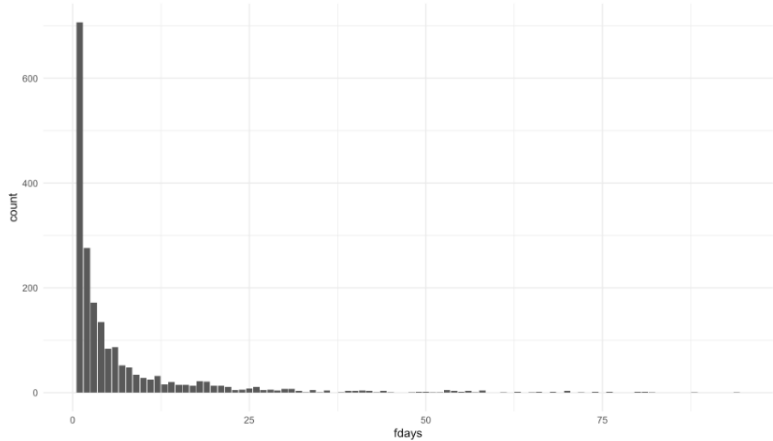
AIS GFW data (for all boats)



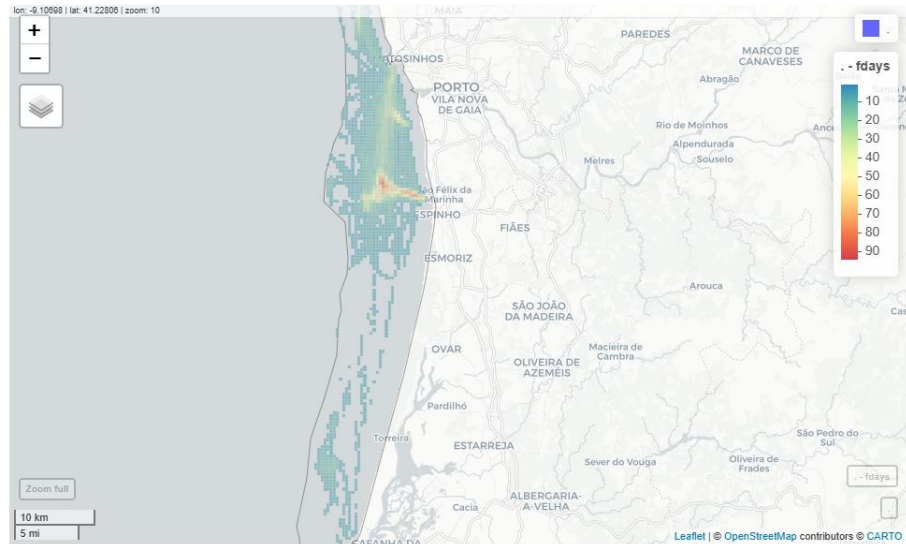
4 GPS Systems on SSF Vessels (Collected by IPMA)

- open data from IPMA (grid resolution 500 m, modelled following Rufino et al. 2023).
- data is pooled (summed) for year 2020.
- the indicator considered was the number of days fishing (n.days.fishing, fdays afterwards), to be compatible with other estimates, for the current CS.

fdays distribution by grid cell, from CS1 (bivalve dredges)

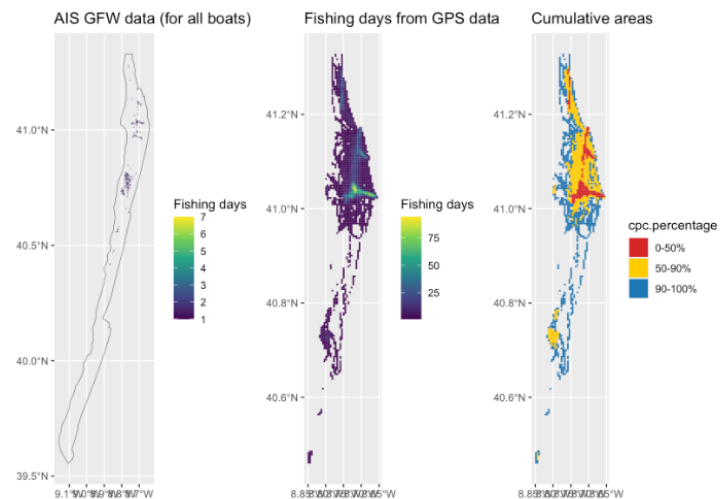


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[1] "Matosinhos_Nazare"

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5 Sentinel-2 Vessel Detections (Global Fishing Watch)

The next step is the analysis of the data from Sentinel 2. We will split this dataset into two blocks: one counting only detections with a match with AIS data, and one with detections without a match with AIS data.

5.1 Sentinel-2 all Vessel Detections (Global Fishing Watch)

Show

[1] "Initial matrix with data from all countries"

Show

[1] 792558 19

Show

[1] "Filter for Portugal (2020, all vessels)"

Show

[1] 15970 7

Show

[1] "From these, with MMSI (from EFR_PRT):"

Show

[1] 4997

Show

[1] "From these, no MMSI (from EFR_PRT):"

If we were using Sentinel data from 2023 only, for Portugal, there are 17991 detections, from which 11 837 have MMSI associated and 6 154.

5.2 Sentinel 2, data with AIS-MMSI (should represent LSF?)

Show

[1] 4997 3

Show

[1] "Dim after adding to the grid:"

Show

[1] 287 2

Show

[1] "Data aggregated by grid cell"

Show

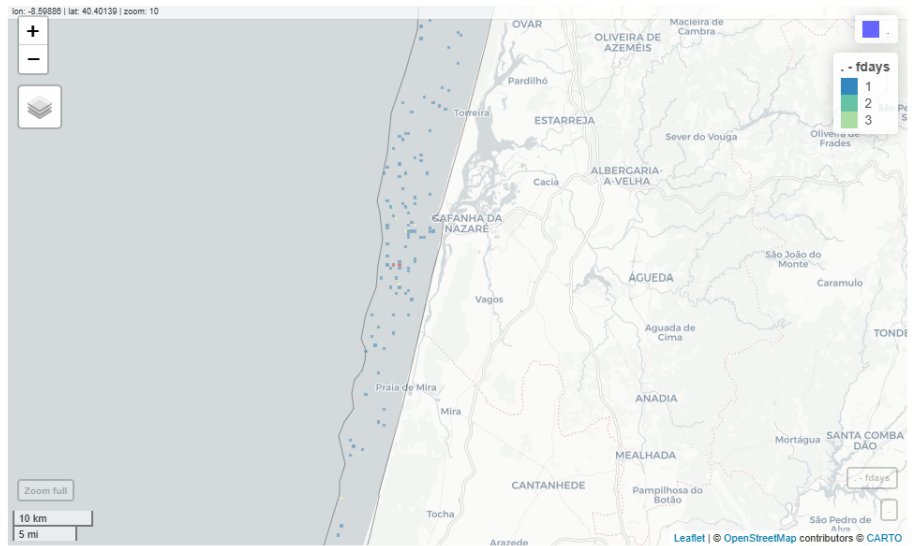
[1] 261 2

Show

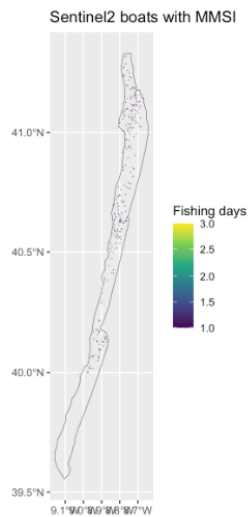
Number of detections with MMSI in S2	
fdays	Matosinhos_Nazare
1	238
2	20
3	3

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5.3 Sentinel 2, data with no AIS-MMSI (should represent SSF?)

## [1]	18973	4
--------	-------	---

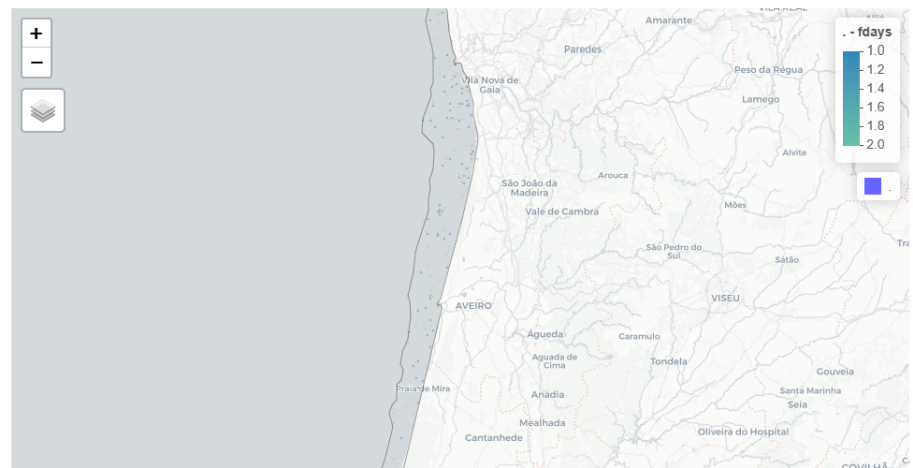
Show

## [1]	263	2
--------	-----	---

Show

## [1]	263	14
--------	-----	----

Show



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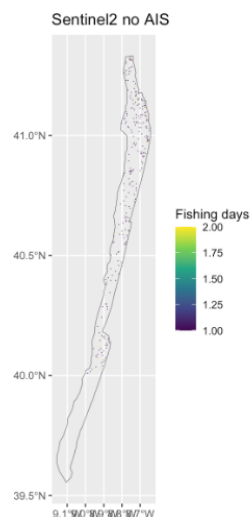
## [1]	"Number of detections with MMSI in S2"	
--------	--	--

Show

fish_area	fdays	n
<fct>	<dbl>	<int>
Matosinhos_Nazare	1	247
Matosinhos_Nazare	2	16

2 rows

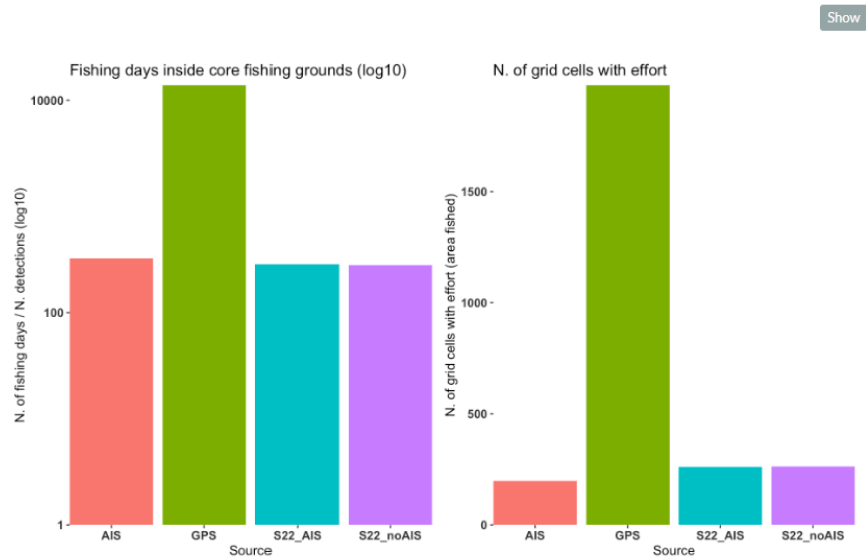
Show



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5.4 Combining all instruments

Compare number of fishing days by source, inside fishing ground polygon and number of grid cells with effort allocated (note the plot is in log).



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- 6 Capacity maps using neural networks**
 - 6.1 MSE trends
 - 6.2 R2
 - 6.3 Sensitivity Analysis
 - 6.4 Confusion matrix
- 7 Maps of predictions

6 Capacity maps using neural networks

```
## Joining with `by = join_by(name)`
```

```
## [1] "nazare, figueira da foz, aveiro, matosinhos, povoa do varzim"
```

```
## Joining with `by = join_by(harbour)`
```

```
## Joining with `by = join_by(ID)`
```

Each code block is followed by a 'Show' button.

This chunk I will not evaluate it - it took me a couple of hours, thus, I saved the resulting data in the file chih I will open when needed.

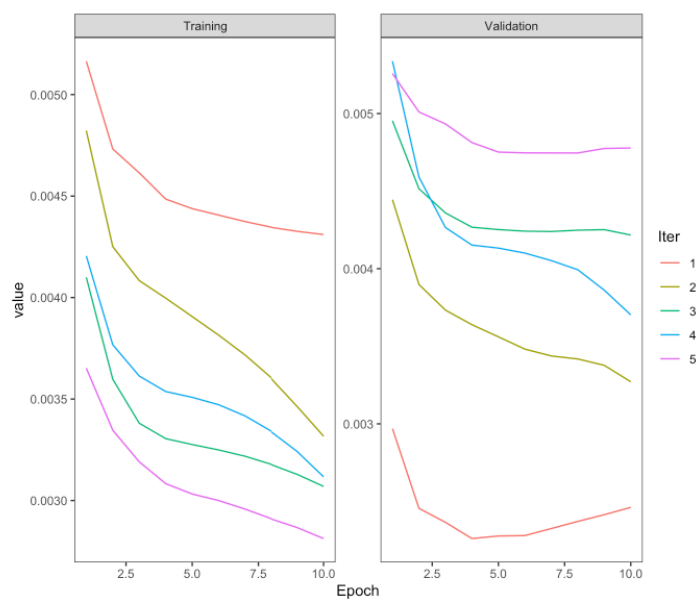
Here we set the parameters of the training phase and train the MPN. All the useful data are appropriately stored in a series of lists

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6.1 MSE trends

First of all, let's inspect the MSE trends during the training

Show

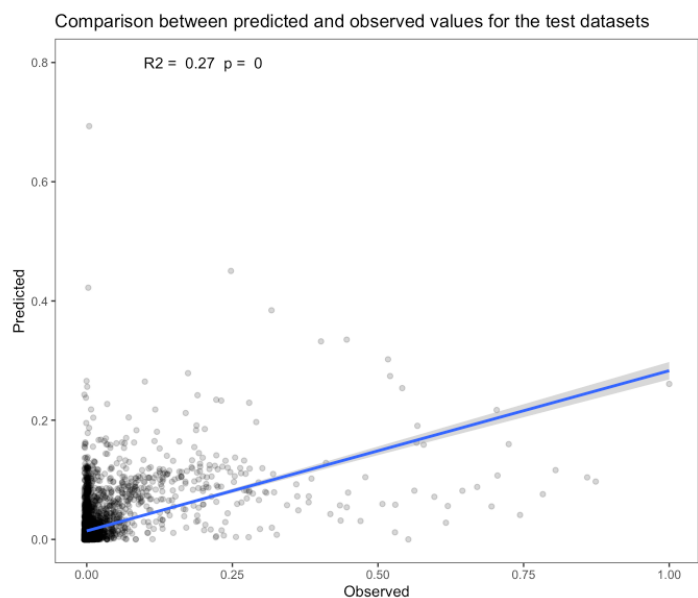


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6.3 Sensitivity Analysis
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6.2 R2

We can inspect the results of the training phase by comparing the predicted and observed values for the test dataset.

