marmade

marine biomass valorization for food and feed innovation

Work Package 1

Deliverable 1.1 - Map of marine biomass sources and hotspots

Project 101213231 - MARMADE - HORIZON-JU-CBE-2024-RIA-05

Circular Bio-based Europe Joint Undertaking

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LIST OF ACRONYMS

Acronym	Description
EMODNET	European Marine Observation and Data Network
EUMOFA	European Market Observatory for Fisheries and Aquaculture Products
MARMADE	MARine bioMass valorizAtion for fooD and fEed ingredients
VC	Value Chain

EXECUTIVE SUMMARY

Deliverable D1.1 of the MARMADE project provides a comprehensive mapping of marine biomass sources and hotspots across Europe to support the development of circular bio-based value chains for food and feed ingredients. The study focuses on two priority value chains: (VC1) crustacean residues and (VC2) macroalgae (seaweeds). Its objective is to identify sustainable biomass sources, assess their geographic distribution and seasonality, and pinpoint locations where biomass can realistically be sourced for downstream biorefinery processes.

The analysis combines official statistics, market reports, scientific literature, stakeholder engagement and bottom-up operator mapping. A key methodological principle is that biomass availability depends not only on production or trade volumes but on where physical processing occurs and residues are generated.

VC1 – Crustacean Residues

The study identifies shrimp residues, Norway lobster residues and emerging crab biomass as the main crustacean resources. Conventional crustacean flows relevant to EU processing amount to approximately 500,000–550,000 tonnes per year (live-weight equivalent), corresponding to an estimated 100,000–110,000 tonnes of potential exoskeleton-rich residues. These figures represent theoretical potential rather than directly available biomass.

The mapping reveals that residue generation does not necessarily follow trade patterns. Spain and Italy emerge as the most important EU hotspots because they combine Mediterranean shrimp fisheries, imports of warm-water shrimp and strong seafood-processing sectors. France functions as both a processing and market node, while Greece is particularly relevant for Mediterranean wild shrimp resources.

Cold-water shrimp supply chains are highly transnational. Denmark serves as the principal EU gateway for *Pandalus borealis*, while the Netherlands and Germany are key nodes for *Crangon crangon*. However, a significant share of peeling operations takes place in Morocco, making it a major residue-generation hotspot outside the EU. Approximately 14,000 tonnes of cold-water shrimp products were exported there in 2024, generating an estimated 3,000 tonnes of shell-rich biomass.

The study also highlights emerging biomass opportunities from invasive and underutilised crustaceans. The Northern Adriatic is identified as the main hotspot for blue crab (*Callinectes sapidus*), with around 2,000 tonnes managed in Veneto during

2024. The Adriatic sand crab (*Liocarcinus depurator*) is recognised as a complementary bycatch-based biomass stream.

VC2 – Macroalgae

The macroalgae assessment covers harvested seaweeds, cultivated seaweeds, aquaculture-related green algae and biomass from the invasive alga *Rugulopteryx okamurae*. Six priority species were selected for future project activities, representing brown, red and green algae sourced from commercial production, aquaculture by-products and invasive biomass streams.

Norway is by far the largest seaweed-producing country in Europe, accounting for more than 50% of total production. France, Ireland and Iceland are the next most important producers. More than 95% of European seaweed biomass currently originates from wild harvesting rather than cultivation.

Brown kelps dominate production volumes, particularly *Laminaria*, *Saccharina latissima* and *Ascophyllum nodosum*. Red algae such as *Palmaria palmata*, *Gelidium* and *Gracilaria* are also significant, while green algae production is largely limited to *Codium* and *Ulva* species. Major applications include phycocolloid extraction, animal feed and human food products.

The mapping further shows that production and processing locations are often geographically separated, as illustrated by the flow of red algae biomass from Morocco to European agar-processing centres. The invasive alga *Rugulopteryx okamurae* is spreading rapidly across the Iberian Peninsula, with the Strait of Gibraltar identified as the main biomass hotspot.

Overall, the deliverable establishes a strategic foundation for MARMADE's biomass sourcing activities by identifying priority biomass streams, processing hubs and collection hotspots that can support future marine biorefinery operations.

1. Introduction and Objectives

1.1. Project and WP1 objectives

The growing global human population, in combination with related issues as the consequences of climate changes, are putting increasing strains on the limited biomass resources of the planet. MARMADE addresses this challenge by pioneering new circular value chains for the future of food and feed ingredients. The project will convert locally sourced European marine biomass, including crustacean residues and macroalgae, into high-value ingredients, such as vitamins, peptides, oligosaccharides, prebiotics, postbiotics, fats, emulsifiers, and digestibility enhancers.

The different technical work packages of the project focus on advanced biorefineries for the sustainable processing of marine biomass (WP2), the validation of food and feed ingredient building blocks in targeted market applications (WP3), and the assessment of quality, safety, nutritional and health aspects of the resulting applications (WP4). Environmental and socio-economic assessments, stakeholder engagement, and consumer acceptance are addressed in WPs 5 and 6.

At the basis of the project is WP1: Sourcing of biomass from circular processes and sustainable cultivation, of which the current deliverable represents the first output. The objective of WP1 is to identify, evaluate and support the sustainable sourcing of biomass for the other work packages, in particular WP2. This includes the assessment of biomass availability, geographic distribution, seasonality, storage conditions and implications for composition and extraction yields, as well as the preliminary identification of relevant regulatory and administrative aspects related to selected biomass sources, including safety concerns, aquaculture by-products, genetic resource regulations and residual biomass from invasive species.

As a first step towards the establishment of a stable biomass supply chain to the other work packages and to clarify major biomass sources in Europe of these two value chains is task 1.1 “Mapping of Available Marine Biomass”, of which this deliverable is the end-product. The task aims to set the stage for understanding and optimizing the sources of biomass from crustacean residues and seaweed. For VC1, major crustacean processing plants and biomass flows regarding crustacean biomass processed in the EU have been identified and catalogued. For VC2, the potential for cultivating and harvesting seaweed across the EU (and other European countries as Norway and the UK) have been examined. This exploration will help to understand how seasonal variations impact seaweed supply and identify the best locations for sourcing. Specific attention has been paid to distribution and harvesting potential of invasive species as the blue crab and *Rugulopteryx okamurae*. Results of these studies are being presented in a series of maps identifying key biomass hotspots.

1.2. Biomass value chains and species selection

The MARMADE project distinguishes two principal value chains (VCs):

VC1 – Crustacean residues.

VC2 – Macroalgae (seaweeds).

1.2.1. VC1: Crustacean residues

VC1 focuses on crustacean residues generated by seafood processing activities, with particular attention to shrimp, Norway lobster and other commercially relevant crustaceans. These residues include heads, shells, tails, legs and other exoskeleton-rich by-products that may become available during peeling, heading, cooking, brining, freezing, repacking or further processing. For MARMADE, this biomass is relevant because it can support circular biorefinery routes for the production of high-value food and feed ingredients.

The mapping carried out for VC1 shows that the geography of crustacean residues does not simply follow the geography of crustacean trade. Large import or export volumes do not automatically correspond to large local residue availability. What matters is where shell-bearing crustaceans are physically transformed, and in which product form they enter each value-chain node. This distinction is essential for identifying realistic biomass-sourcing hotspots.

The analysis therefore distinguishes between production and landing areas, import gateways, trade and redistribution hubs, local processing hotspots and outsourced peeling locations. For example, North Sea common shrimp (*Crangon crangon*) are mainly caught by EU and neighbouring fleets, but a significant share of the peeling activity is outsourced to Morocco before the peeled product re-enters the European market, (EUMOFA, 2024a). Conversely, northern prawn or cold-water shrimp (*Pandalus borealis*) from Greenland, Canada and the Faroe Islands enters the EU mainly through Denmark, often as cooked-frozen product. Denmark is therefore a major trade and redistribution hub, but not necessarily a proportional hotspot of local shell-residue generation, (EUMOFA, 2024a).

For warmwater shrimp, product form is also decisive. Shrimp from Ecuador, mainly whiteleg shrimp (*Litopenaeus vannamei*), may enter Southern European markets as whole, raw or head-on-shell-on product, increasing the probability that residues are generated in EU processing destinations such as Spain, France or Italy. By contrast, shrimp imported from India and Vietnam often arrives in more processed or peeled forms, meaning that part of the exoskeleton residue is generated upstream, outside the EU, (MAC, 2022), (EUMOFA, 2026).

Mediterranean wild shrimps and related crustaceans represent a more localised EU residue stream. These products are mainly landed and processed in Southern European countries, especially Spain, Italy and Greece, where residues are more likely to remain close to ports, auctions, wholesale markets and local processing plants. Spain and Italy therefore emerge as important EU hotspots for locally generated crustacean residues, due to the combination of wild crustacean landings, imported warmwater shrimp flows and established fish-processing industries.

VC1 also includes emerging biomass streams from invasive or underused crustacean species. A relevant example is the Atlantic blue crab (*Callinectes sapidus*), an invasive species native to the western Atlantic that is increasingly affecting European Atlantic and Mediterranean coastal ecosystems, with particular concern for lagoon and shellfish-farming areas (Mancinelli et al., 2017, (Tiralongo et al., 2025). In MARMADE, blue crab is considered not only as an ecological and fishery-management issue, but also as a potential exoskeleton-rich biomass stream, provided that collection, handling and processing routes can be properly organised.

Overall, VC1 mapping aims to identify where crustacean residues are actually generated, when they may become available, and how reliable each sourcing opportunity is. This approach provides the basis for the hotspot maps and for the subsequent evaluation of biomass-sourcing options for MARMADE downstream processing activities.

1.2.2. VC2: Macroalgae (seaweeds)

This value chain involves 3 groups of biomass resources, all sourced within Europe. First of all, there are various green, brown, and red seaweeds from harvesting and from the emerging seaweed cultivation sector. Secondly, green algal blooms, in particular *Ulva* spp. in connection with intensive finfish aquaculture that can be considered as an aquaculture byproduct. And, finally, residues from beach cleaning activities involving the invasive brown alga *Rugulopteryx okamurae*. This is also an invasive species native to the temperate areas of the Northwest Pacific Ocean. It was first observed in the Mediterranean in 2002 and has been progressively expanding both to the East as to the West even into the Northeast Atlantic, currently causing great problems in mediterranean and Atlantic beaches of Spain, Portugal and France and threatening local biodiversity (Díaz-Tapia et al., 2025).

As a first step towards the establishment of a stable biomass supply chain to the other work packages and to clarify major biomass sources in Europe of these two value chains is task 1.1 "Mapping of Available Marine Biomass", of which this deliverable is the end-product. The task aims to set the stage for understanding and optimizing the sources of biomass from crustacean residues and seaweed. For VC1, major crustacean processing plants and biomass flows regarding crustacean biomass processed in the EU have been identified and catalogued. For VC2, the potential for cultivating and harvesting seaweed across the EU (and other European countries as Norway and the UK) have been examined. This exploration will help to understand how seasonal variations impact seaweed supply and identify the best locations for sourcing. Specific attention has been paid to distribution and harvesting potential of invasive species as the blue crab and *Rugulopteryx okamurae*. Results of these studies are being presented in a series of maps identifying key biomass hotspots.

2. METHODOLOGY

2.1. Methodology for VC1 – Crustacean residues

2.1.1. General methodological approach

The mapping of crustacean residues followed a combined top-down and bottom-up approach, aimed at identifying not only where crustaceans are produced, landed, imported or traded, but also where exoskeleton-rich residues are physically generated and could realistically be intercepted for MARMADE biorefinery activities.

The top-down component consisted of a structured desk-based analysis of official market reports, EU statistical sources, scientific literature and sectoral documents. The main sources used included EUMOFA documents, EU Fish Market Reports, Eurostat-derived datasets and market analyses on shrimp and crustacean trade. These sources were used to identify the main commercial species, distinguish between wild-caught and farmed crustaceans, reconstruct major import/export flows, and classify countries according to their role as production areas, landing points, trade hubs, processing hubs or outsourced peeling locations. Particular attention was paid to the distinction between trade volume and residue-generation potential, since shell residues are generated where shell-on, head-on-shell-on or otherwise unpeeled crustaceans are physically processed, not necessarily where they are first imported, stored or re-exported.

The bottom-up component aimed to complement the official and literature-based analysis with operational information from the market. This included the identification of fish-processing factories, fishing cooperatives, associations, ports, auctions, wholesalers and industrial hubs in different countries. The objective was to understand the real organisation of crustacean supply chains, including operational bottlenecks, by-product management practices, confidentiality constraints, willingness to share data, and the practical feasibility of intercepting shell-rich residues. Where possible, operators were classified according to their activity profile, including peeling, cooking, freezing, brining, packing, repacking, foodservice preparation, retail/private-label production, trading or re-export. Several operators and clusters were contacted or screened through publicly available information. In some cases, operators were not willing to disclose detailed volumes or processing data because of commercial sensitivity and competitiveness concerns. Therefore, company-level information was treated cautiously and, where needed, anonymized or aggregated.

This combined approach allowed the mapping to move beyond a simple statistical description of crustacean production and trade. The analysis focused instead on identifying residue-generation points, namely the locations where heads, shells and exoskeleton fractions are separated from the edible fraction during industrial or semi-industrial processing. This is particularly important for MARMADE, because the most promising biomass-sourcing locations are not necessarily the largest import hubs, but the sites where physical transformation of shell-bearing biomass actually occurs.

2.1.2. Data sources and analytical framework

The analysis integrated three main categories of sources. First, official EU and market datasets were used to reconstruct the structure of crustacean flows. EUMOFA reports and profiles provided information on species, catches, landings, first sales, imports, exports, market destinations and country-level processing sectors. These data are based on Eurostat-COMEXT for trade flows, Eurostat-PRODCOM for processed products and Eurostat-SBS for the structure of the fish-processing industry, including the number of companies, employment and turnover. However, these datasets do not directly quantify crustacean shell waste or distinguish “peeling plants” as a separate statistical category. For this reason, they were used as a basis to identify likely biomass flows and processing capacity, rather than as direct measurements of exoskeleton residues.

Second, scientific and technical literature was used to interpret the biological and processing characteristics of the relevant species. The analysis distinguished between cold-water shrimp, Warm-water shrimp, Mediterranean wild shrimps, Norway lobster and several species of crabs. For each group, the production mode was identified where possible, distinguishing between wild-caught and farmed sources. Cold-water shrimp species such as *Crangon crangon* and *Pandalus borealis* were treated as wild-capture resources, while Warm-water shrimps, particularly *Litopenaeus vannamei*, were treated mainly as aquaculture-derived imports. Mediterranean shrimps, including deep-water rose shrimp and miscellaneous shrimp categories, were treated as wild-caught resources landed and processed mainly in Southern Europe.

Third, bottom-up operator mapping was used to validate and refine the residue geography emerging from the desk study. This included the identification of local cooperatives, fishing factories and processing hubs in Southern Europe, Northern

Europe, Eastern Europe and non-EU processing countries. Particular attention was paid to Morocco, because available evidence shows that a significant part of the North Sea common shrimp (*Crangon crangon*) caught by EU fleets is transported there for hand peeling before re-entering the EU market. The analysis also considered northern and eastern European processing links, including factories and operators involved in cold-water shrimp handling, peeling, packing or foodservice preparation. Where company names or exact volumes could not be disclosed or verified, the information was used only to characterise the type of processing activity and the likely relevance of the area as a residue-generation or residue-handling node.

2.1.3. Species and value-chain classification

Crustacean biomass flows were classified according to species group, origin, production mode, product form and processing location. This classification was necessary because the same traded tonnage may correspond to very different residue-generation potentials depending on whether the product is whole, head-on-shell-on, shell-on, cooked, frozen, peeled, prepared or repacked. All these operational treatments represent necessary pre-requirements for the further exploitation through cascade process (WP2).

Cold-water shrimps were divided into two different sub-chains.

The first is the North Sea common shrimp chain, mainly based on *Crangon crangon*, which is wild-caught in North Sea waters and commonly sent to Morocco for hand peeling. In this case, the residue-generation point is often outside the EU, even if the biological resource and part of the landing activity are European. The second is the northern prawn chain, mainly based on *Pandalus borealis*, originating from Greenland, Canada, the Faroe Islands and northern European waters. These products often enter the EU through Denmark as cooked-frozen products and may then be redistributed within Europe or exported to third countries. Denmark therefore represents a major cold-water shrimp trade and redistribution hub, but not necessarily a proportional hotspot of local shell-waste generation.

Warm-water shrimps were treated separately because they are mainly aquaculture-derived imports from third countries. The most relevant species is whiteleg shrimp, *Litopenaeus vannamei*, with Ecuador, India and Vietnam among the key suppliers to the EU market. Product form is decisive in this chain. Ecuadorian shrimp frequently enters Southern Europe as whole raw or head-on-shell-on product, which increases the probability that shell residues are generated in EU processing destinations such as Spain, France or Italy. By contrast, shrimp from India and Vietnam may enter the EU in more processed or peeled forms, shifting part of the exoskeleton residue generation upstream to the producing countries and reducing local shell-waste availability in EU entry hubs such as the Netherlands and Belgium.

Mediterranean wild shrimps, including deep-water rose shrimp and miscellaneous shrimp categories, were analysed as local or regional biomass streams. These species are landed mainly in Southern European countries, especially Spain, Italy and Greece. In this case, residues are more likely to remain close to ports, auctions, wholesalers and local processing plants. Spain and Italy were therefore considered priority EU hotspots for locally generated crustacean exoskeleton residues, because they combine local landings of wild shrimps with established fish-processing sectors and relevant import-processing activities.

Norway lobster and other minor crustaceans were included as additional residue-relevant groups where sufficient information was available. However, because available datasets are less complete than for shrimps, these groups were treated as complementary biomass streams requiring further operator-level validation.

2.1.4. Identification of processing and residue-generation hotspots

The identification of residue hotspots was based on the principle that crustacean residues are generated at the stage of physical transformation, not at the stage of simple trade or storage. Therefore, each country or region was classified according to its dominant role in the value chain: production or fishing area, landing point, import gateway, storage or redistribution hub, processing hub, outsourced peeling hub, or final market.

This distinction was essential for interpreting the main European and extra-European crustacean flows. For example, Denmark handles large volumes of cold-water shrimp from Greenland, Canada and the Faroe Islands, but much of this product enters as cooked-frozen or already partially processed material and is subsequently redistributed or exported. As a result, Denmark is an important biomass-flow node but not automatically a high shell-residue hotspot. Conversely, Morocco emerges as a highly relevant residue-generation hotspot for North Sea common shrimp, because the peeling activity itself is concentrated there. Similarly, Spain and Italy appear as strong EU hotspots because they combine local Mediterranean shrimp landings, Warm-water shrimp imports and established seafood-processing industries.

