WORKING GROUP ON COMPARATIVE ECOSYSTEM-BASED ANALYSES OF ATLANTIC AND MEDITERRANEAN MARINE SYSTEMS (WGCOMEDA, OUTPUTS FROM 2022 MEETING)

VOLUME 5 | ISSUE 38
ICES SCIENTIFIC REPORTS

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ISSN number: 2618-1371

ICES Scientific Reports

Volume 5 | Issue 38

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Recommended format for purpose of citation:

ICES. 2023. Working Group on Comparative Ecosystem-based Analyses of Atlantic and Mediterranean marine systems (WGCOMEDA, outputs from 2022 meeting).
ICES Scientific Reports. 5:38. 48 pp. https://doi.org/10.17895/ices.pub.22598164

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Contents

i Executive summary

The ICES Working Group on comparative analyses between European Atlantic and Mediterranean Ecosystems to move towards an Ecosystem-based Approach to Fisheries (WGCOMEDA) aims to facilitate integrative approaches to analyse and compare Atlantic and Mediterranean marine systems, with the goal of supporting integrated fisheries advice and marine management. WGCOMEDA is structured around four Terms of Reference (ToRs), focusing on functional biodiversity, ecosystem structure and connectivity, resilience and mechanizms of change, and integration between ecological and socio-economic dimensions and cultural systems. In the latest three-year cycle (2020–2022), the Working Group improved the knowledge on functional biodiversity and its resilience, standardized the use of traits, structured an overview of the inclusion of resilience concepts into foodweb modelling approaches, promoted methodological innovations in the field of resilience quantifications, and facilitated the dialogue among researchers from different backgrounds. These interactions resulted in 19 publications in peer-reviewed journals. The cross-ecosystem knowledge and complementary expertise (from the communities to networks, taxonomic and functional approaches, different modelling and innovative tools, and social-ecological systems) have been instrumental for the assessment and comparison of these ecosystems and the development of cutting edge tools and approaches suitable to deal with the emerging ecological and societal challenges.

One of the major challenges of our time from both a scientific and a policymaking point of view, is to pinpoint broadly applicable ecosystem-based tools (e.g. indicators and critical thresholds) to drive management and conservation actions. By collating already developed tools, knowledge, and evidence for conservation and management from both marine systems, WGCOMEDA will continue to improve the baseline knowledge and the tools to support managers, by providing effective options to set and meet legislative objectives, applicable at European level across the two systems.

ii Expert group information

Expert group name	Working Group on Comparative Ecosystem-based Analyses of Atlantic and Mediterranean marine systems (WGCOMEDA)
Expert group cycle	Multiannual fixed term
Year cycle started	2020
Reporting year in cycle	3/3
Chairs	Sofia Henriques, Portugal
	Giovanni Romagnoni, Germany
	Maria Cristina Mangano, Italy
	Paris Vasilakopoulos, EU
Meeting venues and dates	21–25 September 2020, online, 36 participants
	4–8 October 2021, online, 42 participants
	3–6 October 2022, hybrid, Palermo, Italy, 38 participants

1 Progress towards the completion of each ToR

This section offers a synthesis of the most relevant work developed and presented during the latest three-year cycle (2020–2022) within each ToR. These interactions resulted in 19 publications in peer- reviewed journals (https://ices-library.figshare.com/WGCOMEDA).

1.1 Assess the functional biodiversity of demersal and benthic assemblages across Mediterranean and Atlantic systems (ToR A, led by Sofia Henriques)

In this last three-years cycle research on ToR A progressed towards the use of more integrative approaches in the assessment of functional diversity patterns, namely across biological groups (e.g. including the complexity of trophic interactions, linking ToR A and B), and the development of new approaches and frameworks to complete the proposed deliverables. The possible applications of the outcomes and tools in different conservation and management contexts were also considered during the discussions of all the works presented during the meetings.

With the aim of standardizing the use of functional traits (deliverables 1 and 2), the WG discussed a new framework to identify core functional traits for the different taxonomic groups across Mediterranean and Atlantic systems during the current cycle. The selection of the core functional traits (i.e. attributes of the species/individuals that allow us to better understand their performance in the ecosystems and their functioning as well as its regulation) is a challenging task as ultimately it will depend on the context of the analysis. However, the selection of traits will also depend on the availability of information to assign specific traits to the species examined, and therefore, some traits are consistently used in assessment of functional trait patterns. In addition, there is growing evidence about the key role of some traits in driving ecological processes and patterns, such as body size and diet, but such traits alone are not enough to explain all the variance observed in the natural systems. Based on such evidence and the knowledge gathered in the previous and the current WGCOMEDA cycles, the group concluded that the traits with higher ecological meaning should be those used in ecological assessments (i.e. representing different life strategies and also relevant to ways of using natural resources). In addition, trait selection should also consider both the trait-environmental relationships (e.g. understanding on spatial and temporal patterns, i.e. natural variability) and the trait response to anthropogenic pressures (e.g. trait-based indicators to assess anthropogenic impacts). Overall, a more comprehensive trait database has to include traits of all these dimensions (Figure 1.1) and the main drivers and patterns of such traits (i.e. natural variability and sensibility to anthropogenic and climate induced changes) must be understood.

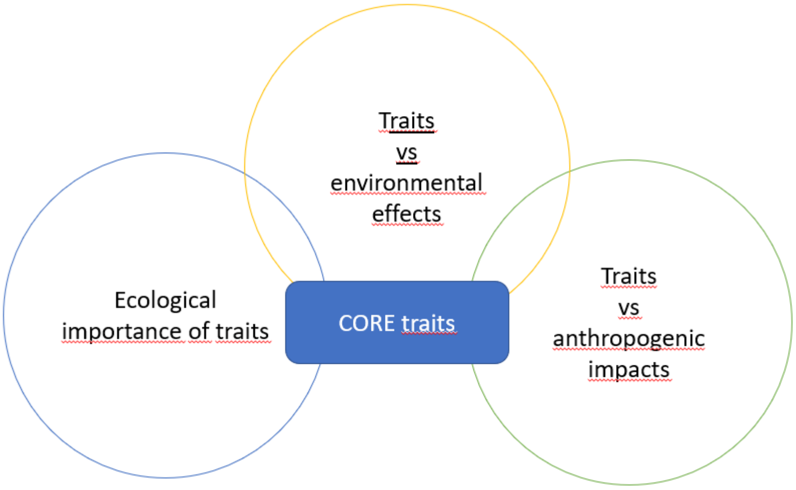


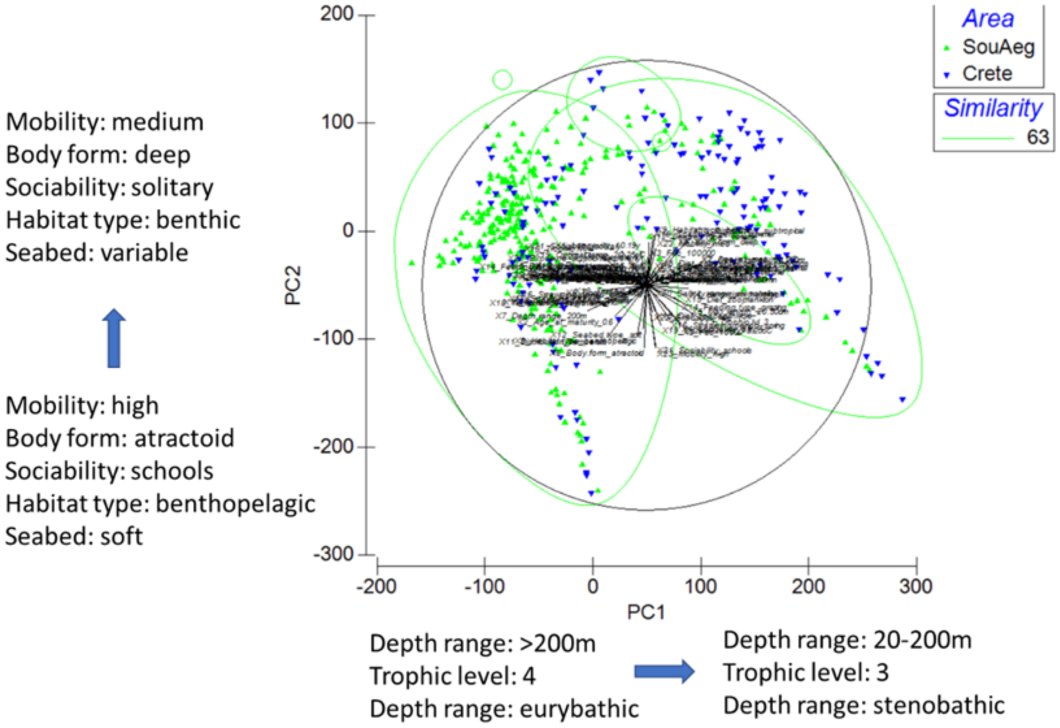
Figure 1.1. Conceptual basis for the selection of Key Functional Traits framework.

The first step to create this comprehensive trait database is to define a standardized single nomenclature and assess trait data availability. In this context the authors completed a systematic literature review, where they identified and compiled 1 127 traits across 37 datasets of fish, invertebrates and zooplankton from freshwater, marine and transition ecosystems. This standardized nomenclature will be presented and discussed in the next WGCOMEDA meeting.

Outcome: *Morim et al. submitted. A roadmap to define and select aquatic biological traits at different scales of analysis.*

Although the deliverables 1 (i.e. define the core functional traits across different taxonomic groups) and 2 (i.e. compile trait data for phytoplankton, zooplankton, fish and invertebrate species), are beyond the schedule, the progress made in the last years (both the review and discussed approaches) is fundamental to standardize the use of traits and to complete the trait database. Therefore, the group aims to continue these activities in the next cycle (if the resolution is approved).

Understanding the multiple processes and drivers of functional diversity patterns has been one of the main topics of research from the beginning of WGCOMEDA in 2014. This understanding, together with the assessment of changes induced by the different anthropogenic impacts and climate change, improve the fundamental knowledge on changes at ecosystem functioning level, allowing the definition of indicators and management targets to monitor marine communities across Mediterranean and Atlantic systems. This is an important step towards the definition of effective tools for Ecosystem-Based Fisheries Management (i.e. improving and optimizing long-term monitoring of fishing effects at ecosystem level), with clear links to the implementation of the Common Fisheries Policy (CFP) and the achievement of Aichi Biodiversity Target 6. Within the framework of the ecosystem approach to fisheries, patterns in the traits distribution within the fish communities may indicate functional differences between areas, highlight important traits and indicate the factors/drivers shaping these differences. During this cycle, the working group attempted to detect patterns in the traits composition of the demersal assemblages of the northern Mediterranean Sea, identify factors shaping traits composition and determine the functional meaning of traits dynamics. To do this the authors used fish abundance data from an experimental trawl survey in the Mediterranean Sea (MEDITS) coming from the South Aegean Sea from Greece, Mediterranean continental Spain and the Gulf of Lions and Corsica from France in combination with a dataset of 23 traits for 235 species (Koutsidi *et al*. 2019). Combining these two datasets resulted in a traits composition across sampling stations. This dataset was analysed with multivariate methods (e.g. PERMANOVA, SIMPER) in order to detect differences in the multivariate space across subareas, depth zones and their interactions and attribute the dissimilarities to specific contrasts in traits. The analyses were carried out at the level of regional sea and also on a pooled dataset including all areas. Significant differences were documented across depth zones and subareas and their interactions and the traits combinations shaping the functional profile of the study areas were identified (Figure 1.2). The contrasts documented may indicate different structure of foodwebs, keystone species, ecosystem dynamics and even a different level of resilience of the regions to stressors. A further step is to analyse the dynamics of these traits systems and detect significant transitions in traits composition in the form of continuous changes or even regime shifts.



Mobility: medium
Body form: deep
Sociability: solitary
Habitat type: benthic
Seabed: variable

Mobility: high
Body form: atractoid
Sociability: schools
Habitat type: benthopelagic
Seabed: soft

Depth range: >200m
Trophic level: 4
Depth range: eurybathic

Depth range: 20-200m
Trophic level: 3
Depth range: stenobathic

Figure 1.2. Principal components PC1 and PC2 resulting from a Principal Components Analysis of the South Aegean Sea data and transition between major traits categories/modalities across each PC axis.

Outcome: *Martha Koutsidi, J. Manuel Hidalgo, Panagiota Peristeraki, George Tserpes, Antonio Esteban, Cristina García, Evangelos Tzanatos (under preparation). Bathymetry & region shape the distribution of demersal fish traits in areas of the northern Mediterranean Sea.*

In order to improve the understanding of ecosystem functioning the authors have used traits to determine ecological niches and define niche overlap and potential competition between fish/nekton species (Koutsidi *et al.* 2020). However, to comprehend species interactions it is essential to quantify this potential competition into actual competition. The authors attempted to create an index of competition, based on biological traits and abundance. Using this index our aim was to evaluate intra- and interspecific competition and to detect whether an individual's competitors are mainly conspecifics or if they belong to other species, whether the pattern of intraspecific competition is shaped by depth and substrate type and whether the community of competitor species affected by depth and substrate type. To do this, the authors used MEDITS data from the South Aegean Sea (2001–2016) combining them with traits data related to resource use to create a competition index that quantifies the competitive impact of any species on a species under examination. The index is asymmetric (i.e. the competitive effect of species A on species B is not equal to the competitive effect of species B on species A). Of the 108 species (94 fishes, 9 cephalopods, 5 crustaceans) analysed, 87 were found to experience higher competition by individuals of other species. For individuals of the remaining 21 species (whose most important competitors were conspecifics, Figure 1.3) intraspecific competition was found to vary across depths and habitat types. In general, the species composition of competitors was found to vary with depth and habitat. The level of competition is relevant to niche width and may have an impact on niche differentiation with an effect on population fitness of the species involved.