Show

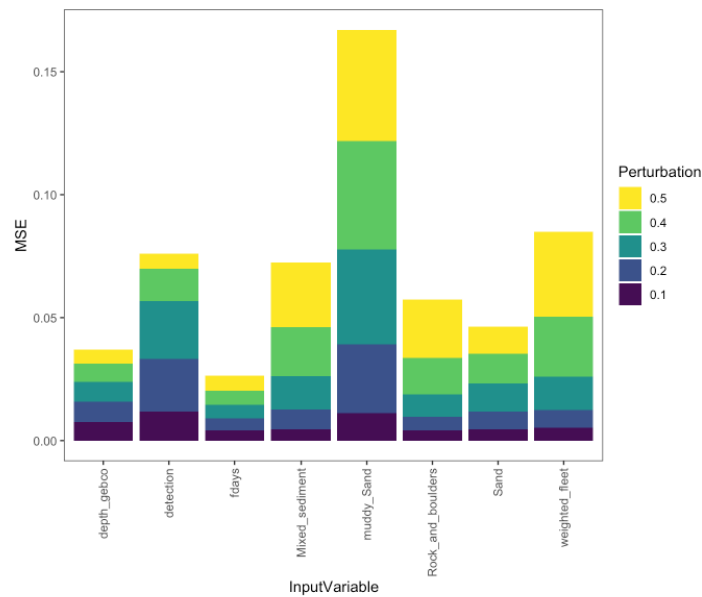


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6.3 Sensitivity Analysis

The last step is the Sensitivity Analysis

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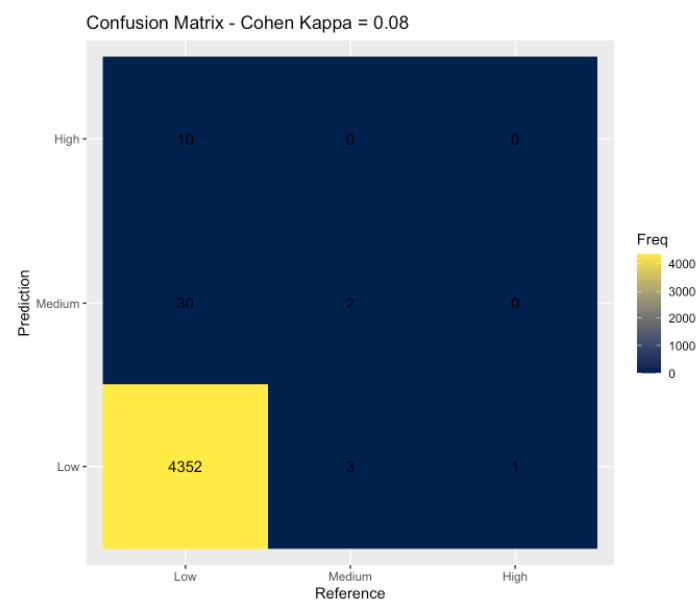
6.4 Confusion matrix

A confusion matrix is an useful tool to inspect the results and assess the predictive power of the MPN on the test dataset. Here we classified the effort in Low, Medium, High levels. The Cohen's Kappa index is used to compare predicted and observed values.