The mapping also distinguished between confirmed hotspots, probable hotspots and contextual nodes. Confirmed hotspots were those where physical processing and residue generation are supported by official reports and/or clear operator evidence. Probable hotspots were those where processing capacity and biomass flows suggest residue generation, but where exact plant-level data were not available. Contextual nodes were countries or regions that are important for understanding the overall value chain, but where residue volumes linked to MARMADE - relevant sourcing could not yet be quantified with confidence.

2.1.5. Bottom-up operator mapping and confidentiality

The bottom-up mapping included the identification of operators involved in crustacean fishing, landing, processing, peeling, packing, cold storage, trading and re-export. This included local cooperatives, fishing associations, processing factories and industrial hubs. The purpose was not to create a public commercial database of companies, but to understand the practical structure of residue availability and the feasibility of sourcing shell-rich biomass.

Information collected from market actors was treated with caution, particularly when related to company-level volumes, client relationships, supply contracts, by-product management or commercial strategies. Some operators expressed reluctance to share data because of competition and market sensitivity. Consequently, the deliverable should not present company-level information but the data aggregation as operators. Furthermore, information are aggregated by country, region, species group or type of processing activity. This approach is consistent with the need to make D1.1 a public deliverable while preserving commercially sensitive information that may be useful for internal MARMADE sourcing activities.

2.1.6. Methodological approach for invasive species

Blue crab (*Callinectes sapidus*) and other promising species as Adriatic Crab (*Liocarcinus depurator*) was treated as a distinct methodological case within VC1 because it follows different biological, ecological, regulatory and market dynamics compared with shrimp and other conventional crustacean residues. Unlike imported or traditionally landed shrimp streams, blue crab in Europe is primarily an invasive species issue, particularly in Mediterranean and Adriatic coastal ecosystems. Its biomass availability is driven by population outbreaks, local control measures, fishing authorisations, cooperative-level collection, market demand and regional management strategies rather than by established international shrimp trade flows.

For this reason, the methodology for invasive crab's species combines literature-based analysis with local bottom-up information from local fishing communities, cooperatives and territorial stakeholders. The analysis focuses on identifying areas where blue crab biomass is being captured, landed, commercialized or potentially processed, with particular attention to the Adriatic context. Unlike the shrimp value chain, where residue generation can often be linked to established processing steps such as peeling, cooking or freezing, crab residue generation depends on whether the animal is sold whole, processed locally, transformed into food or waste products, or treated as a management by-product. Therefore, crab species require specific assessment of fishing volumes, seasonality, processing practices, market outlets, regulatory constraints and potential by-product collection points.

At this stage, Blue crab (*Callinectes sapidus*) and Adriatic Crab (*Liocarcinus depurator*) are considered an emerging biomass opportunity for MARMADE besides a constant residue stream of shrimp. Its analysis will be further developed through dedicated scientific literature, regional data, local stakeholder contacts and operator-level information. The final objective will be to assess whether crabs can represent a stable or seasonal source of exoskeleton-rich biomass, where such biomass could be intercepted, and under which operational and regulatory conditions it could be integrated into MARMADE biorefinery pathways.

2.1.7. Data limitations

Several limitations were identified during the mapping process. First, official datasets report crustacean trade, landings, first sales and the structure of the fish-processing sector, but they do not directly report exoskeleton-rich residue volumes. Second, the number of fish-processing companies available from SBS and EUMOFA country profiles refers to the whole fish-processing sector and not specifically to crustacean-processing or peeling facilities. Third, the product form is not always sufficiently detailed to determine whether the shell fraction is generated in the country of origin, in an EU processing hub, or in a third-country subcontracting location. For example, concerns extra-EU subcontracting nodes such as Morocco, China and Albania: they are clearly important, but the present evidence base provides an estimation of official tonnage series of crustaceans physically peeled in some of those countries for the EU market. That gap is explicitly preserved in Deliverable 1.1, (EUMOFA, 2024a); (MAC, 2022); (EUMOFA, 2026). Fourth, outsourced processing chains, such as shrimp peeling in Morocco or other non-EU locations, are clearly important but are not always quantified through harmonised official statistics. Finally, operator-level data may be commercially sensitive and therefore cannot always be disclosed in a public deliverable.

For these reasons, the mapping presented in D1.1 should be interpreted as a structured identification of biomass-flow patterns, residue-generation potential and priority sourcing hotspots, rather than as a direct statistical quantification of exploitable shell biomass. Quantitative residue estimates should therefore be considered indicative and should be further validated through direct stakeholder engagement, plant-level mass balances and pilot-scale biomass collection activities.

A more accurate quantification of exploitable residual biomass, particularly exoskeleton-rich fractions suitable for conversion into MARMADE chemical building blocks, will be progressively refined through the project's biomass-sourcing, sampling and processing activities. In this context, Biochica has started to intercept, sample and deliver different types of crustacean biomasses to project partners, reflecting real processing and preservation conditions. These include shells and exoskeleton residues derived from crustacean-processing activities, peeled and pre-cooked materials, dehydrated residues, fresh untreated biomass and frozen biomass. The comparison of these different sampling conditions will support the definition of conversion factors between raw residues, stabilized biomass and effectively exploitable fractions for downstream extraction.

These conversion factors will be essential to estimate how much of the mapped residue flow can realistically be used in MARMADE biorefinery processes. They will also help optimize the biomass supply chain by linking residue origin, processing history, preservation method, storage condition and expected extraction performance. This work will be further addressed within the dedicated biomass supply and sampling activities, in connection with WP2 validation of sustainable processing routes and extraction yields.

2.2. Methodology for VC2 – Macroalgae

2.2.1. Macroalgae (seaweeds), selection of species of interest

For the extraction and application of macroalgae later in the project, it was decided to focus on a selected number of six species, allowing for an in-depth analysis of compounds and conservation and extraction methods, rather than doing a more superficial prospective analyses of many species. Selected algae were to come from commercial suppliers (either from harvesting or from commercial cultivation), beach-wrecked invasive species *Rugulopteryx okamurae* from its invaded area (NW Spain, Portugal, SW Spain and mediterranean coasts of Spain, France and Italy), and a last group of green algae accumulations that are a byproduct of finfish aquaculture, growing in their nutrient rich effluents. Furthermore, it was decided to include at least two species of each major macroalgae group (Phaeophyceae – brown algae, Rhodophyceae – red algae, and Chlorophyceae – green algae). Applying these criteria to the three groups of biomass origin led to the following selection:

Brown algae: *Alaria esculenta* (winged kelp, commercial supplier) and *Rugulopteryx okamurae* (invasive species collected by project partner)

Red algae: *Gracilaria gracilis* (slender wart weed, or ogonori, commercial supplier) and *Palmaria palmata* (dulse or dillesk, commercial supplier)

Green algae: *Codium* spp. (sponge weed, species to be defined, commercial supplier or cultivation by project partner CTAQUA), *Ulva ohnoi* (species associated to fish aquaculture plant, collected by project partner CTAQUA).

However, for the mapping of seaweed biomass suppliers, it was decided to broaden the range of species, including all European seaweed suppliers we managed to localize and all the species they have on supply, with the aim to increase the interest of the mapping for all stakeholders of the project. It is important to note that the seaweed biomass production volume reported here only refers to biomass produced in Europe (including Norway, Iceland, Greenland, the Faroe Islands and the UK). Seaweed biomass processed inside Europe but imported from outside Europe is not included in this report.

2.2.2. European macroalgae production (harvest and aquaculture)

The VC2 macroalgae supplier mapping was based on an integrated approach combining secondary data sources, desk research and primary data collection (Circalgae, 2024; I3-4-Seaweed; EU4Algae Knowledge Library). Secondary sources included the EMODnet and EUMOFA databases for spatial and market data, the Phyconomy and Rubisko databases for seaweed industry operators and production volumes, and a structured review of recently published materials available through EU4Algae and linked to Horizon projects. Desk research covered peer-reviewed and relevant literature on European seaweed production, harvesting practices and end-use applications. Primary data collection included direct interviews and surveys with seaweed producers and suppliers across key European production regions. Where supplier-specific information was gathered through interviews, data has been anonymised in line with the confidentiality approach described in Section 2.3.

2.2.3. Mapping of invasive species *Rugulopteryx okamurae*

Current distribution of the invasive alga *R. okamurae*, in Spain locally known as “la alga asiática” (the Asian alga) was based on extensive literature study. Hotspots for presence in the water and beachings were recorded in an Excel spreadsheet, together with quantitative data when available. However, very little biomass data were available. Several popular media (newspapers, local and regional TV stations, etc.) also frequently report biomass estimates, however, as their methodologies and data sources are generally complicated to verify and their units are not always clear, these data were only used when corroborated by scientific literature and official reports from national or regional administrations. All data sources can be found in Annex 2.

2.2.4. Green algae biomass as byproducts of finfish aquaculture

Green algae blooms have caused major ecological and economic impact worldwide, including on the macroalgal community (Mineur et al., 2015). The world’s most extensive green algal bloom can be found in China in the coastal waters of Qingdao in the southern Yellow Sea (Ren et al., 2024). These blooms gained international fame by forming a threat for the the 2008 Olympic sailing competition. A surface area for this bloom of 4993.9 km2 has been reported with an estimated biomass of several million tonnes wet weight. The bloom consists of various species of *Ulva*, however, is dominated by *U. prolifera* (Leliaert et al., 2009). In Europe, the largest blooms by far can be found along the coasts of Brittany, France, in particular on the northern and westernmost coasts (Charlier et al., 2007 for distribution with volumes). Here, the blooms consists of a mixture of foliose Ulva species, such as *U. australis, U. lacinulata, U. rigida*, and other *Ulva* spp.

However, in both of these cases the nutrients that give rise to these blooms stem from agriculture run-off (review in Mineur et al., 2015). Green tides have been well mapped worldwide (see Ren et al., 204 for one of the most recent maps), however, only rarely are they strictly tied to eutrophication caused by effluents from aquaculture installations (see Hernández et al., 2008 for an example from Spain, this particular fish farm is now no-longer in operation). In the Bay of Cádiz, green algae growth in fish farm effluent is generally limited to specific earthen ponds in the former saltworks in this area than reach considerable volumes (> 10 kg/m2 wet weight, Malta et al., pers. obs.) and similar observations exist from other areas in Europe, such as Portugal, Ireland, etc. As little cases have been reported in the literature and they can often be tracked to single companies, mapping of these sites would give an unbalanced picture. Therefore, it was decided to not separately map these sites, although some of them are included in the general map of seaweed providers. The *Ulva* for the MARMADE project will mainly be sourced from the effluent pond of the experimental fish farm of project partner CTAQUA.

2.3. Mapping and data confidentiality approach

The mapping activities carried out in Deliverable 1.1 were based on the integration of literature-derived information, official datasets, project partner inputs and bottom-up operator mapping. For both VC1 crustacean residues and VC2 macroalgae biomass, information was first collected from official reports, EU market and statistical sources, scientific publications, sectoral documents, stakeholder's questionnaires, and available information performed by sector operators. These sources were used to identify relevant species, production areas, biomass flows, processing locations, supplier regions, market nodes and potential biomass hotspots.

The collected information was then organised into structured Excel datasets. For crustacean residues, the datasets included species groups, country-level biomass flows, production or landing areas, import/export routes, processing nodes, operator typologies, and potential residue-generation hotspots. For macroalgae, the datasets included biomass suppliers, species, production or harvesting areas, estimated volumes available, major applications and geographic coordinates. Where precise quantitative information was not available or could not be verified, qualitative classifications and confidence levels were used instead of unsupported numerical estimates.

The spatial analysis and map production for the VC1 and VC2-algae suppliers data were carried out using QGIS software, (QGIS, 2026). The Excel datasets were joined to geographic layers, including administrative boundaries and georeferenced points or areas, in order to visualize biomass distribution, processing nodes, supplier numbers and hotspot patterns. The resulting maps and infographics were designed to support the interpretation of biomass availability and to make the main spatial patterns accessible in the public document. Where appropriate, maps were complemented by summary tables to distinguish between production areas, processing hubs, trade or redistribution nodes, and potential sourcing hotspots. VC2 – *Rugulopteryx okamurae* distribution data were summarized in an Excel spreadsheet and final map production was carried out in R version 4.5.3 (R Core Team, 2026) using a script developed with R Markdown (RStudio).

A common confidentiality approach was applied across both value chains. Since D1.1 is a public deliverable, commercially sensitive information collected through bottom-up contacts, operator screening or partner knowledge was not disclosed at company level unless it was already publicly available and relevant for contextual interpretation. Several operators expressed the need to preserve confidentiality regarding volumes, clients, supply chains, contracts, processing capacities or by-product management practices. Therefore, sensitive information was aggregated by country, biomass type, species group or operator category. In the public version of the deliverable, the emphasis is placed on biomass-flow patterns, hotspot identification and general processing profiles rather than on individual companies or confidential business data.

This approach allows D1.1 to provide a robust and transparent mapping of available marine biomass while respecting market sensitivity and stakeholder confidentiality.

3. Results – VC1 Crustacean residues: species, biomass flows, processing nodes and sourcing hotspots

This chapter presents the results of the mapping carried out for VC1, focusing on crustacean residues. The analysis integrates species-level information, trade and processing flows, country-level industrial capacity, operator typologies and potential sourcing hotspots. Particular attention is given to the distinction between countries where crustaceans are produced, catched, imported or traded and countries or regions where physical processing takes place and residues can realistically be intercepted.

3.1. Overview of crustacean residue streams relevant to MARMADE

Crustacean residues represent a relevant marine biomass stream for MARMADE because they contain exoskeleton-rich fractions that can be further valorised through downstream processing and biorefinery activities.

These residues may originate from different processing steps, including peeling, heading, cooking, freezing, brining, packing, repacking and preparation for foodservice or retail markets.

However, the availability of such residues is highly dependent on the organisation of the value chain and on the form in which the crustacean biomass enters each processing node.

The mapping therefore focused on identifying the main species groups, their origin, production mode, trade routes and processing locations.

Five principal conventional crustacean groups were considered:

1. Cold-water shrimp: *Crangon crangon*, *Pandalus borealis*.
2. Warm-water shrimp: *Litopenaeus vannamei*.
3. Mediterranean wild shrimps and related species: Deep-water rose shrimp (*Parapenaeus longirostris*, Lucas, 1846)
4. Norway lobster and other conventional crustaceans: *Nephrops norvegicus*.
5. Invasive crustacean species: Crabs, (*Callinectes sapidus*), (*Liocarcinus depurator*).

These latest invasive species are included as a separate category and will be further developed in a dedicated section.

A key outcome of the mapping is that crustacean residue availability does not necessarily follow trade volumes. Countries handling large quantities of crustaceans may act mainly as import, storage or redistribution hubs, while the actual generation of shell-rich residues may occur elsewhere, where physical processing such as peeling or heading is performed.

For this reason, the analysis distinguishes between production areas, landing points, trade hubs, outsourced processing nodes and local processing hotspots.

3.2. Species-group synthesis

The fist analysis of the abovementioned crustaceous species is summarized in Table 1. The synthesis is based on the species profile on crustaceous species, in relation to the official data reported by EUMOFA (EUMOFA, 2026).

Table 1 Promising crustacean species to potentially to be exploited for novel food, (EUMOFA 2024a; Mac, 2022; EUMOFA 2021, (Tiralongo et al., 2025).

Group	Main species	Predominant production mode	Main origin / landing geography	Main implication
Cold-water shrimp	*Crangon crangon, Pandalus borealis*	Wild-caught	North Sea, Baltic& Nordic waters, Greenland, Canada, Faroe Islands	Strong split between landing geography and residue geography; peeling often outsourced, especially to Morocco
Warm-water shrimp	Mainly: *Litopenaeus vannamei* ; *Penaeus monodon*; in EU	Mainly aquaculture imports; small local wild component in the Mediterranean	Ecuador, India, Vietnam, Venezuela, Bangladesh; secondary	Product form is decisive; whole/HOSO imports create EU-side residues,

Group	Main species	Predominant production mode	Main origin / landing geography	Main implication
	landings also *Penaeus kerathurus*		Mediterranean landings	peeled/prepared imports shift shell generation upstream
Mediterranean wild shrimps and related species	*Parapenaeus longirostris*, *Aristeus antennatus*, *Aristaeomorpha foliacea*, *Aristeus varidens*, related local crustaceans such as *Squilla mantis*	Wild-caught	Italy, Spain, Greece and adjacent Mediterranean basins	More localized southern EU biomass stream, with residues likely to remain near ports and first-processing nodes.
Norway lobster and other conventional crustaceans	*Nephrops norvegicus*	Wild-caught	Atlantic ocean, North Sea, Bay of Biscay, Atlantic-Iberian coast, Mediterranean	High-value conventional shell-rich stream; important for residue potential but seasonally organised and fisheries-driven.
Crabs and emerging crustaceans	Mainly *Callinectes sapidus*. Secondary candidate streams under	Wild-caught / local removal / control fisheries	Adriatic lagoons, Po Delta, Mediterranean coastal systems	Not a stable trade-led chain; biomass availability is outbreak-driven, local and

Group	Main species	Predominant production mode	Main origin / landing geography	Main implication
	validation: Adriatic crab (*Liocarcinus depurator*)			management-dependent

3.2.1. Cold-water shrimp

Cold-water shrimp in the MARMADE mapping comprise two distinct wild-capture sub-chains: North Sea common or brown shrimp (*Crangon crangon*) and northern prawn (*Pandalus borealis*). There is no aquaculture production of common shrimp or northern prawn. In 2023, world catches of *Crangon crangon* reached 16,175 tonnes and were entirely supplied by the EU and the UK; the Netherlands and Germany accounted for 85% of EU catches. In the same year, world catches of *Pandalus borealis* reached 251,758 tonnes, while the EU contributed only 12% of that total (30,794 tonnes), mainly from Estonia, Lithuania and Denmark (EUMOFA, 2024a).

From a biomass-sourcing perspective, the key point is that the two sub-chains do not generate residues in the same geography. The *Crangon crangon* chain is characterised by outsourced peeling, whereas the *Pandalus borealis* chain is characterised mainly by cooked-frozen import and re-export.

The main product of the shrimp fishery is peeled shrimp sold in the EU and that most EU peeling units are based in Morocco; North Sea shrimp caught by the EU fleet are transported there by truck for hand peeling before being re-exported to Europe.

By contrast, EU extra-EU imports of cold-water shrimp in 2024 concerned mainly cooked-frozen products (98% of import volume), sourced above all from Greenland (47,550 tonnes) and, at lower levels, the Faroe Islands (4,339 tonnes) and Canada (3,587 tonnes), with Denmark accounting for 96% of EU imports from third countries (EUMOFA, 2024a).

The trade pattern confirms this split geography. In 2024-2025, Denmark was the main EU exporter of cold-water shrimp to third countries and mainly targeted the Chinese market, while the Netherlands strongly targeted Morocco. EUMOFA explicitly links Dutch exports to North Sea catches sent to Morocco for peeling by specialised units, sometimes owned by Dutch companies.