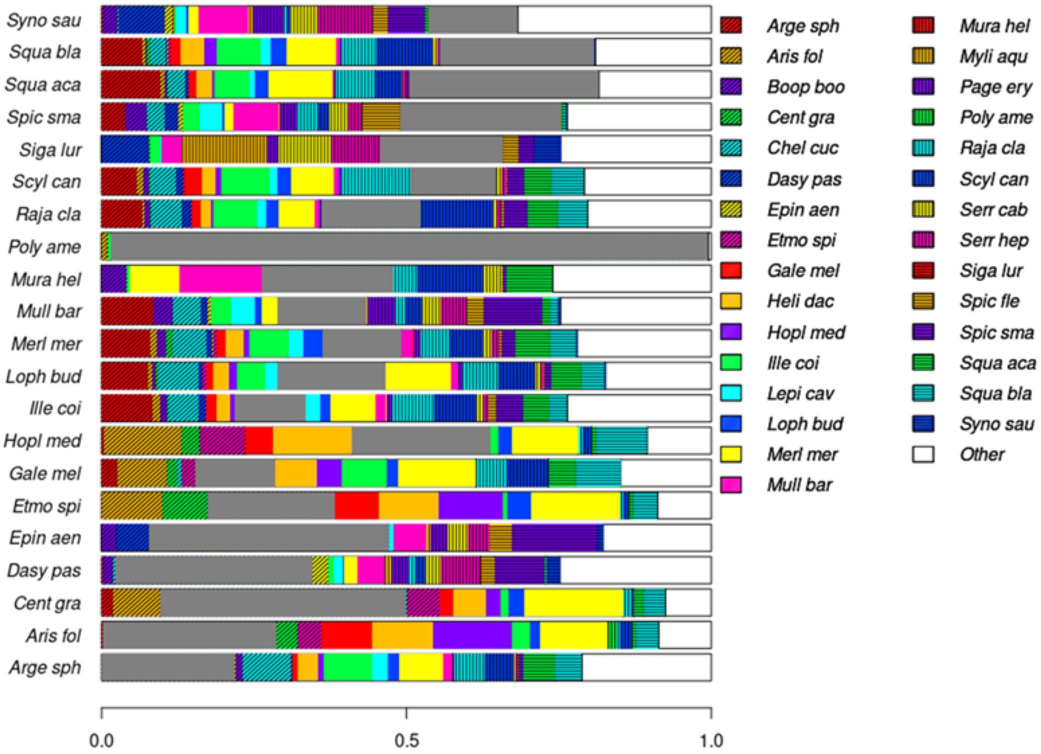


Figure 1.3. Competition index scores by species. Illustration of 20 species (left) denoted by the four first letters of the genus and the three first letters of the species with the competitive effect of 32 important competitors (also denoted in a similar way). Competition by individuals of the same species (intraspecific competition) is shown as the grey bar in each case.

Outcome: *Martha Koutsidi, Alexis Lazaris, Panagiota Peristeraki, George Tserpes, Evangelos Tzanatos (submitted). Quantification of intraspecific and interspecific competition in marine fish species of the Aegean Sea.*

The work on this topic continued investigating the interplay between anthropogenic drivers of functional trait patterns and possible relationships with foodwebs vulnerability. In fact, management targets for biodiversity preservation are shifting from individual species to an ecosystem-wide focus. The perturbation analysis of interaction networks, such as foodwebs, better captures the response of biodiversity to environmental pressures than single-species considerations.

In this context, a new framework was proposed to examine foodweb robustness to a given perturbation based on life-history traits and the topology of the foodweb, at different scales: local (species), intermediate (species directly linked together by a trophic interaction), and global (foodweb). Applying this framework to the Celtic Sea, a historically exploited fishing ground, the study showed that the species sensitive to fishing were not the most central (i.e. those with many interaction links, estimated based on eigenvector centrality) and that there are no both highly sensitive and exposed species to fishing (Figure 1.4).

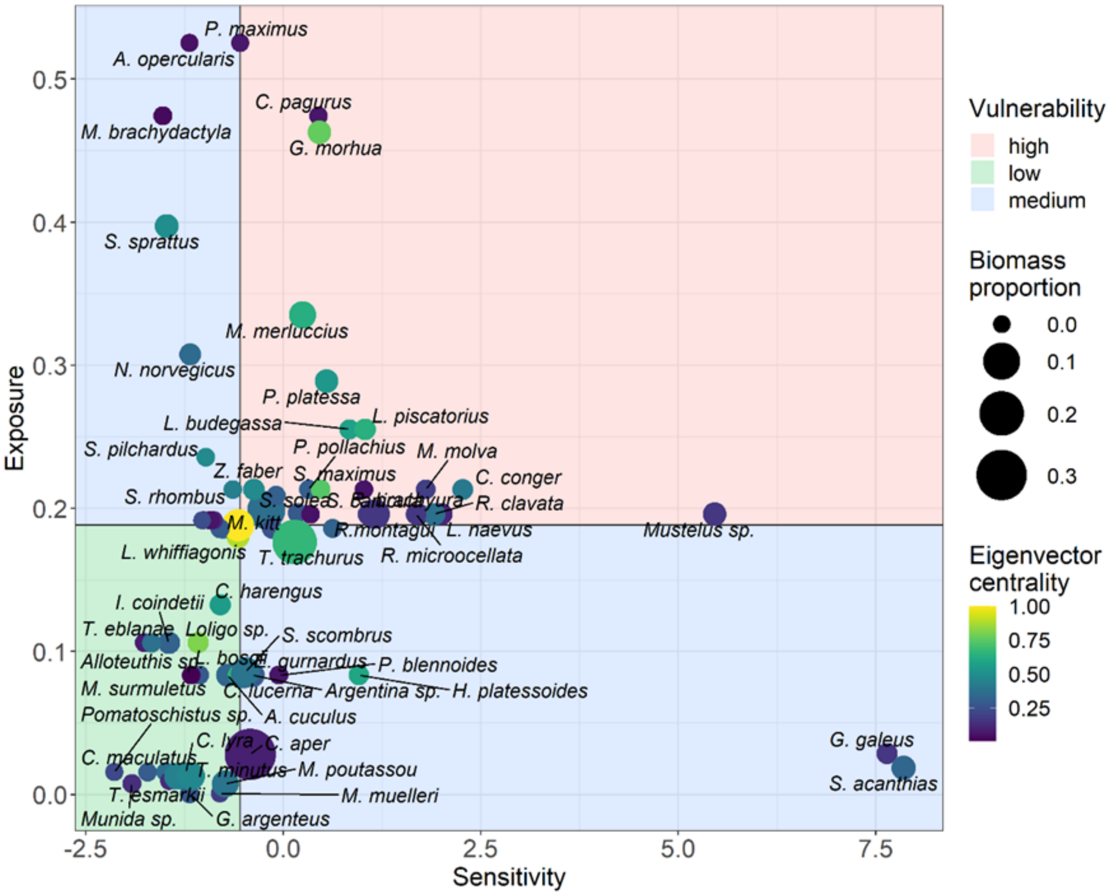


Figure 1.4: Summary plot of the vulnerability of species (sensitivity combined with exposure), species biomass, and the potentiality for the perturbation at the species-level to spread (eigenvector centrality). Solid lines depict median values of sensitivity and exposure. Species relative biomass (each species biomass is divided by the total biomass of the 69 studied species) is given as a proxy of their importance in trophic flux. Proportions lower than 0.1 are in the 0 category in the graph legend. Vulnerability is determined graphically accounting for the position of the median values of sensitivity (median=0.55) and exposure (median=0.19). From: Merillet et al., 2022.

The study then investigated how the loss of central, sensitive and exposed species to fishing could affect the robustness of the foodweb. The results showed that the foodweb was the least robust to the simulated loss of species with many predators (i.e. forage species) and most exposed to fishing pressure, indicating that conservation priority could be focused on these species. Estimating species' sensitivity to fishing was insufficient to predict foodweb robustness since the simulated removal of the most sensitive species led to a robustness level similar to that of a random removal sequence. Unlike what is often documented, the network appeared relatively robust to the simulated loss of the most central species, due notably to their implication in redundant trophic interactions and the fact that their disappearance increases modularity. This suggests that species-level metrics such as centrality should be completed by analysis at the scale of the whole foodweb to prioritize species conservation.

Outcome: *Merillet, L., Robert, M., Hernvann, P., Pavoine, S., Mouchet, M. & Primicerio, R. (2022). Effects of life-history traits and network topological characteristics on the robustness of marine food webs. Glob. Ecol. Conserv., 34.*

Apart from investigating functional changes due to fishing impacts, the group also challenged the assessment of global warming effects on the functional diversity of fish across marine ecosystems. Several studies, either based on spatial or temporal patterns, have documented a potential increase of small, fast-growth species in the marine communities as a response to warming. However, most of these studies are located in temperate biomes whereas other biomes might have had a different temporal response due to distinct environmental and historical conditions and trends. In this study, the authors investigate temporal trends in the community composition of fish communities in terms of life-history strategies across multiple ecosystems to answer whether (i) the trends are spatially homogeneous and (ii) if not, whether this spatial heterogeneity can be due to contrasting environmental trends. Following the theoretical framework of Winemiller and Rose (1992), another study classified 1600 demersal fish species along the Equilibrium-Periodic-Opportunistic axis using an archetypal analysis on the species life-history traits. The authors used bottom trawl surveys in the European Seas and North America covering a period from 1993 to 2018 to calculate the community weighted mean proportion of each life-history strategy (CWM-LHS) for each year on a regular spatial-grid. The study found that trends in CWM-LHS are spatially heterogeneous. The proportion of opportunistic species have increased in most European waters but have decreased in northern Barents Sea, New-Foundland and northern Bering Sea (Figure 1.5). The Periodic species have overall increased in the eastern North American coast, Northern Barents Sea and Bering Sea and decreased in southern Barents Sea. The proportion of Equilibrium species in fish communities seems to have increased in most of the areas apart from Icelandic and Scotian shelves where it decreased. Fish communities in the west coast of North America did not have clear directional trends. The authors explained the observed trends in CWM-LHS as a function of changes in the mean, variability and predictability of the environment (SST, SBT, CHL) and anthropogenic disturbance (Fishing). CWM-LHS trends were depending on the environmental baseline of fish communities. Communities in relatively cold and warm waters had an increased proportion of Periodic species while temperate waters had an increase of Opportunistic species. The fish communities did not respond to environmental stability and predictability as expected by the Winemiller and Rose (1992) framework. Equilibrium species responded positively to reduced human impact. Note that the study is still ongoing and that the results might change when the statistical analysis will be improved.