Show

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction  Low Medium High
##      Low   4352    30   10
##      Medium    3     2    0
##      High     1     0    0
##
## Overall Statistics
##
##           Accuracy : 0.99
##           95% CI : (0.9866, 0.9927)
##      No Information Rate : 0.9905
##      P-Value [Acc > NIR] : 0.6588
##
##           Kappa : 0.0815
##
##      McNemar's Test P-Value : NA
##
## Statistics by Class:
##
##           Class: Low Class: Medium Class: High
## Sensitivity           0.99908      0.0625000      0.0000000
## Specificity           0.04762      0.9993129      0.9997721
## Pos Pred Value        0.99089      0.4000000      0.0000000
## Neg Pred Value        0.33333      0.9931710      0.9977257
## Prevalence            0.99045      0.0072760      0.0022738
## Detection Rate        0.98954      0.0045480      0.0000000
## Detection Prevalence  0.99864      0.0011369      0.0002274
## Balanced Accuracy      0.52335      0.5309064      0.4998861
```

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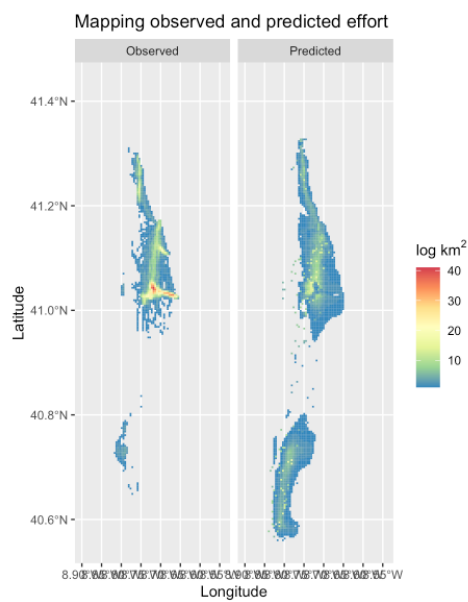


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7 Maps of predictions

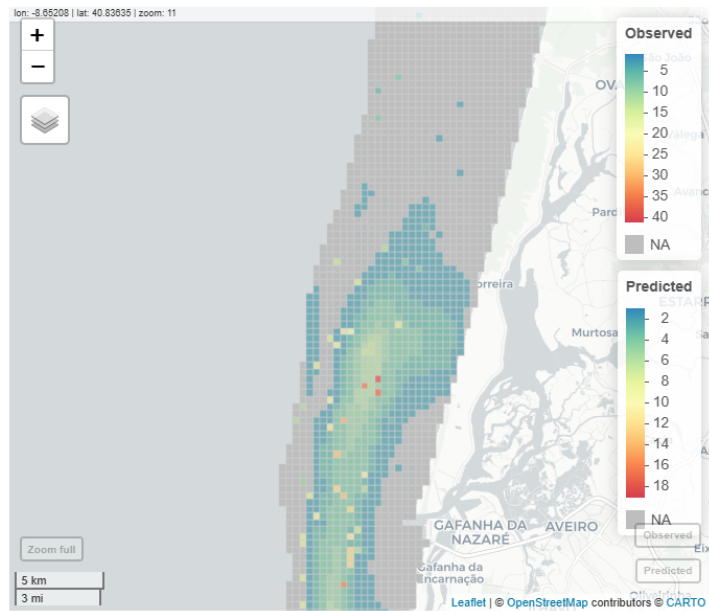
Finally, we can plot the results as maps.

Show



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Annex 4 Results from Case Study 2 (Basque Country Region, Cantabrian Sea)

Notebook 1 - [HTML document](#) (needs to be downloaded for viewing)

1 Overview
2 Load resources
3 Processing AIS Class B
4 Assessing the coverage of different tracking instruments

MAP-SSF: Mapping Small Scale Fisheries - Case Study 2 Basque Country

Code ▾

Mateo M., Russo T, Marsaglia L
junio 12, 2025

1 Overview

This notebook was elaborated to provide guidance in combining various sources of data during the MAP-SSF workshop. In here, we will apply data to case study 2 (CS2), that corresponds to the Basque Margin of the Cantabrian Sea, multi-gear fishery.

2 Load resources

The first step would be to load information specific to the case study such as the registry where fishing vessels are registered, in this case the General Fishing Fleet Register (MAPA ministry). As the MMSI isn't indicated in this registry, the EU Fleet Register is also used. A grid is created using the bounding box of the area to aggregate the data on and the others shapefiles such as land and the bounding box.

3 Processing AIS Class B

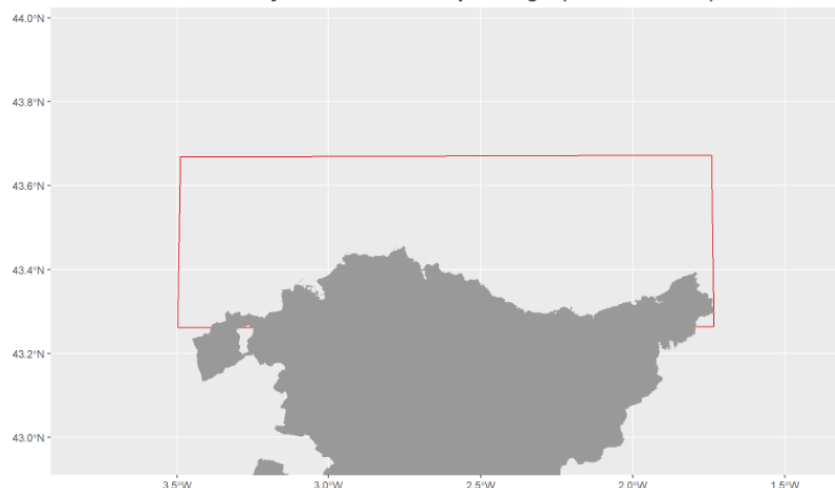
For Case Study No. 2, the study area is the Basque Region in the Cantabrian Sea, and the AIS Class B data were provided by AZTI. These data serve as the primary source for identifying fishing grounds in this analysis. Using AIS Class B data as a starting point for mapping fishing areas offers several advantages:

- **High Resolution and Accuracy** – AIS Class B data provides high-resolution tracking of vessel movements, allowing for precise identification of fishing activities and locations.
- **Comprehensive Coverage** – AIS Class B covers those vessels that voluntarily install AIS equipment. This provides a more comprehensive view of fishing activities compared to other methods that might miss smaller or less regulated vessels, offering a more detailed view of SSF activity. The coverage is limited to the subset of vessels equipped with these devices, making representativeness a key consideration.
- **Integration with Other Data Sources** – AIS data can be linked with other official data sources such as logbooks and sales notes to provide a more complete picture of fishing activities. This integration helps in associating fishing gears and landings with AIS pings, enhancing the accuracy of the data.
- **Behavioral Insights** – AIS data allows for the analysis of vessel behavior, such as speed profiles and movement patterns, which can be used to distinguish between different fishing activities and states (e.g., steaming, actively fishing, maneuvering).
- **Real-Time Data**

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Case Study 2 - SSF in the Basque Margin (Cantabrian Sea)



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3.1 AIS Class B on SSF Vessels (Collected by AZTI)

The first step of the analysis is the loading and pre-processing of the data collected.

The AIS Class B data have been previously cleaned (removal of points on land and port and anomalous values in speed and ping rate). The signals come from 23 vessels less than 15 meters in length that voluntarily installed AIS Class B devices.

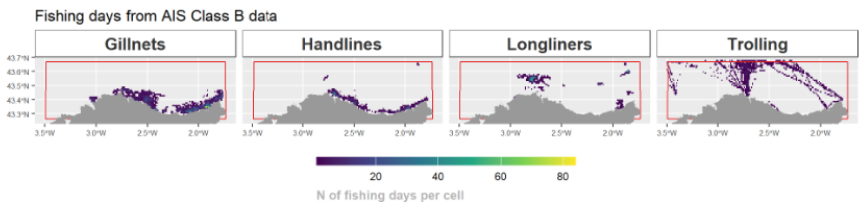
The fishing gear used in Class B AIS data refers to the information reported in logbooks and/or sales notes by combining both data sources through vessels and dates.

This data will be our reference for subsequent analysis. The manipulation steps of the data are the following:

- **Load the AIS Class B dataset** containing fishing events.
- **Crop the dataset** to match the predefined study area (`area_box`) to focus the analysis on the relevant region.
- **Convert the spatial data into a non-spatial format** to facilitate further manipulation and analysis.
- **Reshape the data into a long format** to standardize the representation of fishing effort across different métiers.
- **Recode métier classifications** to group similar fishing practices and improve interpretability.
- **Filter out irrelevant categories**, such as unknown or non-fishing activities, to refine the dataset.
- **Aggregate fishing effort data** by métier and grid cell to obtain a comprehensive view of fishing intensity.
- **Merge the processed data back with the spatial dataset**, ensuring that fishing effort is correctly linked to our grid

Now we can plot by Metier of level 4 (Gear). In the case of trolling, the vessels 'leave' the territorial waters following the schools of Albacore tuna.

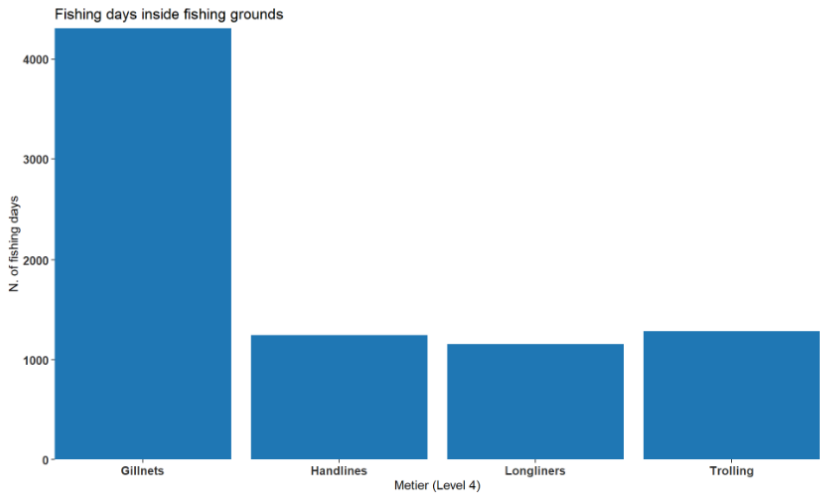
Show



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The fishing grounds by gear are defined as clusters of cells, taking into account all fishing events present in the AIS Class B data. These sets will be used to assess the coverage of the different tracking devices and to train the ANN-based model.

Then we compute the amount of effort in the fishing grounds from AIS Class B.



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4 Assessing the coverage of different tracking instruments

In this section, we evaluate the spatial and temporal coverage of various vessel tracking instruments used to monitor fishing activity in the study area. Understanding the strengths and limitations of each data source is essential for assessing their effectiveness in capturing fishing effort, particularly for small-scale fisheries (SSF), which are often underrepresented in traditional tracking datasets. The instruments analyzed include:

- **Vessel Monitoring System (VMS):**
 - Primarily used for monitoring larger commercial fishing vessels.
 - Provides periodic position reports (typically every 1-2 hours), making it suitable for tracking long-duration fishing operations but potentially missing fine-scale movements.
 - Limited applicability for SSF vessels, as many are not required to carry VMS transmitters.
- **Sentinel-2 Vessel Detections (Global Fishing Watch):**
 - Derived from optical satellite imagery, providing a direct observation of vessel presence on the water.
 - Useful for detecting both AIS-equipped and non-AIS vessels, including those that operate without transponders.
 - Limited by cloud cover, revisit time, and image resolution, which may affect the detection of smaller SSF vessels.
- **Automatic Identification System (AIS) Data (Global Fishing Watch):**
 - A global tracking system that provides frequent vessel position updates, enabling real-time monitoring.
 - Effective for large-scale commercial fleets but has **significant gaps** for SSF, as many smaller vessels are not equipped with AIS.
 - Can be used to validate and complement other datasets when cross-referenced with independent vessel detection sources.

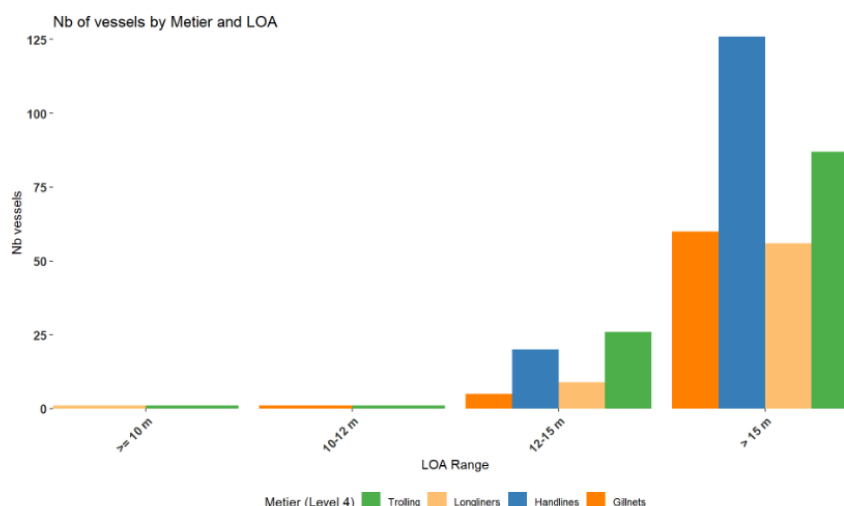
By comparing these different tracking systems, we aim to assess their respective contributions to mapping fishing effort, identify potential biases, and explore how they can be integrated to improve the monitoring of fishing activity, particularly for SSF operations.

4.1 Vessel Monitoring System (VMS)

LOA_Range	MMSI	percentage
<chr>	<int>	<dbl>
10-12 m	1	0.4424779
12-15 m	27	11.9469027
> 15 m	197	87.1681416
>= 10 m	1	0.4424779

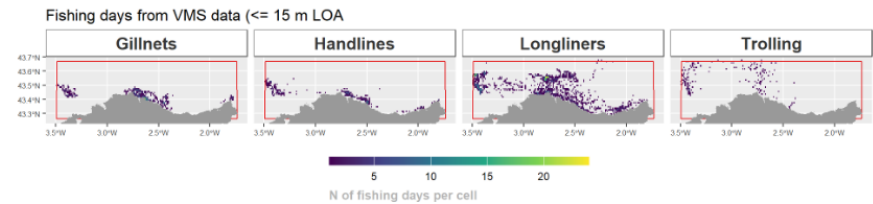
4 rows

The fishing gear used in VMS data refers to the information reported in logbooks by combining both data sources through vessels and dates. Due to the exception in regulation EC No 1224/2009, vessels with an overall length of less than 15 meters do not need to use VMS devices if they undertake fishing trips of less than 24 hours and operate exclusively in the territorial waters of the Member State. We can observe that only 12.83% of the vessels < 15 m use these devices.



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Therefore, since most of the activity in this data source comes from vessels over 15m LOA, we removed these vessels from the data set in order to combine the results with those from the AIS Class B reference data.



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4.2 Sentinel-2 Vessel Detections (Global Fishing Watch)

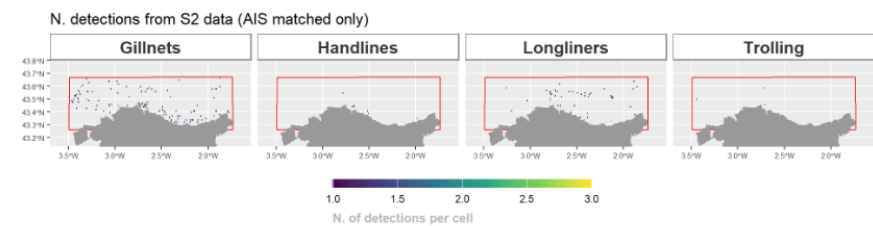
The next step is the analysis of the data from Sentinel 2. We will split this dataset into two blocks: one counting only detections with a match with AIS data, and one with detections without a match with AIS data.

In the 'EU Fleet Register', the main fishing gear is specified, which can change depending on the season. Therefore, the main fishing gear registered in the 'EU Fleet Register' has been used first, then this information has been updated with the fishing gear reported in logbooks and/or sales notes (currently available in VMS and AIS Class B data). The link has been made by MMSI and UTC variables."

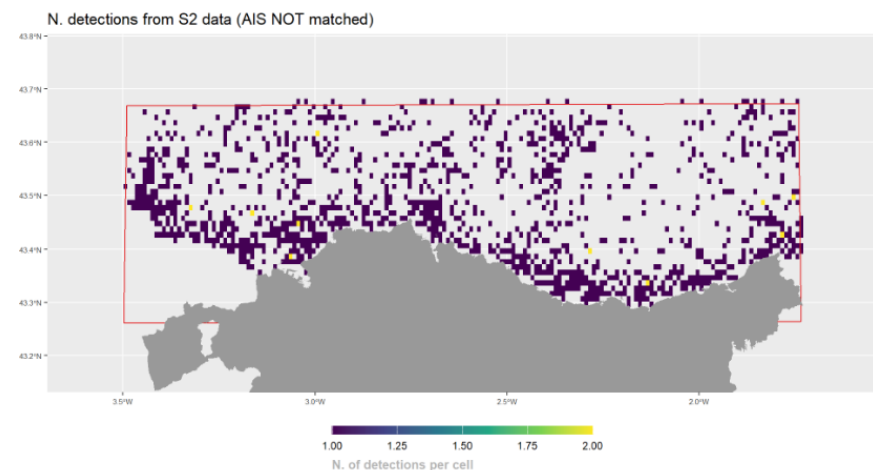
Show

The main problem of this source of data is that 75.75% of the dataframe doesn't contain MMSI!!!

Show



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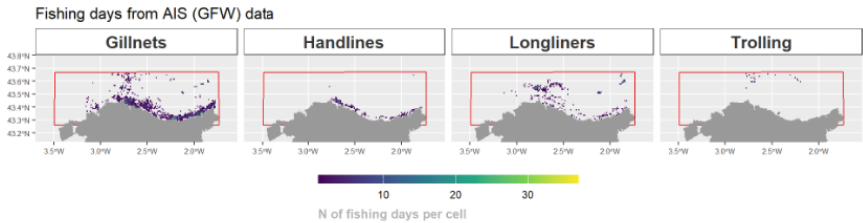


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4.3 Automatic Identification System (AIS) Data (Global Fishing Watch)

We have used the same filter as for the VMS, removing from this data source those vessels larger than 15 m LOA.

As in the previous case, the main fishing gear registered in the 'EU Fleet Register' has been used first, then this information has been updated with the fishing gear reported in logbooks and/or sales notes (currently available in VMS and AIS Class B data). The link has been made by MMSI and UTC variables."

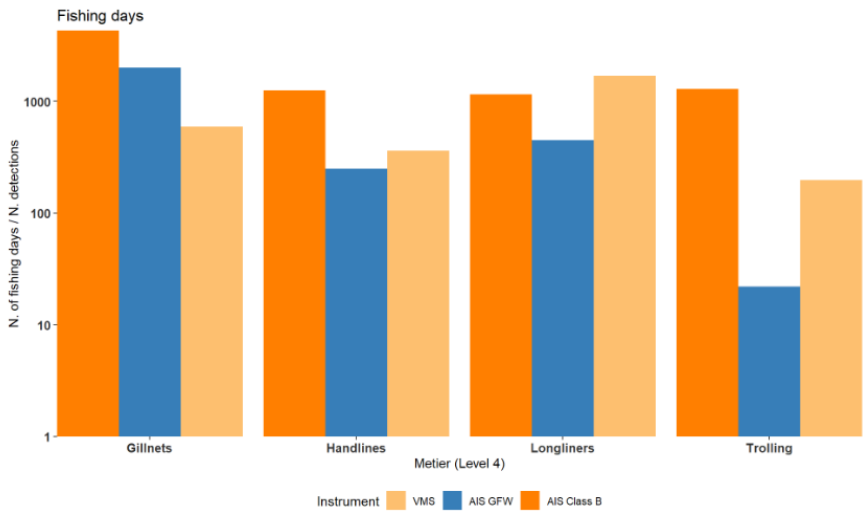


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4.4 Combining all instruments

We can now compare the effort (as number of fishing days or detections of vessels) broken down by fishing gear and by data source or instrument. Note: a logarithmic scale is used.

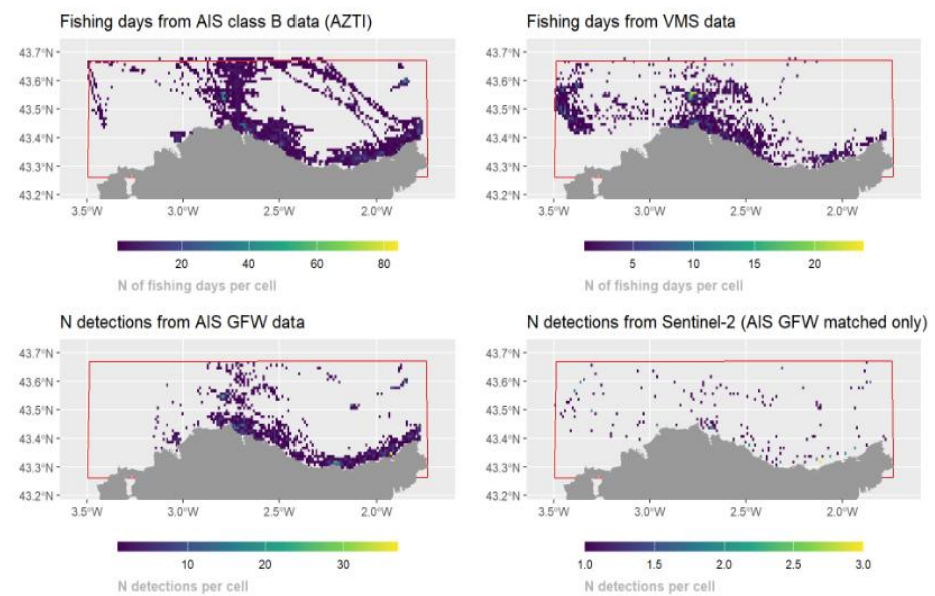
Show



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We can also map the total effort estimated as fishing days or number of detection of vessels from all the data sources or instruments used in this case study.

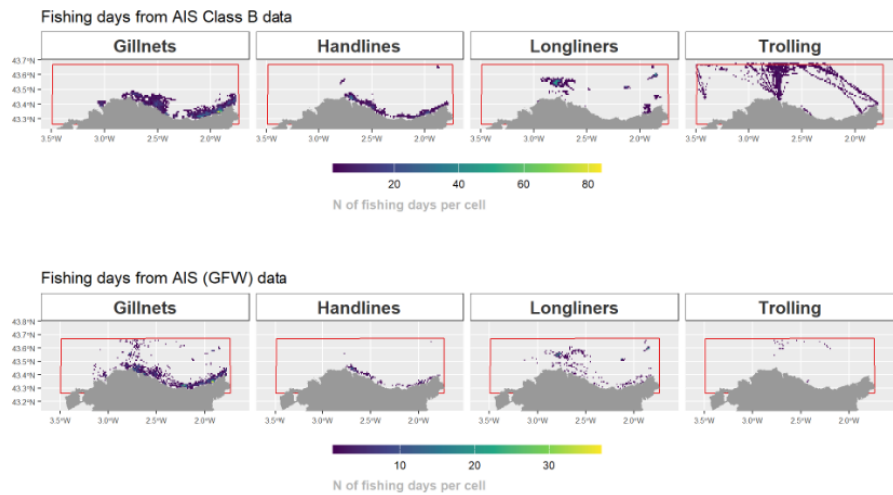
Show



Finally, since two different AIS data sources are used, we can map them together and check the results.

Show

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Annex 5 Results from Case Study 3 (Murcia)

Notebook 1 - [HTML document](#) (needs to be downloaded for viewing)

1 Overview
2 Load resources
3 Processing questionnaires data
4 Assessing the coverage of different tracking instruments

MAP-SSF: Mapping Small Scale Fisheries - Case Study 3: Murcia-Alicante

Russo T, Marsaglia L
mayo 09, 2025

Code ▾

1 Overview

This notebook was elaborated to provide guidance in combining various sources of data during the MAP-SSF workshop. This case study analyzes the small-scale fishery in a region located in the southeastern part of Spain, specifically covering the Region of Murcia and the southern area of Alicante.

This case study aims to contribute to the project's objectives by exploring and developing the potential of questionnaires as a tool to enhance knowledge and understanding of the spatial distribution and dynamics of small-scale fisheries.

The data analysed in the case study comes from questionnaires, AIS and Sentinel 2 data.

2 Load resources

The first step would be to load information specific to the case study such as the registry where fishing vessels are registered, in this case the General Fisheries Commission of the Mediterranean (GFCM) Authorised Vessel List is used. But also loading a grid that will be used to aggregate the data on and the others shapefiles such as land and the bounding box.

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3 Processing questionnaires data

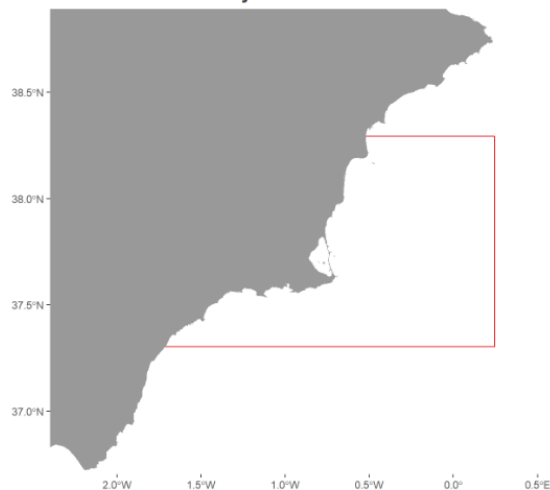
For Case Study No. 3, the study area is the South of Alicante and the region of Murcia in the Western-Mediterranean Sea, and the questionnaire data were provided by the fisherman. These data serve as the primary source for identifying fishing grounds in this analysis. Using questionnaire data as a starting point for mapping fishing areas offers several advantages:

- **Fisher Knowledge and Experience** – Fishers possess deep, long-term knowledge of their fishing areas, which may not always be captured by technological tracking methods. They provide historical and seasonal insights that AIS or S2 data might miss, especially for small-scale fisheries that do not always use tracking devices.
- **Coverage of Non-Tracked Vessels** – Many fishing vessels, particularly those below a certain size threshold, are not required to carry GPS, AIS or VMS. Questionnaire data help fill this gap by capturing the activities of these vessels, which are significant contributors to regional fisheries.
- **Spatial and Temporal Detail** – Fishers can describe fishing grounds with high spatial resolution, identifying areas of concentrated effort, gear-specific usage, and habitat preferences. They also provide insights into temporal variations, such as seasonal shifts in fishing grounds due to species movements or regulatory changes.
- **Validation and Ground-Truthing** – Combining questionnaire data with remote sensing or AIS-based fishing detection allows for cross-validation. Areas identified by fishers can be compared with observed fishing effort from tracking data or satellite, helping to refine and improve fishing ground maps.
- **Social and Economic Context** – Beyond spatial data, questionnaires provide valuable context about fishing behavior, target species, economic drivers, and regulatory constraints. This information is essential for understanding not just *where* fishing occurs, but *why* certain areas are more intensively used.

In the case of the Case Study 3, using questionnaire data from fishers ensures that local fishers' expertise is incorporated into the analysis. It also provides an initial dataset that can be refined and cross-checked with other sources, such as AIS, S2, or onboard observations, to improve the accuracy and representativeness of the mapped fishing areas.

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Case Study 4 - SSF in Murcia - Alicante



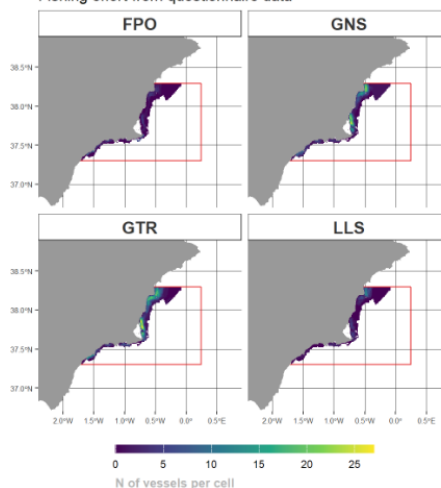
Show

The first step of the analysis is the loading and pre-processing of the data collected through the questionnaires. This data will be our reference for subsequent analysis. The manipulation steps of the questionnaire data are the following:

- Load the questionnaire dataset containing gridded polygons representing fishing activity.
- Crop the dataset to match the predefined study area (`area_box`) to focus the analysis on the relevant region.
- Convert the spatial data into a non-spatial format to facilitate further manipulation and analysis.
- Reshape the data into a long format to standardize the representation of fishing effort across different métiers.
- Recode métier classifications to group similar fishing practices and improve interpretability.
- Filter out irrelevant categories, such as unknown or non-fishing activities, to refine the dataset.
- Aggregate fishing effort data by métier and grid cell to obtain a comprehensive view of fishing intensity.
- Merge the processed data back with the spatial dataset, ensuring that fishing effort is correctly linked to our grid

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Fishing effort from questionnaire data



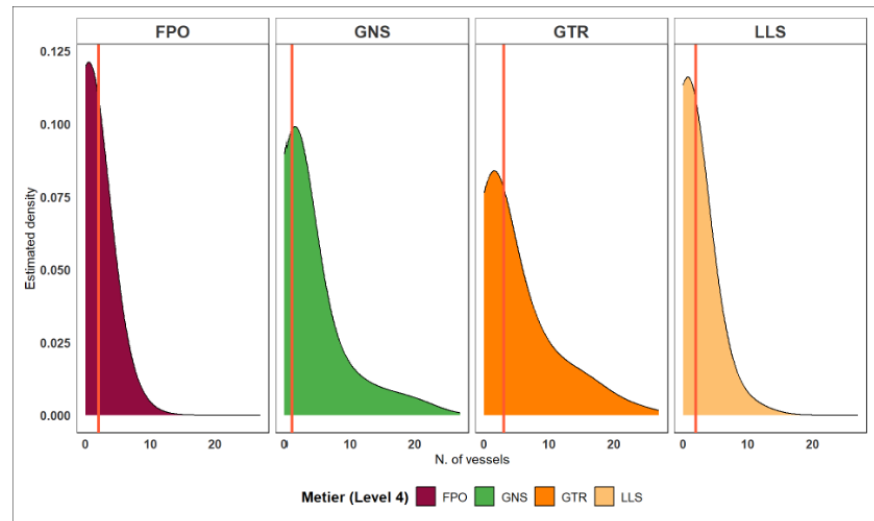
Show

In this maps we can see the effort distribution (in number of vessels per cell) of the selected fishing gears. GNS (gillnets) and GTR (trammel nets) gears generate the most effort, especially around the main ports.

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Now, for each gear, it is possible to explore the distribution of the effort in number of vessels, in this case we are using `geom_density()` function in `ggplot2` creates a kernel density estimate (KDE), which is a smoothed version of a histogram. It estimates the probability density function (PDF) of a continuous variable, essentially showing how the data is distributed across a continuous range.

Show



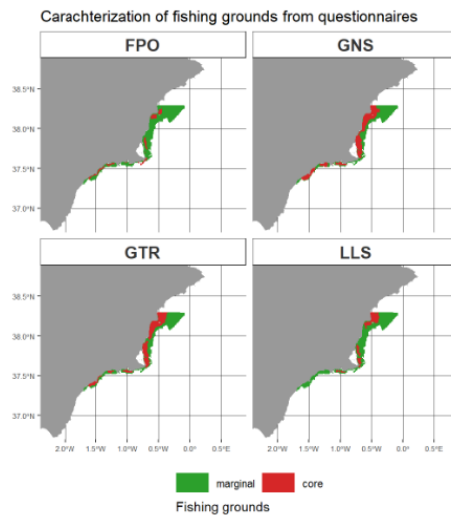
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Highest density estimates correspond with a few number of vessels, 1-2 vessels, for all gears. For FPO and LLS the estimated density decreases rapidly as the number of vessels increases, while GTR and GNS show greater variability in the number of vessels operating with these gears.

We can also use a simple quantile-based rule to identify the core-fishing grounds by gear. This will be used in the next section to assess coverage of different tracking devices

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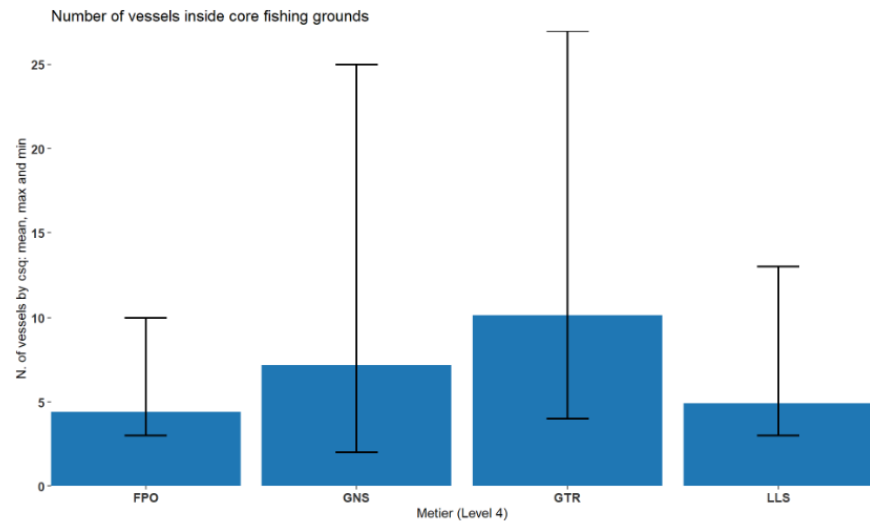
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The data from the CS3 Murcia case study is the number of vessels instead of fishing days. Therefore we believe it may be appropriate to use a higher `qcore` range to include almost 0 to 2 vessels as 'marginal' and classify 3 vessels and above as 'core'. We have tested with `qcore=0.4` and the results are more consistent, as shown in the plot above. The maps show that the greatest effort for GNS and GTR is found practically in the shallower area all along the coast. Whereas for FPO and LLS the greatest effort is found around the main ports.

The core fishing grounds by gear are defined as clusters of cells. These core sets will be used to assess the coverage of the different tracking devices and to train the ANN-based model.

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Then we compute the amount of effort in the core fishing grounds from questionnaires



GTR and GNS are the most widely used gears, showing both the highest average number of vessels operating across the c-squares of the core fishing grounds and the highest maximum number of vessels recorded in at least one of those c-squares

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4 Assessing the coverage of different tracking instruments

In this section, we evaluate the spatial and temporal coverage of various vessel tracking instruments used to monitor fishing activity in the study area. Understanding the strengths and limitations of each data source is essential for assessing their effectiveness in capturing fishing effort, particularly for small-scale fisheries (SSF), which are often underrepresented in traditional tracking datasets. The instruments analyzed include:

- **Vessel Monitoring System (VMS):**
 - Primarily used for monitoring larger commercial fishing vessels.
 - Provides periodic position reports (typically every 1-2 hours), making it suitable for tracking long-duration fishing operations but potentially missing fine-scale movements.
 - Limited applicability for SSF vessels, as many are not required to carry VMS transmitters.
- **GPS Systems on SSF Vessels (Collected by CNR):**
 - High-resolution tracking data collected directly from small-scale fishing vessels.
 - Offers a more detailed view of SSF activity, including nearshore and seasonal fisheries that are often missing from AIS and VMS datasets.
 - Coverage is limited to the subset of vessels equipped with these devices, making representativeness a key consideration.
- **Sentinel-2 Vessel Detections (Global Fishing Watch):**
 - Derived from optical satellite imagery, providing a direct observation of vessel presence on the water.
 - Useful for detecting both AIS-equipped and non-AIS vessels, including those that operate without transponders.
 - Limited by cloud cover, revisit time, and image resolution, which may affect the detection of smaller SSF vessels.
- **Automatic Identification System (AIS) Data (Global Fishing Watch):**
 - A global tracking system that provides frequent vessel position updates, enabling real-time monitoring.
 - Effective for large-scale commercial fleets but has **significant gaps** for SSF, as many smaller vessels are not equipped with AIS.
 - Can be used to validate and complement other datasets when cross-referenced with independent vessel detection sources.

By comparing these different tracking systems, we aim to assess their respective contributions to mapping fishing effort, identify potential biases, and explore how they can be integrated to improve the monitoring of fishing activity, particularly for SSF operations.

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4.1 Sentinel-2 Vessel Detections (Global Fishing Watch)

The next step is the analysis of the data from Sentinel 2. We will split this dataset into two blocks: one counting only detections with a match with AIS data, and one with detections without a match with AIS data.

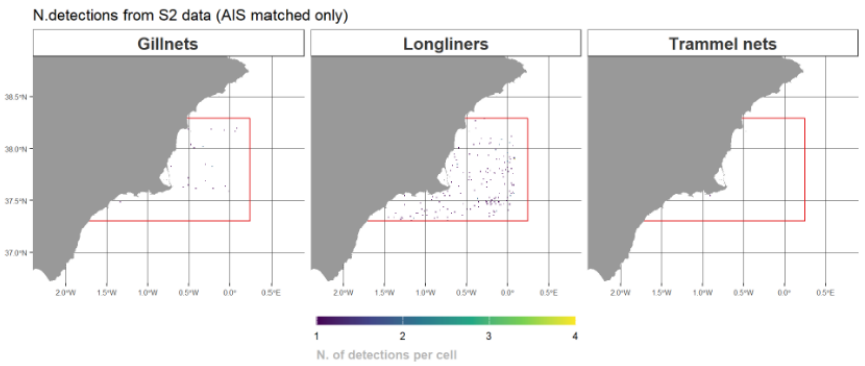
Show