For *Pandalus borealis*, the 2023-2025 EU supply balance reached 96,512 tonnes/year in live weight equivalent, of which 30,794 tonnes/year came from production, 65,718 tonnes/year from imports, and 73,337 tonnes/year were exported again.

This means that cold-water shrimp is a highly transnational value chain in which biomass production, import statistics, peeling activity and shell-residue generation are often located in different countries (EUMOFA, 2024a).

A further practical point is seasonality. In fact EUMOFA monitoring shows that *Crangon* first-sales volumes are seasonal, peaking in March-May in Denmark and in September-November in Belgium and the Netherlands. "Cold-water shrimp" first-sales patterns also differ between Denmark, Sweden and Spain, reflecting different landing structures and market calendars. The cold-water shrimp should therefore be treated as a wild-caught, transnationally processed species group, in which residue availability depends more on the "location of peeling" rather than on the location of landings or imports (EUMOFA, 4/2021).

3.2.2. Warm-water shrimp

Warm-water shrimp differ fundamentally from cold-water shrimp because they are dominated by aquaculture-based imports from third countries rather than by EU fisheries. The estimated total EU shrimp supply was at 789,000 tonnes/year (2020 – 2021), of which 780,000 tonnes/year were imported from third countries, confirming the structural import dependence of the EU market.

The dominant imported farmed species is whiteleg shrimp (*Litopenaeus vannamei*; also reported in some market sources as *Penaeus vannamei*), while Asian supplies also include giant tiger shrimp (*Penaeus monodon*), (MAC, 2022), (EUMOFA, 2026).

In current trade terms, warm-water shrimp are the dominant shrimp segment in the EU import basket. According to latest data publication, shrimp were the fourth most consumed aquatic species in the EU since 2023, and in 2024 they reached 0% of total EU import volume and 13% of total value. Within this broader shrimp category, Warm-water shrimp represented 54% of shrimp import volume and 52% of value, primarily sourced from Ecuador. In the more detailed extra-EU crustacean breakdown, warm-water shrimp reached 329,487 tonnes and EUR 2.0 billion in 2024, accounting for 49%

of crustacean import volume and 44% of value. Ecuador supplied 54% of imported volume, followed by India (13%), Venezuela (12%), Vietnam (8%) and Bangladesh (4%), (EUMOFA, 2026).

Within this context, the decisive variable is not simply country of origin, which can affect the supply chain, but product form at import stage. For example, shrimp from India and Vietnam enter both Southern and Northern Europe as prepared products and as whole products, whereas shrimp from Ecuador are imported especially into Southern Europe as whole raw and unpeeled material.

Furthermore, Ecuador mainly exports whiteleg shrimp and that most Ecuadorian shipments are head-on-shell-on (HOSO), while a large share of Indian shipments are peeled. This leads to a very different geography of crustacean by-products generation: when the product arrives whole or HOSO, shell-rich residues are much more likely to be generated in EU processing countries; when the product arrives peeled or otherwise prepared, shell generation is displaced upstream to the country of origin, (MAC, 2022); (EUMOFA, 2026).

This is also reflected in the geography of EU entry points. In 2024, the first points of entry for warm-water shrimp were Spain, France and the Netherlands, although EUMOFA notes that Rotterdam and Antwerp often act as logistic hubs for subsequent redistribution within the EU. This means that for MARMADE Project, warm-water shrimp should be interpreted as a mainly imported aquaculture chain, with the highest EU-side residue potential in those destinations where whole shrimp are physically transformed rather than simply transited.

At last, official landings statistics also contain a small EU "Warm-water shrimp" component, mainly caramote prawn (*Penaeus kerathurus*), but this represented only 10% of EU shrimp landing volume and 12% of value during last years. Therefore, the strategic relevance of the group lies primarily in imported tropical shrimp and then pealed in EU, rather than in EU landings, (EUMOFA, 2026).

3.2.3. Mediterranean wild shrimps and related species

Mediterranean wild shrimps represent a much more localized and regionally structured biomass stream than tropical imported shrimps. The most relevant species group is deep-water rose shrimp (*Parapenaeus longirostris*), complemented by the EUMOFA group "miscellaneous shrimps", which mainly includes giant red shrimp (*Aristaeomorpha foliacea*), blue and red shrimp (*Aristeus antennatus*), and striped, red shrimp (*Aristeus varidens*). These are wild-caught fisheries concentrated in Southern

Europe, and they are highly relevant for MARMADE because they combine landings, first sale and a large share of primary handling within the same macro-region.

In 2023, deep-water rose shrimp became the most landed shrimp species in the EU for the first time, accounting for 35% of total EU shrimp landings. Italy, Spain and Greece together represented more than 90% of total EU deep-water rose shrimp volume. Italy remained the leading country with 5,944 tonnes, followed closely by Spain with 5,759 tonnes, while Greece landed 3,215 tonnes. In the same year, the "miscellaneous shrimps" group was also heavily concentrated in Southern Europe: Italy and Spain together accounted for around 90% of all these shrimps landed in the EU. Spain landed 3,573 tonnes worth EUR 77 million, while Italy landed 2,736 tonnes worth EUR 67 million.

These data are important because can indicate where shell-bearing Mediterranean shrimp biomass is most likely to remain within Europe. Unlike the Crangon-Morocco chain or the tropical shrimp flows driven by long-distance imports, Mediterranean shrimps are far more likely to be landed, auctioned, transported and processed within the same regional system, especially in Italy, Spain and Greece. This makes them particularly relevant for identifying southern EU hotspots where exoskeleton-rich residues may be intercepted close to ports, auctions, wholesalers and local processing sites (EUMOFA, 2026).

The category of "related species" should also include Mediterranean crustaceans that are not strictly shrimps but are operationally relevant to the same local chains. EUMOFA's crustacean monitoring highlights spottail mantis squillid (*Squilla mantis*) as a strongly Mediterranean resource, occurring in high densities in the basin and with Italy and Spain among the most important EU catching nations. Its fishery is markedly seasonal, with catches occurring mainly in winter and spring. For MARMADE Project, this group reinforces the idea that Mediterranean crustacean biomass tends to generate residues close to the zone of capture and first commercialization.

However, the crustaceans mentioned are commercialized without peeling, therefore the exploitation of the by-products become secondary if compared with imported crustaceans' species, (EUMOFA, 4/2021).

3.2.4. Norway lobster and other conventional crustaceans

Norway lobster (*Nephrops norvegicus*) is a high-value conventional crustacean that differs from shrimp both biologically and commercially but remains highly relevant for MARMADE because it is a shell-rich, wild-caught resource with established EU fisheries and processing routes. According to the recent statistical data, the species occurs throughout the Atlantic, from Iceland, the Faroe Islands and Norway to the Azores and the Mediterranean Sea. It inhabits muddy bottoms at 20-800 m depth, feeds on crustaceans and worms, and is mainly caught by trawling, often in mixed demersal fisheries. Commercially important EU stocks are located in the Irish and North Seas, the Bay of Biscay, and along the Atlantic-Iberian coast (EUMOFA, 4/2021).

The market importance of *Nephrops* norvegicus is very clear in first-sales data. In January 2021, Norway lobster alone represented 30% of the first-sales value of the crustaceans' group across the reporting Member States considered by EUMOFA, and together with spottail mantis squillid it accounted for 38% of total crustacean first-sales value. This confirms that *Nephrops* is not a marginal by-product stream but one of the main value-carrying conventional crustaceans in the European seafood economy (EUMOFA, 2024a).

Seasonality is also well documented. In Denmark, the highest first sales over the last decade, February 2018 - January 2021, series occurred in August 2019 (861 tonnes) and August 2020 (720 tonnes), while winter activity was much lower because of weather conditions. In France, peaks were recorded mainly in May and June, and in Sweden fluctuations were associated not only with temperature and catchability but also with tourism and seasonal shellfish consumption traditions. Price dynamics reflected this seasonality: for example, France recorded higher prices in low-supply months, particularly around December holiday demand, (EUMOFA, 4/2021).

In the context of MARMADE Project, Norway lobster should therefore be treated as a "conventional EU crustacean stream" with strong shell-value potential, but one that is "organised through fisheries calendars", and therefore subjects to the seasonability. This factor is determinant for the supply chain and respective exploitation of the by-products within the circular bioeconomy overview.

In practical terms, residue availability from *Nephrops* is likely to depend on landing seasons, auction concentration and downstream processing choices, (EUMOFA, 2026), (EUMOFA, 4/2021), but the species remains one of the clearest conventional crustacean candidates for high quality exoskeleton-rich biomass sourcing.

3.2.5. Crabs and emerging crustaceans

The category of "crabs and emerging crustaceans" is more heterogeneous and, at present, less statistically standardised than the shrimp and *Nephrops* chains. For

MARMADE, the most relevant case is the Atlantic blue crab (*Callinectes sapidus*), not because it already forms a mature EU processing chain, but because it is generating increasingly visible and locally concentrated biomass in Mediterranean coastal and lagoon systems, particularly in the Adriatic.

Unlike conventional shrimp chains, which are largely driven by established international trade flows, blue crab biomass is driven by local proliferation, control measures, fisher response, market uptake, primary handling capacity and emerging management strategies (Marchessaux et al., 2023), (Della Ceca et al., 2026).

Within the MARMADE project, blue crab is therefore treated as an emerging biomass source whose operational logic differs fundamentally from that of imported or conventionally landed crustaceans. The chain is not primarily shaped by long-established EU import routes, but by population outbreaks, local containment actions, experimental or pilot fishing, fish-market activation, cooperative-level collection, commercial experimentation and potential export-oriented routes towards non-EU markets (i.e.: USA, and South Corea). In this context, by-products and exoskeleton-rich residues would be generated mainly in EU catching, landing and primary-handling and processing areas.

Recent evidence from Po Delta illustrates this shift very clearly. A 2025 study based on field data collected between August and December 2023 in the Canarin and Scardovari lagoons documented clear seasonal fluctuations in C. sapidus abundance, with higher catches during the warmer months, and reported a severe predatory impact on clam farming, with production approaching near-zero levels in early 2024. The authors argue that economic valorisation of *C. sapidus* should be considered as part of the management response. This is fully coherent with the MARMADE perspective, because blue crab biomass is simultaneously an ecological problem, a fishery-management challenge and a potential exoskeleton-rich feedstock if interception, handling and stabilization can be organised properly (Tiralongo et al., 2025).

The rapid growth of blue crab catches in northern Adriatic areas further confirms its relevance as an emerging biomass stream. According to recent Italian regional evidence, (Della Ceca et al., 2026), blue crab landings in Veneto increased from about 100 t, specifically 97 t, in 2022 to 630 t in 2023, corresponding to an increase of approximately 550%. In the first half of 2024 alone, catches had already reached 687 tons/year. In Emilia-Romagna, particularly in the Sacca di Goro, the increase was even marked, from 90 tons/year in 2022 to 936 tons/year in 2023, corresponding to a rise of approximately 940%. In 2024, around 1,894 tons/year of blue crab passed through regional fish markets and the Polesine Fishermen's Cooperative Consortium of

Scardovari, although only 714 tons/year were actually placed on the market. These figures should not yet be interpreted as a stable national production series, but they clearly indicate the scale and concentration of the biomass in specific Adriatic hotspots.

The management dimension is also relevant for biomass sourcing. The UNEP/MAP-SPA/RAC review on blue crab management in the Mediterranean reports that the Italian containment plan for 2025–2026 aims to protect biodiversity, control the spread of invasive blue crabs, reduce economic losses and support the recovery of fisheries and aquaculture activities. The measures include targeted fishing, support for the landing, quantification and disposal of crabs through fish markets, cooperatives and local administrations, as well as the assessment of economic uses beyond human consumption. These actions are particularly relevant for MARMADE because they indicate where biomass could be intercepted in practice by involving stakeholder engagement: local fishing cooperatives, lagoon-management systems, depuration and sorting centres, fish markets, landing sites, disposal circuits and emerging processing facilities, (UNEP/MAP-SPA/RAC, 2026).

At the Mediterranean scale, the blue crab case also shows how invasive biomass can evolve from an ecological problem into an industrial or semi-industrial value chain. Tunisia provides a non-EU example of advanced blue crab valorisation, mainly related to *Portunus segnis*. The Tunisia has 49 seafood-processing factories, 17 of which specifically process blue crabs, and reports a large processing facility in Ghannouch with a capacity of 110 tons/day and cold storage capacity up to 6,000 t. In 2022, approximately 25,000 tons/year of blue crabs were caught in Tunisia, with around 6,000 tons/year exported worldwide and nearly USD 30 million generated by the sector. Although this Tunisian case cannot be directly transferred to the Italian Adriatic context, it demonstrates that invasive Portunid crabs can become relevant biomass and processing streams when collection, market organisation and industrial handling are established, (UNEP/MAP-SPA/RAC, 2026).

However, an important limitation remains: *C. sapidus* is not yet systematically captured in major international or national statistical databases in the same way as conventional fishery or aquaculture products. Available figures therefore derive from regional records, institutional monitoring, market data, project-based evidence, media-supported institutional summaries and ad hoc scientific studies. For this reason, blue crab should be presented as a locally abundant and rapidly expanding biomass stream, but not yet as a fully harmonised EU production chain. Its availability is likely to be strongly seasonal, local and management dependent.

A second emerging stream already relevant to the MARMADE context is the Adriatic “sand crab”, *Liocarcinus depurator*. This species differs from blue crab because it is not primarily an invasive-management biomass, but rather a by-catch associated resource from demersal fisheries. The FLAG Costa Blu scientific report describes L. depurator as one of the dominant crab species of muddy Mediterranean continental shelf bottoms, distributed in the North Sea, Atlantic Ocean, Mediterranean Sea and Black Sea, and associated with sandy-muddy seabeds from shallow waters to deeper demersal habitats. In the Mediterranean it is considered one of the important bycatch species of demersal fisheries and is frequently captured by bottom trawling (FLAG Costa Blu, 2021).

The same FLAG Costa Blu project provides useful local evidence from the central Adriatic. In the Giulianova area, field activities were carried out in July and August 2021 using the trawler M/P Rossella, operating with standard bottom-trawling gear and without structural modifications to fishing equipment. Seven dedicated hauls were carried out over three fishing trips, in an area between approximately 6 and 8 nautical miles from the coast and at depths of around 50–60 m. The monitoring collected approximately 116 - 120 kg of crabs, all belonging to *Liocarcinus depurator*, confirming the presence of a locally concentrated biomass potentially suitable for chitin and chitosan extraction trials, (FLAG Costa Blu et al., 2021).

From an operational point of view, *L. depurator* should therefore be considered a complementary, location-specific biomass source rather than a mature commercial chain.

Unlike blue crab, its relevance is not linked to invasive population outbreaks or containment plans, but to the valorisation of low-value or discarded bycatch from bottom-trawl fisheries. The FLAG Costa Blu, stakeholder of MARMADE Project, report also highlights practical aspects that are directly relevant to the project, including manual sorting on board, washing with seawater, refrigerated storage at 5–8 °C during summer, alternative winter storage in closed containers, transport to land-based facilities, freezing at around -20 °C, drying to reduce water content, and possible pre-processing through grinding or drying before extraction, (FLAG Costa Blu et al., 2021).

Overall, crabs and emerging crustaceans should be framed within this document as locally important, potentially high-value and sometimes highly abundant biomass streams, but also as less predictable and less statistically harmonised than shrimp or *Pandalus* flows. Blue crab represents an invasive-management-driven biomass, with high local abundance, strong ecological and economic impacts, and increasing interest in commercialization, control-through-consumption and alternative uses.

Liocarcinus depurator, by contrast, represents a fishery-bycatch valorisation stream, potentially useful for circular bioeconomy applications but currently supported mainly by local evidence and project-based trials.

In both cases, the biomass may generate concentrated exoskeleton-rich streams close to lagoons, estuaries, depuration areas, landing points, fish markets, collection centres and local processing sites. However, the full exploitable potential of these resources still requires targeted sampling, fishery monitoring, operator engagement and biomass-supply validation within MARMADE Project.

3.3. Country-level processing and market nodes

The country-level analysis of crustacean biomass flows shows that the European crustacean value chain is organised through a combination of production areas, landing points, import gateways, processing hubs, outsourced peeling nodes and redistribution markets. For MARMADE, this distinction is essential because the availability of exoskeleton-rich residues depends less on total trade volume and more on where shell-bearing crustaceans are physically transformed.

Three main categories of nodes were identified:

1. The first includes EU local-processing hotspots, where crustaceans are landed or imported and then processed domestically, generating residues close to ports, markets, factories or wholesale platforms. although the interception of biomass residues could be promising, its constant supply chain could be difficult due to logistic residues optimization not still implemented. Spain and Italy fall mainly into this category, due to the combination of Mediterranean wild shrimp landings, Warm-water shrimp imports and established seafood-processing sectors. France also plays a relevant role, although the available evidence suggests a more mixed profile combining import, processing, distribution and final-market functions.
2. The second category includes EU trade, storage and redistribution hubs. Denmark, the Netherlands, Belgium and Germany are key examples. These countries handle large crustacean volumes, but their local residue-generation potential varies considerably depending on product form and processing stage. Denmark, for example, is the main EU entry and export hub for cold-water shrimp from Greenland, Canada and the Faroe Islands, but much of this flow consists of cooked-frozen *Pandalus* products, meaning that local shell-residue generation is not proportional to total import volume. Similarly,

the Netherlands and Germany are important for North Sea common shrimp and warm-water shrimp trade, but part of the peeling or shell-removal step is outsourced outside the country, especially to Morocco for *Crangon crangon*.

3. The third category includes non-EU origin and outsourced-processing nodes. These countries are essential to understand the real geography of shell generation. Morocco is the clearest example of an outsourced peeling hotspot for North Sea common shrimp, while Greenland, Canada and the Faroe Islands are primary origin areas for *Pandalus borealis*. Ecuador, India, Vietnam and Argentina are major origins for warm-water or miscellaneous shrimp products entering the EU market. China, although not a primary sourcing target for MARMADE, is relevant as a global processing and consumption hub, especially for cold-water shrimp exported from Denmark.

For emerging crab biomass, Tunisia and Turkey provide examples of non-EU Mediterranean systems where blue crab biomass has already been partially converted into commercial or industrial value chains, with probability to concentrate most of their by-product's processes.

Overall, the countries-level mapping confirms that crustacean residue availability does not simply follow the largest import or export flows. The most relevant sourcing nodes are those where shell-on, head-on-shell-on or unpeeled biomass is handled and transformed in ways that generate recoverable exoskeleton fractions.

Within this context, relevant attention of supply chain for by products should be addressed to the east and Mediterranean countries where most of the crustacean peeling processes are implemented, Morocco, followed by Spain and Italy, EU-East countries for shrimps, Tunisia, Turkey followed by Italy for crabs, (Add references of the maps).