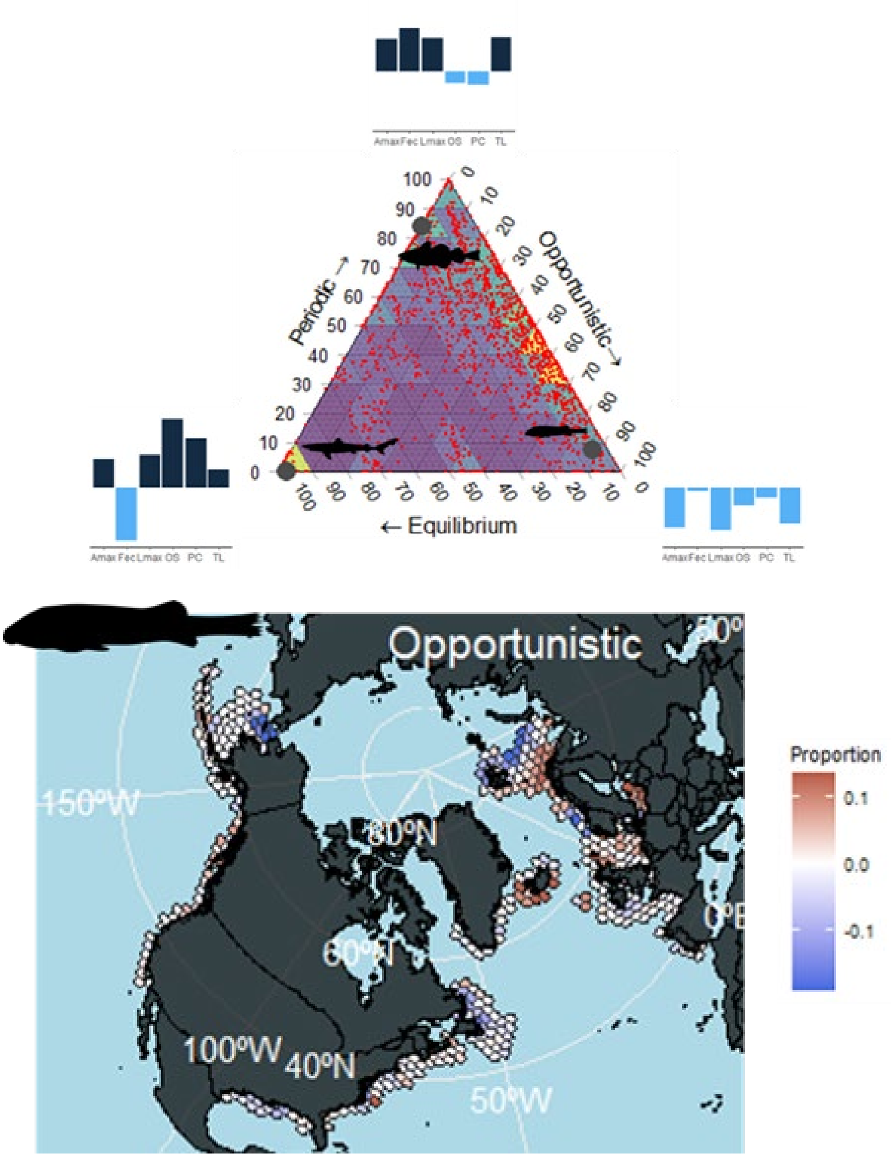


Figure 1.5. Top panel: Classification of >1 000 fish species into three life-history strategies based on species' traits (left). Each red dot represents a species, the shading inside the triangle from purple to yellow represents the density of species. The relative trait values characterizing each end-point (i.e. archetype) life-history strategy are represented at each triangle corner. Bottom panel: Temporal changes in the abundance proportion of opportunistic species in the fish communities. The temporal changes was calculated as the linear slope of the Opportunistic proportion for the period 2000–2020. From: Pecuchet et al., 2022.

Outcome: *Pecuchet, L, Lindegren, M, Hidalgo, M, et al. 2022. From traits to life-history strategies: Deconstructing fish community composition across European seas. Global Ecol Biogeogr. 2017; 26: 812–822.*

Locally, species distribution is also influenced by the interaction between their functional traits and the environmental gradients and habitats to which they are associated. Under this topic the WG discussed the results showing a link between meadow structure of *Posidonia oceanica* and functional traits of resident benthic macroinvertebrates. The main aim of the study was to provide insights on the functional diversity of polychaete communities, a dominant benthic group, between three habitat types of *P. oceanica* that show strong differences in meadow structure (plain meadow, strips/patches and dead matte). An additional goal was to pilot trait-based indicators of habitat structure modification. Results may aid the development of regional management plans, and broaden our knowledge on the relations between functional diversity and biogenic habitat structure. For the analyses, a total of 11 traits of polychaetes were used, which were related to important ecosystem functions, as well as meadow structure, such as traits involved in the interaction and modification of the surrounding substrate. Trait modalities related to ecosystem engineering (rigid tubes, within-sediment galleys, no burrows) may constitute a promising indicator of habitat change, since the modification of seagrass structures (e.g. rhizomes and matte) are expected to directly exclude or favour these modalities. Also, identifying in turn their associated modalities within species' trait combinations could provide insight on how key ecosystem functions would be affected by change. The analyses performed included ordinations testing significance of trait distributions across the different habitat types (e.g. RLQ, Fourth-corner, ANOSIM).

The habitat of unmodified plain meadow was found different from those of strips/patches and dead matte in functional composition and diversity; however, an overlap was observed between dead matte and living *P. oceanica*, due to the remaining matte structure. A trait modalities combination of non burrowing, small/thread-shaped, carnivorous/herbivorous epifaunal species with high sensory ability were related to plain meadow and to some extent, dead matte. In strips and patches, a different combination of galley-dwelling, detritus-feeders with limited mobility and with low sensory was dominant. In addition, suspension feeding, and rigid tubes were linked to living canopy and were among the major traits that differentiate dead matte from the other habitat types. The results suggest that change in modalities combination patterns may affect the key ecosystem functions (e.g. energy recycling). Such changes would alter the multi-layered pathway of healthy *P. oceanica* meadows, where filtering is important in the upper layer, detritus-feeding in the lower, while both layers merge by migrating, carnivorous or grazing species. Also, the classification of species to types of ecosystem engineering successfully distinguished communities of unmodified plain meadow and strips/patches (Figure 1.6), showing potential for use in impact assessments as a trait-based index of habitat modification.

The overlap between dead matte and unmodified plain meadow indicates the need of including the former in conversational legislation, since the remaining matte structure is both important in ecosystem functioning and highly vulnerable to several human activities. The application of classifying species to ecosystem engineering types as a tool in assessing impacts on matte benthic communities may be investigated in a wider future study for various cases of human activities.

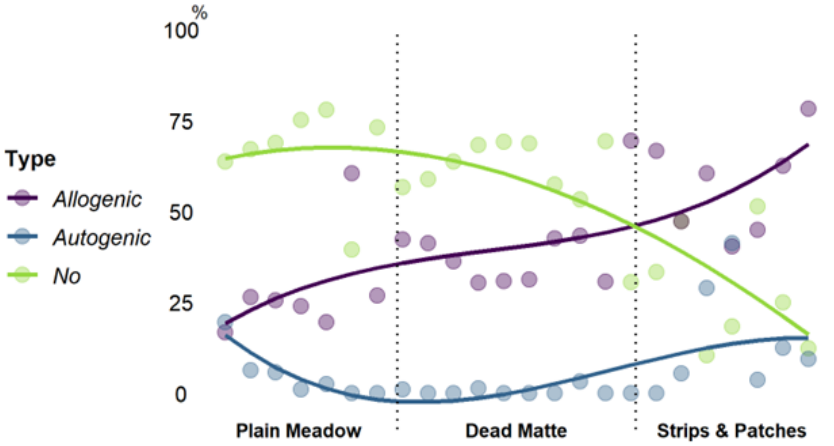


Figure 1.6. Proportions of each Ecosystem Engineering Type along habitat types, with overlayed smooth lines (splines polynomial formula). Autogenic = rigid tube, Allogenic = galley-forming, No = non-burrowing. From: Katsiaras et al., 2022.

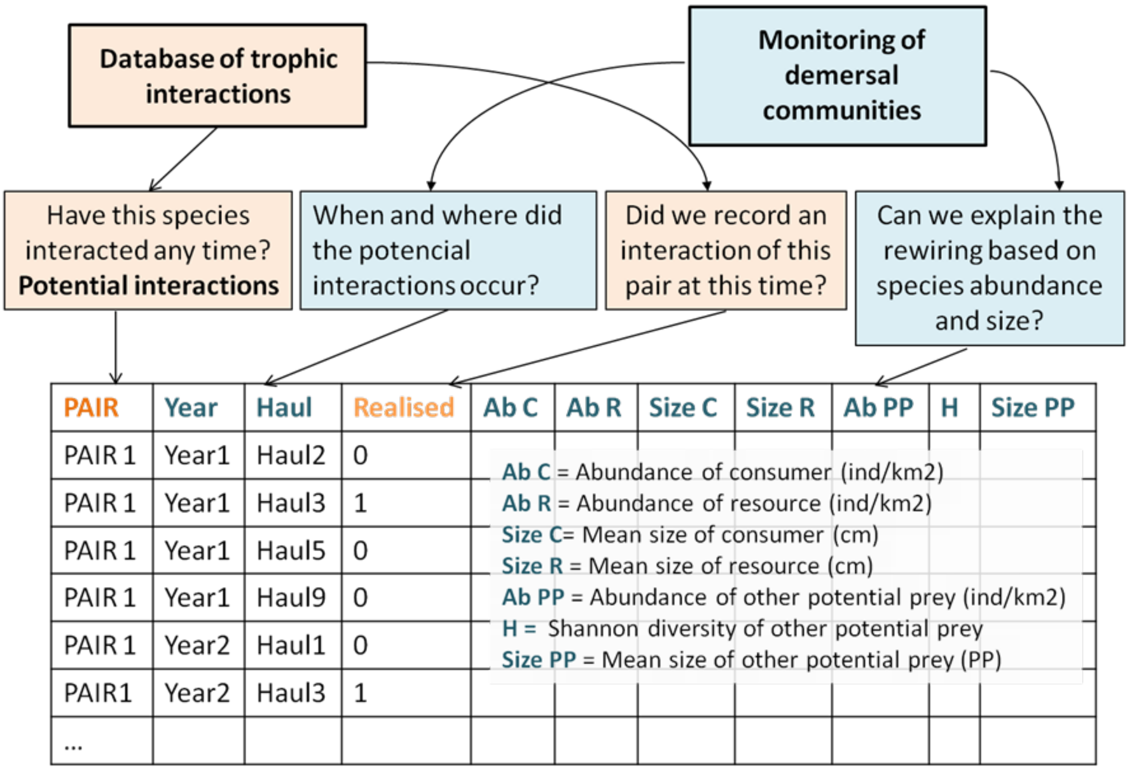
Outcome: *Katsiaras N., Evagelopoulos A., Simboura N., Atsalaki A., Koutsoubas D. 2022 Functional traits of polychaetes change between different types of Posidonia oceanica habitats. Marine Environmental Research 181, 105731*

Understanding how species traits mediate responses to environmental change within communities is one or the central task addressed in ToR1. Recent advances in joint species distribution modelling (JSDM) frameworks now provide us with valuable tools to investigate community-wide responses to the surrounding environment, while simultaneously accounting for species-specific attributes, namely their traits, as well as phylogenetic constraints in species responses (Ovaskainen and Abrego 2020). Especially when investigating community assembly, JSDMs provide the advantage of modelling species with an underlying joint structure that takes abiotic and biotic filtering into account at the same time, instead of modelling species independently from each other. In the talk "Quantifying community change, structure and drivers with Hierarchical Modeling of Species Communities (HMSC) – a joint species distribution modelling framework" Benjamin Weigel presented a cutting-edge statistical framework, HMSC (Ovaskainen *et al.* 2017, Tikhonov *et al.* 2020), and its application in R, that can help shed light on trait environment relationships and how environmental change contributes to functional changes in communities. The presentation highlighted the underlying concept of the framework and its practical application in two studies addressing functional changes in a community context (Murillo *et al.*, 2020, Weigel *et al.*, 2023). Such modelling approaches not only allow us to quantify the contribution of traits in species responses to environmental drivers and human activities, such as fishing pressure, but also to predict communities and their associated functional characteristics in unsampled areas. Furthermore, this framework can be used to forecast future community developments following climate projections or different fishing and management scenarios.

1.2 Integrate the complexity of marine biota to understand how ecosystem structure and connectivity support the stability of communities (ToR B, led by Giovanni Romagnoni)

During the course of the last three years, ToR B focused on critical gaps and novel methods for the provision of effective input and guidance for ecosystem-based management. ToR B advanced multiple aspects related to these goals: among the others, progressing in identifying the link between structure and stability across ecosystems, understanding spatio-temporal dynamics of foodwebs, and exploring methods and approaches to investigate and predict past and future vulnerabilities of communities to fishing disturbances or biological invasions. With respect to integration between ecosystem dynamics and approaches for evaluation of ecosystem resilience, a structural review of the existing applications of foodweb models for evaluating ecosystem resilience was undertaken. This analysis bridges ToR B and C by evaluating existing approaches for investigating ecosystem resilience through foodweb models, and the remaining gaps and potential. The outcomes shall permit the group to better understand the possible applications of existing approaches for evaluating ecosystem changes in a resilience perspective. Relevant studies that have been presented and discussed in WGCOMEDA annual meetings over the past three years are provided hereafter.

The design of trophic networks relies on assumptions about theoretically plausible foodweb interactions, however, empirical studies evidence that feeding interactions do not always take place whenever a potential consumer and resource species co-occur. The study from Lopez-Lopez *et al*. made use of an extensive time-series of empirically determined feeding interactions. The data stem from annual oceanographic surveys between 1990 and 2020, whose primary objective was to evaluate the status of the demersal ecosystem in the Southern Bay of Biscay. In this survey, the trophic interactions for a large number of fish predators are empirically determined through stomach content analysis. The main aim of this study was to investigate the drivers affecting the different occurrence of realized (empirically measured) and potential (modelled through a local foodweb) trophic interactions, respectively. To this end, the authors recorded, for each sampling point and year, all the potential feeding interactions based on species co-occurrences, and the realized interactions based on the empirical data, converted to binary data. They explored the resulting patterns using GAMs with a wide set of explanatory variables such as the consumer-resource body size ratio, the consumer and resource abundances and the abundance, diversity and relative size of alternative prey. Preliminary results indicate that prey abundance does not only determine interaction strength but also the probability of an interaction to take place. Results also provide essential information on how to produce more realistic trophic networks in the absence of empirical dietary information and avoid unrealistic assumptions that may affect network analyses. The group plans to complement these results incorporating in the models interaction strength, rather than binary information on the consumer-resource pairs (Figure 1.7).