```
##
##          Beam trawls          Drifting longlines
##          6191              1070
##   Gear Not Known or Not Specified   Midwater pair trawls
##          150              5974
##          Purse seines          Set gillnets (anchored)
##          1676              139
##          Set longlines   Single boat bottom otter trawls
##          211              34984
##   Single boat midwater otter trawls Surrounding nets without purse lines
##          228              8
##          Trammel nets          Traps (nei)
##          3              1
##          Twin bottom otter trawls
##          1380
```

Show

```
##
##          Drifting longlines          Purse seines
##          199              127
##   Set gillnets (anchored)   Single boat bottom otter trawls
##          23              5298
##          Trammel nets
##          1
```

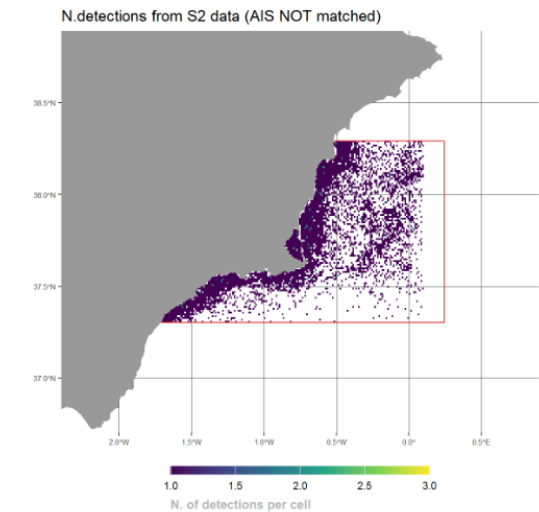
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This section presents the number of detections from S2 data that match AIS signals within the study area. Longlines show the highest number of matches, followed by gillnets. Trammel nets have very limited matching data, while no matches were found for pots.

Show



Show

The number of detections per cell that do not match any AIS vessel is much higher than the number of detections that do match. Possibly due to the fact that most SSF vessels do not have AIS.

In the Murcia case study we focused on the refinement of the questionnaires as main data source, there is no VMS or GPS data available to be matches with AIS data.

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4.2 Automatic Identification System (AIS) Data (Global Fishing Watch)

Show