3.3.1. EU processing and market nodes

Within the EU, Spain and Italy emerge as the most relevant local-processing hotspots for crustacean residues.

Infact, Spain combines an important seafood-processing industry, a strong position in Southern European shrimp markets and relevant flows of warm-water and miscellaneous shrimps. The country is particularly important for warm-water shrimp imports, including products from Ecuador and other third-country suppliers, and for Mediterranean crustacean landings. Since part of the product enters Southern

European markets in whole, raw or head-on-shell-on form (HOSA), processing activities in Spain may generate locally recoverable shell-rich residues, especially where cooking, peeling, packing or preparation for retail and foodservice markets are performed, (Table 2), (MAC, 2022); (EUMOFA, 2026).

Italy represents a second key EU hotspot. Its relevance is based on three complementary streams: Mediterranean wild shrimps and related species landed through Southern and Adriatic ports, imported warm-water shrimp products, and emerging crab biomass, especially Callinectes sapidus in the northern Adriatic. For conventional shrimp, residues are more likely to be generated close to ports, auctions, wholesale markets and local processing facilities. For blue crab, the logic is different: the biomass is generated by invasive-species proliferation, control measures, fishing response and local market activation rather than by consolidated import flows. Recent regional evidence from Veneto and Emilia-Romagna confirms that blue crab biomass is becoming locally concentrated in lagoon and shellfish-farming areas, although it is not yet captured by harmonised national or EU statistical systems, (Table 2), (Della Ceca et al., 2026).

France should be considered a mixed processing and market node. It is a relevant EU seafood market and an entry point for some shrimp products, but its role as a residue hotspot depends on the extent to which imported product is processed domestically rather than entering the market already peeled, cooked or prepared. France is also relevant for Atlantic and Mediterranean crab and crustacean markets, but the available evidence is less direct for quantifying shell-residue generation from crustacean processing due to a certain approach of protectionism of their data, with aim to avoid competition from potential EU competitors regarding the exploitation of their shellfish residues (Information provided by French stakeholders of the project), (Table 2).

Denmark is a major EU cold-water shrimp hub, but its role must be interpreted carefully. In 2024, EU extra-EU imports of cold-water shrimp products amounted to 59,229 t, mainly cooked-frozen products. Denmark accounted for 96% of these extra-EU imports, with Greenland, the Faroe Islands and Canada as the main suppliers. Denmark was also the main extra-EU exporter of cold-water shrimp products, accounting for 69% of EU exports, with China representing approximately 47% of extra-EU export destinations. This confirms Denmark's function as an import, storage, processing-light, redistribution and re-export hub. However, because much of the product is cooked-frozen and may already have undergone primary processing, Denmark should not be treated as a proportional shell-waste hotspot, (Table 2), (EUMOFA, 2024a).

The Netherlands and Germany play a different but equally important role. For North Sea common shrimp (*Crangon crangon*), they are central catching, trading and export nodes. In 2023, the Netherlands and Germany were the main EU producers of common shrimp, accounting together for most EU catches. However, the EUMOFA cold-water shrimp profile indicates that most EU peeling units for common shrimp are based in Morocco, where shrimp caught in the North Sea by EU fleets are transported by truck for hand peeling before re-entering the EU market. Therefore, the Netherlands and Germany should be mapped as important production and trade nodes, but not necessarily as the main locations of shell-residue generation for *Crangon*, (Table 2), (EUMOFA, 2024a).

Belgium is relevant mainly as a trade and market gateway, particularly for processed or prepared shrimp products entering north-western Europe. Together with the Netherlands, it is connected to shrimp imports from Asian suppliers, especially India and Vietnam, where a significant share of the product may already be peeled or prepared before reaching the EU. This reduces the probability that large exoskeleton fractions are generated locally in Belgium, unless specific processing or repacking operations are identified at operator level, (MAC, 2022); (EUMOFA, 2026).

Sweden, Poland, Bulgaria and Estonia should be considered secondary or niche processing nodes. Their relevance is mostly linked to cold-water shrimp markets, foodservice-oriented products, brining, packing, hand-peeling or private-label processing. Available evidence suggests that these countries may host specific crustacean-processing activities, but their role remains less statistically visible than that of Spain, Italy, Denmark, the Netherlands, Germany or Morocco. Therefore, they are mapped as potential secondary nodes requiring further operator-level validation, (Table 2).

For emerging crab biomass, the EU map highlights the northern Adriatic as a distinct hotspot. The Veneto and Emilia-Romagna regions are particularly relevant for C. sapidus, while the central Adriatic is also relevant for *Liocarcinus depurator* as a by-catch associated biomass stream. The stakeholders of the project, FLAG Costa Blu and Bluemarine Service provided local evidence from Giulianova and San Benedetto del Tronto ports, showing that *L. depurator* can be intercepted through bottom-trawl activities, with availability distributed across the year and peaks in July, October and December. However, these data although still local, demonstrate that it is becoming a promising, yet still not fully exploited, biomass resource that can be able to strengthen the local bioeconomy growth by reversing a threat in a new opportunity growth, (Table 2), (FLAG Costa Blu et al., 2021).

Table 2 Main EU processing and market nodes for crustacean residue mapping, (data elaborated by Biochica, 2026).

Country / node	Main function in the value chain	Main species or product groups	Relevance for MARMADE sourcing
Spain	Local processing hotspot, import gateway, Southern EU market	Warm-water shrimp, miscellaneous shrimp, Mediterranean wild shrimps	High relevance where whole or shell-on products are processed locally
Italy	Local processing hotspot, landing area, emerging crab hotspot	Mediterranean shrimps, warm-water shrimp, blue crab, Adriatic crabs	High relevance for local residues and emerging invasive/bycatch biomass
France	Mixed market, processing and distribution node	Warm-water shrimp, cold-water shrimp, crabs, lobster products	Medium relevance; residue potential depends on domestic processing stage
Denmark	Cold-water shrimp import, storage, redistribution and re-export hub	*Pandalus borealis*, cooked-frozen cold-water shrimp	High trade relevance but lower proportional local shell-residue potential
Netherlands	North Sea shrimp production/trade node and Warm-	*Crangon crangon*, warm-water shrimp	Important production/trade node; much

Country / node	Main function in the value chain	Main species or product groups	Relevance for MARMADE sourcing
	water shrimp gateway		*Crangon* peeling outsourced
Germany	North Sea shrimp production/trade and packing node	*Crangon crangon*, cold-water shrimp	Important production/trade node; local residues depend on processing stage
Belgium	Import and market gateway	Warm-water shrimp, prepared shrimp products	Medium-low residue potential if product enters already peeled/prepared
Sweden	Nordic seafood market and cold-water shrimp processing niche	Cold-water shrimp, brined/packed shrimp products	Secondary node; requires operator-level validation
Poland-Bulgaria-Estonia	Niche cold-water shrimp processing and hand-peeling nodes	*Pandalus borealis*, brined or prepared shrimp	Potential secondary nodes; data less harmonised
Northern Adriatic (Italy: Emilia Romagna-Veneto Regions)	Emerging invasive-crab hotspot	*Callinectes sapidus*	High local biomass potential, but not yet harmonised statistically
Central Adriatic (Italy)	Bycatch-associated crab biomass	*Liocarcinus depurator*	Complementary local stream; evidence from

Country / node	Main function in the value chain	Main species or product groups	Relevance for MARMADE sourcing
			project-based monitoring

3.3.2. Non-EU origin and outsourced-processing nodes

Non-EU nodes are essential for understanding the real geography of crustacean residues entering or linked to the European market. In several cases, biomass may be biologically produced or caught outside the EU, processed outside the EU, and only then imported into Europe as a semi-processed or finished product. In other cases, EU-caught biomass is exported outside the EU for labour intensive processing and then re-imported. This is particularly important for residue mapping, because exoskeleton-rich fractions may be generated outside the EU even when the final market is European.

Morocco is the clearest outsourced-processing node for MARMADE Project. In fact, most of EU peeling units for common shrimp are based in Morocco, and that shrimp caught in the North Sea by EU fleets are transported there by truck for hand peeling. The peeled product is then exported back to the EU market. This means that Morocco is a confirmed residue-generation hotspot for *Crangon crangon*, even though the biological resource is largely linked to EU and neighboring North Sea fisheries. Morocco should therefore be mapped not only as a non-EU node, but specifically as an outsourced peeling and shell-residue concentration point, (EUMOFA, 2024a).

Greenland, Canada and the Faroe Islands represent the main origin nodes for cold-water shrimp entering the EU through Denmark. In 2024, Greenland supplied 47,550 tonnes/year of EU cold-water shrimp imports, while the Faroe Islands and Canada supplied 4,339 tonnes/year and 3,587 tonnes/year, respectively. Since these flows mainly concern cooked-frozen *Pandalus* products, part of the shell-removal or primary-processing residue may be generated before the product reaches EU hubs. These countries are therefore mapped as primary origin nodes rather than as EU-accessible residue hotspots, unless direct sourcing or processing partnerships are developed, (EUMOFA, 2024a).

Ecuador is a key origin node for warm-water shrimp, mainly whiteleg shrimp (*Litopenaeus vannamei*). Its relevance for residue mapping depends strongly on product form. When shrimp is exported as whole raw or head-on-shell-on product (HOSA), residue generation may occur in EU processing destinations such as Spain, France or Italy. When processing is performed in the origin country, residues remain upstream. Previous Biochica work in collaboration with its stakeholders on Ecuadorian "Camarones" residues showed the potential valorisation relevance of this biomass, with preliminary observations indicating a protein-rich fraction and an estimated chitin fraction of approximately 10–15% in the analysed residues. This supports the technical relevance of warm-water shrimp residues in some EU countries, although their estimation is still interpreted but not clearly known.

India and Vietnam are also major Warm-water shrimp suppliers to the EU, but their role differs from Ecuador because part of the product reaches Europe in peeled, prepared or higher-value processed forms. As a result, shell and head residues are more likely to be generated upstream, in the producing or processing countries, rather than in EU trade gateways such as the Netherlands and Belgium. For MARMADE Project, this means that India and Vietnam are important for understanding the global residue geography, but less immediately relevant as EU-based sourcing hotspots unless residues are intercepted through upstream partnerships or imported as stabilized by-products (MAC, 2022); (EUMOFA, 2026).

Argentina is relevant for miscellaneous or red shrimp flows entering Southern Europe, particularly Spain and Italy. Depending on product form, residues may be generated either in Argentina or in EU processing destinations. The available evidence supports its inclusion as an origin node in the wider crustacean-flow map, but it should be treated cautiously in residue estimates unless product-form-specific trade data are used.

China is considered as a global processing and consumption node rather than as a direct MARMADE sourcing hotspot. In fact, data from EUMOFA show that China represented approximately 47% of EU extra-EU cold-water shrimp export destinations in 2024, and that almost all Chinese imports of cold-water shrimp from the EU originated from Denmark. This indicates a "Denmark - China re-export and processing/market relationship". However, the extent to which the product is further processed in China, consumed domestically or re-exported is not sufficiently quantifiable from the available official database, (EUMOFA, 2024a). China therefore remains a contextual node, not confirmed as MARMADE residue hotspot.

Tunisia provides an important Mediterranean example for emerging crab biomass. Unlike the Italian blue crab case, where the value chain is still developing and the biomass is not yet systematically recorded in standard statistics, Tunisia has already implemented an industrial valorisation strategy for blue crabs, especially *Portunus segnis*. In fact, Tunisia currently has 49 seafood-processing factories, 17 of which specifically focus on blue crab processing. Since during 2022, approximately 25,000 tonnes/year of blue crabs were caught in Tunisia, and around 6,000 tonnes/year were exported worldwide, and the sector generated nearly USD 30 million in revenue. This example shows that invasive Portunid crabs can become a significant processing and residue-generating chain if collection, market demand, industrial capacity and export channels are organised.

Turkey is another non-EU node where blue crab is commercially exploited. Currently, around 300–500 t of blue crabs are exported annually from Turkey, particularly from areas such as the Göksu Delta, Dalyan and Akyatan Lagoon. Although the Turkish case is not directly linked to EU biomass sourcing, it provides additional evidence that blue crab can move from an ecological nuisance to an economically exploited crustacean resource. However, this also raises management concerns, because promoting commercial exploitation without adequate invasive-species control may support the persistence or spread of the species, (UNEP/MAP-SPA/RAC, 2026).

Norway and the United Kingdom are also considered contextual northern nodes for crustacean flows, including cold-water shrimp, Norway lobster and crab products. Their relevance for MARMADE depends on whether residues are generated through local processing or whether the products enter EU markets already processed. Brown crab and king crab are also relevant in wider North Atlantic biomass mapping, but the present evidence based on informal information from project stakeholders are not sufficient to quantify shell-residue availability from these streams.

Overall, the non-EU analysis confirms that crustacean-based biomass residues analysis of the MARMADE project distinguishes between origin countries, outsourced processing countries and final-market countries.

For sourcing purposes, Morocco is the strongest confirmed outsourced residue hotspot for *Crangon crangon*.

Ecuador, India, Vietnam, Argentina, Greenland, Canada and the Faroe Islands are important origin nodes for warm-water shrimps, but their residue relevance depends on product form and processing location. Tunisia and Turkey are relevant examples of emerging crab valorisation outside the EU.

While China is an important global market and processing node, but not a directly quantifiable residue-sourcing hotspot for the MARMADE project.

Table 3 Main non-EU origin and outsourced-processing nodes, (data elaborated by Biochica, 2026).

Country / node	Main function in the value chain	Main species or product groups	Relevance for residue mapping
Morocco	Outsourced peeling hub	*Crangon crangon*	Very high: confirmed hand-peeling and shell-residue generation node
Greenland	Origin country for cold-water shrimp	*Pandalus borealis*	High origin relevance; residues may be generated upstream
Canada	Origin country for cold-water shrimp	*Pandalus borealis*	High origin relevance; direct EU residue potential depends on product form
Faroe Islands	Origin country for cold-water shrimp	*Pandalus* spp.	Origin node feeding EU/Danish cold-water shrimp flows
Ecuador	Warm-water shrimp origin	*Litopenaeus vannamei*	High relevance if HOSO or shell-on product is processed in the EU
India	Warm-water shrimp origin and processing country	Penaeid shrimps	Residues often generated upstream if product enters EU peeled/prepared

Country / node	Main function in the value chain	Main species or product groups	Relevance for residue mapping
Vietnam	Warm-water shrimp origin and processing country	Penaeid shrimps	Residues often generated upstream; EU residue potential lower for prepared products
Argentina	Origin of miscellaneous/red shrimp	Argentine red shrimp / miscellaneous shrimp	Relevant for Spain and Italy; residue location depends on product form
China	Global processing and consumption node	Cold-water shrimp and other shrimp products	Context node; EU-linked residue volumes not quantifiable.
Tunisia	Blue crab valorisation and processing node	*Portunus segnis* and blue crab products	Demonstrates industrial potential of invasive crab biomass
Turkey	Blue crab commercialisation/ export node	*Callinectes sapidus*	Contextual non-EU example of commercialized blue crab biomass
Norway / UK	Northern crustacean origin and market nodes	Cold-water shrimp, Norway lobster, crab products	Context nodes; further product-specific validation needed

3.4. Processing operators and industrial capacity and trade flow

The residues become available where shell-bearing crustaceans are physically transformed through peeling, heading, cooking, freezing, brining, packing, repacking or preparation for retail and foodservice markets. Therefore, the mapping of crustacean residues are complemented by an analysis of processing operators, industrial capacity and trade flows. This step is necessary because the availability of exoskeleton-rich biomass cannot be inferred only from production, landing or import volumes.

For this reason, the analysis combined official fish-processing statistics with bottom-up operator mapping. Official statistics were used to describe the general fish-processing capacity of each country, while operator-level information was used only in aggregated and anonymized form to identify the type of activity performed in each area, wherever possible. The company names, contacts, confidential volumes and commercially sensitive information are not reported in the main text, while the analysis classifies operators by country, species group and processing profile.

The resulting picture confirms a fragmented but highly specialised industrial landscape. Some countries host large fish-processing sectors but are not necessarily major crustacean-residue hotspots. Others, such as Morocco for North Sea common shrimp, host specific peeling activities that make them highly relevant for exoskeleton-residue generation even if they are not production areas purely of European Union.

A third group includes emerging crab-related chains, where operators are still developing collection, handling, marketing or transformation systems rather than operating mature industrial processing chains.

3.4.1. Official fish-processing company counts

Official fish-processing company counts were used as a first proxy for national industrial capacity. These data derive mainly from Eurostat database as reported in EUMOFA country profiles. They refer to the whole fish-processing sector and should not be interpreted as the number of crustacean-processing or peeling plants. Nevertheless, they are useful to identify countries with established seafood-processing infrastructure, employment, turnover and potential capacity to manage by-products (Tab.4), (EUMOFA, 2026a), (EUMOFA, 2026b); (EUMOFA , 2026c); (EUMOFA, 2026d); (EUMOFA, 2026e); (EUMOFA, 2026f); (EUMOFA, 2026g).

The available official data show that Italy, Germany, the Netherlands, Denmark, Belgium, Sweden and Finland all have structured fish-processing sectors, although their relevance for crustacean residues differs considerably.

Italy and Spain are particularly relevant for local and Southern European processing of Mediterranean and Warm-water crustaceans.

Denmark, the Netherlands, Belgium and Germany are more closely linked to trade, storage, redistribution and processing of imported or North Sea crustaceans.

Sweden, Finland, Poland and Estonia represent smaller or more specialised northern and eastern processing contexts.

Table 4 Official fish-processing capacity indicators relevant to VC1, (Biochica, 2026).