PAIR	Year	Haul	Realised	Ab C	Ab R	Size C	Size R	Ab PP	H	Size PP
PAIR 1	Year1	Haul2	0							
PAIR 1	Year1	Haul3	1							
PAIR 1	Year1	Haul5	0							
PAIR 1	Year1	Haul9	0							
PAIR 1	Year2	Haul1	0							
PAIR1	Year2	Haul3	1							
…										

Ab C = Abundance of consumer (ind/km2)
Ab R = Abundance of resource (ind/km2)
Size C= Mean size of consumer (cm)
Size R = Mean size of resource (cm)
Ab PP = Abundance of other potential prey (ind/km2)
H = Shannon diversity of other potential prey
Size PP = Mean size of other potential prey (PP)

Figure 1.7. Conceptual diagram showing the construction of the database based on two paired data sources, the demersal community abundance and size distributions from the bottom trawls (in blue) and the empirically measured trophic interactions (in orange).

***Outcome**: Lopez-Lopez L, et al. (in preparation). Ecological network metrics as ecological traits: realised vs. potential networks*

The topic of cross-system comparison between Mediterranean and Atlantic systems, one of the main focus of the WG, was addressed by a study investigating differences in the changes in trophic position and habitat use of demersal species along ontogeny in Atlantic and Mediterranean ecosystems. Ontogenetic shifts in habitat use and diet are common, if not ubiquitous, among marine taxa. These organisms, which commonly undergo indirect development, increase their size by several orders of magnitude during their lifespan, necessarily changing their feeding modes and patterns of habitat use. Diet is more commonly studied than habitat use, and thus trophic ecology is one of the main proxies to study habitat changes. Ontogenetic shifts in diet are commonly linked proximately to changes in habitat and may also be related to prey selectivity, energetic demand, metabolism or changes in foraging ability due to the increased gape size and swimming ability. Lopez-Lopez *et al*. explored changes in the feeding habitat along the ontogeny of several demersal species (*Micromesistius poutassou, Merluccius merluccius, Parapennaeus longirostris, Galeus melastomus, Scyliorhinus canicula* and *Etmopterus spinax*) in two Natura 2 000 sites in Atlantic and Mediterranean ecosystems of the Spanish continental shelf and slope. To this aim the group discussed the use of different natural tracers (stable isotopes and fatty acids) as a proxy, and the possibility of calculating some of the indicators (e.g. trophic level) using different approaches (incremental and additive).

Preliminary results confirm that trophic level tends to increase along ontogeny for all demersal species and that trends are similar between Atlantic and Mediterranean ecosystems, with species of similar size having approximately the same trophic level in both areas. These changes in trophic level were accompanied by a higher vertical mobility of the species, which was identified by their relatively higher utilization of the pelagic vs. benthic energy pathway with size. However, this vertical change in the feeding habitat did not appear to affect the quality of food. In fact, no changes in DHA/EPA, a common indicator of feeding habitat quality, were observed along ontogeny suggesting that higher trophic level reflects the inclusion of larger prey in the diet but not a change towards higher quality resources. However, species grouped well by their fatty acids profile, regardless of their Atlantic or Mediterranean origin (Figure 1.8).

The group plans to complement these results with additional studies on changes in the quality of feeding habitat along ontogeny in relation to anthropogenic impacts and different management strategies.

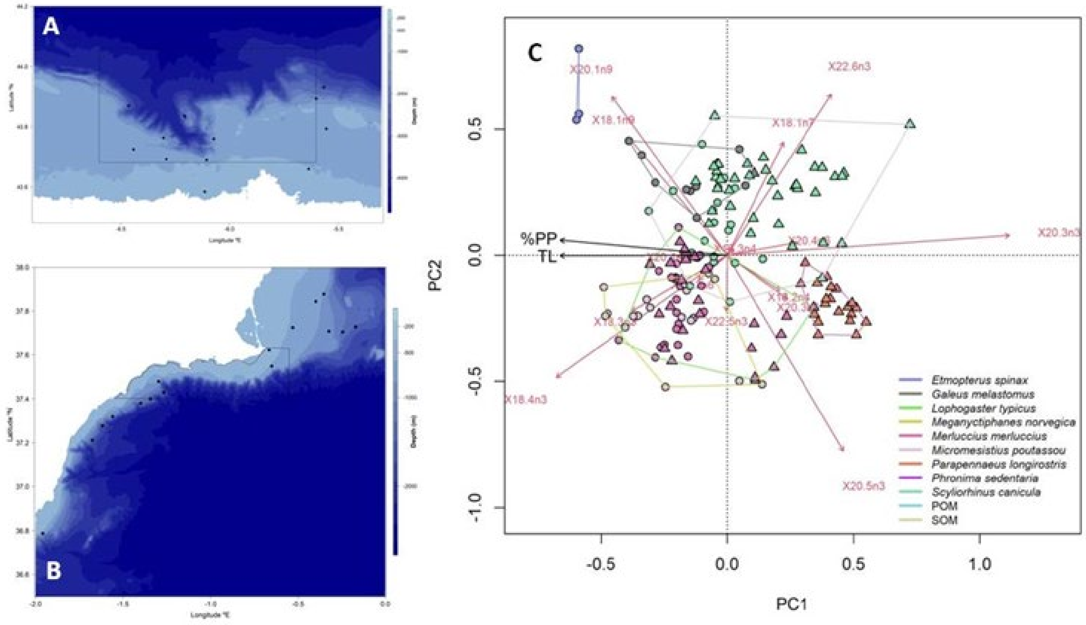


Figure 1.8. Map of the study areas and sampling stations around the Natura 2000 sites (A) Aviles Canyon System and (B) Submarine Valleys of the Mazarrón Scarp. Principal component analysis of 16 fatty acids commonly used as trophic tracers in the demersal communities, triangles correspond to samples from the Mazarrón Scarp and circles to the Aviles System. Trophic level and % of production from pelagic origin are superimposed as explanatory variables.

Outcome: *Lopez-Lopez L, et al. (in preparation). Changes in trophic position and habitat use of demersal species along ontogeny in Atlantic and Mediterranean ecosystems*

Another focus of ToR B was the advancement of methods and approaches which can help us better understand ecosystem structure and dynamics. The contribution by Kortsch *et al*. focused on this aspect, showing how the full extent of the temporal foodweb changes was only revealed through the complementarity between unweighted and weighted network approaches linking structure and function.

To disentangle how foodwebs vary over time in the Gulf of Riga, they explored multiple approaches to describe foodweb structure and function. The authors compared the traditional topological approach based on species presence and absence using unweighted foodwebs and two weighted approaches - node-weighted and link-weighted - which include information on species biomasses and magnitude of feeding interactions. Node-weighted foodweb metrics weigh nodes with species biomass and describe the dominance of species in the foodwebs, whereas link-weighted metrics, based on energetic modelling, can capture changes in the magnitude of interactions. The advantage of link-weighted metrics is that they can reveal changes in the energy flow and foodweb function.

The results show that unweighted and weighted foodweb descriptors vary substantially, and distinctively, over the 34-year time-series. The authors identified five distinct periods with unique foodweb characteristics that represent distinct ecosystem structures and functions. The full extent of the temporal foodweb changes reported was only revealed through the complementarity between unweighted and weighted network approaches linking structure and function. Thus, this study demonstrates the benefit of using multiple methods to draw a more complete picture of temporal ecosystem dynamics. The authors recommend employing a range of descriptors from both unweighted topology-based and weighted (e.g. flux-based) foodweb approaches in order to characterize the dynamic and multifaceted nature of structural and functional changes in ecosystems.

Outcome*: Kortsch S., Frelat R., et al. (2021). Disentangling temporal food web dynamics facilitates understanding of ecosystem functioning. Journal of Animal Ecology 90: 1205–16 https://doi.org/10.1111/1365-2656.13447*

The stability and predicted changes in ecosystem structure and functioning as result of past, present, and likely future impacts from various sources are a key focus of ToR B. Community changes and species invasion as a consequence of topicalization in Mediterranean sea or borealization in Nordic seas is an obvious research topic, the development of which will increase global capacity to face future management challenges. In their study, Pecuchet *et al*. (2020), investigated the poleward expansion of boreal species in the Barents Sea, which, with a decreased abundance of Arctic species, are causing a rapid borealization of the Arctic communities. This borealization might have profound consequences on the Arctic foodweb by creating novel feeding interactions between previously non co-occurring species. An early identification of new feeding links is crucial to predict their ecological impact. However, detection by traditional approaches, including stomach content and isotope analyses, although essential, cannot cope with the speed of change observed in the region, nor with the urgency of understanding the consequences of species redistribution for the marine ecosystem. In this study, the authors used an extensive foodweb (metaweb) with nearly 2 500 documented feeding links between 239 taxa coupled with a trait dataset to predict novel feeding interactions and to quantify their potential impact on Arctic foodweb structure. The authors found that feeding interactions are largely determined by the body size of interacting species (Figure 1.9), although species foraging habitat and metabolic type are also important predictors. Further, they found that all boreal species will have at least one potential resource in the Arctic region should they redistribute therein. During 2014–2017, 11 boreal species were observed in the Arctic region of the Barents Sea. These incoming species, which are all generalists, change the structural properties of the Arctic foodweb by increasing connectance and decreasing modularity. In addition, these boreal species are predicted to initiate novel feeding interactions with the Arctic residents, which might amplify their impact on Arctic foodweb structure affecting ecosystem functioning and vulnerability. Under the ongoing species redistribution caused by environmental change, the authors propose merging a trait-based approach with ecological network analysis to efficiently predict the impacts of range-shifting species on foodwebs.

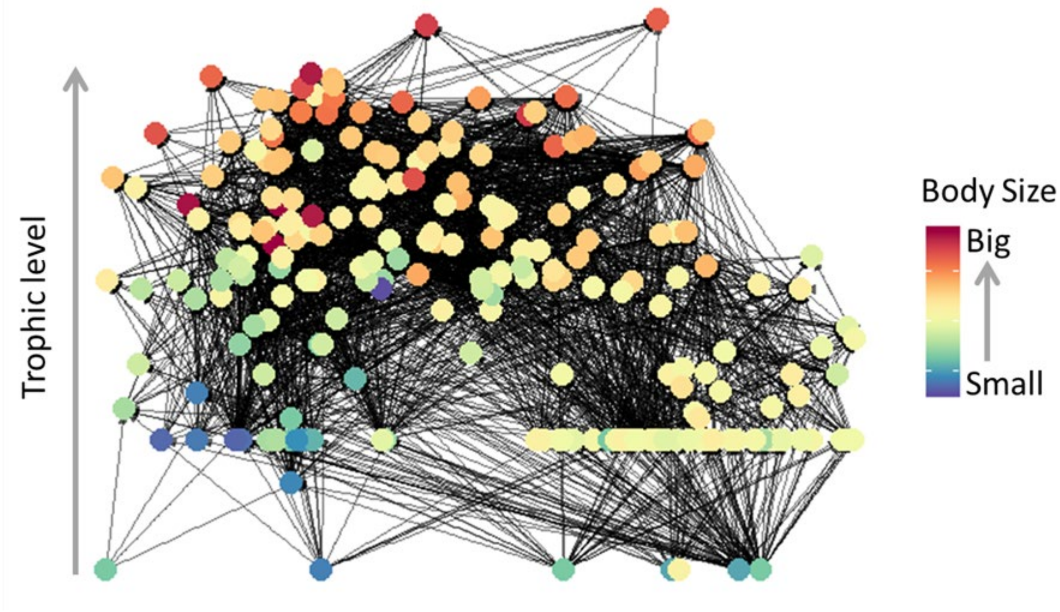


Figure 1.9. Marine foodwebs are structured by species' traits, especially species body size. This figure is a representation of the Barents Sea foodweb (239 species), each species is represented by a dot and the colour of the dot represents the body size of the species. From: Pecuchet et al., 2020.

***Outcome**: Pecuchet L., et al. (2020). Novel feeding interactions amplify the impact of species redistribution on an Arctic food web. Global Change Biology, 26, 4894 – 4906. https://doi.org/10.1111/gcb.15196*

Comparing ecosystems across spatial scales may help to disentangle endogenous from exogenous drivers to understand system thresholds and responses under human pressures and climate change. The study of Papantoniou and colleagues explores whether resilience, vulnerability and thresholds are system-specific properties since apart from local, regional and global exogenous stressors (e.g. physical forcing, habitat degradation and climate warming) they are also associated with endogenous features (e.g. species plasticity, species interactions, predator-prey effects) of each ecosystem. To that end, the authors presented the EwE model developed for Saronikos Gulf (SG), a small-scale heavily impacted coastal ecosystem and discussed the relative influence of environmental and anthropogenic stressors in relation to North Aegean, a larger ecosystem and one of the most important fishing grounds in Greece, providing a comprehensive insight in the functioning of marine ecosystems in the E Mediterranean ecoregion. Finally, ecological indices that will be used for the definition of ecosystem thresholds for the Eastern Ionian Sea (GSA 20) via ecosystem modelling with EwE were also discussed.