```
## [1] 238
```

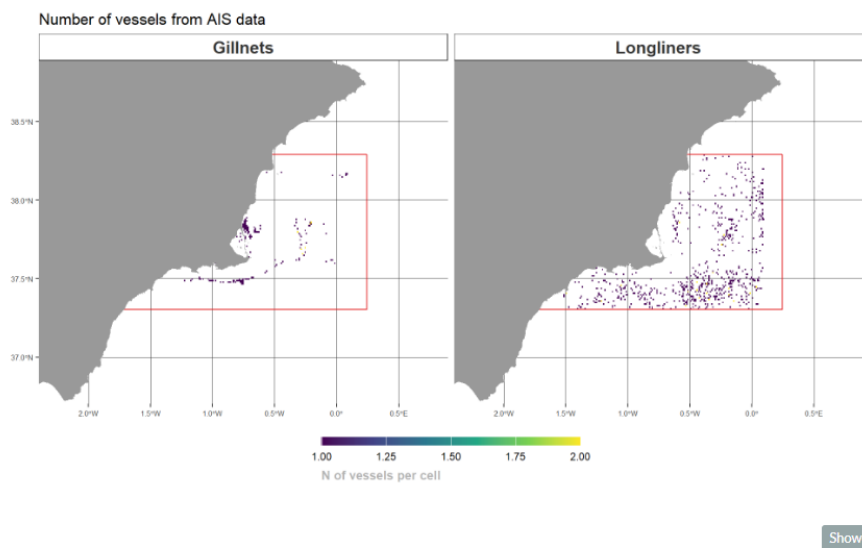
Show

```
## [1] 238
```

Show

##		
##	Drifting longlines	Purse seines
##	805	2487
##	Set gillnets (anchored)	Single boat bottom otter trawls
##	252	11978
##	Twin bottom otter trawls	<NA>
##	9	1672

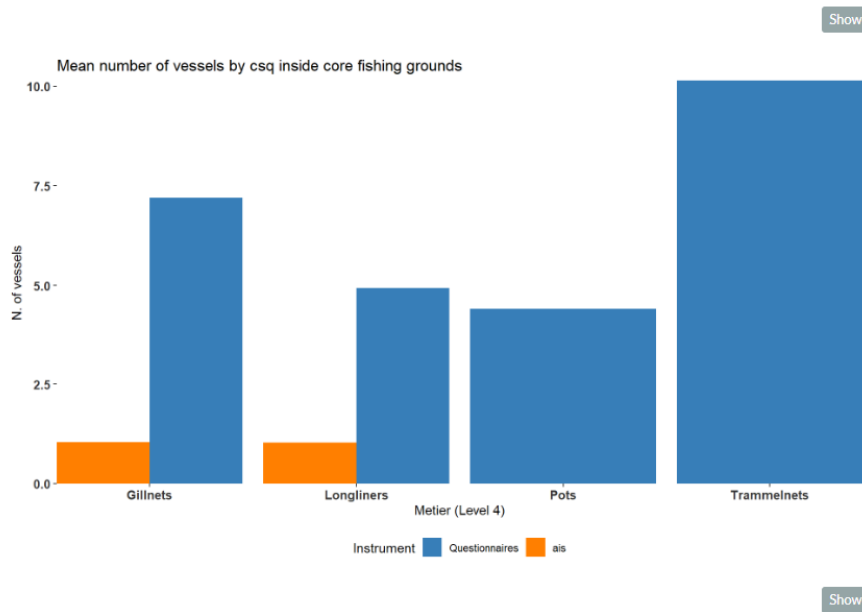
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The number of vessels using either gear type is very low within the study area, but their spatial distribution differs. Based on the depth of the detected activity (and distance to coast), most of these AIS detections occur in deep waters where the small-scale fleet does not operate.

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4.3 Combining all instruments



For CS3 in Murcia, it's not feasible to directly compare number of vessels from questionnaires versus number versus AIS. For CS3 we have used the mean number of vessels along the csquares of the core fishing ground for each gear. Not being directly comparable either, we can see the pattern is different: In the survey data, there is a greater number of vessels using nets (trammel nets (GTR) and gillnets (GNS)) followed by longlines (LLS) and pots (FPO).

Annex 6 Results from Case Study 4 (CS4 Marche Region, Adriatic Sea)

Notebook 1 - [HTML document](#) (needs to be downloaded for viewing)

1 Overview
2 Load resources
3 Processing questionnaires data
4 Assessing the coverage of different tracking instruments

MAP-SSF: Mapping Small Scale Fisheries - Case Study 4 Adriatic Sea

Code ▾

Russo T, Marsaglia L

May 15, 2025

1 Overview

This notebook was elaborated to provide guidance in combining various sources of data during the MAP-SSF workshop

2 Load resources

The first step would be to load information specific to the case study such as the registry where fishing vessels are registered, in this case the General Fisheries Commission of the Mediterranean (GFCM) Authorised Vessel List is used. But also loading a grid that will be used to aggregate the data on and the others shapefiles such as land and the bounding box.

1. Loading the GFCM Fleet Register
2. Loading the area_box - polygon defining the area where SSF can operate
3. Creating a grid from the area_box (1kmx1km cell) - this grid will be used if gridded effort from questionnaires is not available
4. Loading the land

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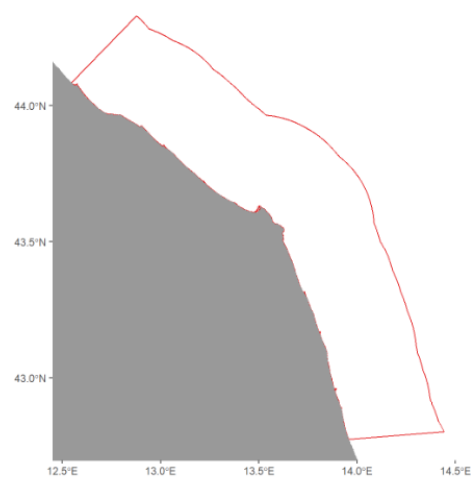
3 Processing questionnaires data

For Case Study No. 4, the study area is the Marche Region in the Adriatic Sea, and the questionnaire data were provided by CNR. These data serve as the primary source for identifying fishing grounds in this analysis. Using questionnaire data as a starting point for mapping fishing areas offers several advantages:

- **Fisher Knowledge and Experience** – Fishers possess deep, long-term knowledge of their fishing areas, which may not always be captured by technological tracking methods. They provide historical and seasonal insights that AIS or S2 data might miss, especially for small-scale fisheries that do not always use tracking devices.
- **Coverage of Non-Tracked Vessels** – Many fishing vessels, particularly those below a certain size threshold, are not required to carry GPS, AIS or VMS. Questionnaire data help fill this gap by capturing the activities of these vessels, which are significant contributors to regional fisheries.
- **Spatial and Temporal Detail** – Fishers can describe fishing grounds with high spatial resolution, identifying areas of concentrated effort, gear-specific usage, and habitat preferences. They also provide insights into temporal variations, such as seasonal shifts in fishing grounds due to species movements or regulatory changes.
- **Validation and Ground-Truthing** – Combining questionnaire data with remote sensing or AIS-based fishing detection allows for cross-validation. Areas identified by fishers can be compared with observed fishing effort from tracking data or satellite, helping to refine and improve fishing ground maps.
- **Social and Economic Context** – Beyond spatial data, questionnaires provide valuable context about fishing behavior, target species, economic drivers, and regulatory constraints. This information is essential for understanding not just *where* fishing occurs, but *why* certain areas are more intensively used.

In the case of the Marche Region, using questionnaire data from CNR ensures that local fishers' expertise is incorporated into the analysis. It also provides an initial dataset that can be refined and cross-checked with other sources, such as AIS, S2, or onboard observations, to improve the accuracy and representativeness of the mapped fishing areas.

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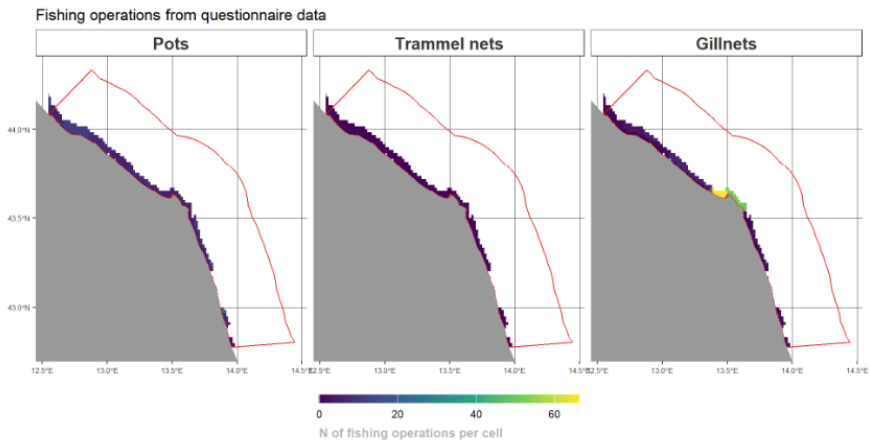
The first step of the analysis is the loading and pre-processing of the data collected through the questionnaires. This data will be our reference for subsequent analysis. The manipulation steps of the questionnaire data are the following:

- **Load the questionnaire dataset** containing gridded polygons representing fishing activity.
- **Crop the dataset** to match the predefined study area (`area_box`) to focus the analysis on the relevant region.
- **Convert the spatial data into a non-spatial format** to facilitate further manipulation and analysis.
- **Reshape the data into a long format** to standardize the representation of fishing effort across different métiers.
- **Recode métier classifications** to group similar fishing practices and improve interpretability.
- **Filter out irrelevant categories**, such as unknown or non-fishing activities, to refine the dataset.
- **Aggregate fishing effort data** by métier and grid cell to obtain a comprehensive view of fishing intensity.
- **Merge the processed data back with the spatial dataset**, ensuring that fishing effort is correctly linked to our grid

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Now we can plot by Metier of level 4 (Gear): Pots, Trammel nets, Gillnets

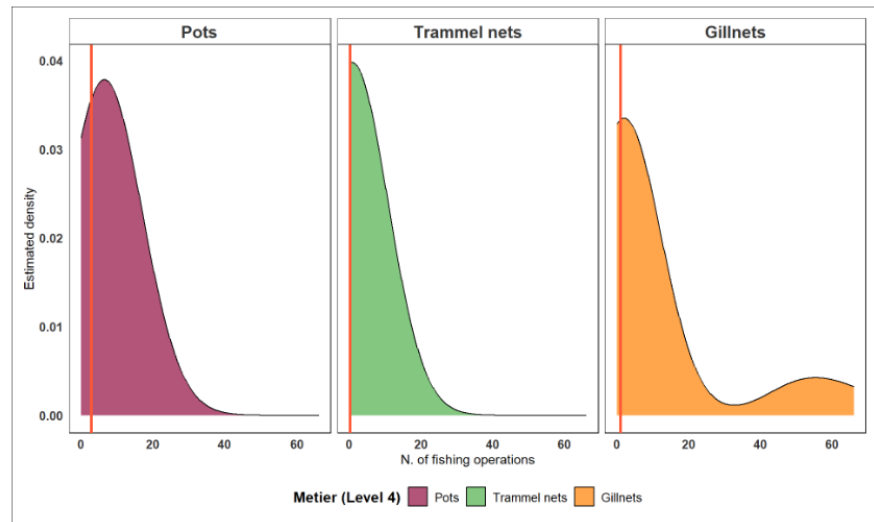
Show



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Now, for each gear, it is possible to explore the distribution of the effort in fishing operations, in this case we are using `geom_density()` function in `ggplot2` creates a kernel density estimate (KDE), which is a smoothed version of a histogram. It estimates the probability density function (PDF) of a continuous variable, essentially showing how the data is distributed across a continuous range.

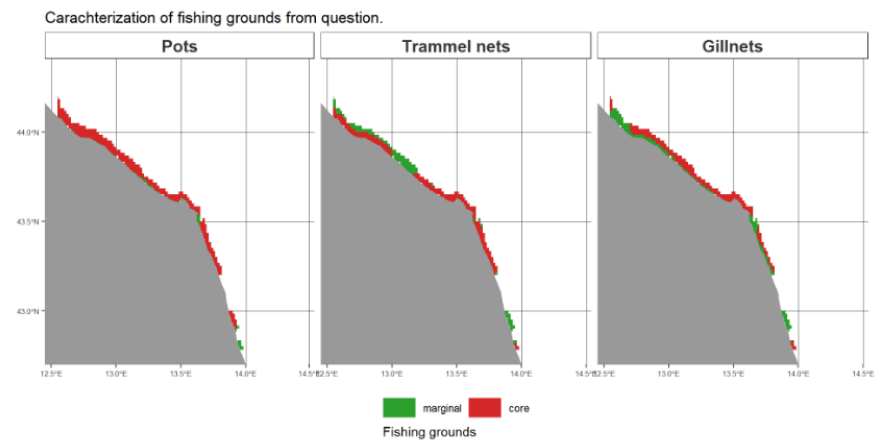
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We can also use a simple quantile-based rule to identify the core-fishing grounds by gear. This will be used in the next section to assess coverage of different tracking devices

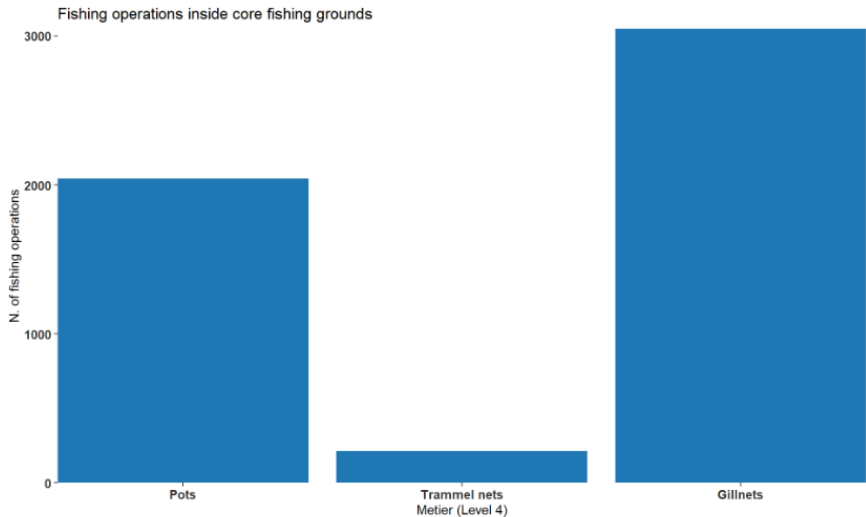
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The core fishing grounds by gear are defined as clusters of cells. These core sets will be used to assess the coverage of the different tracking devices and to train the ANN-based model.

Then we compute the amount of effort in the core fishing grounds from questionnaires



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4 Assessing the coverage of different tracking instruments

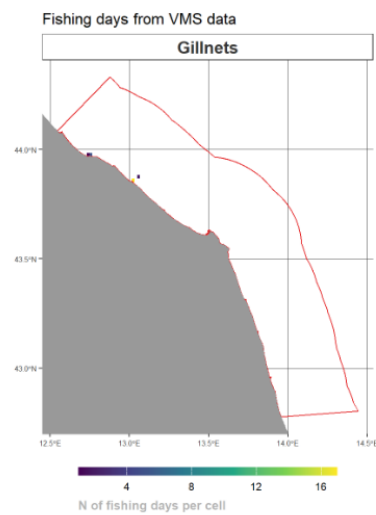
In this section, we evaluate the spatial and temporal coverage of various vessel tracking instruments used to monitor fishing activity in the study area. Understanding the strengths and limitations of each data source is essential for assessing their effectiveness in capturing fishing effort, particularly for small-scale fisheries (SSF), which are often underrepresented in traditional tracking datasets. The instruments analyzed include:

- **Vessel Monitoring System (VMS):**
 - Primarily used for monitoring larger commercial fishing vessels.
 - Provides periodic position reports (typically every 1-2 hours), making it suitable for tracking long-duration fishing operations but potentially missing fine-scale movements.
 - Limited applicability for SSF vessels, as many are not required to carry VMS transmitters.
- **GPS Systems on SSF Vessels (Collected by CNR):**
 - High-resolution tracking data collected directly from small-scale fishing vessels (60 seconds ping rate).
 - Offers a more detailed view of SSF activity, including nearshore and seasonal fisheries that are often missing from AIS and VMS datasets.
 - Coverage is limited to the subset of vessels equipped with these devices, making representativeness a key consideration.
- **Sentinel-2 Vessel Detections (Global Fishing Watch):**
 - Derived from optical satellite imagery, providing a direct observation of vessel presence on the water.
 - Useful for detecting both AIS-equipped and non-AIS vessels, including those that operate without transponders.
 - Limited by cloud cover, revisit time, and image resolution, which may affect the detection of smaller SSF vessels.
- **Automatic Identification System (AIS) Data (Global Fishing Watch):**
 - A global tracking system that provides frequent vessel position updates, enabling real-time monitoring.
 - Effective for large-scale commercial fleets but has **significant gaps** for SSF, as many smaller vessels are not equipped with AIS.
 - Can be used to validate and complement other datasets when cross-referenced with independent vessel detection sources.

By comparing these different tracking systems, we aim to assess their respective contributions to mapping fishing effort, identify potential biases, and explore how they can be integrated to improve the monitoring of fishing activity, particularly for SSF operations.

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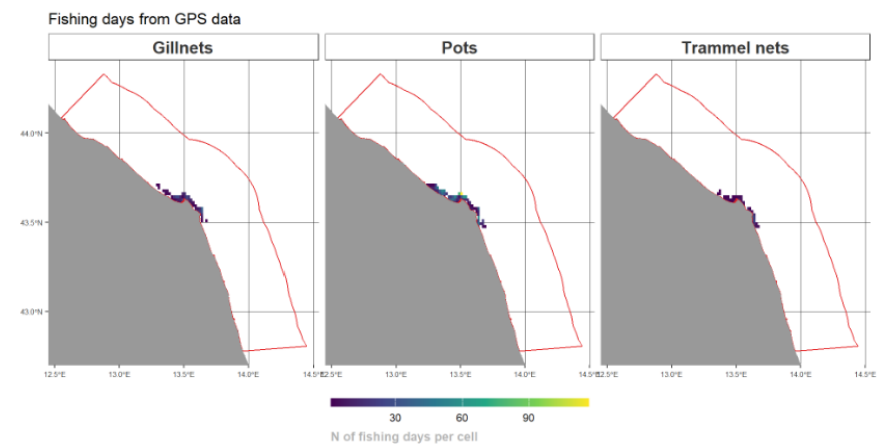
4.1 Vessel Monitoring System (VMS)



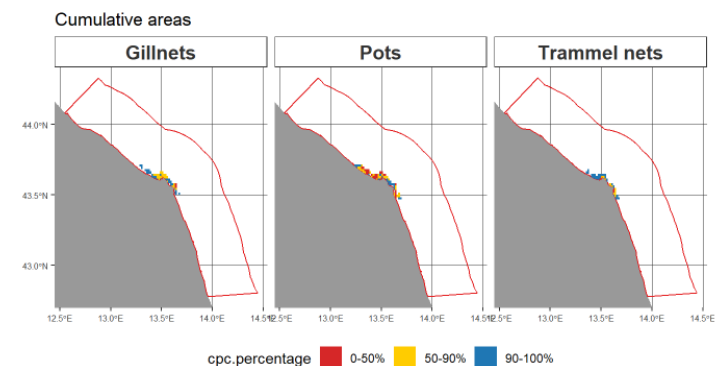
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4.5 Combining all instruments

4.2 GPS Systems on SSF Vessels (Collected by CNR)

GPS devices installed onboard 10 vessels from the Ancona harbour
Fishing effort = soak time measured in fishing hours, but transformed into fishing days



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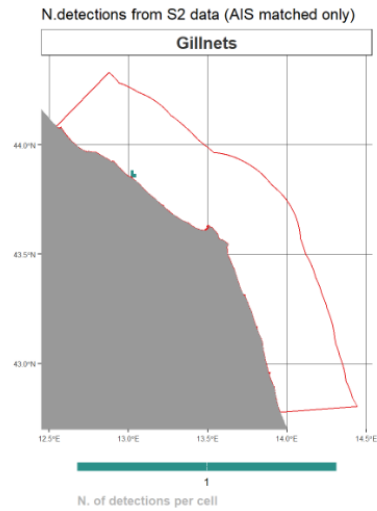
4.3 Sentinel-2 Vessel Detections (Global Fishing Watch)

The next step is the analysis of the data from Sentinel 2. We will split this dataset into two blocks: one counting only detections with a match with AIS data, and one with detections without a match with AIS data.
(Not just SSF vessels plotted)

Show

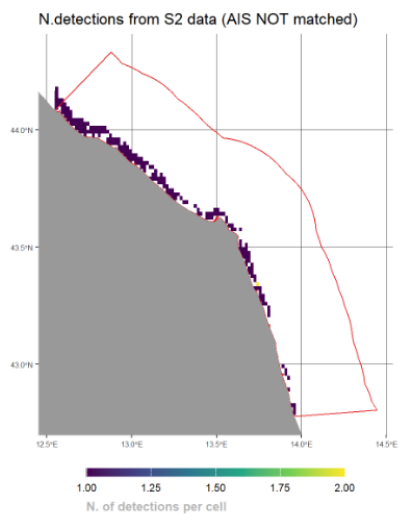
Sentinel2 matching AIS

Show



Sentinel2 not matching AIS (ssvid == NA)

Show



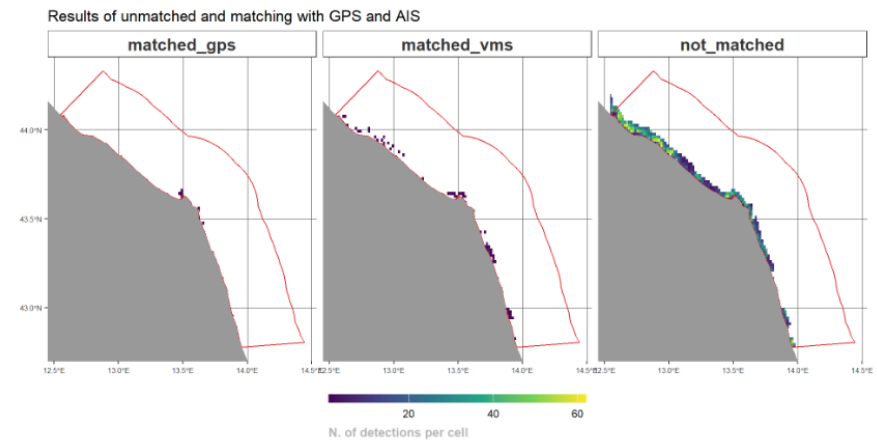
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We have also matched the detections with VMS and GPS data. This information could be used to potentially train a model to make a conclusion on all unmatched detections.

Sentinel2 matching VMS or GPS

Show



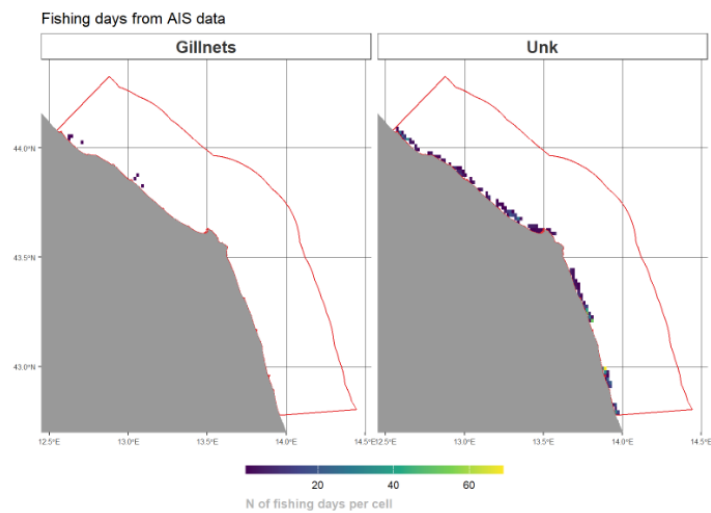
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4.4 Automatic Identification System (AIS) Data (Global Fishing Watch)

Show

[1] "fishing"

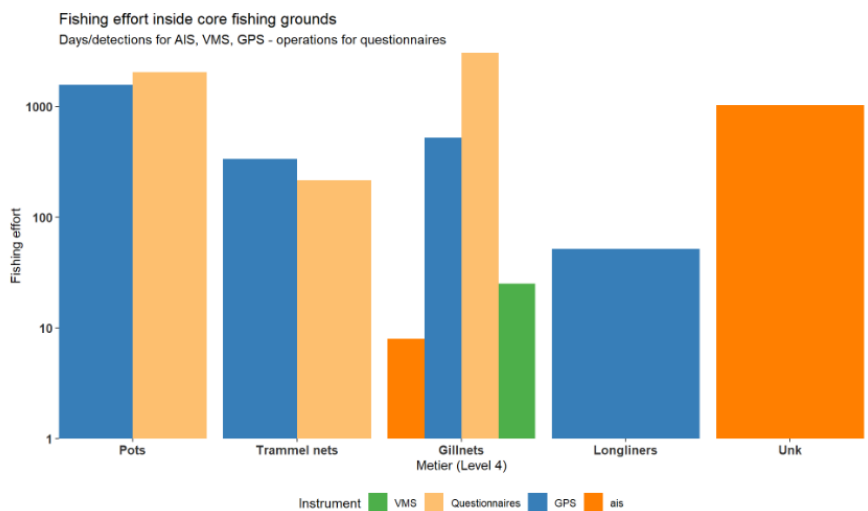
Show



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4.5 Combining all instruments

Show



Annex 7 Results from Case Study 4 (CS4 Marche Region, Adriatic Sea)

Notebook 2 - [HTML document](#) (needs to be downloaded for viewing)

1 Short intro

2 Input Data

3 Preprocessing

4 The Multilayer Perceptron Network (MPN)

5 Results

MAP-SSF: Predicting fishing footprint - Case Study 4 Adriatic Sea

Russo T,

June 09, 2025

1 Short intro

This paper presents the development and application of a neural network (Multilayer perceptron network), inspired by [Russo et al., \(2019\) Predicting Fishing Footprint of Trawlers From Environmental and Fleet Data: An Application of Artificial Neural Networks](#), with the aim of training a suitable model to provide a prediction of the distribution of fishing effort for the SSF.

2 Input Data

2.1 Fishing capacity

Fishing capacity is one of the key input data. Knowledge of the size of the fleet, in terms of the number of vessels per port and per gear, will allow us (together with the distance of each cell from each port) to estimate the potential area of influence of the fleet