Country	Official fish-processing companies	Employment in fish processing	Turnover / Added value	Interpretation for VC1 crustacean mapping
Italy[1]	384	6,403 persons	EUR 3.14 billion turnover; EUR 447 million added value	Strong Southern European processing base; relevant for Mediterranean shrimps, warm-water shrimp and emerging crab biomass
Denmark[2]	82	2,522 persons	EUR 1.78 billion turnover; EUR 262 million added value	Major cold-water shrimp trade and processing-light hub; high flow relevance but not

[1] (EUMOFA, 2026a)
[2] (EUMOFA, 2026b)

Country	Official fish-processing companies	Employment in fish processing	Turnover / Added value	Interpretation for VC1 crustacean mapping
				proportional shell-residue hotspot
Germany[3]	190	6,714 persons	EUR 3.5 billion turnover; EUR 866 million added value	Important North Sea shrimp, packing, wholesale and processing node; local residue potential depends on product form and outsourcing
Netherlands[4]	206	3,351 persons	EUR 1.5 billion turnover; EUR 215 million added value	Key North Sea shrimp and warm-water shrimp trade node; important link with outsourced peeling
Belgium[5]	61	1,475 persons	EUR 837.5 million turnover; EUR 137 million added value	Import-dependent processing and re-export node; local shell generation depends on whether product enters peeled/prepared

[3] (EUMOFA , 2026c)
[4] (EUMOFA, 2026d)
[5] (EUMOFA, 2026e)

Country	Official fish-processing companies	Employment in fish processing	Turnover / Added value	Interpretation for VC1 crustacean mapping
Sweden[6]	190	1,587 persons	EUR 582 million turnover; EUR 78 million added value	Nordic processing and market node; relevant for cold-water shrimp and Norway lobster but secondary for residue quantification
Finland[7]	156	907 persons	EUR 394 million turnover; EUR 48 million added value	Small and fragmented processing sector; limited crustacean-specific evidence
Spain[8]	573	n.d.	n.d. in this synthesis	Major Southern European seafood-processing country; highly relevant for warm-water shrimp and Mediterranean crustaceans
France[9]	381	n.d.	n.d. in this synthesis	Large seafood market and processing sector; mixed role as

[6] (EUMOFA, 2026f)
[7] (EUMOFA, 2026g)
[8] (EUMOFA, 2026i)
[9] (EUMOFA, 2026i)

Country	Official fish-processing companies	Employment in fish processing	Turnover / Added value	Interpretation for VC1 crustacean mapping
				importer, processor and final market

Table 4 provides the industrial background, but this does not identify where shell residues are generated. For that purpose, it must be combined with product-form analysis and bottom-up information on specific processing activities, especially peeling, cooking, brining and repacking, (EUMOFA, 2024a); (MAC, 2022).

3.4.2. Identified crustacean-processing and peeling operators

The bottom-up operator screening identified several types of crustacean-related operators: fishing cooperatives, auctions, wholesalers, fish-processing factories, peeling plants, brining and packing facilities, cold-storage operators, foodservice/private-label processors, exporters and emerging crab-management actors. The data are reported in aggregated form by country and processing profile, (Table 5).

The strongest and most clearly documented crustacean-peeling cluster linked to EU flows is located in Morocco. Publicly available information and operator screening indicate the presence of several operators connected to North Sea shrimp and Dutch/European value chains. These include hand-peeling facilities, shrimp/prawn processing sites, cold-storage and export platforms, and at least one publicly reported shell-reprocessing activity adjacent to a shrimp-processing facility. This confirms Morocco as a strategic node for shell-rich residues generated from outsourced peeling.

In the EU, the Netherlands and Germany are key upstream nodes for *Crangon crangon*. They are important for catches, auctions, first sales, trade and export, but part of the physical peeling is performed outside the country. Denmark is a major hub for *Pandalus borealis* and cold-water shrimp products, with strong import, storage, redistribution and re-export functions. However, because much of the product enters as cooked-frozen and partly processed material, Denmark is considered as a "flow-hub" rather than as a proportional "residue-generation hotspot" instead Morocco, (EUMOFA, 2024a), (EUMOFA, 2026b), (EUMOFA , 2026c), (EUMOFA, 2026d).

Eastern and northern European operators provide additional but more specialised evidence. Poland hosts a publicly documented hand-peeling facility for North Atlantic cold-water prawns serving Scandinavian markets. Estonia hosts a publicly documented operator specialised in hand-peeling and packaging *Pandalus borealis*, with about 3,500 tonnes of seafood processed annually. These examples confirm that crustacean processing in eastern and northern Europe exists, but it appears as a niche or specialised activity rather than a large harmonised statistical cluster (Eurofish, 2025).

For crabs, the operator picture is different. In Italy, blue crab is in part involved in small mature industrial processing chain located in principally located in Veneto and Emilia Romagna regions, (Della Ceca et al., 2026). Instead, the operational nodes are fishing cooperatives such as Goro's cooperative, lagoon systems, fish markets, or in small industrial fishing factory and sorting centres, local and emerging processing or disposal channels.

In the Adriatic, *Liocarcinus depurator* is not linked to a dedicated commercial processing chain, but to by-catch valorisation from bottom-trawl fisheries and project-based trials, as those implemented by Bluemarine and Flag Ship (FLAG Costa Blu et al., 2021), in collaboration with Biochica since 2022.

Tunisia, by contrast, shows that invasive Portunid crabs can become industrially organised when collection, processing capacity, export channels and public support are coordinated (UNEP/MAP-SPA/RAC, 2026).

Table 5 Operator typologies identified for crustacean processing, (elaborated information by Biochica, 2026).

Country / region	Main operator typologies identified	Main species / biomass	Processing activities	Relevance for shell-residue sourcing
Morocco	Outsourced peeling plants, shrimp-processing factories, cold-storage/export platforms, shell-reprocessing actors	*Crangon crangon*, cold-water prawns, red shrimp	Hand peeling, freezing, export, shell handling / reprocessing	Very high; confirmed outsourced shell-generation node

Country / region	Main operator typologies identified	Main species / biomass	Processing activities	Relevance for shell-residue sourcing
Netherlands	Auctions, traders, processors, North Sea shrimp operators, Warm-water-shrimp importers	*Crangon crangon*, warm-water shrimp	First sales, trade, packing, export, outsourced peeling links	High flow relevance; residues often displaced to Morocco
Germany	Auctions, wholesalers, cooperative processing/filleting units, packing and trade actors	*Crangon crangon*, imported shrimp products	First sales, wholesale, packing, processing, redistribution	Medium-high; local residues depend on processing stage
Denmark	Importers, cold-storage hubs, packers, distributors, exporters	*Pandalus borealis*, Norway lobster, cold-water shrimp	Storage, brining, packing, redistribution, re-export	High trade relevance; lower proportional shell-residue generation
Belgium	Import-dependent processors, wholesalers, re-exporters	Warm-water shrimp, prepared shrimp products	Import, processing, re-export, distribution	Medium-low if products enter peeled/prepared
Spain	Seafood processors, cookeries, import-processing actors, fish markets	Warm-water shrimp, Mediterranean shrimps, blue crab in Catalonia	Cooking, freezing, packing, local processing, marketing	High for warm-water and Mediterranean streams where shell-on product is handled
Italy	Fish markets, wholesalers,	Mediterranean shrimps, Norway	Local processing, sorting, primary	High

Country / region	Main operator typologies identified	Main species / biomass	Processing activities	Relevance for shell-residue sourcing
	processors, cooperatives, lagoon/blue-crab collection actors	lobster, blue crab, *Liocarcinus depurator*	handling, experimental valorisation	for local residues and emerging crab biomass
France	Seafood processors, markets, coastal management actors for blue crab	Warm-water shrimp, crabs, mixed crustaceans	Import, processing, distribution, market development	Medium; residue potential requires product-form validation
Sweden	Auctions, Nordic seafood processors, cold-water shrimp market actors	Cold-water shrimp, Norway lobster, lobster	Auction, processing, packing, distribution	Secondary but relevant Nordic node
Poland	Specialised cold-water prawn hand-peeling processor	North Atlantic cold-water prawns	Hand peeling, brining, retail/private-label and foodservice products	Direct but niche residue-generation node
Estonia	Specialised *Pandalus* hand-peeling and packaging operator	*Pandalus borealis*	Hand peeling, packaging, wholesale, retail/private-label	Direct but niche residue-generation node
Finland	Small processors and distributors	Mixed seafood products	Processing, distribution, prepared products	Low/uncertain crustacean-specific relevance

Country / region	Main operator typologies identified	Main species / biomass	Processing activities	Relevance for shell-residue sourcing
Tunisia	Seafood-processing factories, blue crab processing factories, export-oriented facilities	Blue crabs, mainly *Portunus segnis*	Processing, freezing, export, industrial valorisation	High non-EU example of organised invasive-crab valorisation
Turkey	Blue-crab commercial/export actors	*Callinectes sapidus*	Capture, marketing, export, planned industrial processing	Contextual non-EU example
Greenland / Canada / Faroe Islands	Origin fisheries and primary-processing/export actors	*Pandalus borealis*	Fishing, cooking/freezing, export	Important origin nodes; EU-accessible residues depend on upstream processing
Norway / UK	Northern crustacean fisheries and market actors	Norway lobster, cold-water shrimp, crab products (i.e.: king crabs)	Fishing, landing, local processing, export	Contextual nodes requiring product-specific validation

3.4.3. Processing profiles by country

The operator mapping allowed countries to be classified by dominant processing profile. This classification is more useful within the MARMADE project than a simple list of companies because it can be useful and indicate where shell-rich residues are more likely to be generated or intercepted. Within the context highlighted, five processing profiles were identified as follow, (Table 6):

1. Outsourced peeling hubs, where shell-on product from EU or neighboring fisheries is physically peeled outside the original catching country. Morocco is the strongest example for North Sea common shrimp.

2. Local-processing hotspots, where crustaceans are landed or imported and then cooked, peeled, packed or prepared domestically. Spain and Italy fall mainly into this category.
3. Trade and redistribution hubs, where large volumes are imported, stored, repacked or re-exported, but where residue generation depends strongly on product form. Denmark, the Netherlands, Belgium and Germany belong to this group.
4. Specialised niche processing nodes, where specific operators carry out hand peeling, brining, packing or private-label production for cold-water shrimp. Poland and Estonia are the clearest examples.
5. Emerging invasive/bycatch biomass nodes, where biomass availability is driven by control measures, bycatch valorisation or local abundance rather than by mature trade flows. Northern Adriatic blue crab areas and central Adriatic Liocarcinus depurator trials belong to this category.

Table 6 Processing-profile classification for VC1, (Information elaborated by Biochica 2026).

Processing profile	Countries / regions	Main species	Typical activity	Residue implication
Outsourced peeling hub	Morocco	*Crangon crangon*, cold-water prawns	Hand peeling, freezing, export	High local shell generation outside EU
Local-processing hotspot	Spain, Italy	Warm-water shrimp, Mediterranean shrimps, Norway lobster, blue crab	Cooking, peeling, sorting, packing, local processing	High potential where shell-on biomass is transformed
Trade / redistribution hub	Denmark, Netherlands, Belgium, Germany	*Pandalus*, *Crangon*, warm-water shrimp	Import, storage, auction, packing, re-export	Residue generation variable and often lower than trade volume suggests
Specialised niche processing node	Poland, Estonia, Sweden	*Pandalus borealis*, cold-water prawns	Hand peeling, brining, packing,	Relevant but localized and less

Processing profile	Countries / regions	Main species	Typical activity	Residue implication
			private label, foodservice	visible in official statistics
Emerging invasive/ by-catch node	Northern Adriatic, Central Adriatic, Tunisia, Turkey	*Callinectes sapidus*, *Portunus segnis*, *Liocarcinus depurator*	Targeted fishing, collection, sorting, disposal, pilot processing, export	Potentially high but seasonal, local and management-dependent
Origin / upstream processing node	Greenland, Canada, Faroe Islands, Ecuador, India, Vietnam, Argentina	*Pandalus*, warm-water shrimp, red shrimp	Fishing/aquaculture, cooking/freezing, peeling or export	Residues may be generated upstream before product reaches EU

3.4.4. Trade flows and import/export volumes

Trade-flow analysis was based mainly on EUMOFA, (EUMOFA, 2024a) and Eurostat-COMEXT, (Eurostat - COMEXT, 2026) data. These data are essential for reconstructing the movement of crustacean biomass into, within and out of the EU. However, trade flows must be interpreted together with product form. A tonne of whole or head-on-shell-on shrimp has a very different residue implication from a tonne of peeled, cooked or prepared shrimp (MAC, 2022).

For cold-water shrimp, EU extra-EU imports of *Crangon crangon* and *Pandalus* products reached 59,229 tonnes in 2024. These imports consisted mainly of cooked-frozen products, with Greenland, the Faroe Islands and Canada as the main suppliers. Denmark accounted for 96% of EU extra-EU imports in volume terms. This confirms Denmark as the main EU gateway for cold-water-shrimp trade, but not necessarily as the main shell-residue hotspot.

The export side confirms the same interpretation. EU extra-EU exports of cold-water shrimp products reached 61,106 tonnes/year especially during 2024, mostly cooked-frozen products. China represented approximately 47% of extra-EU destinations, while Morocco accounted for around 23%. Denmark was the main EU exporter, while Dutch exports to Morocco correspond to North Sea shrimp flows sent for hand peeling and then re-exported to the EU market.

Therefore, Denmark should be mapped as a cold-water shrimp trade and redistribution hub, whereas Morocco should be mapped as an outsourced peeling and shell-residue generation hub.

For warm-water shrimp, the main EU suppliers include Ecuador, India and Vietnam, but their residue implications differ. Ecuadorian shrimp frequently enters Southern European markets as whole or head-on-shell-on product, which increases the probability of shell-residue generation in Spain, France or Italy, (EUMOFA, 2024a).

By contrast, Indian and Vietnamese shrimp often enter EU markets in more processed, peeled or prepared forms, shifting part of the residue generation upstream to Asia and reducing the amount of shell biomass available in EU import hubs such as the Netherlands and Belgium, (EUMOFA, 2026).

For Mediterranean wild shrimps and Norway lobster, trade-flow data should be complemented by first-sales, landings and local market information. These streams are more likely to generate residues near Southern European ports, auctions, wholesalers and processing plants. Italy, Spain and Greece remain particularly relevant for this category, although exact residue quantities require plant-level validation (EUMOFA, 2026a), (EUMOFA, 2026).

For crabs, the available trade data are less harmonised. Blue crab in Italy is not yet systematically recorded in major statistical databases such as FAO, national statistical database such as FishStat or Italian ISTAT fisheries datasets. Nevertheless, as previous mentioned , the regional and institutional evidence shows fast-growing biomass availability in Veneto and Emilia-Romagna. In Tunisia, by contrast, blue crab valorisation is already much more industrialised, with specific processing factories, export volumes and public support mechanisms (UNEP/MAP-SPA/RAC, 2026) (EUMOFA, 2024a).

3.4.5. Selected data series for direct use.

The purpose of this subsection is to document which figures are sufficiently reliable for public reporting and how they should be interpreted.

It provides the most robust quantitative series identified for shrimp shell and crabs' shells. These data are the base value for the mapping of biomass fluxes and hotspots.

Table 7 Selected data series for direct use

Data series	Value / indication (tons/year)	Year	Source	Context
World catches of common shrimp (*Crangon crangon*)	16,175	2023	(EUMOFA, 2024a)	Cold-water shrimp production context
Share of common-shrimp catches by the Netherlands and Germany	85% of common-shrimp catches	2023		Supports NL-DE as main North Sea production/trade nodes
World catches of northern prawn (*Pandalus borealis*)	251,758	2023		Cold-water shrimp production context
Share of northern-prawn production by Greenland and Canada	61% of world production	2023		Supports Greenland/Canada as main origin nodes
EU catches of northern prawn	30,794	2023		EU production context
EU extra-EU cold-water shrimp imports	59,229	2024	(EUMOFA, 2024a); (Eurostat - COMEXT, 2026); (Information by stakeholders)	Trade-flow map; not direct residue estimate
Share of cooked-frozen products in EU cold-water shrimp imports	98%	2024		Explains why import volume is not equivalent to local shell residue

Data series	Value / indication (tons/year)	Year	Source	Context
Main EU cold-water shrimp suppliers	Greenland 47,550 t; Faroe Islands 4,339 t; Canada 3,587 t	2024		Origin-flow mapping
Denmark share of EU extra-EU cold-water shrimp imports	96%	2024		Denmark as main gateway hub
EU extra-EU cold-water shrimp exports	61,106	2024		Export-flow map
China share of EU extra-EU cold-water shrimp export destinations	47%, corresponding to 30,016	2024		Denmark-China contextual flow
Morocco share of EU extra-EU cold-water shrimp export destinations	23%	2024		Supports Morocco as outsourced peeling destination
Dutch exports to Morocco linked to North Sea shrimp peeling	83% of Moroccan imports from the EU originated from the Netherlands	2024		Supports North Sea shrimp outsourced peeling route
Italian fish-processing companies	384	2024		Industrial-capacity indicator, not crustacean-specific

Data series	Value / indication (tons/year)	Year	Source	Context
Danish fish-processing companies	82	2024		Industrial-capacity indicator
German fish-processing companies	190	2024		Industrial-capacity indicator
Dutch fish-processing companies	206	2024		Industrial-capacity indicator
Belgian fish-processing companies	61	2024		Industrial-capacity indicator
Swedish fish-processing companies	190	2023/2024		Industrial-capacity indicator
Finnish fish-processing companies	156	2024		Industrial-capacity indicator
Publicly documented Morocco hand-peeling facility	3,500 employees; 7,000 t of brown shrimp, cold-water prawns and Argentinian red shrimp products	Public company evidence, 2022		Operator evidence; anonymised in public table
Publicly documented	Approx. 35 million kg final products annually; own hand-peeling facility in Tétouan	Public company evidence		Operator evidence; anonymised in public table

Data series	Value / indication (tons/year)	Year	Source	Context
Dutch/Moroccan shrimp processor				
Publicly documented Polish hand-peeling processor	Europe's last remaining hand-peeling facility for prawns; supplies Sweden, Norway and Denmark	Public company evidence, 2025		Secondary/niche processing node
Publicly documented Estonian *Pandalus* processor	3,500 t seafood processed annually; hand-peeling and packaging of *Pandalus borealis*	Public company evidence		Secondary/niche processing node
Veneto blue crab landings	97 t in 2022; 630 t in 2023; 687 t in first half of 2024	2022–2024	(Tiralongo et al., 2025), (Della Ceca et al., 2026) (Marchessaux et al., 2023)	Emerging crab biomass; regional, not harmonised EU series
Sacca di Goro blue crab catches	90 t in 2022; 936 t in 2023	2022–2023		Northern Adriatic hotspot
Blue crab through regional markets / Scardovari cooperative	1,894 t collected/passed through; 714 t marketed	2024		Indicative management/market flow
Tunisia blue crab processing factories	49 seafood-processing factories; 17 focused on blue crabs	2024/2025 report	(UNEP/MAP-SPA/RAC, 2026)	Non-EU industrial valorisation benchmark
Tunisia blue crab catches and exports	Approx. 25,000 t caught; 6,000 t exported	2022		Non-EU invasive-crab processing benchmark

Data series	Value / indication (tons/year)	Year	Source	Context
Turkey blue crab exports	Approx. 300–500 t/year	2025 report		Contextual non-EU commercial example
Liocarcinus depurator project sampling in central Adriatic	Approx. 116 - 120 kg/sample collected in dedicated trials	2021	(FLAG Costa Blu et al., 2021)	Contextual Adriatic example

3.5. VC1 – Maps and Hotspot interpretation

The mapping of VC1 crustacean residues is presented through three complementary maps. These maps should be read together because they describe different layers of the same value-chain system: conventional EU crustacean-processing hotspots, extra-EU origin and outsourced-processing routes, and emerging crab biomass streams linked to invasive species and Adriatic bycatch.