The base Ecopath model represented the ecosystem of Saronikos Gulf during the period 1998–2000 via 40 functional groups and 7 fleets (Papantoniou *et al.*, 2021) and the Ecosim model was fitted to time-series of historical data from 2000 to 2020. The main focus during the parametrization of Ecosim for SG was to explore the driving parameters of change during the hindcast period and also to forecast future projections under different climate (RCP 4.5 and RCP 8.5) and fishery reduction scenarios (10% and 25% reduction by 2025 in FE10 and FE25, respectively). SG presented typical features of Mediterranean ecosystem functioning (e.g. importance of detrital pathways, strong benthic-pelagic coupling, dominance of the pelagic production and consumption). Ecological indicators depicted a large and immature ecosystem with its strengths in reserve being affected by environmental degradation while exploitation indices classified fishing activities in SG as unsustainable, affecting several target groups including high trophic level species.

The comparison between the Saronikos Gulf and the North Aegean sea showed similarities in the patterns, with the Ecosim model highlighting the synergistic impact of environmental and anthropogenic stressors on modelled ecosystem dynamics. Retrospective simulations highlighted that both systems demonstrated signs of biomass and catch recovery towards the end of the hindcast period (Figure 1.10A) while fluctuations of estimated ecological indices (biomass, Shannon's Index, catch, FiB and TLc) suggested that recovery is likely more sustainable in the NA. Future projections (Figure 1.10B) illustrated variable reactions to climate warming and fishing reduction scenarios among the two communities, suggesting that species plasticity and trophic interactions play a predominant role in shaping responses in both systems. Finally, in the Ionian Sea EwE model the indicators that will be explored in a GSA level encompass species composition (mean maximum length, MML) and size-structure (typical geometric mean length, TyL, Large Fish Indicator, LFI) indices.

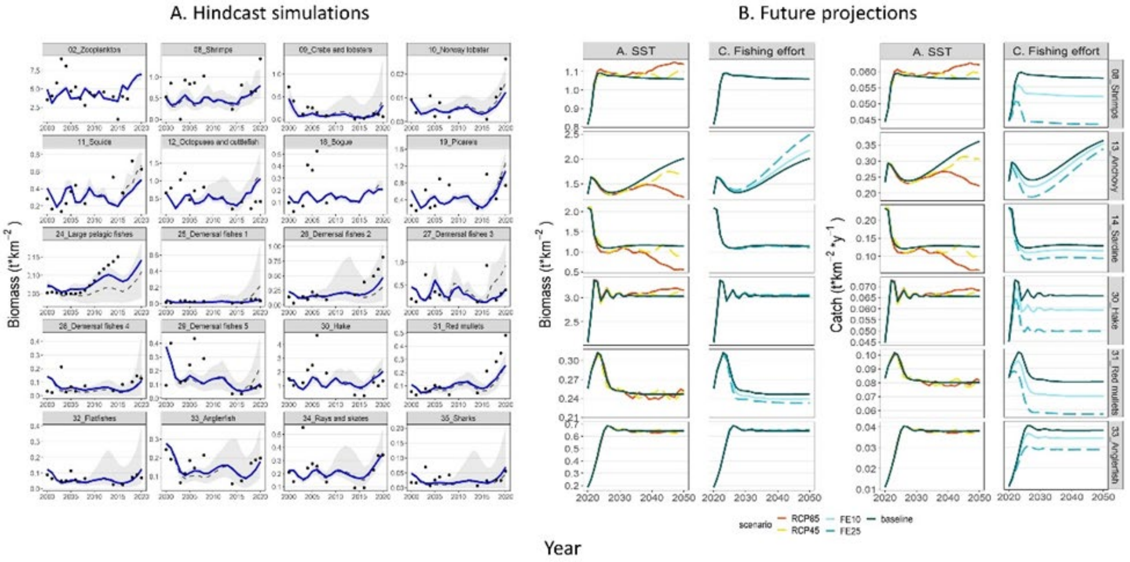


Figure 1.10. Predicted (solid lines) vs. observed biomass (t km^{-2}) for the groups with available data for Saronikos gulf ecosystem model for the period 2000–2020 (A) and future biomass and catch projections under two climatic and two finishing reduction scenarios (B).

***Outcome**: Papantoniou G., et al. (in preparation). Unravelling the environmental and anthropogenic drivers underlying ecosystem dynamics in Saronikos gulf (E Mediterranean) through hindcasts and forecasts using time dynamic ecosystem modelling (EwE).*

Another contribution focused on developing an empirical approach for the identification of tipping points leading to regime shifts in an ecosystem under potential pressures, isolated or in combination. The incidence of tipping points in marine ecosystems can manifest with dramatic impacts but its mechanizms may be difficult to identify, understand and more so predict. Here, the authors present an approach to identify tipping points using an Ecopath with Ecosim ecosystem model, parameterized from the Peruvian Upwelling system as a case study but widely applicable for Mediterranean or North Atlantic existing ecosystem models. Abrupt system changes are simulated as exogenous factors affecting either the environmental drivers or fisheries dynamics, and their resulting effects on the system are captured through a set of ecosystem indicators. The capability of the systems indicators to capture irreversible systemic changes and to characterize the regime shifts thresholds as tipping points is measured through comparison with a statistical CUSP model, derived from catastrophe theory. The cross-model comparison allows assessment of consistency of tipping points detections, and the respective strengths and limitations of indicators and of the model structure itself. This can help the discussion on the very concept and definition of tipping points, advancing our capability to apply models to understand their dynamics and, in perspective, of utilizing them for informing ecosystem and fishery management through the design of adaptation policies. In particular, the approach through iterative search and cross-model comparison identified thresholds over which an increase of fishing effort leads to an irreversible regime shift, pointing at the potential of the approach to identify tipping points in the system (Figure 1.11); moreover, the analysis highlighted the interaction of fishing and environmental pressures: the level of effort identified as sustainable under constant environmental variable becomes unsustainable under varying environment scenarios, pointing at the importance of exploring scenarios with multiple stressors combined.

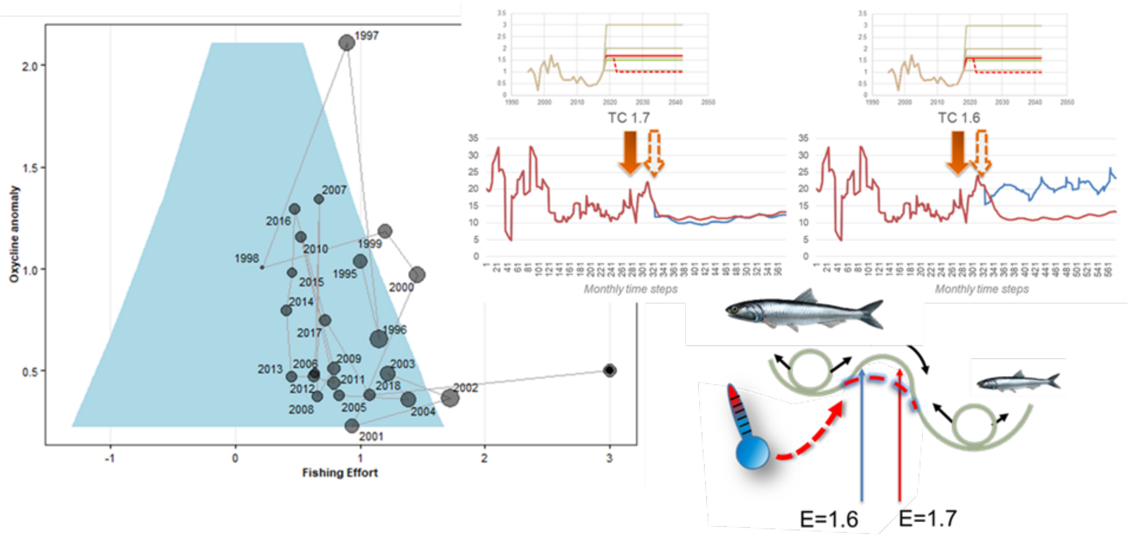


Figure 1.11. Model simulations allow to design scenarios with increasing effort levels to test the presence of tipping points of irreversible ecosystem regime shift. In the example (see panels at the top right), at effort level (E) of 1.6 (as multiplier of current effort level in this example), the system indicator (in this case, total catches, TC) declines (red line) after the onset of the driver (solid orange arrow) compared to the historical timeline; however, upon removal of the pressure (dashed orange arrow) the system recovers (blue line). The corresponding experiment with a marginal higher level of effort (from 1.6 to 1.7) yields a different result: the indicator TC does not recover even after removal of the pressure (blue line remaining stably low even after dashed arrow) and the system is restricted in a worse, stable and irreversible state. These analyses are corroborated by the comparison with a cusp model (left 2-d plot) that confirms the presence of an effective regime shift occurring in the onset of the pressure. The identified tipping point between effort levels 1.6 and 1.7 in the example is the tipping point, or threshold over which the system flips between one stable state represented as large fish or higher "cup" in the classical cup and ball figure (bottom, right), and a lower one. However, scenarios with varying environmental drivers show that the effort level of 1.6 leads to an irreversible change in the system, so that the diagram changes shape (red dashed line) and the new tipping point is encountered at a lower effort level.

***Outcome**: Romagnoni G., et al. (in preparation). Identification of ecosystem-level tipping points under a multi-model approach*

One of the deliverables of the ToR B focused on reviewing existing foodwebs models across Mediterranean and Atlantic systems. A preliminary literature review in this direction was started by Frélat *et al.* This analysis had as geographic focus the EU marine area, and methods focus on network models and empirical studies, excluding plankton and bacterial foodweb, higher trophic level, and end-to-end models. The literature search retrieved 1 262 studies, 93 of which were considered relevant. In a preliminary analysis (Figure 1.12), the number of publications is increasing in time, with a predominance of studies in the Mediterranean, followed by the North Sea. The number of nodes is generally below or around 50, with the exception of the Barents Sea. These preliminary results shed some light on the diversity and similarities on the modelling approaches in the WG study area.

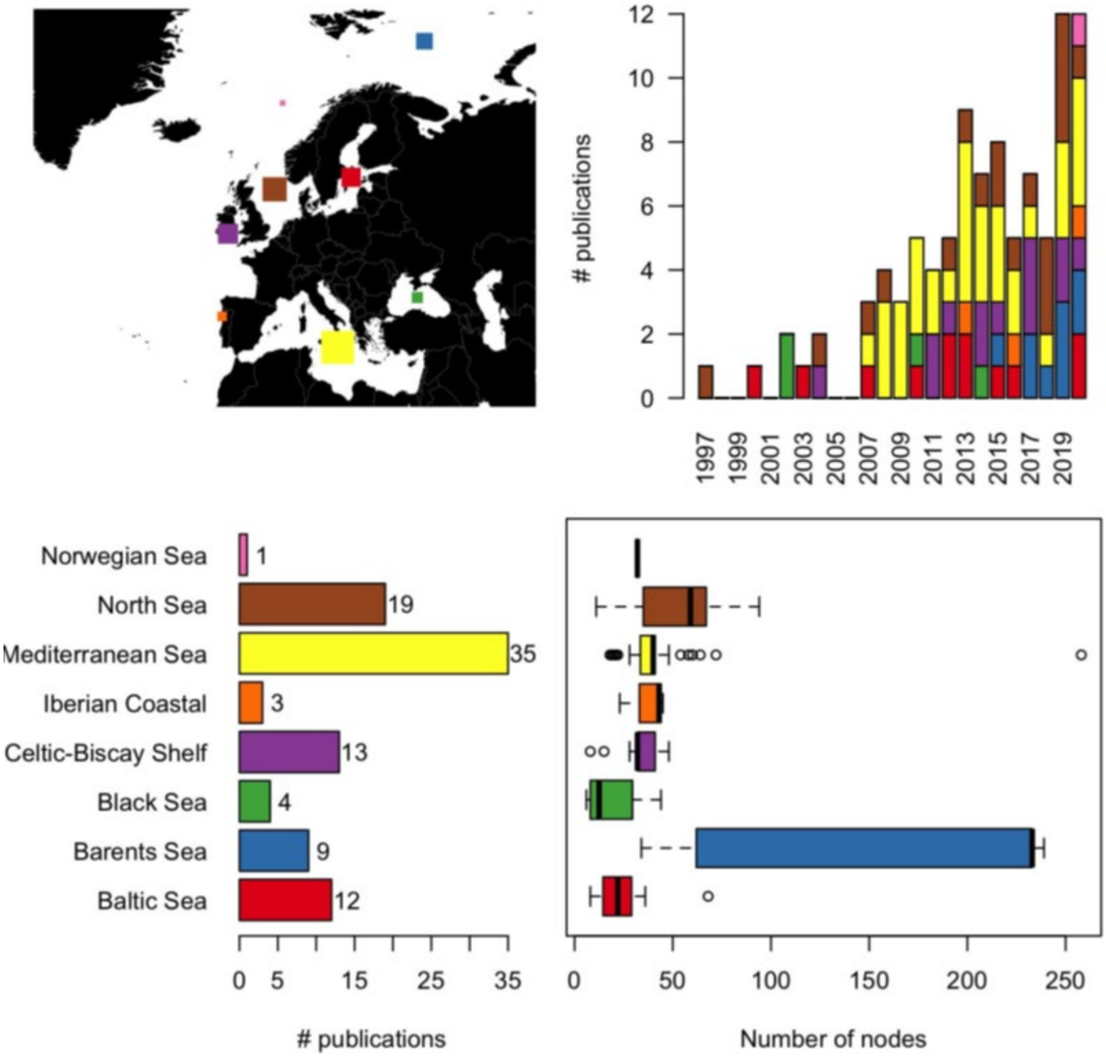


Figure 1.12. Results from the preliminary literature review on foodweb models in Mediterranean and Atlantic seas.