```
fishing_capacity = read.csv("Fishing_capacity/fishing_capacity_main_gear_EU_fleet_register_31122024.csv")
fishing_capacity = fishing_capacity %>% filter(Main.fishing.gear %in% c("GNS", "GND", "GTR"))
```

2.2 Fleet register

At the same time, the GFCM fleet register will be needed to analyse Sentinel 2's data and determine to which gear it belongs

```
fleet_register = read.xlsx("Resources/GFCM-FleetRegister.xlsx")
fleet_register = fleet_register %>%
  filter('MMSI.(if.applicable)' != "") %>%
  dplyr::select('MMSI.(if.applicable)', LOA, Main.fishing.gear)
colnames(fleet_register)[1] = "MMSI"
```

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2.2 Fleet register
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2.4 The sea bottom substrates
2.5 The sea bottom depth
2.6 The area of study
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2.3 The harbours

So we need the topography of the ports to calculate the distance of each cell from each port (this will be the 'weight' to estimate the effect of fishing capacity)

```
harbours = read_sf("Resources/ITA_marche_region_ports_wgs84.shp")
harbours = harbours %>%
  st_centroid(geometry) %>%
  dplyr::rename(harbour = name) %>%
  mutate(harbour = ifelse(harbour == 'Ancona - porto principale', 'Ancona', harbour))
harbours$harbour = tolower(harbours$harbour)
harbours = harbours %>% filter(harbour %in% tolower(fishing_capacity$Place.of.registration.name))
```

2.4 The sea bottom substrates

The EUNIS [the European Nature Information System](#) is to source of the information about the Substrate of the sea bottom in each cell

```
eunis = read_sf("Resources/eunismedscale_4326.shp")
eunis = st_make_valid(eunis)

# eunis_mod <- st_crop(eunis, area_box)
# ggplot() +
#   geom_sf(data=eunis_mod, aes(fill=Substrate))
# rm(eunis_mod)
```

2.5 The sea bottom depth

[GEBCO - The General Bathymetric Chart of the Oceans](#) is our source of info for the sea bottom depth

```
gebco = stack("Resources/gebco_2019_emodnet_med_clip.tif")
```

Last but not least, we need to define the area of study

2.6 The area of study

```
area_box = read_sf("Resources/ITA_marche_region_bbox_0-20_nm_wgs84_26012025.shp")
bbox=st_bbox(area_box)
```

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2.7 The questionnaires and the grid

Questionnaires will be the main source of data to train our model and to test its predictive capabilities.

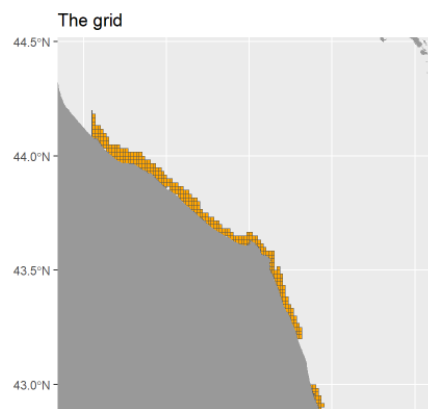
```
qdata_sf = read_sf("Questionnaires/Grati_SSF_polygons_gridded_wgs84.shp")
qdata_sf$ID = as.character(qdata_sf$ID)
qdata_sf = st_crop(qdata_sf, area_box)
qdata_sf = qdata_sf %>%
  mutate(across(where(is.numeric), ~ .x / sum(.x > 0, na.rm = TRUE)))
```

Also, the grid used in the Questionnaires will represent our spatial structure

```
grid_sf = qdata_sf # Here we also set the general grid to be used throughout the analyses
land = read_sf("Resources/Med_land.shp")

land = st_transform(land, crs = st_crs(area_box))

ggplot(data = grid_sf) +
  geom_sf(fill = "orange") +
  geom_sf(data = land, fill = "grey60", color = NA) +
  coord_sf(xlim = c(bbox$xmin-0.1, bbox$xmax+0.1),
    ylim = c(bbox$ymin-0.1, bbox$ymax+0.1)) +
  ggtitle("The grid")
```



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3 Preprocessing

3.1 Grid topology

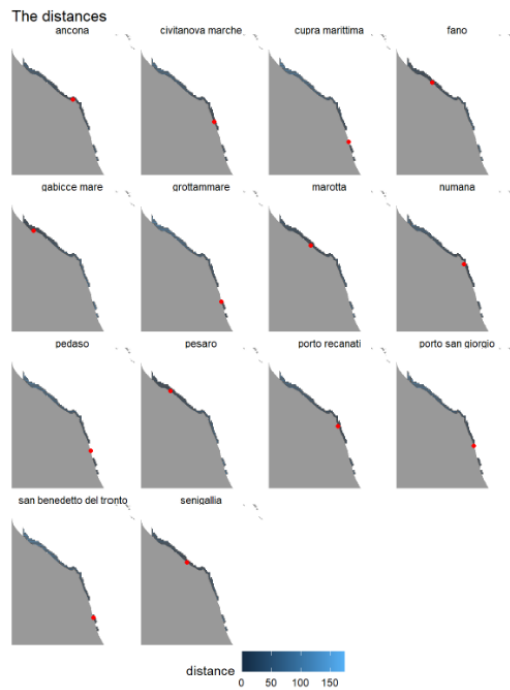
Let's compute the distance of the centroid of each cell from each port

```
# Get harbours-cells distances
mDist = as.data.frame(st_distance(grid_sf, harbours))/10^3
colnames(mDist) = harbours$harbour
mDist = cbind(grid_sf$ID, mDist)
colnames(mDist)[1] = "ID"
mDist_long = melt(data = mDist, id.vars = "ID")
colnames(mDist_long)[2:3] = c("harbour", "distance")
mDist_long$distance = as.numeric(mDist_long$distance)

grid_sf_distances = left_join(grid_sf, mDist_long)

ggplot(data = grid_sf_distances) +
  geom_sf(aes(fill = distance)) +
  geom_sf(data = land, fill = "grey60", color = NA) +
  geom_sf(data = harbours, pch = 19, colour = "red") +
  coord_sf(xlim = c(bbox$xmin-0.1, bbox$xmax+0.1),
    ylim = c(bbox$ymin-0.1, bbox$ymax+0.1)) +
  facet_wrap(~ harbour, ncol = 4) +
  ggtitle("The distances") +
  theme_void() +
  theme(legend.position = "bottom")
```

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3.2 Depth by cell

Generate a dataframe containing the depth by cell

```
df_bathy = data.frame(ID = grid_sf$ID,
                      Lon = st_coordinates(st_centroid(grid_sf))[1],
                      Lat = st_coordinates(st_centroid(grid_sf))[2])
df_bathy$depth_gebco = as.numeric(extract(x = gebco, y = data.matrix(df_bathy[, c("Lon", "Lat")]))[,1])
```

3.3 Substrates by cell

Generate a dataframe containing the substrates

```
# Seabed from EUNIS# Seabegrid_sfd from EUNIS
df_eunis = as.data.frame(st_intersects(grid_sf, eunis)) #row.id: index of the feature in grid_sf, col.id:
df_eunis$Substrate = eunis$Substrate[df_eunis$col.id]
df_eunis$ID = grid_sf$ID[df_eunis$row.id]
df_eunis = dcast(data = df_eunis %>% dplyr::select(ID, Substrate), ID ~ Substrate)
```

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3.4 Sentinel2

Another data layer is represented by the Sentinel2 data

```
# SAR2
S22_data = read.csv("SAR-Optical/optical_detections_all.csv")
S22_data$UTC = as.numeric(chron(dates = as.character(as.Date(S22_data$detect_timestamp)),
                              format = c(dates = "y-m-d"))))
S22_data$MMSI = as.character(S22_data$ssvid)
S22_data = left_join(S22_data, fleet_register)
S22_data$year = as.numeric(substr(S22_data$detect_timestamp, 1, 4))
S22_data = S22_data %>% filter(pred_fishing_nn == TRUE,
                              year == 2023,
                              case_study == "adriatic") %>%
  dplyr::select(MMSI,ssvid, UTC, detect_lon, detect_lat, LOA, Main.fishing.gear, length_m_inferred)

S22_data = S22_data %>% mutate(metier4 = recode(Main.fishing.gear,
                                                "Combined gillnets-trammel nets" = "Gillnets",
                                                "Set gillnets (anchored)" = "Gillnets",
                                                "Pots" = "Pots",
                                                "Gear Not Known or Not Specified" = "Unk",
                                                "Midwater pair trawls" = "Pair Trawl",
                                                "Single boat bottom otter trawls" = "Otter Trawl",
                                                "Purse seines" = "Purse Seines",
                                                "Trammel nets" = "Trammel nets",
                                                "Surrounding nets without purse lines" = "Surrounding nets",
                                                "Beam trawls" = "Beam Trawls",
                                                "Drifting longlines" = "Longliners",
                                                "Handlines and hand-operated pole-and-lines" = "Handlines",
                                                "Set longlines" = "Longliners",
                                                "Towed dredges" = "Dredges",
                                                "Fyke nets" = "Fyke nets",
                                                "Encircling gillnets" = "Gillnets",
                                                "Twin bottom otter trawls" = "Bottom otter trawl",
                                                "Longlines (nei)" = "Longliners",
                                                "Drift gillnets" = "Gillnets",
                                                "Harpoons" = "Harpoons",
                                                "Bottom trawls (nei)" = "Bottom otter trawl"))
```

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3.5 Final dataset

Now we can assembly the dataset including all the input layers (with the exception of substates)

```
# Final input dataset
df_input = left_join(st_drop_geometry(grid_sf), df_bathy %>% dplyr::select(ID, depth_gebco))
df_input = left_join(df_input, S22_data_agg_AIS)
df_input = left_join(df_input, S22_data_agg_NOAIS)

if(length(which(is.na(df_input$detection)))>0)
  df_input$detection[which(is.na(df_input$detection))] = 0
if(length(which(is.na(df_input$fdays)))>0)
  df_input$fdays[which(is.na(df_input$fdays))] = 0
```

3.6 Case study: GNS (Gillnet) in the Adriatic Sea

In the following chunk we subset the data to restrict the analysis. We also combine topology, fishing capacity, and substrates.