Map 1 focuses on EU crustacean-processing hotspots and estimated residue availability from conventional crustacean chains, mainly warm-water shrimps, cold-water shrimps, Mediterranean wild shrimps and Norway lobster.

Map 2 reconstructs the extra-EU origin countries, outsourced peeling routes and trade-flow connections that explain why residue generation does not always occur where crustaceans are imported, traded or consumed.

Map 3 separates the emerging crab biomass stream, especially blue crab and Adriatic bycatch crabs, because these resources follow management-driven and locally concentrated dynamics rather than mature shrimp trade patterns.

The maps are not intended to provide a direct statistical measurement of exploitable shell biomass. Rather, they integrate official trade data, EUMOFA and Eurostat-COMEXT evidence, scientific literature, regional information and bottom-up operator mapping to identify the most relevant biomass-flow nodes and likely residue-generation hotspots, (EUMOFA, 2024a); (EUMOFA, 2026); (Eurostat - COMEXT, 2026); (MAC, 2022). The interpretation distinguishes between production areas, import gateways, processing hotspots, outsourced peeling nodes, trade and redistribution hubs, emerging biomass nodes and contextual occurrence areas.

For conventional crustaceans, the reference assumption used for indicative residue estimation is that approximately 20% of live weight may become processing residue, including heads, shells, tails, legs and other exoskeleton-rich by-products. This conversion factor should be interpreted with caution because the actual residue fraction depends on species, product form and processing stage. Whole, raw, shell-on or head-on-shell-on products generate very different residue streams compared with peeled, cooked-frozen, prepared or repacked products (MAC, 2022); (EUMOFA, 2026).

For emerging crab biomass, especially *Callinectes sapidus* and *Liocarcinus depurator*, the approach is different. These streams are not yet captured by harmonised EU-wide production statistics and are strongly influenced by local proliferation, containment measures, fishing authorisations, cooperative-level collection, market demand, disposal routes and emerging commercialisation pathways (Marchessaux et al., 2023); (Della Ceca et al., 2026); (UNEP/MAP-SPA/RAC, 2026); (FLAG Costa Blu et al., 2021). Therefore, Map 3 combines documented catches, marketed quantities, disposal volumes, export evidence and project-based bycatch data, always indicating when values are partial-year, regional or benchmark figures.

The hotspot interpretation is summarised in Table 8. The table should be read as a qualitative confidence matrix supporting the three maps, and not as additional quantitative dataset. It helps distinguish high-confidence residue-generation hotspots, high-confidence trade-flow nodes, medium-confidence processing areas and contextual nodes requiring further validation.

3.5.1. Map 1 – EU crustacean-processing hotspots and estimated residue availability

Map 1 (Fig. 1) summarizes the main EU hotspots for shrimp and conventional crustacean processing, with an emphasis on estimated residue availability. The map focuses on conventional crustacean chains and deliberately excludes emerging blue crab streams, which are treated separately in Map 3. The main species groups represented are warm-water shrimps, cold-water shrimps, common shrimp, Mediterranean shrimps and Norway lobster.

At EU level, the map uses an indicative total of approximately 500,000 - 550,000 tonnes/year of live weight processed, corresponding to an estimated residue potential of about 100,000 - 110,000 tonnes/year when applying an average 20% residue factor. This estimate is useful for visualizing the order of magnitude of exoskeleton-rich biomass potentially generated by crustacean processing, but it should not be interpreted as a directly available biomass stock. Availability depends on product form, processing location, storage conditions, food-safety requirements and operator willingness to collect and separate residues (EUMOFA, 2024a); (EUMOFA, 2026); (MAC, 2022).

Spain, France and Italy appear as the main Southern European processing hotspots. Spain is particularly relevant for warm-water shrimp and Mediterranean shrimp chains, combining imported tropical shrimp flows with local seafood-processing capacity. The estimated value shown in Map 1, around 9,300 tonnes/year, should be interpreted as a residue-relevant indicator linked to Mediterranean shrimps and local processing of imported shell-bearing products. France is represented as a mixed processing and market node, with relevant domestic processing, redistribution and final-market functions. Italy is also a key hotspot, with an indicative value around 8,700 tonnes/year, reflecting the combined relevance of Mediterranean shrimps, imported warm-water shrimp and local crustacean processing.

Northern and north-western European countries play a different role. Denmark is the main EU gateway for cold-water shrimp, especially *Pandalus borealis* from Greenland, the Faroe Islands and Canada. The map reports approximately 56,900 tonnes/year as a cold-water shrimp gateway indicator. This is primarily a trade-flow figure, not a direct local residue estimate, because much of the product enters as cooked-frozen or already partially processed material. Denmark therefore has high relevance as a flow, storage and redistribution node, but a lower proportional relevance as a local shell-residue hotspot (EUMOFA, 2024a).

The Netherlands and Germany are central nodes for North Sea common shrimp, *Crangon crangon*. Their role is important because they are production, trade and export nodes, but shell generation is often displaced to Morocco, where hand peeling is outsourced. This distinction is crucial for MARMADE: the Netherlands and Germany are high-confidence flow nodes, while Morocco is the stronger residue-generation hotspot for the *Crangon* chain (EUMOFA, 2024a).

Secondary and niche nodes are also included. Estonia is shown as a seafood-processing node with around 3,500 tonnes/year of seafood processed, while Sweden is represented as a secondary Nordic crustacean-processing node. Greece is included for deep-water rose shrimp, with around 3,200 tonnes/year, supporting its role as a Mediterranean crustacean hotspot. Ireland and the United Kingdom are represented for Norway lobster-related flows, with Ireland around 6,000 tonnes/year and the United Kingdom showing a *Nephrops* catch indicator of 29,336 tonnes/year. These values help contextualize shell-rich conventional crustacean streams, although direct residue availability still requires operator-level validation (EUMOFA, 4/2021); (EUMOFA, 2026).

Overall, Map 1 shows that the strongest EU-side sourcing opportunities are likely to be concentrated in Spain, Italy and selected French processing areas for warm-water and Mediterranean shrimps, while Denmark, the Netherlands and Germany should be interpreted mainly as trade and redistribution nodes whose local residue potential depends on product form and processing stage.

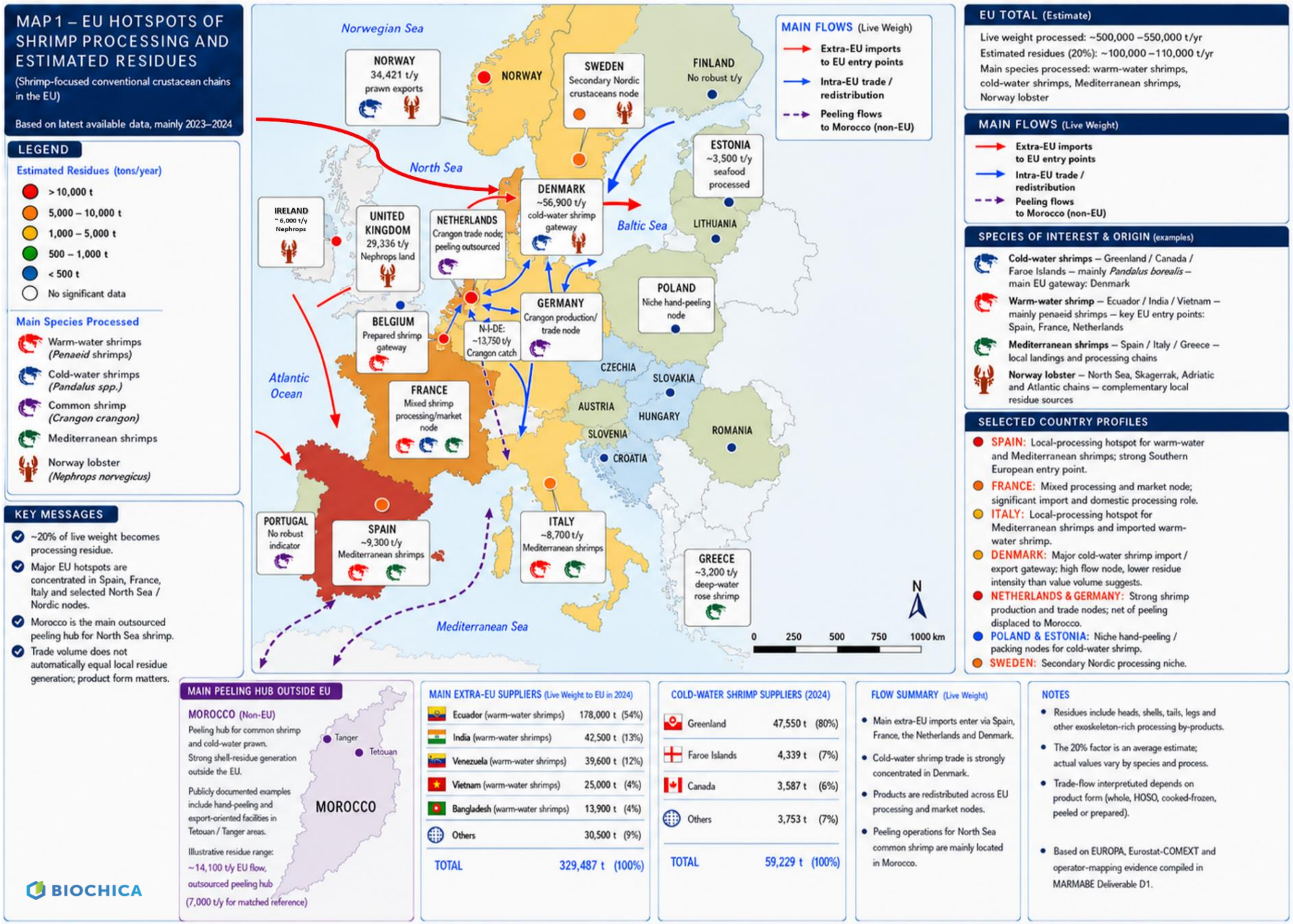

Figure 1 - Map 1, EU Hotspots of shrimp processing and estimated residues, (data elaborated by Biochica 2026).

3.5.2. Map 2 – Extra-EU origin countries, outsourced peeling routes and trade-flow connections

Map 2 (Fig.2) explains the external origin and processing geography behind the EU crustacean residue system. It shows that the largest biomass flows entering the EU are not necessarily those generating residues inside the EU. The decisive factor is where physical shell removal, peeling, heading or further preparation takes place.

For warm-water shrimps, the map identifies Ecuador, India, Venezuela, Vietnam and Bangladesh as the main extra-EU suppliers. In 2024, warm-water shrimp imports to the EU reached approximately 329,487 tonnes live-weight equivalent. Ecuador represented the largest share, with about 178,000 tonnes, followed by India with around 42,500 tonnes, Venezuela with around 39,600 tonnes, Vietnam with around 25,000 tonnes and Bangladesh with around 13,900 tonnes. These flows are represented with red arrows because they correspond to extra-EU imports entering the EU market (EUMOFA, 2026); (Eurostat - COMEXT, 2026). The main EU entry and processing destinations for warm-water shrimp are Spain, France, the Netherlands/Belgium and Italy. Spain is a strong Southern European entry and processing point, especially when shrimp arrives as whole, raw or head-on-shell-on product. France and Italy also receive warm-water shrimp flows and may generate residues where shell-bearing product is physically transformed. The Netherlands and Belgium act primarily as logistic and redistribution gateways, especially for prepared or processed products. Therefore, Map 2 distinguishes between entry, processing and redistribution roles (MAC, 2022); (EUMOFA, 2026).

The cold-water shrimp chain has a different geography. Greenland, the Faroe Islands and Canada are shown as the main origin countries for cold-water shrimp entering the EU through Denmark. The cold-water shrimp suppliers represented in the map include Greenland with 47,550 tonnes, the Faroe Islands with 4,339 tonnes, Canada with 3,587 tonnes and other suppliers with 3,753 tonnes, for a total of 59,229 tonnes in 2024. Denmark is therefore represented as the main EU cold-water shrimp gateway. However, as in Map 1, this does not automatically imply proportional residue generation in Denmark, because imported products are mainly cooked-frozen. Map 2 also shows the Danish export route towards China. EU extra-EU exports of cold-water shrimp are strongly concentrated in Denmark, and China represents a major destination. The map therefore includes a blue dashed export arrow from Denmark to China, labelled with approximately 30,016 tonnes/year. This flow is important for interpreting the Danish role: Denmark acts as an import, storage, redistribution and export hub, while only part of the biomass may generate locally accessible residues (EUMOFA, 2024a).

The outsourced peeling route to Morocco is a central element of Map 2. Purple dashed arrows represent the *Crangon crangon* chain, in which North Sea common shrimp from the Netherlands, Germany and related North Sea routes is sent to Morocco for hand peeling. Morocco is therefore not simply a trade partner but a confirmed outsourced peeling and shell-residue generation hub. The map reports an indicative residue-relevant flow of approximately 14,100 tonnes/year connected to EU flows, together with a documented reference of about 7,000 tonnes/year for brown shrimp, cold-water prawns and related shrimp-processing activities. This makes Morocco one of the most relevant non-EU nodes for understanding the real geography of shell residues linked to the European market (EUMOFA, 2024a); Biochica operator mapping, 2026).

Overall, Map 2 (Fig.2) demonstrates that EU crustacean residue availability cannot be inferred from import statistics alone. The same import volume may generate residues in the EU, in the origin country or in a third-country peeling hub, depending on product form and processing route. For MARMADE, this means that sourcing strategies should prioritise locations where shell-bearing biomass is physically transformed, not only locations where large trade volumes are recorded.

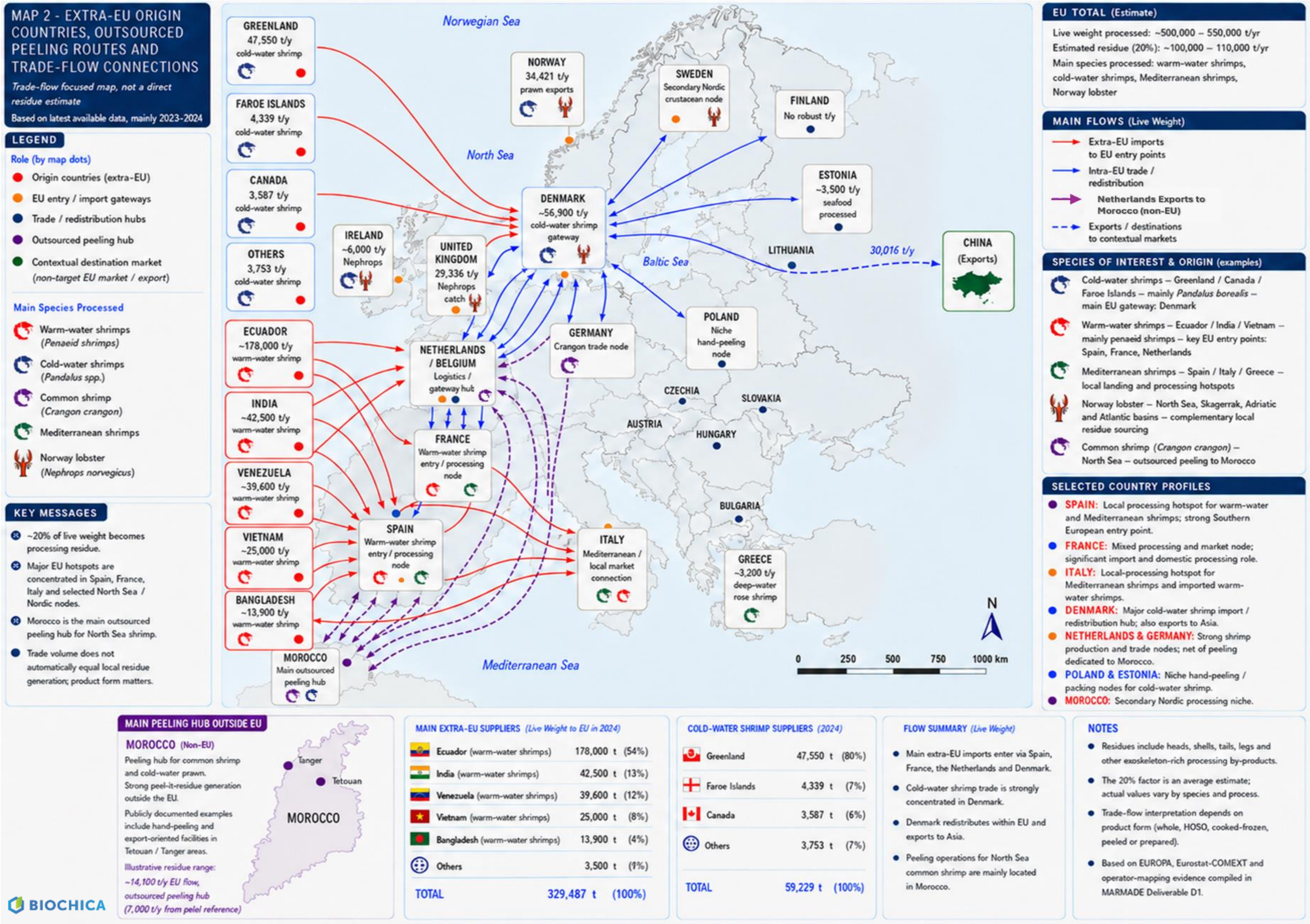

Figure 2 - Map2, Extra Eu Origin Countries, Outsourced Peeling Routes and Trade-Flow Connections, (data elaborated by Biochica, 2026).

3.5.3. Map 3 – Emerging crab biomass: blue crab and Adriatic bycatch streams

Map 3 (Fig. 3) focuses on emerging crab biomass, with particular attention to blue crab in the Mediterranean and Adriatic regions, Adriatic bycatch streams and the Nordic invasive red king crab context. This map is separated from Map 1 and Map 2 because crab biomass follows different ecological, commercial and regulatory dynamics compared with conventional shrimp chains.

The main EU hotspot is the Northern Adriatic, especially the Po Delta, Veneto and Emilia-Romagna. Here, Callinectes sapidus has rapidly shifted from an ecological and aquaculture threat to a locally concentrated biomass stream. The map reports Po Delta and Northern Adriatic catches increasing from approximately 180 - 200 tonnes in 2022 to around 1,500 - 1,600 tonnes in 2023 and around 1,800 - 2,000 tonnes in 2024. The map 3 in the Fig. 3 highlights the rapid growth of the biomass but should be interpreted as regional and management-driven evidence rather than as a harmonised national production series (AAC, 2025); (Della Ceca et al., 2026).

For 2025, the map includes partial data for April - July. In Veneto, around 780 tonnes were caught, of which around 231 tonnes were marketed. In Emilia Romagna, around 463 tonnes were caught, of which around 90 tonnes were marketed. These data show that a large share of captured biomass may not yet enter commercial food chains and may instead be channelled towards disposal or containment routes. This confirms the need to distinguish between caught, managed, marketed and exported volumes, (Regione Veneto, 2025); (Della Ceca et al., 2026).