***Outcome**: Frelat et al. (in preparation). Review existing foodwebs models across Mediterranean and Atlantic systems.*

The results however may be somewhat limited by the search string: no studies were found in Iceland, Greenland and Faroe for example, while a few models from these areas are known to exist. For this reason, the analysis was reviewed. The group discussed the possibility to extend and redirect the current scope towards a different focus, incorporating the scope of inclusion of resilience concepts in foodwebs. The new focus is thus: "How have resilience and related concepts been studied through foodweb models in aquatic ecosystems?" A new, systematic literature review has been undertaken. The search string yielded 26 146 and the process of screening the papers for relevance is currently ongoing. The discussion of results and analysis of the outcomes of this work, that links ToR B and ToR C, will be undertaken under the next cycle. At the same time, the scope of the previously planned review (Review existing foodwebs models across Mediterranean and Atlantic systems) may be picked up again in the future, perhaps with a focus on potential for application for informing management, as discussed by the group.

Outcome: *Romagnoni, G., Moullec, F. et al. (in preparation). How have resilience and related concepts been studied through food web models in aquatic ecosystems?*

1.3 Investigate resilience and mechanizms of change in complex marine systems impacted by anthropogenic and environmental drivers (ToR C, led by Paris Vasilakopoulos).

During the course of the last three years, members of the working group carried out resilience assessments of several marine ecosystems both in the Mediterranean and the Atlantic, using a range of different sensitivity/resilience indicators. This has allowed us to elucidate regime shifts, better understand the temporal and spatial dimensions of resilience, pinpoint the main drivers of change (e.g. sea warming, primary production, fishing and combinations thereof) and illustrate the 'winners' and 'losers' of such changes. Relevant studies that have been presented and discussed in WGCOMEDA annual meetings over the past three years are provided hereafter.

A framework that can test key components promoting resilience by accounting for the role of biodiversity has been developed by Flensborg *et al.* (submitted). In that study, an indicator-based approach was applied to assess the potential resilience of marine ecosystems, using the North Sea as an illustrative case study (Figure 1.13). More specifically, the study evaluated and compared multiple indicators of ecological resilience estimated based on high-resolution monitoring data on marine demersal fish species combined with information on ecological traits. Results show a pronounced spatial structuring of indicators, including both similarities and differences among individual metrics and indicators. This implies that high resilience cannot be achieved by maximizing all individual aspects of resilience, simply because there seem to be inherent trade-offs between these components.

Outcome: *Flensborg L, et al. (submitted). An indicator-based approach for assessing marine ecosystem resilience.*

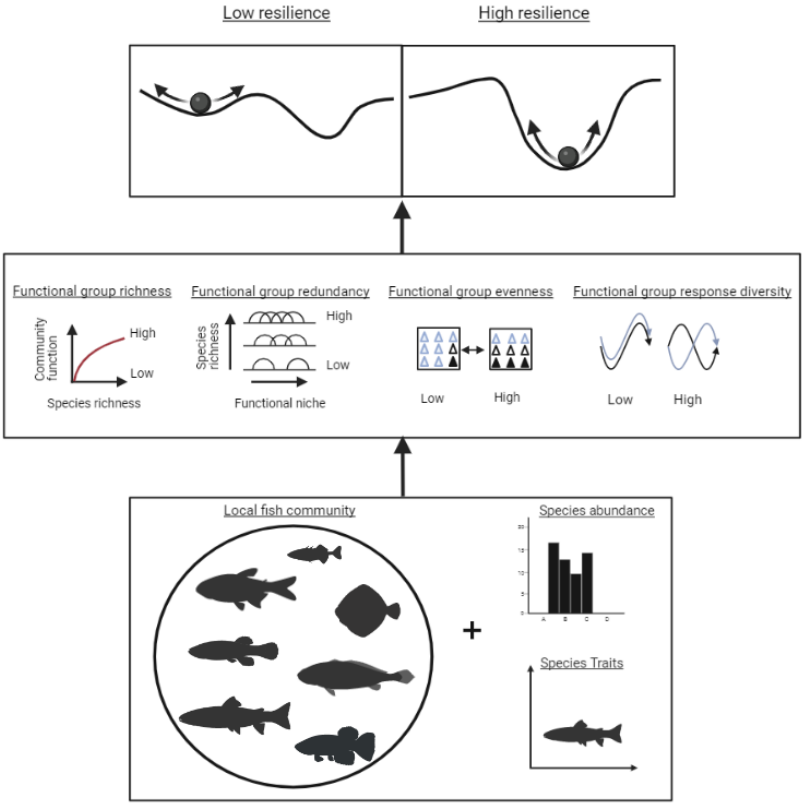


Figure 1.13. A conceptual illustration of ecosystem states with high and low resilience and the four components contributing to resilience, as well as the underlying data used to estimate these.

Another case study from the North Sea focused on the temporal and the spatial scale of regime shifts. The North Sea is one of the most studied examples of a large-scale ecosystem that underwent regime shift, driven by environmental and anthropogenic factors, and cod (*G. morhua*), is considered now in a persistent depleted state and with a generally low recovery potential. Recent observations suggest that multiple populations of cod exist in the area, and so the present consideration of just one stock might not be an optimal choice (Figure 1.14a). This study investigated if the detected regime shift for the North Sea cod could have happened differently in separate areas, South, North-West and Viking (North-East), designed according to the ICES stock assessment results for cod, possibly revealing different recovery potential for the various populations. A number of statistical tools were applied to characterize the dynamics of cod, such as the change point analysis (Figure 1.14c, d, e) and the stochastic cusp models, to find and eventually describe the involvement in a regime shift for each area, demonstrating marked differences in cod populations' behaviour, especially in response to fishing pressure, largely considered among the most impactful drivers. This work pointed out a negative situation regarding cod in the Southern area, which is largely involved in a regime shift, with a low recovery potential and high instability. In the other areas instead, the dynamics are improving in the last years, possibly constituting a stable and "manageable" situation, even if the Viking area actually underwent a regime shift over the past years. Furthermore, this study highlights the general importance of looking at regime shifts also from a spatial point of view and shows that different dynamics can emerge at different spatial levels, and in this specific case, possibly providing useful information for the future management of cod in the North Sea.

Outcome: *Cecapolli E, et al. (in preparation). Evidence of spatial regime shifts: Contrasting spatial dynamics of three populations of cod in the North Sea*

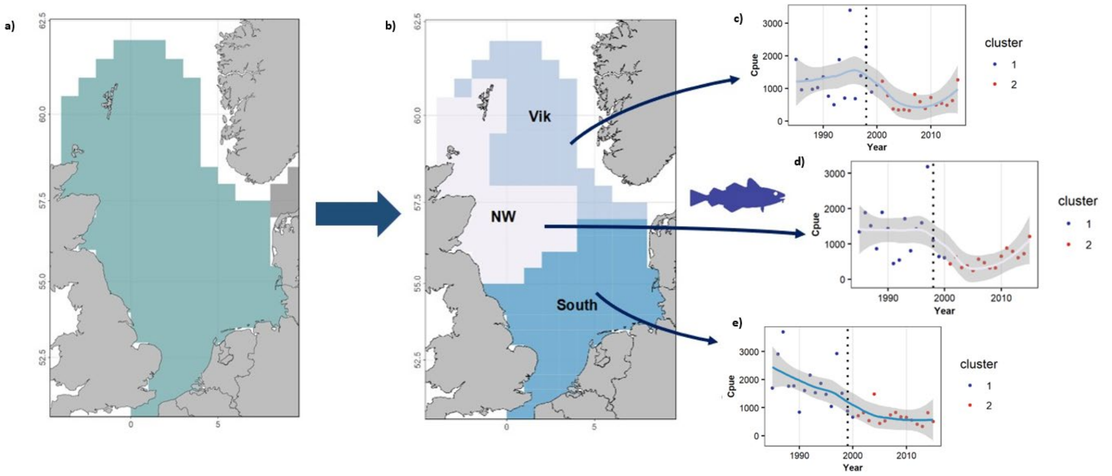


Figure 1.14. Time-series of the three populations of cod in the North Sea. a) Map of the entire North Sea and b) Distribution of the three different cod populations in the North Sea as identified by the ICES Stock Assessment Group. Time-series of CPUE of cod in c) The Vikings North Sea, d) the Northwestern North Sea, e) Southern North Sea. The different colours of the point correspond to the data before 2000 (blue) and after 2000 (red). The line passing through the dots is the smoothed trend done by fitting a loess to better visualize the trend of the populations. In grey the confidence interval of the line. The vertical dotted line corresponds to the change point identified by the change point analysis (1998 for North-West and Viking cod and 1999 for Southern cod).

Another study involving sensitivity indicators was the exploration of the vulnerability of Atlantic and Mediterranean assemblages to warming and trawling by Polo *et al.* (in prep.). This was carried out through the creation of two sensitivity indicators based on the scoring of trait categories prone to be affected by either one of the pressures. Building on trait-based climate change vulnerability assessments and indices of sensitivity to trawling, that study examined the spatio-temporal variation of species sensitivity to fishing and warming in two affected marine ecosystems in the North and Southeast Iberian Peninsula. The study identified species life-history traits and ecological properties expected to condition species responses to climate change and fishing. To approach bentho-demersal communities' vulnerability, species were classified according to their sensitivity to combined anthropogenic impacts and their sensitivity scores were extrapolated to community level. The analyses of these sensitivity indicators revealed Atlantic and Mediterranean ecosystems have two contrasting pathways of community performance (Figure 1.15; Figure 1.16). The Atlantic community shows a generalized recovery from a long history of overfishing while the Mediterranean shows spatial diversity in its response. Both areas appear to respond discontinuously to the combined effects of warming and fishing. This kind of integrative analyses of sensitivity indicators may provide a solid characterization of the mechanizms of recovery against perturbations under different ecological contexts.

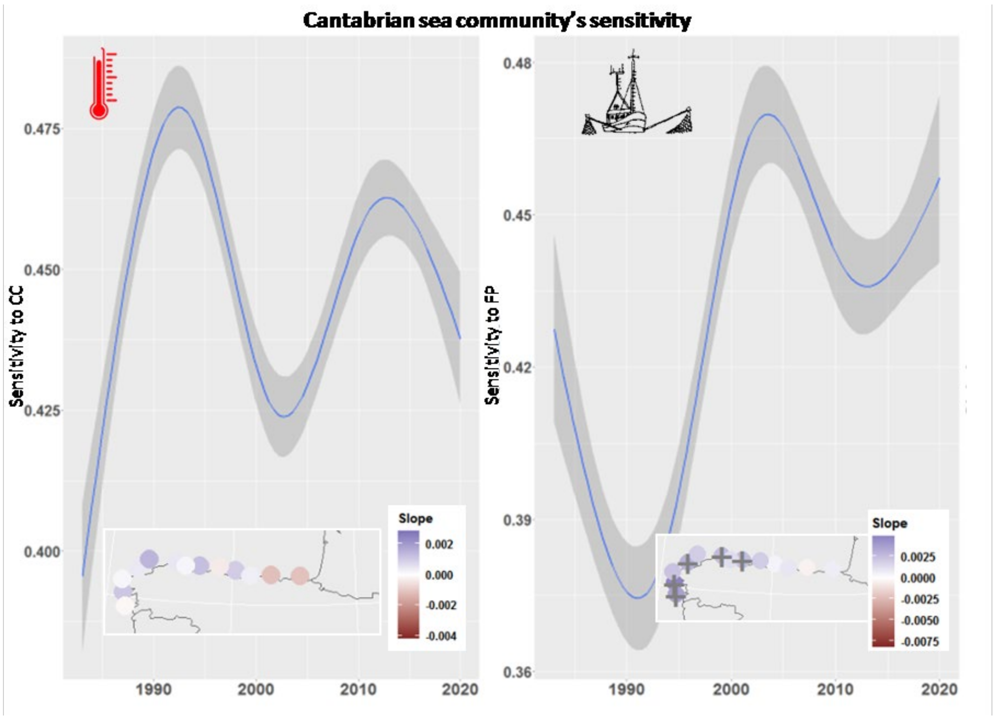


Figure 1.15. Temporal trends of Cantabrian Sea's bentho-demersal community's sensitivity indicators to global change (a) and sensitivity to fishing pressure (b). The map inserted in the figures indicates whether the tendency was spatially homogeneous and statistically significant (marked with a cross). The slope refers to the estimate of modelling the indicators in linear models using year as explanatory variable.