```
# GNS (Gillnet)
df_input_GNS = df_input %>% dplyr::select(ID, GILLNET_SO, GILLN_MUGI, GILL_WFIS, depth_gebco, fdays, detect)
fleet_GNS = data.frame(harbour = tolower(fishing_capacity$Place.of.registration.name),
                      gear = fishing_capacity$Main.fishing.gear,
                      nvessels = fishing_capacity$boats_count)
fleet_GNS = fleet_GNS %>% filter(gear == "GNS") %>% dplyr::select(harbour, nvessels)

# Elaborate the fleet index by
fleet_index = left_join(mDist_long, fleet_GNS) %>% dplyr::select(ID, distance, nvessels)
if(length(which(fleet_index$distance == 0))>0)
  fleet_index$distance = fleet_index$distance + 1
fleet_index$distance = 1/as.numeric(fleet_index$distance)

fleet_index <- fleet_index %>%
  group_by(ID) %>%
  summarize(weighted_fleet = weighted.mean(nvessels, distance, na.rm = TRUE))

df_input_GNS = left_join(df_input_GNS, fleet_index)
df_input_GNS$effort = apply(df_input_GNS %>% dplyr::select(GILLNET_SO, GILLN_MUGI, GILL_WFIS), 1, sum, na.rm = TRUE)
```

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4 The Multilayer Perceptron Network (MPN)

In this section we set the structure of the MPN

```
IDs = df_input_GNS$ID

#Store the native range of effort
effort_range = range(df_input_GNS$effort)

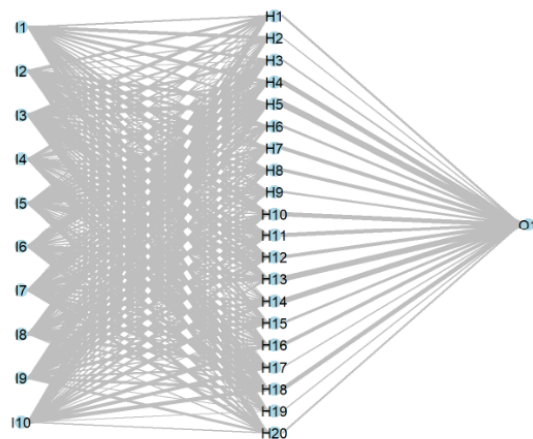
df_input_GNS = decostand(df_input_GNS %>% dplyr::select(-c(ID)), MARGIN = 2, method = "range") #range stand

OutputVar = "effort"
InputVars = setdiff(colnames(df_input_GNS), OutputVar)

nHs = 2 * length(InputVars) # number of hidden units (neurons) in the first hidden layer, as twice the num

modL = mlp(x = matrix(0, 1, length(InputVars)),
           y = matrix(0, 1, 1),
           size = nHs)

plot.nnet(modL, var.labs = F, circle.col="lightblue",
          max.sp = T, circle.cex = 2,
          pos.col="grey", neg.col = "grey", rel.rsc=7)
```



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Here we set the parameters of the training phase and train the MPN. All the useful data are appropriately stored in a series of lists

```
pTraining = 60
pValidation = 20
pTest = 100 - (pTraining + pValidation)
ntryset = 5 #Number of randomly extracted datasets

list_Training_set = list()
list_Validation_set = list()
list_Test_set = list()
trained_mpn = list()

df_predictions = data.frame(ID = numeric(0),
                             Iter = numeric(0),
                             Observed = numeric(0),
                             Predicted = numeric(0))

show.step = 50000
n.shows = 10

set.seed(1234) # Ensures full replicability

for(j in 1:ntryset){
  Training_set = sample(1:nrow(df_input_GNS),
                       round(nrow(df_input_GNS)*pTraining/100,0), rep=T)
  Validation_set = sample(setdiff(1:nrow(df_input_GNS), Training_set),
                        round(nrow(df_input_GNS) * pValidation/100,0),rep=T)
  Test_set = sample(setdiff(1:nrow(df_input_GNS),
                          c(Training_set, Validation_set)),
                   round(nrow(df_input_GNS) * pTest/100,0), rep=T)

  list_Training_set[[j]] = Training_set
  list_Validation_set[[j]] = Validation_set
  list_Test_set[[j]] = Test_set

  # Reset seed before initializing the network to make weight init reproducible
  set.seed(4321 + j) # Different but reproducible for each model
```

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```
net = newff(n.neurons = c(length(InputVars), nHs, 1),
  learning.rate.global = 1e-2,
  momentum.global = 0.1,
  error.criterion = "LMS",
  Stao = NA,
  hidden.layer = "sigmoid",
  output.layer = "sigmoid",
  method = "ADAPTgdm")

result = train(net,
  P = df_input_GNS[Training_set, InputVars],
  T = df_input_GNS[Training_set, OutputVar],
  Pval = df_input_GNS[Validation_set, InputVars],
  Tval = df_input_GNS[Validation_set, OutputVar],
  error.criterion = "LMS",
  report = FALSE, show.step = show.step, n.shows = n.shows)

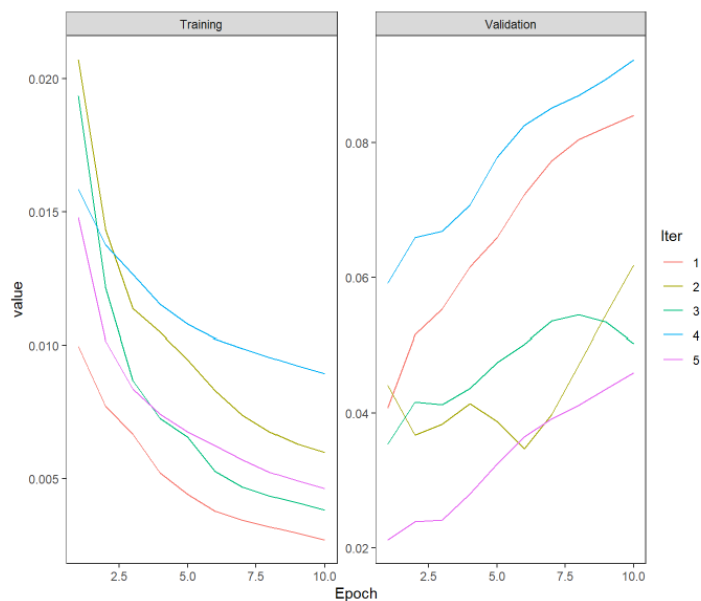
trained_mpn[[j]] = result
Observed = as.numeric(df_input_GNS[Test_set, OutputVar])
Predicted = as.numeric(sim.MLPnet(result$net,
  df_input_GNS[Test_set, InputVars]))
df_predictions_add = data.frame(ID = IDs[Test_set],
  Iter = j,
  Observed = Observed,
  Predicted = Predicted)
df_predictions = rbind(df_predictions, df_predictions_add)
}
```

5 Results

First of all, let's inspect the MSE trends during the training

```
Merror_all = do.call(rbind, lapply(trained_mpn, function(x) x$Merror))
Merror_all = data.frame(Iter = rep(1:ntryset, each = (nrow(Merror_all)/ntryset)),
  Epoch = rep(1:(nrow(Merror_all)/ntryset), ntryset),
  Training = Merror_all[,1],
  Validation = Merror_all[,2])
Merror_all = melt(data = Merror_all, id.vars = c("Iter", "Epoch"))
Merror_all$Iter = factor(Merror_all$Iter)

ggplot(data = Merror_all,
  aes(x = Epoch, y = value, colour = Iter, group = Iter)) +
  geom_line() +
  facet_wrap(~ variable, ncol = 2, scales = "free_y") +
  theme_test()
```



```
ggsave("MPN/error_plot.png", width = 12, height = 8, dpi = 300)
```

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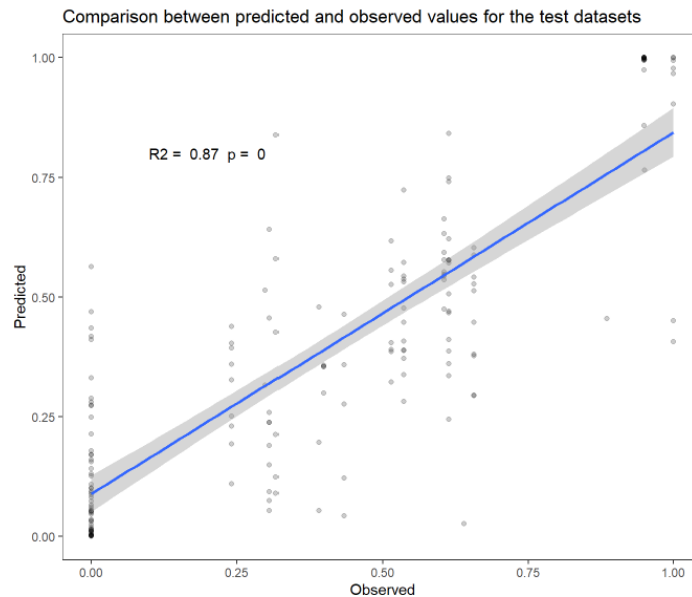
We can inspect the results of the training phase by comparing the predicted and observed values for the test dataset.

```
df_predictions_GNS = aggregate(data = df_predictions %>% dplyr::select(-Iter),
                               . ~ ID, FUN = "mean")

R2 = summary(lm(data = df_predictions_GNS, Predicted ~ Observed -1))$adj.r.squared
pvalue = summary(lm(data = df_predictions, Predicted ~ Observed -1))$coefficients[4]

ggplot(data = df_predictions_GNS,
       aes(x = Observed, y = Predicted)) +
  geom_jitter(alpha = 0.2) +
  geom_smooth(method = "lm") +
  theme_test() +
  ggtitle("GNS") +
  annotate("text", x = 0.2, y = 0.8,
         label = paste("R2 = ", round(R2,2), " p = ", round(pvalue, 5))) +
  ggtitle("Comparison between predicted and observed values for the test datasets")
```

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```
ggsave("MPN/r2_plot.png", width = 12, height = 8, dpi = 300)
```

The last step is the Sensitivity Analysis

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```

pert <- c(0.1, 0.2, 0.3, 0.4, 0.5) # Levels of perturbation applied
MSE = matrix(NA, length(InputVars), length(pert))[0,]

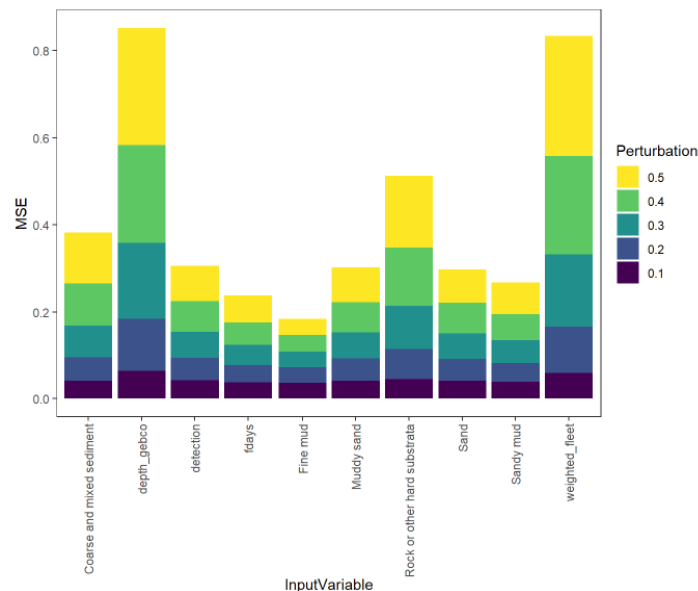
for(j in 1:ntryset){
  MSEj = matrix(NA, length(InputVars), length(pert))
  iter_net = trained_mpn[[j]]
  Training_set = list_Training_set[[j]]
  Validation_set = list_Validation_set[[j]]
  Test_set = list_Test_set[[j]]
  Observed <- df_input_GNS$effort[Test_set]
  Predicted <- sim.MLPnet(iter_net$net, df_input_GNS[Test_set,])[,1]
  for (k in 1:length(pert)) {
    Input_Test = df_input_GNS[Test_set, InputVars]
    for(i in 1:length(InputVars)) {
      Input_pert <- Input_Test
      Input_pert[,i] <- Input_Test[,i] + pert[k]
      predict_pert1 <- sim.MLPnet(iter_net$net, Input_pert)[,1]
      Input_pert <- Input_Test
      Input_pert[,i] <- Input_Test[,i] - pert[k]
      predict_pert2 <- sim.MLPnet(iter_net$net, Input_pert)[,1]
      MSEj[i,k] <- as.numeric((mean((Observed-predict_pert1)^2, na.rm = TRUE) +
                                   mean((Observed-predict_pert2)^2, na.rm = TRUE))/2)
    }
  }
  MSE = rbind(MSE, MSEj)
}

MSE = as.data.frame(MSE)
MSE$InputVar = rep(InputVars, ntryset)
colnames(MSE)[1:length(pert)] = pert
MSE = melt(data = MSE,
           id.vars = "InputVar")
colnames(MSE) = c("InputVariable", "Perturbation", "MSE")
MSE = aggregate(data = MSE, MSE ~ InputVariable + Perturbation, FUN = "mean")
MSE$Perturbation = factor(MSE$Perturbation, levels = rev(c(0.1, 0.2, 0.3, 0.4, 0.5)))

ggplot(data = MSE,
       aes(x = InputVariable, fill = Perturbation, y = MSE)) +
  geom_bar(stat = "identity") +
  theme_test() +
  theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust=1)) +
  scale_fill_viridis_d(direction = -1)

```

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```
ggsave("MPN/sensitivity_plot.png", width = 12, height = 8, dpi = 300)
```

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A confusion matrix is an useful tool to inspect the results and assess the predictive power of the MPN on the test dataset. Here we classified the effort in Low, Medium, High levels. The Cohen's Kappa index is used to compare predicted and observed values.

```
qeffort = seq(0, 1, 0.33)
qeffort[4] = 1

qObserved = factor(c("Low", "Medium", "High")[findInterval(df_predictions_GNS$Observed, qeffort)],
  levels = c("Low", "Medium", "High"))
qPredicted = factor(c("Low", "Medium", "High")[findInterval(df_predictions_GNS$Predicted, qeffort)],
  levels = c("Low", "Medium", "High"))

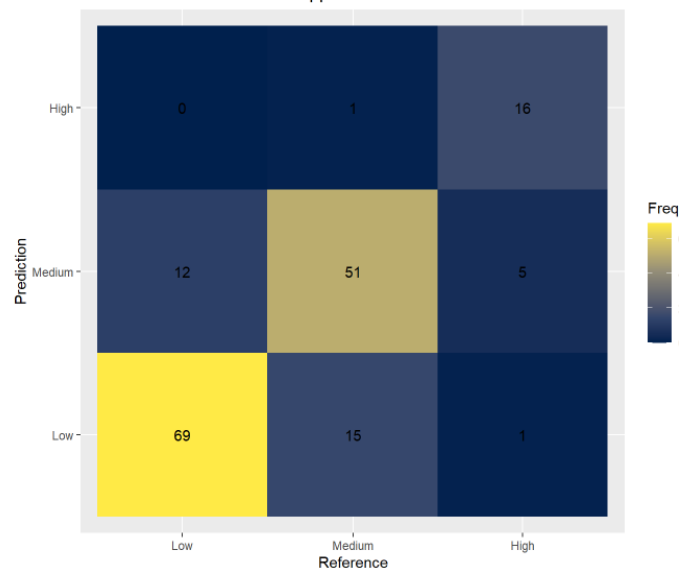
cm = caret::confusionMatrix(qPredicted, qObserved,
  dnn = c("Prediction", "Reference"))

plt <- as.data.frame(cm$stable)
plt$Prediction <- factor(plt$Prediction, levels=levels(plt$Prediction))

ggplot(plt, aes(Prediction, Reference, fill = Freq)) +
  geom_tile() +
  geom_text(aes(label=Freq)) +
  scale_fill_viridis_c(option = "cividis") +
  labs(x = "Reference", y = "Prediction") +
  scale_x_discrete(labels=c("Low", "Medium", "High")) +
  scale_y_discrete(labels=c("Low", "Medium", "High")) +
  ggtitle(paste0("Confusion Matrix - Cohen Kappa = ", round(as.numeric(cm$overall["Kappa"]), 2)))
```

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Confusion Matrix - Cohen Kappa = 0.66



```
ggsave("MPN/confusion_matrix.png", width = 12, height = 8, dpi = 300)
```

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Finally, we can plot the results as maps.