Veneto is also represented through its 2024 management and market flow. In that year, about 1,894 tonnes were managed or passed through markets and the Scardovari cooperative system, of which about 714 tonnes were marketed and about 1,180 tonnes were directed towards disposal. This is a critical distinction for MARMADE because both marketed and non-marketed biomass may theoretically represent exoskeleton-rich feedstock, but their suitability depends on handling, preservation, regulatory classification and intended use (Regione Veneto, 2025); (Della Ceca et al., 2026).

The Goro with COPEGO node is highlighted as an emerging export channel. In 2025, publicly documented information indicates that more than 110 tonnes were exported from Goro by June, with three containers sent to South Korea and one container planned for the United States. A smaller national-market flow of around 20 - 30 tonnes was also reported. In Map 3, green arrows represent these emerging commercialisation and export routes. These flows are not added to total catches as separate biomass because they may already be included within marketed quantities; instead, they are used to show that a new commercial chain is developing around the Goro/Veneto area (ANSA, 2025).

Tunisia is included as a non-EU industrial benchmark for blue crab valorisation, mainly linked to *Portunus segnis*. In 2022, approximately 25,000 tonnes of blue crabs were caught in Tunisia, with around 6,000 tonnes exported according to UNEP/MAP-SPA/RAC and approximately one third exported according to recent EUMOFA market reporting. Tunisia also has a structured seafood-processing sector, including 49 seafood-processing factories, 17 of which are reported to focus on blue crab processing. The Ghannouch facility is reported with a processing capacity of about 110 tonnes/day and a cold-storage capacity of about 6,000 tonnes. Although the Tunisian model cannot be transferred directly to the Northern Adriatic, it shows that invasive portunid crabs can become an organised industrial biomass stream when public support, collection systems, processing capacity and export demand are aligned (UNEP/MAP-SPA/RAC, 2026); (EUMOFA, 2026).

Turkey is represented as a second non-EU commercial node. Available evidence indicates around 300 - 500 tonnes/year of blue crab exports, especially from areas such as the Göksu Delta, Dalyan and Akyatan Lagoon. Turkey is therefore mapped as an export and commercialisation example that could be interesting as promising, as a direct MARMADE sourcing area (UNEP/MAP-SPA/RAC, 2026).

The Central Adriatic box represents *Liocarcinus depurator* as a bycatch-based biomass stream. Unlike blue crab, *Liocarcinus depurator* is not primarily an invasive-management biomass but a local bycatch resource from bottom-trawl fisheries. Project-based evidence from Giulianova and San Benedetto del Tronto confirms its availability across the year, with seasonal peaks in July, October and December. Dedicated trials carried out in the Giulianova area collected approximately 116 - 120 kg of *Liocarcinus depurator* from seven hauls, confirming the presence of a locally concentrated biomass potentially suitable for chitin and chitosan extraction tests. However, this evidence remains local and project-based, and no harmonised EU annual production series is currently available (FLAG Costa Blu et al., 2021).

The map also includes contextual Mediterranean occurrence areas such as Spain, Southern France, Slovenia, Croatia, Albania and Greece. These areas are shown as documented occurrence or fisheries-interest zones, but without tonnage values when reliable annual catch or commercialisation data are not available. This avoids overstating the biomass potential of areas where blue crab presence is documented but not yet quantified (Marchessaux et al., 2023); (Della Ceca et al., 2026); (UNEP/MAP-SPA/RAC, 2026).

Finally, Norway is included as a Nordic invasive-crab context through the red king crab, *Paralithodes camtschaticus*. This species is different from the Mediterranean blue crab and is not part of the same supply chain, but it provides a useful comparison of an invasive crab that has become a managed commercial resource. The map reports a 2023 catch of about 2,794 tonnes, a partial 2025 catch of around 2,130 tonnes and a 2026 male quota of 900 tonnes. This inset should be interpreted as a northern contextual example rather than as part of the Mediterranean blue crab system (Norwegian Directorate of Fisheries, 2024); (Fisheries, 2025a); (Norwegian Directorate of Fisheries, 2025b); (Norwegian Directorate of Fisheries, 2026).

Figure 3 - Map 3, Invasive Species: Emerging Crabs in EU countries, (data elaborated by Biochica, 2026).

3.5.4. Cross-map interpretation: hotspot relevance, seasonality and confidence level

Table 8 Hotspots, main biomass residues, and interpretation data (Biochica 2026).

Hotspot / node	Main biomass	Role	Confidence	Interpretation for MARMADE
Morocco	*Crangon crangon*	Outsourced peeling hub	High	Strong shell-residue generation outside EU
Spain	Warm-water shrimp, Mediterranean shrimps	EU processing hotspot	High/medium	Relevant where shell-on imported/local biomass is processed
Italy	Mediterranean shrimps, blue crab, *Liocarcinus*	EU local/emerging hotspot	High/medium	Strong potential, especially Adriatic and local processing chains
Denmark	*Pandalus borealis*	Import/re-export hub	High as flow node, lower as residue node	Important trade node, but not proportional shell-residue hotspot
Netherlands/Germany	*Crangon crangon*	Production/trade nodes	High as flow nodes	Shell generation partly displaced to Morocco

Hotspot / node	Main biomass	Role	Confidence	Interpretation for MARMADE
Poland/Estonia	Coldwater shrimp	Niche peeling/processing nodes	Medium	Relevant but localised and less statistically visible
Tunisia/Turkey	Blue crabs	Non-EU valorisation examples	Medium/high	Useful benchmark for emerging crab chains
Greenland/Canada /Faroe Islands	*Pandalus borealis*	Origin countries	High as origin nodes	Residues may be generated upstream

4. VC2 - Macroalgae biomass: species, suppliers and biomass hotspots

4.1. General overview

European seaweed production is predominantly concentrated along the Atlantic arc, spanning Iceland and Norway in the north, through the British Isles, France, and the Iberian Peninsula. This geographic distribution reflects the natural abundance of cold-temperate and temperate macroalgae species in the North Atlantic, as well as the historical and cultural traditions of seaweed harvesting in Ireland, France (Brittany), and Galicia (Spain).

The Phyconomy dataset, combined with primary survey and Interview data collected between October 2025 and April 2026, identifies approx. 180 active or emerging seaweed enterprises across 15 countries or territories. The distribution reveals a stark contrast between the commercially mature Atlantic nations and the nascent sectors of Northern, Eastern, and Southern Europe.

4.2. Biomass production: country reports

Before presenting a brief overview of seaweed biomass production in Europe, a few remarks need to be made. Until roughly 10 – 15 ago, the European seaweed sector consisted mainly of long-term traditional practices, exercised by a limited number of producers in a handful of European countries. The majority of biomass in those days were harvested for phycocolloid production (e.g. alginates, agar, etc.) and locally (especially in Ireland, the Brittany coast of France, NW Spain, parts of Scandinavian countries, etc.) also for uses as food, fertilizers and other minor applications. At this moment the sector is at the verge of developing into a much more controlled industrial sector, expanding to professionalization of harvesting techniques and entering the area of seaweed cultivation. It must be borne in mind that these practices are mostly still in their infancy and consequently highly dynamic. New companies come and go, production may start and cease in a specific country from one year to the next, etc. Biomass production in general is still quite low, so low in fact that mostly there is no obligation for its reporting to the national administrations. Discrepancies exist in reported volumes and active companies in scientific and grey literature and year-to-year variation in those parameters can be considerable. In addition, some databases the difference between seaweed production and procession of imported seaweed biomass is not always as explicitly clear as desirable. The data presented here should be regarded as a kind of snapshot of the current status of the European seaweed sector, based on the best available data.

A total of 17 European seaweed producing countries has been identified. Four countries clearly lead the production (with an estimated annual biomass production of at least 1 order of magnitude higher than other European countries, Table 9).

Table 9 Leading European countries in seaweed biomass production

Country	Companies	Production	Key Species	Method
Norway	78	150,000-170,000 t Aquaculture: 530 t in 2022	*Laminaria* spp., *Ascophyllum nodosum, Saccharina latissima*	Wild harvest & aquaculture
France	31	70,000-90,000 t Aquaculture: 320 t in 2022	*Ulva* spp., *Palmaria palmata, Saccharina latissima, Himanthalia elongata, Ascophyllum nodosum*	Wild harvest & aquaculture
Ireland	36	30,000-35,000 t Aquaculture: 42 t in 2019	*Alaria esculenta, Palmaria palmata, Chondrus chrispus, Laminaria* spp.	Wild harvest & aquaculture
Iceland	10	20,000 – 23,000	*Ascophyllum nodosum*	Wild harvest

Still, more than 95% of the biomass comes from wild harvests, although the amount of biomass from cultivation is slowly increasing. Many counties also view an increase in number of new permits, concessions and new installations for cultivation.

With respect to main species and number of species, kelp species (brown algae) dominate in volume (over 90% of total biomass production, as these are the main crops of the top 4 producing countries. Major harvested species are *Saccharina latissimi* (sugar kelp), *Laminaria* spp. (kombu), *Ascophyllym nodosum*, *Alaria esculenta* (winged kelp), etc. Important food species are *Himanthalia elongatum* (sea spaghetti) and *Undaria pinnatifida* (wakame, invasive species in Europe). This is followed by a variety of red algae species where main volumes as used for agar production (e.g. *Gelidium* and *Gracilaria* spp. and *Furcellaria lumbricalis* in Estonia) and important production in Ireland, France, Spain and Portugal for food production and other applications. Main species here are *Palmaria palmata* (together with *Mastocarpus* sp. known as dulse), *Chondrus crispus* (Irish moss) and *Porphyra* / *Porypia* spp. (nori). Finally, green algae are mainly represented by the genera *Ulva* and *Codium*.

Destiny of seaweed biomass is predominantly for phycocolloid production as alginates, agar, etc. again, due to the dominant position of Norway. Furthermore, uses for animal feed and human food applications and use for fertiliser and plant biostimulants are important. A variety of other uses has been reported, including extraction of a variety of compounds for personal care products and nutraceuticals, pharmaceuticals, etc.

Fig. 4 summarizes these findings in an infographic, presenting identified number of operators (harvesters or farmers or combination of both) and average reported production volumes (left panel), distribution of species among major species groups (brown, red and green algae, middle panel) and value chain and main applications as declared by the operators (right panel). Pie size for the species distribution indicates number of species, not the volume of production. Pie size for the applications are related to reported volumes as taken from declarations from operators. As these could not be identified for all operators, these data must be interpreted with care. In the following paragraphs the situation per country is briefly discussed.

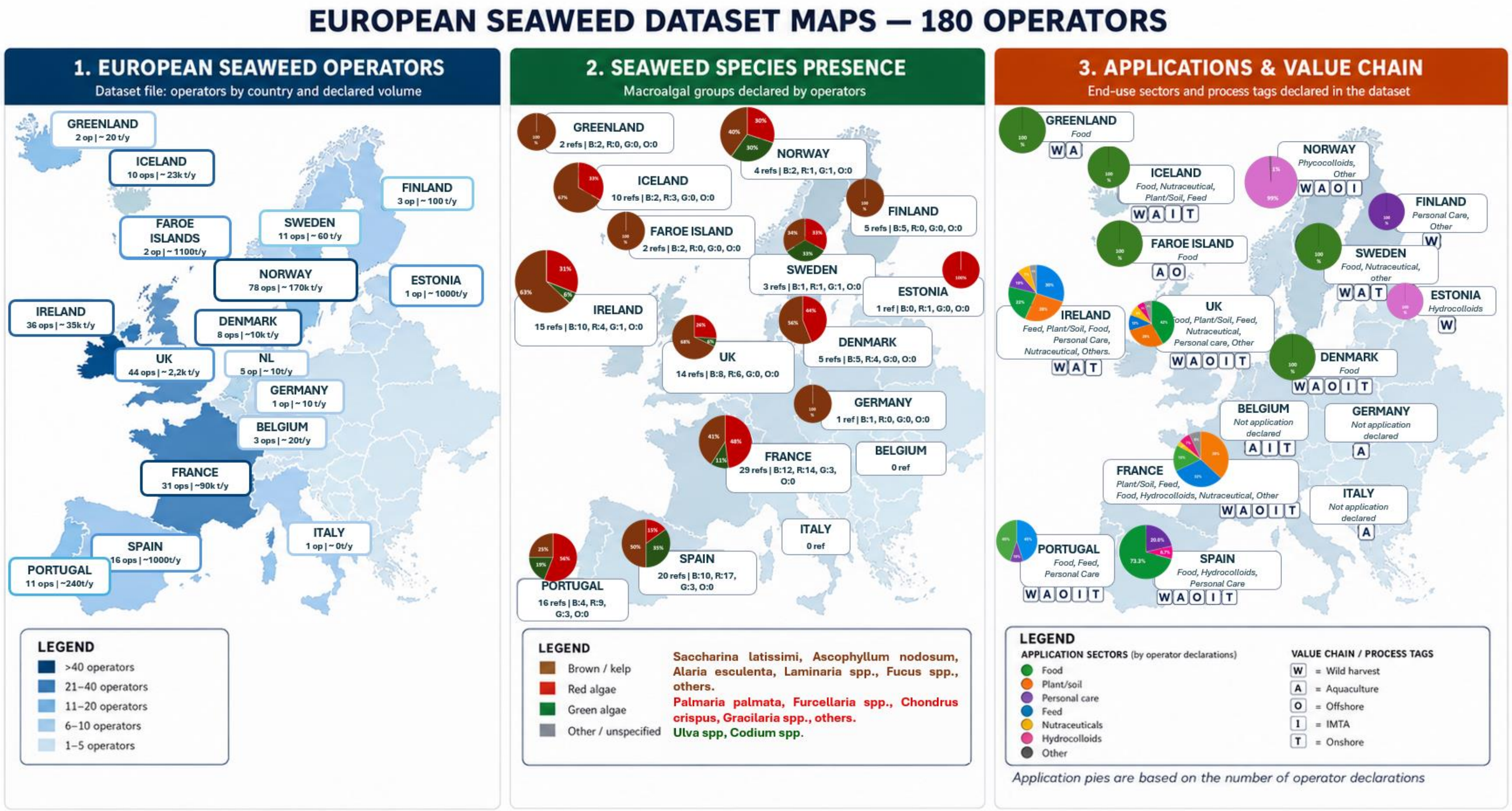

Figure 4 – European data for seaweed production volumes, operators, species distribution and main applications.

* Maps implemented by the partners : ALGAESCOPE, CTAQUA, BIOCHICA. MARMADE Project, 2026.

4.2.1. Norway

Norway is by far the largest biomass producer in Europe, its single production almost being equal to the rest of the European countries summed together. Biomass comes almost exclusively from wild harvest, although more recently cultivation appears to become more important, especially as IMTA practices in combination with salmon farming (e.g. Ellis & Tiller 2019). Norwegian production is dominated by kelp (brown algae) species as *Laminaria* spp., *Ascophyllum nodosum*, *Saccharina latissimi*, etc. The latter is the seaweed that is now also mostly cultivated. Almost all biomass produced is used in the phycocolloid industry (alginates mainly), although other uses as food, fertilizer and animal feed products are increasingly important.

4.2.2. France

France accounts for 31 documented producers, concentrated primarily in Brittany (Finistere, Morbihan) where industrial-scale wild harvesting of *Laminaria* spp., *Palmaria palmata*, and *Ascophyllum nodosum* has been practiced for decades. Novel species include *Himanthalia elongata* (commercialised as food under the name "Sea spaghetti" and several red algal species, however those volumes are still minor. A considerable among of green tide *Ulva* is also harvested annually from the beaches of the Brittany coast (see 2.2.4.), although it could not be verified what amount is actually being processed. France benefits from a well-established regulatory framework for commercial harvest (arretes prefectoraux) and a mature food-grade supply chain. France is a large importer of seaweed biomass from Asia and Morocco for phycocolloid production and other applications.

4.2.3. Ireland

Ireland is home to 36 documented seaweed enterprises, making it the second largest by number but arguably the most commercially mature per capita. *Alaria esculenta* (winged kelp, or Atlantic Wakame) and *Palmaria palmata* (Dulse) are the flagship commercial species. Several operators have achieved food-grade certification under EU Regulation 852/2004. The Irish coastline, particularly the western seaboard and Co. Clare / Co. Galway areas, supports both wild harvesting and at-sea cultivation. Various companies experiment also with on-land cultivation and IMTA set-ups (combinations with shellfish, abalone, others), however, for the moment, biomass volume is still limited.

4.2.4. Iceland

Iceland, as the smallest of the "Big four" producers has a longstanding tradition of seaweed harvesting, for food and also increasingly fertilizer and plant biostimulant applications. Its flagship species is the brown alga *Ascophyllum nodosum*, additionally various other brown and red species are produced. Wild harvesting is still by far the most important source in biomass volume, however, a number of new company initiatives focus on cultivation, especially focusing on the market of premium food products.

4.2.5. Other Northern Europe (Denmark, Faroe Islands, Sweden, Greenland)

Of the smaller producing countries in the North Sea and Atlantic region of Scandinavia, Denmark and the Faroe Islands clearly take the lead. Danish production is centered in the Kattegat region and consists still for a large part of wild harvest. However, cultivation of a variety of species is on the rise. Being confronted with severe space limitations, Denmark is actively looking to combine use of available space for multiple functions, such as integration of bivalve and seaweed cultivation in offshore wind farm. Denmark also has various companies that work on premium algae biomass cultivated in on-land installations.

The Faroe Islands are home of one of the largest and oldest European offshore seaweed farms. Production consists almost exclusively of cultivated *Saccharina latissimi*. Companies are experimenting with other seaweeds as well, in particular the red alga *Palmaria palmata*.

Swedish seaweed production is concentrated mainly on the West coast (Kattegat and Skagerrak area) focusing on kelp harvesting and cultivation (mainly *Saccharina latissimi*), although some of the production also takes place in the brackish waters of the Baltic Sea (harvesting and cultivation of *Fucus* spp. and the green alga *Ulva*).

The Greenland seaweed sector is small. As for other countries in the region, its production is almost exclusively kelp algae from wild harvesting, although seaweed cultivation is in start-up phase.

4.2.6. Spain and Portugal

Seaweed production for the Iberian Peninsula is mainly concentrated on the Atlanic coast. Nevertheless, activities on the mediterranean coasts of Spain are increasing, where 3-4 start-ups have been formed in the last 5 years. There is a longstanding tradition of harvesting of a variety of brown, red and green species in the regions of NW Spain (Galicia) and the north of Portugal for food and fertilizer applications. Later, Spain in particular became home of a flourishing agar producing sector, mainly using wild harvest *Gelidium* and *Gracilaria* species. This industry is still important, also producing other phycocolloids as carrageenans, however, the majority of *Gelidium* is now important from Morocco due to collapses of natural populations in Spain and Portugal, possibly related to overexploitation (Santos & Melo, 2018). Spain also imports significant quantities of *Gracilaria* and tropical red algae from the Philippines and other Asian countries for the phycocolloid sector.