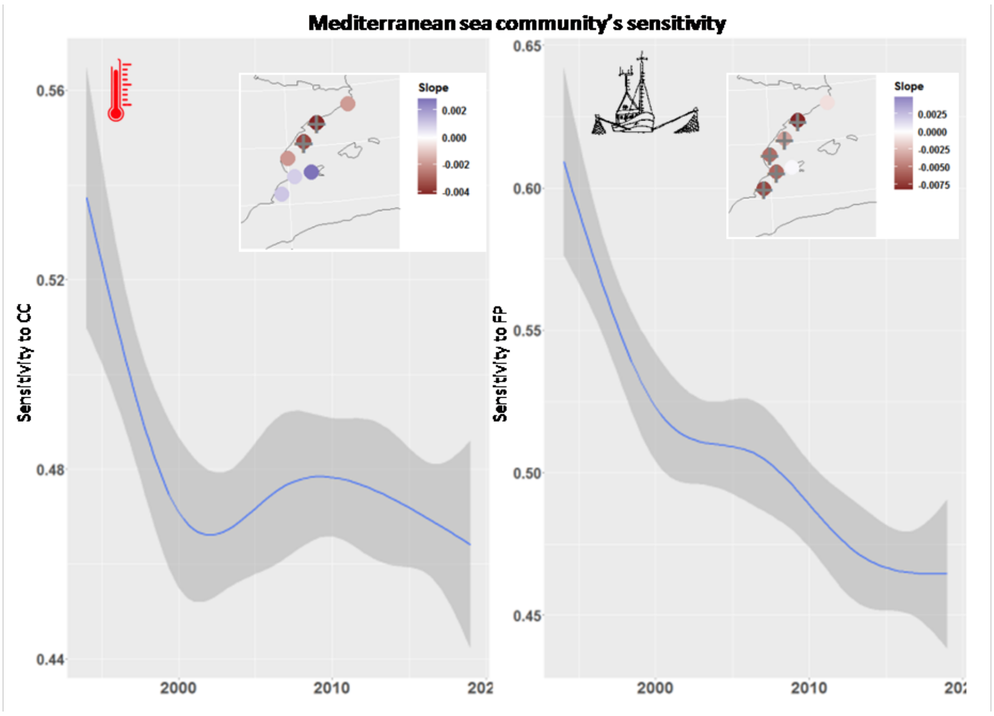


Figure 1.16. Temporal trends of Mediterranean Sea's bentho-demersal community's sensitivity indicators to global change (a) and sensitivity to fishing pressure (b). The map inserted in the figures indicates whether the tendency was spatially homogeneous and statistically significant (marked with a cross). The slope refers to the estimate of modelling the indicators in linear models using year as explanatory variable.

As part of the group efforts to comparatively study the impacts of climate change on Atlantic and Mediterranean assemblages, this study also focused on how warming can trigger shifts in species distributions, eventually altering their biogeography. The composition of a community in terms of its species' ecological niche informs about a community's response to environmental conditions and impacts, which is central for a timely conservation. The thermal niche has been widely explored, as it gives a straight overview of warming effects on a community, but in this research, the multivariate nature of a species niche was acknowledged so as to provide relevant insights of the reorganizations taking place at a community-level. The effects of warming on the composition of two bentho-demersal communities' with contrasting exposure to warming were explored, in Spanish Mediterranean and Cantabrian Seas. Preliminary results revealed major temporal changes and spatial structuring in the mean and the variance of 10 ecological traits and ranges explored, relative to thermal and salinity preferences, occupied area of distribution, latitude and depth. The results confirmed the expected general poleward, deep-ward shift, and found it has taken place along a widening of thermal and latitudinal ranges, with temporal patterns that reflect how communities have adjusted around regime shifts known in both areas. Regional differences arose concerning the variance of depth ranges and area of distribution, as well as to the global evolution of the communities, when the ecological features were summarized in a multivariate indicator. The authors expect the findings of this study will improve the understanding of global-change effects on marine fauna, which ultimately informs adaptive management.

Outcome: *Polo J, et al. (in preparation) Marine communities' niche traits reflect climate change impacts*

Another study, from the US, focused on properties of trophic networks that can confer resilience. Specifically, it is believed that omnivory, a high degree of connectivity, a mix of weak and strong trophic interactions, a high degree of matter cycling, and a balance between efficiency and redundancy in trophic pathways can all increase resilience within a foodweb. Ecological Network Analysis (ENA) provides a framework for quantifying these properties; additionally, the ENA metric known as "relative efficiency" has qualities that make it a useful, actionable indicator (Fath *et al.*, 2019). However, our understanding of network properties rarely, if ever, informs management decisions. Therefore, this work aims for a novel workflow towards operationalizing the use of relative efficiency and other ENA metrics in fisheries management. A model of the Gulf of Maine foodweb has been built using the Rpath mass balance modelling tools, using a Bayesian synthesis approach to estimate a distribution of relative efficiency scores (Figure 1.17). This study further probes the tails of this distribution to understand which combination of flow patterns might pull the system towards a more or less efficient (or resilient) state. Once fully developed, these methods can be applied to any ecological network model to inform resilience management.

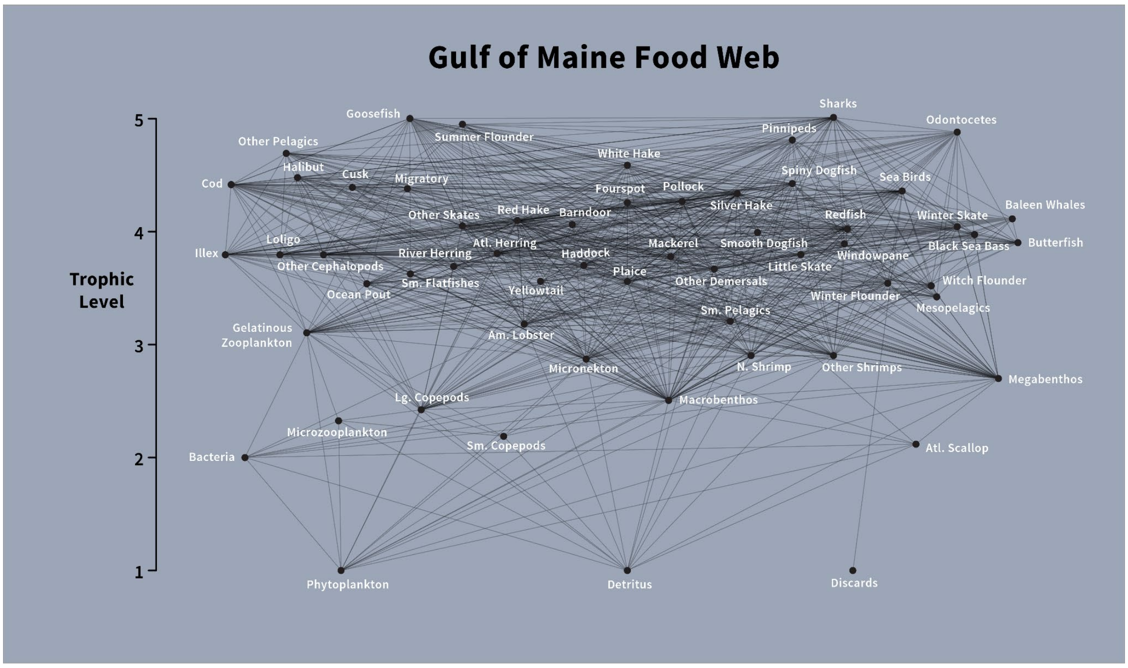


Figure 1.17. Network map of the balanced Gulf of Maine model (1980–1985), created in Rpath. Nodes represent species or functional groups; lines reflect trophic interactions between nodes.

Outcome: *Weisberg S, et al. (in preparation). Food Web Modelling and Ecological Network Analysis to Inform Ecosystem-Level Resilience Management*

Another study, published in 2022 (Polo *et al.*, 2022), carried out a resilience assessment of the bentho-demersal community of the Cantabrian Sea applying the Integrated Resilience Assessment (IRA) framework (Vasilakopoulos *et al*. 2017). The IRA is a methodological framework to quantify resilience dynamics, determine environmental thresholds and build stability landscapes of complex natural systems. Specifically, that study explored the temporal evolution of 63 fish species representing the Cantabrian bentho-demersal community in response to environmental changes and fishing pressure in the period 1983–2018, using survey data. Following the IRA framework, the biotic system data were summarized inside a composite variable (PCsys), corresponding to the Principal Components Analysis (PCA) first dimension. Multivariate analysis and non-additive modelling of the PCsys, the community index, and the system’s main stressors, revealed two decadal-scale regimes, suggesting a non-linear response of the community to its environment. The IRA elucidated the response mechanizm to the candidate stressors and allowed quantifying resilience dynamics (Figure 1.18). The decline in fishing pressure in the 1990s was associated with a gradual transition of the system, while further decline during the 2000s eroded the resilience of the system towards changes in its stressors, leading to a discontinuous response expressed as an abrupt, possibly irreversible shift in the 2010s. Given the teleconnected character of marine ecosystems, this regional study endorses the scientific effort for actions facing the dynamic impacts of climate change on exploited marine ecosystems.

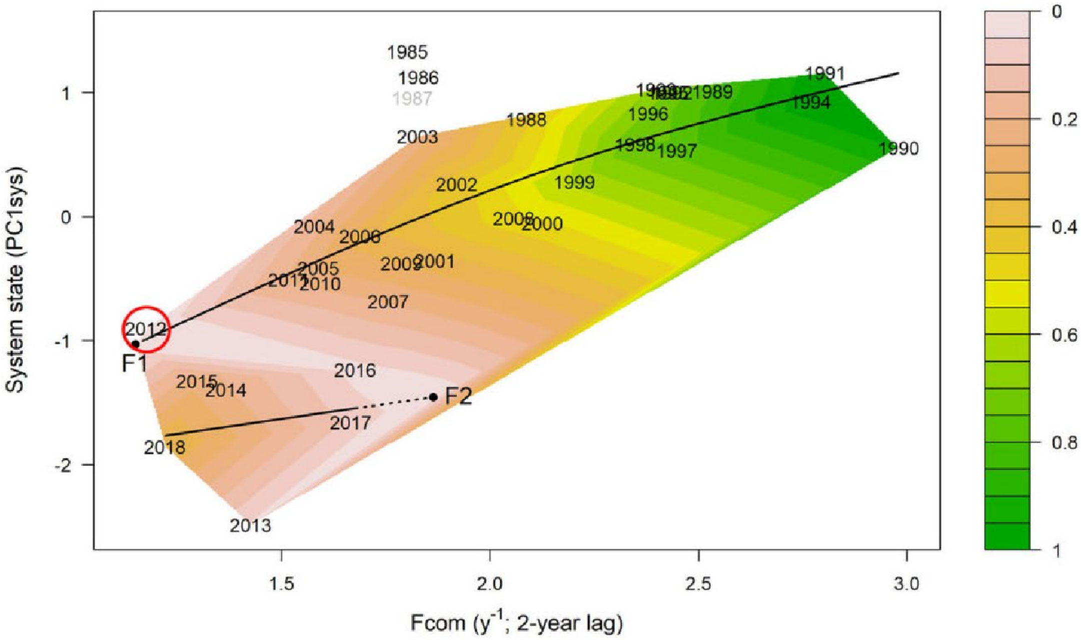


Figure 1.18. Folded stability landscape and relative resilience estimates for the Cantabrian Sea bentho-demersal community. The system's change has a horizontal component in which conditions (2-year lagged fishing mortality of the community, or *F*com) change, and a vertical component which represents system's state changes. Dotted black line indicates the possible extensions of the linear attractors (mean numerical properties of the system for a given period). F1 and F2 are indicating the tipping points assumed locations. Threshold year 2012 is highlighted by a red circle. From: Polo *et al.*, 2022.

Outcome: *Polo J, Punzon P, Vasilakopoulos P, Somavilla R, Hidalgo M (2022). Environmental and anthropogenic driven transitions in the demersal ecosystem of Cantabrian Sea. ICES Journal of Marine Science 79, 2017-2031.*

Another study using the IRA framework was published in 2022 (Hidalgo *et al.*, 2022). This study assessed whether observed changes in the demersal communities of the Western Mediterranean were associated to the erosion or variation of ecological resilience, and which were the main drivers of change. In this study, IRA was applied to assess the resilience dynamics associated with climate-driven ecosystems transitions, expressed as changes in the relevant contribution of species with different life-history strategies, in two bentho-pelagic systems of the Western Mediterranean: the Spanish Iberian Peninsula and the Alboran Sea. To do that, data were analysed from 1994 to 2019 coming from a scientific bottom trawl survey in the two aforementioned environmentally contrasting ecosystems in the western Mediterranean Sea. The authors categorized the bentho-pelagic species according to their life-history strategies (opportunistic, periodic and equilibrium), ecosystem functions and habitats, and used a diversity of natural environmental drivers to investigate the potential mechanistic processes. The study demonstrated that both ecosystems responded to changes in Chlorophyll-a concentration more than any other stressor. The response in Northern Spain indicated an overarching regime shift in 2009, while a less pronounced transition was detected in the Alboran Sea in 2001 (Figure 1.19). Opportunistic fish were unfavored in both ecosystems in the recent periods, while invertebrate species of short life cycle were generally favoured, particularly benthic species in the Alboran Sea. In addition, in the two systems, species with higher thermal affinities were favoured. The study illustrates that the resilience dynamics of the two ecosystems were mostly associated with fluctuating productivity, but subtle and long-term effects from sea warming and fishing reduction were also discernible. Such dynamics are typical of systems with wide environmental gradients such as Northern Spain, as well as systems with highly hydrodynamic and of biogeographical complexity such as the Alboran Sea.