```
dfp = as.data.frame(matrix(NA, nrow(df_input_GNS), ntryset))
for(j in 1:ntryset){
  iter_net = trained_mpn[[j]]
  dfp[, j] <- sim.MLPnet(iter_net$net, df_input_GNS)[,1]
}

df_input_GNS$predicted_effort = apply(dfp, 1, mean)

df_effort_models = data.frame(ID = IDs,
                              Observed = exp(df_input_GNS$effort * effort_range[2]),
                              Predicted = exp(df_input_GNS$predicted_effort * effort_range[2]))

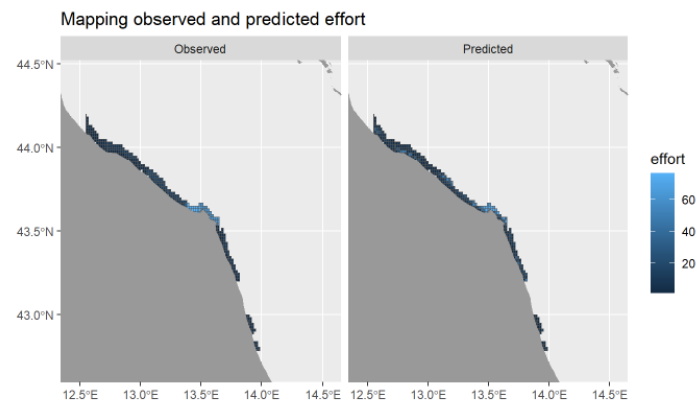
# Rescale to native effort range

df_effort_models_long = melt(data = df_effort_models,
                             id.vars = "ID")
colnames(df_effort_models_long) = c("ID", "source", "effort")

grid_sf_models = left_join(grid_sf, df_effort_models_long)

ggplot(data = grid_sf_models) +
  geom_sf(aes(fill = effort)) +
  geom_sf(data = land, fill='grey60', color=NA) +
  coord_sf(xlim = c(bbox$xmin-0.1,bbox$xmax+0.1),
           ylim = c(bbox$ymin-0.1,bbox$ymax+0.1)) +
  facet_wrap(~ source, nrow = 1) +
  ggtitle("Mapping observed and predicted effort")
```

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```
ggsave("MPN/observed_vs_predicted_map.png", width = 12, height = 8, dpi = 300)

grid_sf_models <- grid_sf_models %>%
  relocate(geometry, .after=effort)

write_sf(grid_sf_models, "MPN/output_predicted_observed.shp")
```

Annex 8 Spatial overlaps and potential conflicts

Link: [Shared Excel table \(live document\)](#)

SSF spatial conflicts (Blue economy context)				
Category	Sub-category	Factor	Relative data	Links or contacts
Human impact	Fisheries	Trawling	AIS/VMS	GFW for AIS: https://github.com/GlobalFishingWatch/gfwr ; ? for VMS
		Dredges		
		Recreational fishing		
	Barriers	Artificial reefs		
		Breakwater barriers		
	Dumping	Dumping areas		
	Energy	Gas/Oil Platforms	EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/aca3dd01-77ac-47fe-8291-6ca916daaa6d
		Pipelines	EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/8201070b-4b0b-4d54-8910-abcea5dce57f
	Aquaculture	Windfarms	EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/55886bab-2932-4d6d-bfe3-06626b0172ab
		Shellfish	EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/03c35b79-808f-4168-9d30-2de44a55a6f4
		Marine Finfish	EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/7b849214-e6ae-4199-a3f0-d4539f1f1289
	Maritime traffic	Algae production	EMODnet Human Activities	
		Pleasure boating		
	Shipping routes		GFW	GFW for AIS: https://github.com/GlobalFishingWatch/gfwr
	Military areas		EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/579e4a3b-95e4-48c6-8352-914ebae0ae1d
	Wrecks		EMODnet Human Activities	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog.search#/metadata/108ef240-fa6e-4b83-8569-09b509e2959d
	Management measures			Nationally designated areas (NatDA), • Natura 2000, • Emerald Source EEA, https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/df7f30a8-9bdd-491f-b586-28fbf8b7a6cd
				OSPAR Convention MPAs shapefile 2023
				Source: OSPAR; https://carto.mpa.ospar.org/fr/1/ospar.map
				Helsinki Convention MPA (BSPA) shapefile 21/12/2022
	MPAs			Source: HELCOM; https://metadata.helcom.fi/geonetwork/srv/eng/catalog.search#/metadata/d27df8c0-de86-4d13-a06d-35a8f50b16fa
		EEA, Ospar, HELCOM		
		Temporary fishing bans		
	Area closures (e.g., FRA)			

Other factors influencing SSF spatial extension				
Natural factors	Environmental constrain	Wave height	Copernicus	https://data.marine.copernicus.eu/product/GLOBAL_ANALYSISFORECAST_WAV_001_027/description
		Current speed		
		Bottom topography		
	Biological constraints	Algal blooms		
		Dolphins depredation		
		Polybius henslowi (swimming crab)		
		Isopods		

- Case Study 1 (Bivalve dredges Iberian Coast, Portugal)

SSF spatial conflicts (Blue Economy context)									
Category	Sub-category	Factor	Useful for the CS?	Layer availability	Description	Source (project or website)	Open data	Link	Reference
Human impact	Fisheries	Trawling	N						
		Dredges	Y	Y					
		Recreational fishing	Y	N					
	Barriers and wrecks	Artificial reefs	N		depends on the type of reefs				
		Breakwater barriers	N						
		Wrecks	Y	Y	these might occupy part of the area, but in gene				
	Dumping areas		Y	N	these are defined but would require to be digitiz				
	Energy	Gas/Oil Platforms	N						
		Pipelines	N						
		Windfarms	N		Not in Portugal, for the moment				
	Aquaculture	Shellfish	Y	Y	DGRM				
		Marine Finfish			?				
		Algae production	N						
	Maritime traffic	Pleasure boating	Y	N	can be, but more in terms of interaction				
		Shipping routes	N						
	Military areas		N						
	Management measures	MPAs	Y	Y					
		Fishing bans (e.g., FRA)			we don't have fishing bans, but have temporal c				
		Area closures (e.g., 500m around platforms)	N		only around wrecks sand closures spefici for ce				

- Case Study 2 (Basque Country region, Cantabrian Sea)

SSF spatial conflicts (Blue Economy context)									
Category	Sub-category	Factor	Useful for the CS?	Layer availability	Description	Source (project or website)	Open data	Link	Reference
Human impact	Fisheries	Pair trawling	Y	Y	Fishing effort	VMS data (owner: Spanish gove	Y - shareable		
		Purse seiners	Y	Y	Fishing effort	VMS data (owner: Spanish gove	Y - shareable		
		Longliners	Y	Y	Fishing effort	VMS data (owner: Spanish gove	Y - shareable		
		Dredges	N	-			-		
		Recreational fishing	Y	N	No spatial data available for recreational fisheries		-		
	Barriers and wrecks	Artificial reefs	Y	Y	Submerged artifi	PIE-REEF project	Y - already published	https://www.miteco.gob.es/content/dam/miteco/es/costas/participacion-pu	
		Breakwater barriers	N	-			-		
		Wrecks	N	N			-		
	Dumping areas		Y	N	Only an impact occurs at the treatment stations a		-	https://emodnet.ec.europa.eu/geoviewer/	
	Energy	Gas/Oil Platforms	Y	Y	Oil platform used	Sites of geological interest (Base	Y - already published	https://www.euskadi.eus/web01-a2inguru/eu/contenidos/informacion/lig/e	
		Pipelines	Y	N	Spain-France un	inelle	-	https://www.inelle.eu/en/projects/bay-biscay	
		Windfarms	Y	Y	First offshore wi	GEROA project	Y - already published	https://saitec-offshore.com/en/projects/geroa/	
		Marine Energy Platform	Y	Y	Infrastructure for	BIMEP	Y - already published	https://www.bimep.com/en/bimep-area/technical-characteristics/	
	Aquaculture	Shellfish	Y	Y	Production of bivalve molluscs		Y - already published	https://www.euskadi.eus/contenidos/informacion/zonas_produccion_molu	
		Marine Finfish	Y	Y	A live bluefin tur	Itsas Bafego - AZT	Y - already published	https://www.euskadi.eus/informacion_publica/proyecto-de-acuicultura-atu	
		Algae production	N	-	They experiment with algae production at the faci		-		
	Maritime traffic	Pleasure boating	Y	Y	We don't know the impact of the SSF fleet. We ca		-		
		Shipping routes	Y	Y	We don't know the impact of the SSF fleet. We ca		-		
	Military areas		N	-			-		
	Management measures	MPAs	Y	Y	There are differe	Spanish Government	Y - already published	https://www.miteco.gob.es/es/biodiversidad/temas/biodiversidad-marina/e	
		Fishing bans (e.g., FRA)	Y	Y	In Gipuzkoa: The use of gillnets and trammel nets		Y - already published	https://www.azti.es/rim/wp-content/uploads/2023/02/RIM_29_2_alta.pdf	
		Area closures (e.g., 500m around platforms)	Y	Y			-		

- Case Study 3 (Murcia region, Mediterranean Sea)

SSF spatial conflicts (Blue Economy context)									
Category	Sub-category	Factor	Useful for the CS?	Layer availability	Description	Source (project or website)	Open data	Link	Reference
Human impact	Fisheries	Trawling	Y	Y	An aggregated, anonymized layer developed by		Y - shareable	https://www.miteco.gob.es/con	MITECO. Ministry for the Ecological Transition and the I
		Dredges	N		No dredgers in the area				
		Recreational fishing	Y	N	No data available for recreational fisheries				
	Barriers and wrecks	Artificial reefs	N		Some artificial reefs have been established in th				
		Breakwater barriers	N		Several coastal	https://www.miteco.gob.es/con	Y - already published	https://infomar.miteco.gob.es/	MITECO. Ministry for the Ecological Transition and the I
		Wrecks	N	N	There are several wrecks throughout the case s				
	Dumping areas		Y	N	Cala Reona (Murcia), Cabo Huertas (Alicante)				
	Energy	Gas/Oil Platforms	N		No Gas/Oil Platforms in the area		Y - already published	https://infomar.miteco.gob.es/	MITECO. Ministry for the Ecological Transition and the I
		Pipelines	N	N	Main cables in the Med area out of our study ar		Y - already published	https://www.miteco.gob.es/con	MITECO. Ministry for the Ecological Transition and the I
		Windfarms	N		No Windfarms in the area				
	Aquaculture	Shellfish	Y		Some shellfish p	https://www.miteco.gob.es/con	Y - already published	https://www.miteco.gob.es/con	MITECO. Ministry for the Ecological Transition and the I
		Marine Finfish	Y	Y	tuna, sea bass,	https://servicio.pesca.mapama.gob.es/	Y - already published	https://servicio.pesca.mapama.gob.es/	MAPA. Ministry of Agriculture, Fisheries and Food.
		Algae production	N		No Algae production in the area				
	Maritime traffic	Pleasure boating	Y	N	Estimation made from AIS for Marine Strategy F		Y - already published	https://www.miteco.gob.es/con	MITECO. Ministry for the Ecological Transition and the I
		Shipping routes	Y	N	Estimation made from AIS for Marine Strategy F		Y - already published	https://www.miteco.gob.es/con	MITECO. Ministry for the Ecological Transition and the I
	Military areas		N		There are military zones around the port of Cart				
	Management measures	MPAs	Y		3 Marine Reserve (Cabo Tiñoso, Cabo de Palos		Y - already published	https://www.mapa.gob.es/es/pesca/temas/proteccion-recursos-pesqueros	
		Fishing bans (e.g., FRA)	Y		Bottom trawling	Real Decreto 502/2022, de 27	Y - already published	https://www.boe.es/buscar/doc.php?id=BOE-A-2022-10675	
		Area closures (e.g., 500m around platforms)							

- Case Study 4 (Marche region, Adriatic Sea)

SSF spatial conflicts (Blue Economy context)										
Category	Sub-category	Factor	Useful for the CS?	Layer availability	Description	Source (project or website)	Open data	Link	Reference	
Human impact	Fisheries	Trawling	Y	Y	Fishing effort	AIS - Global Fishing Watch	Y - already published	https://globalfishingwatch.org/	https://globalfishingwatch.org/	
		Dredges	Y	Y	Fishing effort	Confidential	N	-	-	
		Recreational fishing	Y	N	-	-	-	-	-	
	Barriers and wrecks	Artificial reefs	Y	Y	Submerged artificial reefs	ADRIREEF project	Y - already published	https://www.sea-rii.eu/	https://doi.org/10.5194/essd-13-1905-2021	
		Breakwater barriers	Y	N	-	-	-	-	-	
		Wrecks	N	Y	E.g., Nicole shipwreck	ADRIREEF project	Y - already published	https://www.sea-rii.eu/	https://doi.org/10.5194/essd-13-1905-2021	
	Dumping areas	-	Y	Y	-	Confidential	N	-	-	
	Energy	Gas/Oil Platforms	Y	Y	Offshore installations locations	MASE - Ministero dell'Ambiente	Y - already published	https://unmig.mise.it/	https://www.mase.gov.it/	
		Pipelines	Y	Y	-	Nautical chart	Y - sharable	-	-	
		Windfarms	N	-	-	-	-	-	-	
	Aquaculture	Shellfish	Y	Y	Numana facility, Porto Recanati facility	EMODnet Human Activities	Y - already published	https://emodnet.ec.europa.eu/geonetwork/srv/eng/catalog	-	
		Marine Finfish	N	-	-	-	-	-	-	
		Algae production	N	-	-	-	-	-	-	
	Maritime traffic	Pleasure boating	Y	N	-	-	-	-	-	
		Shipping routes	Y	Y	Main shipping routes	Nautical chart	Y - sharable	-	-	
	Military areas	-	N	-	-	-	-	-	-	
	Management measures	MPAs	N	-	-	-	-	-	-	-
		Fishing bans (e.g., FRA)	Y	Y	3 nm fishing ban (trawlers not allowed within 3 nm)	Regulation EC/1967/2006 prohibited	Y - already published	https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1967	Regulation EC/1967/2006	-
		Area closures (e.g., 500m around ports)	Y	Y	Restricted areas: fishing and anchoring prohibited	Nautical chart	Y - sharable	-	-	
		Y	Y	Under the Petroleum Act 1987 the Secretariat of State for the Environment	Nautical chart	Y - sharable	-	-		

- Blue Economy sectors

NACE Rev. 2.1	Code	CNAE-2025	Code	Blue Economy Sector	Description
A03.11	311	311	Marine Living Resources	Marine fishing (includes SSF and LSF)	Coastal fisheries, trawling, purse seine, artisanal boats
A03.12	312	312	Marine Living Resources	Inland fishing (includes SSF and LSF)	River fishing, lake fishing, small-scale inland fishing
A03.21	321	321	Marine Living Resources	Marine aquaculture	Fish farming (e.g. sea bass), mollusc farming, seaweed
A03.22	322	322	Marine Living Resources	Freshwater aquaculture	Freshwater fish farming (e.g. trout), tanks, ponds
B08.92	892	892	Marine Non-Living Resources	Marine mineral extraction	Sand, gravel, salt, polymetallic nodules
B09.10	910	910	Marine Non-Living Resources	Offshore oil/gas support	Offshore platform services, seismic surveys
C21.10	2110	2110	Marine Biotechnology	Pharma & biotech (marine)	Marine-derived medicines, algae bioactives
C30.11	3011	3011	Shipbuilding and Repair	Ship construction	Large vessels, ferries, tankers
C33.15	3315	3315	Shipbuilding and Repair	Ship repair & maintenance	Drydocks, hull maintenance, refitting
D35.11	3511	3511	Marine Renewable Energy	Energy production	Offshore wind farms, tidal turbines
E36.00	3600	3600	Desalination	Water treatment	Desalination plants, brine management
F42.22	4222	4222	Marine Renewable Energy	Infrastructure for marine energy	Subsea cables, offshore platforms
F42.99	4299	4299	Marine & Coastal Protection	Civil works (reefs, barriers)	Artificial reefs, submerged breakwaters
H50.10	5010	5010	Maritime Transport	Passenger sea transport	Ferries, cruise ships, water taxis
H50.20	5020	5020	Maritime Transport	Freight sea transport	Container shipping, tankers, cargo barges
H52.22	5222	5222	Port Activities	Port operation	Piloting, berthing, port logistics
H52.24	5224	5224	Port Activities	Cargo handling	Container loading, dock cranes, port labor
I55.10	5510	5510	Coastal Tourism	Hotels & resorts	Seaside hotels, eco-lodges
I55.20	5520	5520	Coastal Tourism	Holiday accommodation	Campsites, bungalows, vacation homes
I56.10	5610	5610	Coastal Tourism	Food services	Beach restaurants, seafood bars
M71.12	7112	7112	Marine Engineering & Energy	Technical consultancy	Offshore design, marine surveys, reef design
M72.11	7211	7211	Marine Biotech & Protection	Scientific R&D (marine)	Genomics of marine species, conservation biology
M72.20	7220	7220	Marine & Coastal Protection	Environmental R&D	Climate adaptation, ocean monitoring, biodiversity
N79.11	7911	7911	Coastal Tourism	Tour operators	Marine tours, whale watching, nautical packages
N93.29	9329	93293	Coastal Tourism / Leisure	Recreational diving & marine leisure	Scuba diving schools, snorkeling, dive charters
Q86.90	8690	8690	Marine & Coastal Protection	Health & monitoring services	Marine pollution monitoring, eco-health surveys