In Spain, harvesting is still by far the most important source of biomass. For Portugal, cultivation is becoming increasingly important, both at sea and on land, especially in an IMTA setting. Portugal is home of one of the most important seaweed farms of Europe that has been on the forefront of innovation in European seaweed cultivation. A striking aspect of the seaweed production on the Iberian Peninsula is the relatively large number of species that is being produced, reflecting the large range of habitats, temperature and salinity. It is probably also the region where at the moment there is most emphasis on green algae. Correspondingly, the range of applications is also relatively high, although dominant production is probably for human food applications. Both Spain and Portugal have companies dedicated to harvesting and/or cultivating green algae (mainly *Ulva* spp.) in the effluent of finfish aquaculture farms.

4.2.7. Baltic Sea (Estonia and Finland)

Not many algae thrive in the low salinity waters of the eastern Baltic Sea. Nevertheless, Finland still manages to harvest a significant amount of biomass, mainly brown algae (*Fucus* spp.) and some green (*Ulva* spp.) and red algae (*Furcellaria umbricalis*), mainly used for extraction of compounds for personal care products. As far as known, cultivation only occurs on an experimental level. Production in Estonia depends entirely on one red alga species: *Furcellaria umbricalis*, forming the basis for a small agar industry. Biomass mainly comes from wild harvest, there are pilot scale initiatives for cultivation.

4.2.8. Central North Sea (Germany, The Netherlands and Belgium)

Due to their lack of natural hard substrate (with the exception of the German island of Helgoland), the Central North Sea countries Germany, The Netherlands and Belgium have little history in seaweed biomass production. Until recently, biomass recollection was limited mainly to traditional personal collection for food consumption in the SW Netherlands, although during some time (roughly from the fifties to the seventies) of the 20th century a company has been actively harvesting and exploiting *Ascophyllum nodosum* biomass. Currently, production is nearly 100% cultivation, carried out by a small number of operators. Main species are the *Saccharina latissimi*, *Ulva* sp. various others. All three countries are actively looking to integrate seaweed cultivation with offshore wind farms and shellfish cultivation.

4.2.9. Mediterranean Sea (Italy, Greece, others)

The oligotrophic mediterranean is not an area for traditional exploitation of seaweed resources, probably due to the generally low biomass. This appears to be slowly changing; in the last few years initiative for cultivation have been developed in Spain (see above), France, Italy and Greece, although mainly on an experimental or pilot scale. There is interest in a range of brown, green and red algal species, especially for food or as a source of potentially valuable extracts.

4.2.10. Biomass flows between countries

As has been mentioned in various of the country reports, important flows of biomass exist both between European countries, as well as with the rest of the world. Production and processing hubs are not always in the same place and companies develop their activities in more than one country. Noticeable are the major flows of red algae biomass from Morocco and Tunesia to Spain, France and other countries for agar production. An overview of these flows and final applications is shown in Fig. 5. Again, data are not always available and depend largely on declarations from the producers, where it must be said that data are usually stronger for initial processors than for downstream extract buyers.

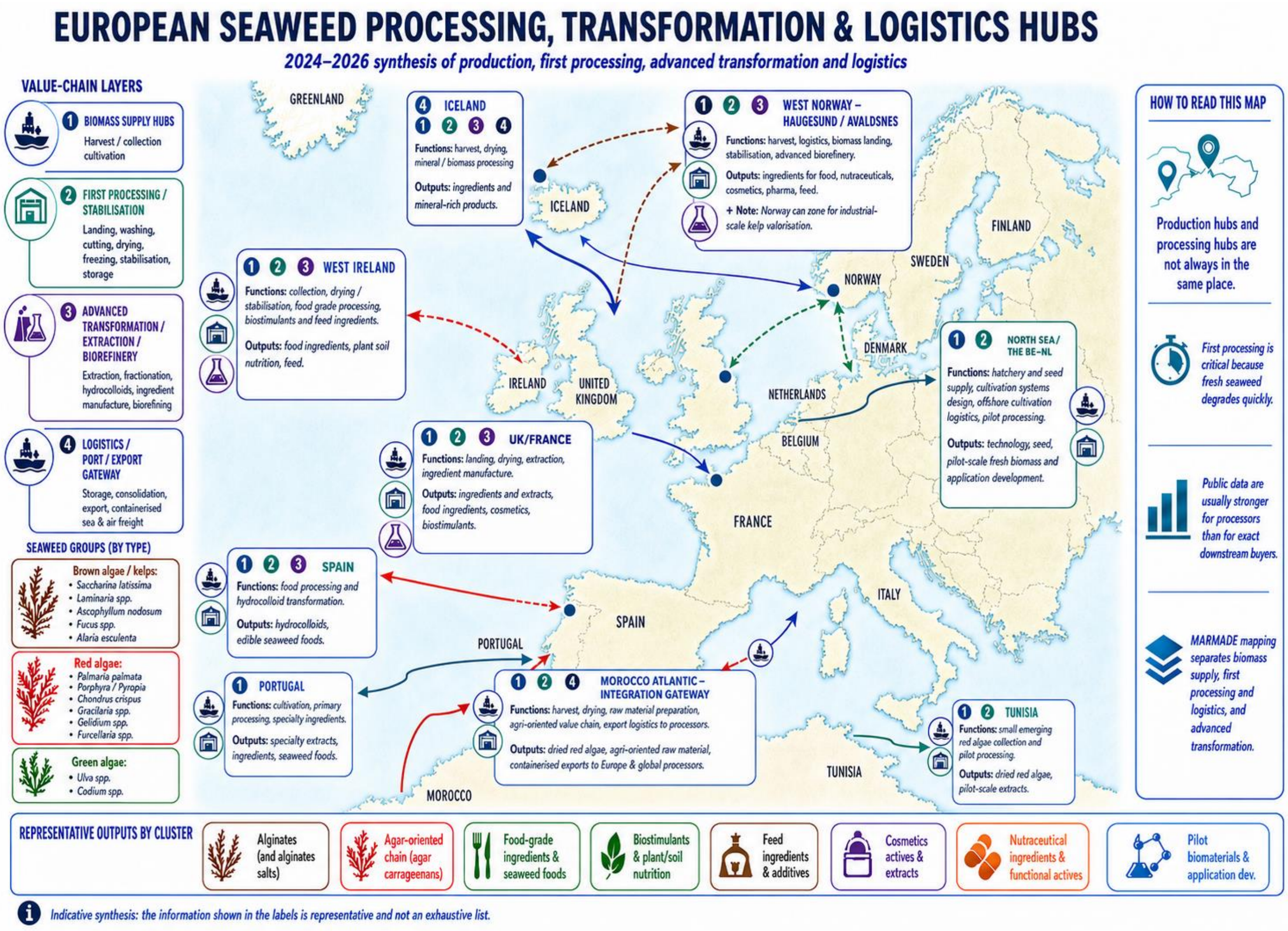

Figure 5 – European seaweed processing, transformation & logistic hubs.

4.3. Distribution of invasive alga *Rugulopteryx okamurae*

Rugulopteryx okamurae is a species common to the Western Pacific, first collected in Europe in the Thau lagoon in the mediterranean coast of France in 2002 (Verlague et al., 2009). According to these authors, it was most likely introduced with Japanese oysters (*Magallana gigas*), that is widely introduced in Europe for aquaculture purposes. Due to its great morphological similarity to the native European species *Dictyota dichotoma*, initially its introduction went unnoticed. Since its introduction in the Thau lagoon, the species has spread both eastwards and westwards. Main secondary introduction vectors over larger distances are again Japanese oyster aquaculture, and due to marine traffic (e.g. hull fouling, ballast water), whereas for shorter distances also algae attached to anchors and fishemen's nets can have been responsible (Román & Vázquez, 2025). At this moment, the most easternmost site in which it has been observed is Bari, whereas to the West it has been observed in at least some on most of the Macaronesian islands (Canary Island, Madeira and the Azores), the western part of the Algarve in Portugal and very recently all up to the northwestern coast of Spain with observations near Vigo, La Coruña and even into the Bay of Biscay (port of Bilbao) (Díaz-Tapia et al., 2025). There are also various observations from the coasts of Morocco in the Strait of Gibraltar area. Fig. 6 shows the progression of the invasion along the mediterranean and Iberian Atlantic coasts.

4.3.1. *Rugulopeteryx okamurae* biomass data

Providing a quantitative estimate of the biomass on the beaches proved to be complicated as there is little uniformity in the way these data are reported in literature. Some studies are limited to beach-wrecked biomass, whereas other studies also include biomass in the upper subtidal zone. Furthermore, data can be presented as kg/m beach transect, percentage or area of beaches covered by the algae, g/m^2 either fresh weight or dry weight (not always reported), tonnes fresh weight removed from the beaches per time unit (varies from day to total per season), number of individuals per m^2, etc. To give an indication of the quantities observed on beaches, Table 10 presents data of beach transects of 5 beaches along the Spanish Atlantic coasts of the Strait of Gibraltar (Rodil et al., 2024).

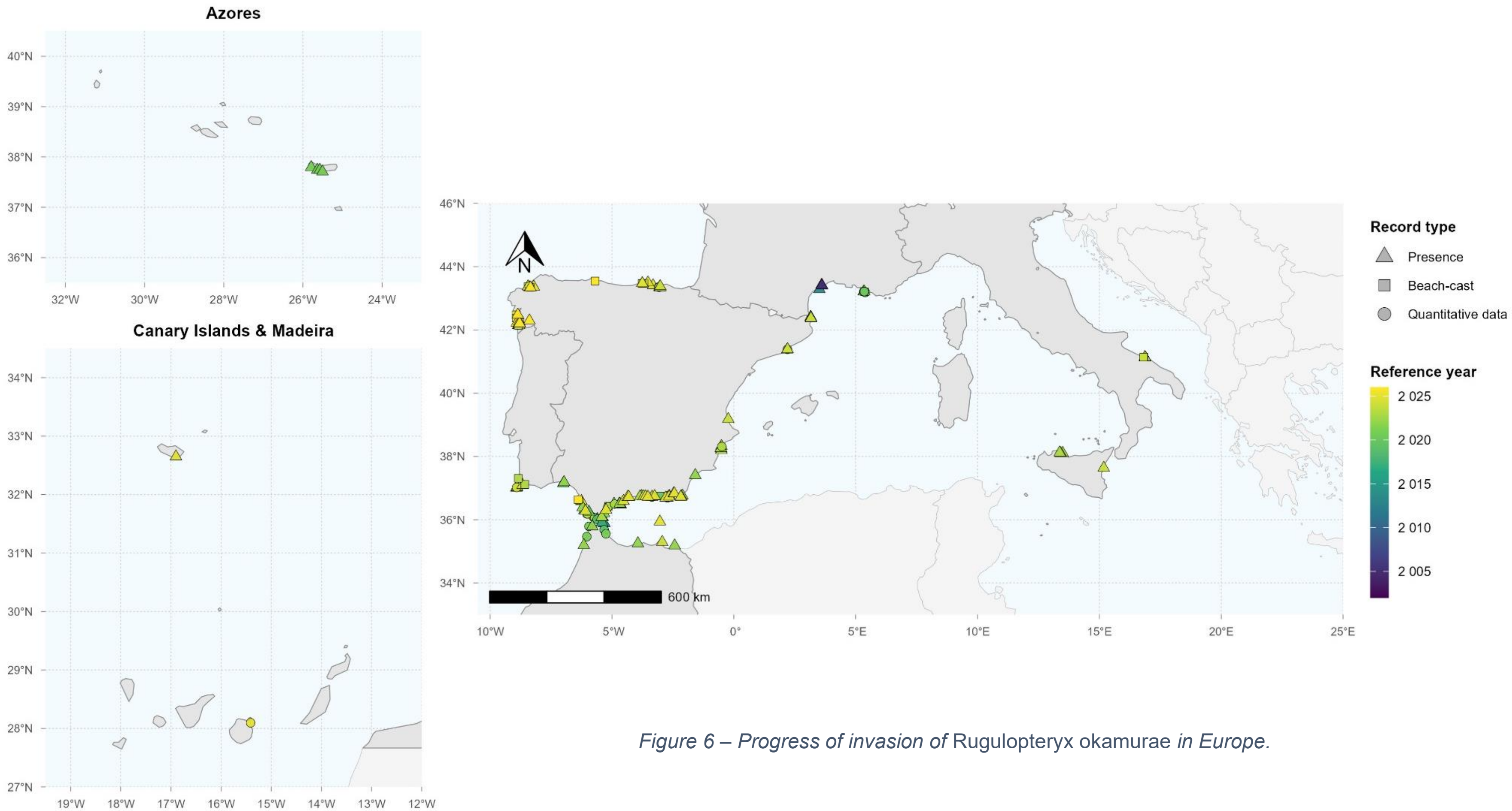

Figure 6 – Progress of invasion of Rugulopteryx okamurae *in Europe.*

Source: MARMADE matrix compiled from scientific literature, SEF bulletins, and official/institutional sources.
Coordinates displayed in EPSG:4326 / WGS84.

Table 10 Rugulopteryx okamurae *biomass estimations on 5 Spanish beaches along the Strait of Gibraltar*

Municipality	Location	Biomass ± SE	Unit
Barbate	Playa Hierbabuena	8694.6 ± 841.5	Kg/m transect
Tarifa	Playa de Los Lances Norte	968.3 ± 287.7	Kg/m transect
Barbate	Playa Marisucia	9209.8 ± 1279.4	Kg/m transect
Barbate	Playa El Pirata	1131.5 ± 201,7.	Kg/m transect
Tarifa	Playa Punta Paloma	1131.5 ± 201.7	Kg/m transect

As can be seen, biomass amounts are significant. Data from other beaches support this. The municipality of Rota (Gulf of Cádiz, Spain) reports to have removed 120 tonnes from its beaches on one day in May and 217 tonnes in June. Estimates on Moroccan beaches alongside the Strait of Gibraltar range from 14 to 358 tonnes fresh weight.

4.3.2. Prediction of future expansion of *Rugulopteryx okamurae*

Predicting the fate and progress of invasive species is always a complicated task. Newcomers in ecosystems generally have the advantage that there are no species specialised in predating (grazing in this case) on them and specific pathogens might be lacking, however, with time this can change. Local herbivore populations can adapt to the invader, perhaps due to changes in their intestinal microflora, which could eventually lead to considerable reductions in biomass. In the case of *R. okamurae*, initially low acceptance as feed by sea-urchins was reported for this species, likely due to the high diterpene concentrations in this alga. However, recent research reports a potential of biomass control of newly invaded sites by sea-urchins (Bernal-Ibáñez et al., 2025).

Nevertheless, factors like potential grazing are impossible to predict. Major factors controlling seaweed distribution worldwide are temperature and salinity. Based on its distribution in its native region, the species can be classified as a warm-temperate alga, adapted to average marine salinity (30 – 37 psu) (Román & Vázquez, 29025).

The alga's progression towards Atlantic waters and studies on ecophysiological characteristics of the alga (Rosas-Guerrero et al., 2025) indicate a great resilience and acclimatization capacity to changes in temperature, salinity and light conditions and seem to indicate a preference for slightly lower maximum temperatures. This makes it likely that the alga will permanently settle in the north-Iberian Atlantic area and perhaps even further north along the French Atlantic coast. Long-term high-water temperatures of the eastern mediterranean might be limiting eastward progression of the species, although other factors might influence this as well. Monitoring programmes and early-warning programmes, such as proposed for Greece in the project GuardIAS and the use of remote-sensing technologies (Roca et al., 2022) can be helpful to monitor *R. okamurae* expansion on the longer term.

5. SUMMARY OF MAIN CONCLUSIONS

5.1. VC1: Crustacean residues

The main crustacean biomass sources identified for VC1 are shrimp residues, Norway lobster residues and emerging crab biomass. Conventional crustacean flows relevant to EU processing represent an indicative order of magnitude of about 500,000 - 550,000 t/year live-weight equivalent, corresponding to roughly 100,000 - 110,000 t/year of potential exoskeleton-rich residues when applying the 20% indicative residue factor. These figures indicate potential biomass, not directly available material, since availability depends on product form, processing location and residue collection practices.

The main EU hotspots for locally generated shrimp residues are Spain and Italy, where Mediterranean wild shrimps, imported warmwater shrimp and established seafood-processing sectors overlap. France is a mixed processing and market node, while Greece is relevant for Mediterranean wild shrimps. Norway lobster represents an additional shell-rich stream, especially in north-western European fisheries, although availability is seasonal.

For coldwater shrimp, Denmark is the main EU gateway for *Pandalus borealis*, while the Netherlands and Germany are key *Crangon crangon* production and trade nodes. However, Morocco is the clearest outsourced peeling hotspot. In 2024, about 14,000 t of EU coldwater-shrimp product were exported to Morocco; this represents around 3,000 t/year of potential shell-rich biomass generated outside EU processing chains.

For emerging crabs, the main EU hotspot is the Northern Adriatic. In 2024, around 2,000 t/year of blue crab biomass were managed in Veneto, of which 800 t were marketed and around 1,200 t directed to disposal. Partial 2025 data for Veneto and Emilia-Romagna already indicate more than 1,200 t caught, while *Liocarcinus depurator* is a complementary Central Adriatic bycatch stream.

Overall, MARMADE aims to map and prioritise real processing and collection points in addition to the other logistics hubs.

5.2. VC2: Macroalgae (seaweeds)

The main seaweed biomass producing country in Europe is Norway, on its own responsible for more than 50% of the European production. Other main producers are France, Ireland and Iceland. More than 95% of produced biomass comes from wild harvesting.

With respect to the species produced, kelp (brown algae) takes the lead by far. Main species include *Laminaria* spp., *Saccharina latissimi* and *Ascophyllum nodosum*. Of the red algae species, *Palmaria palmata* is probably the most cultivated, whereas for harvest, *Gelidium* spp. and *Gracilaria* spp. are main species among various others. In the Baltic Sea area, *Furcellaria umbricalis* is the main species. Green algae harvested or grown are basically limited to *Codium* and *Ulva* spp.

The main application (in volume) for seaweed biomass is for phycocolloid production (alginates, laminarian, fucoidans, agar, etc.) followed by animal feed and human food applications. Tracing macroalgae biomass flows in Europe has made clear the production and processing can take place in separate sites. Notable is the flow of red algae biomass from Morocco to Spain, France and other countries for agar production.

Considering the mapping of invasive species *Rugulopteryx okamurae*, it can be seen that the alga is spreading rapidly and has now also colonised the NW Iberian Peninsula. Main biomass hubs are along the beaches of the Strait of Gibraltar.

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ANNEXES

Annex 1: Data sources used for mapping of European macroalgae production (harvest and aquaculture)

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Annex 2: Data sources used for mapping of *Rugulopteryx okamurae* distribution

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