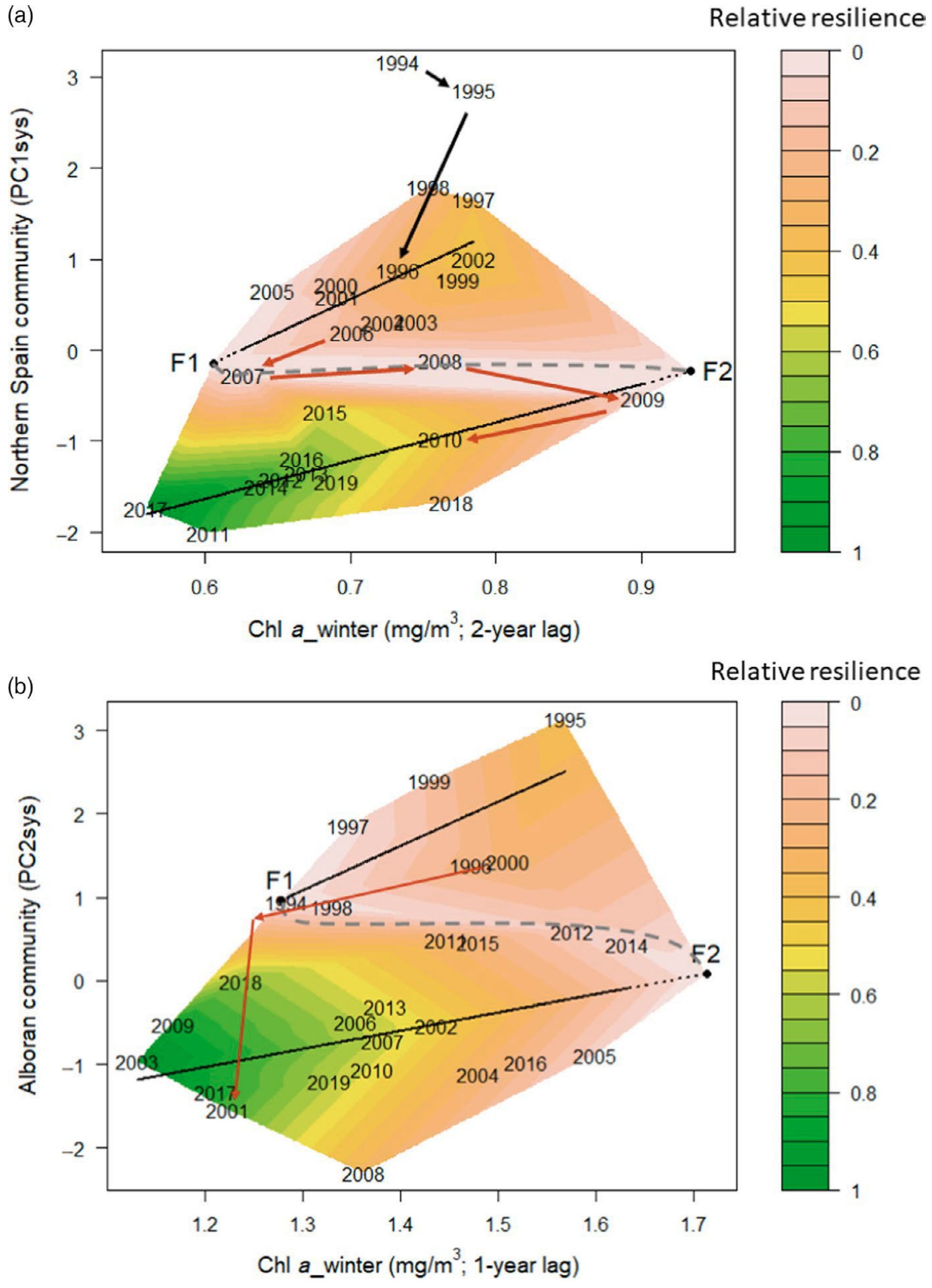


Figure 1.19. Stability landscapes and estimated relative resilience for the ecosystems of Northern Spain (a) and Alboran (b). The folded stability landscape of each ecosystem exhibited two basins of attraction and two tipping points (F1, F2). Continuous black lines indicate the attractors, dotted black lines indicate the possible extensions of the attractors, grey dashed lines indicate the boundaries of the basins of attraction, and red arrows indicate the pathways of the regime shifts. Note that the x-axes refer to 2-year and 1-year lagged Chlorophyll *a* concentration in winter for the Northern Spain and Alboran respectively. From: Hidalgo *et al.*, 2022.

Outcome: *Hidalgo M, Vasilakopoulos P, García-Ruiz C, Esteban A, López-López L, García-Gorriz E (2022). Resilience dynamics and productivity-driven shifts in the marine communities of the Western Mediterranean Sea. Journal of Animal Ecology, 91(2), 470-483.*

Another ongoing study from the Mediterranean Sea aims for a systematic comparison of marine areas with regards to the integrated development of the demersal communities as captured by a scientific bottom trawl survey, from the mid-1990s onwards. The goal is to carry out a series of

IRAs (Figure 1.20) to elucidate the dynamics of ecological resilience of the demersal communities responding to a range of environmental stressors (e.g. sea temperature, oceanic productivity, macronutrients) estimated by a basin-scale biogeochemical model. Specifically, this study aimed to assess whether there have been synchronized in the resilience erosion and regime shifts of the Mediterranean demersal communities, if 'winners' and 'losers' of these shifts are consistent across the Mediterranean Sea, and which environmental stressors act as key drivers at different scales and areas. Finally, the authors plan to examine what the observed changes suggest in terms of the functional outlook of the Mediterranean ecosystems. This study facilitates the operationalization of resilience in the management of Mediterranean marine resources, thus enhancing the adaptive capacity of the fisheries management regimes.

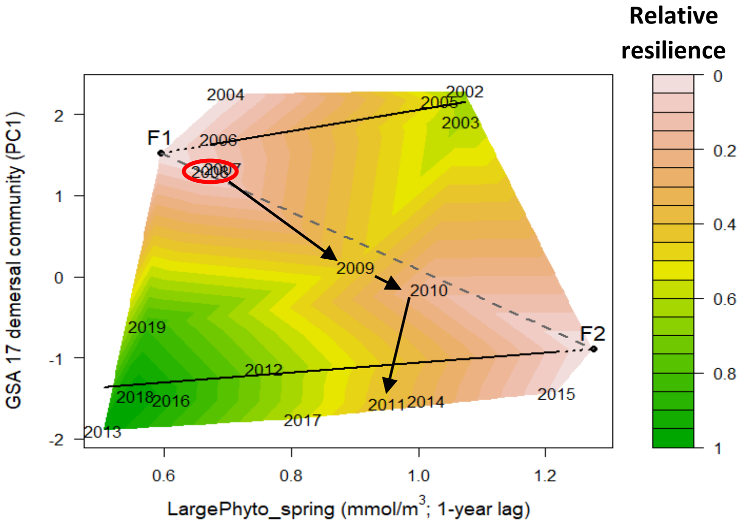


Figure 1.20. Stability landscape and estimated relative resilience for the demersal community of GSA 17 (Adriatic Sea) in relation to spring concentration of large phytoplankton (1-year lagged). Continuous black lines indicate the attractors, dotted black lines indicate the possible extensions of the attractors, the grey dashed line indicates the boundaries of the basins of attraction, red circle indicates the threshold year (2008) and arrows indicate the pathway of the regime shift.

Outcome: *Vasilakopoulos P et al. (in preparation). Resilience dynamics of Mediterranean demersal communities in response to climate change.*

WGCOMEDA has also facilitated the development of a new methodology to quantify resilience based on empirical data by combining the IRA and the stochastic cusp model into a Cusp Resilience Assessment (CUSPRA). CUSPRA satisfies three principles: i) it estimates resilience based on multiple drivers and their interactions, ii) it is comparable across multiple systems and applicable to different data types, and iii) it produces straightforward results on resilience dynamics suitable for management (Figure 1.21). The stochastic cusp model is a model derived from catastrophe theory and it is able to model dynamics of a system based on the interaction of two drivers, from linear to discontinuous. Moreover, it determines a transition area based on the combination of the two drivers, where the system will cross a tipping point and switch into a new state. Based on these features, the study implemented a way to calculate the resilience of a system depending on the combination of the drivers by measuring how far is the system from the transition area and the tipping point. After validating the model, the authors showed possible applications of our new method to time-series of Atlantic cod stock biomass but also of ecosystems such as the North Sea and the Mediterranean Sea. The application to different examples demonstrates that CUSPRA is useful i) to understand the resilience status of a system depending on interacting drivers, ii) to determine thresholds of multiple stressors associated with the system tipping to an alternate state, and iii) how the system reacts in comparison to similar systems in different areas. Thus, the new method not only advances empirical studies in resilience science, but could also be directly applicable in ecosystem management settings by informing managers about potential tipping points and about the vulnerability of a system to external drivers. This is urgently needed in order to manage constantly changing and adapting systems under global climate change.

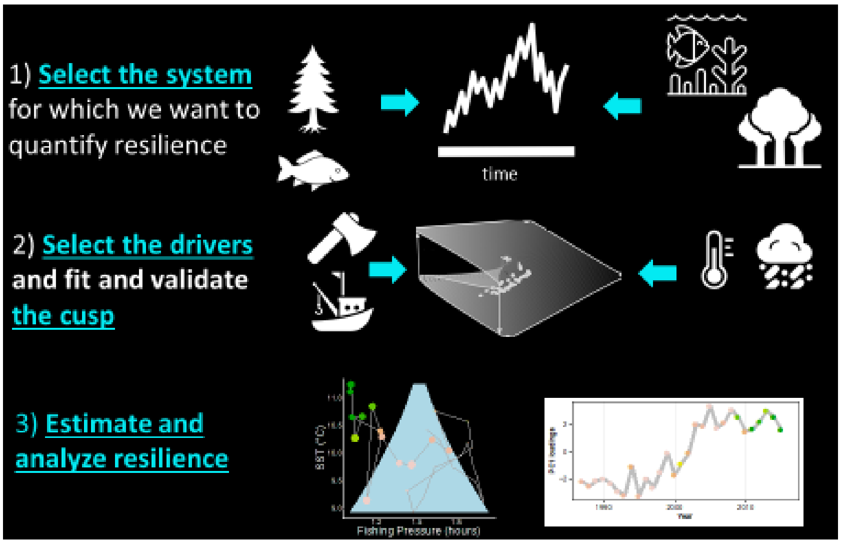


Figure 1.21. The three steps of applying the CUSPRA.

Outcome: *Sguotti C et al. (in prep.). CUSPRA: a new method to assess ecological resilience to multiple interactive drivers*

1.4 Explore options to integrate ecological and socio-economic dimensions to support integrated fisheries advice and marine management (ToR D, led by M. Cristina Mangano)

ToR D has been only recently integrated into the routed WGCOMEDA's framework – since the last resolution 2020–2022 – mainly with the aim to facilitate the dialogue among researchers from different backgrounds dealing with marine resources management, specifically recognizing the relevance for an effective, salient and credible integration of the human dimension on the Integrated Ecosystem Approach. ToR D has been shaped during the three years cycle (half of which affected by COVID-19 pandemic and related management measures), the participants list is now more consolidated, and the ToR is now ready to produce more specific outcomes that integrate the WGCOMEDA and the ICES WGs community more widely (see resolution 2023–2025). The dialogue with Working Group on Social Indicators (WGSOCIAL) and Working Group on Balancing Economic, Social and Ecological Objectives (WGBESEO) as well the Strategic Initiative on the Human Dimension (SIHD) will be consolidated in the next cycle's resolution.

The transition toward Ecosystem Based Fisheries Management (EBFM) guided by the formulation of Integrated Ecosystem Approach (IEA) represents a positive step toward integrating multiple ecosystem components and scientific disciplines. However, up to date, the integration effort has been higher on the biophysical complexity while the human integration has been jeopardized (Kittinger *et al.*, 2012; Levin *et al.*, 2016). Human interactions with marine resources are highly heterogeneous resulting from a multitude of co-occurring, iterative, or asynchronous factors. A poor understanding of social systems can generate and exacerbate social conflict, diminish adaptive capacity, undermine trust between managers and stakeholders, make ineffective ecosystem assessments and decrease resilience while limiting the accuracy of predictions about human responses (Szymkowiak, 2021).

During the 3-years cycle 2020–2022 ToR has invited scientists to present case studies assessing and reporting the social and cultural significance of marine resources management – mainly commercial and artisanal fishing – across coastal regions in both the Med and Atlantic. The ToR D discussion has moved around three main cornerstones of human dimension integration: the inclusion of stakeholders for a more effective reading of society needs when dealing with ecosystems management and conservation; the study of human (stakeholders) behaviour to tailor credible mitigation measures; the presentation of exploitable indicators based on available quantitative and qualitative data. Relevant studies that have been presented and discussed in ToR D at WGCOMEDA annual meetings over the past three years are provided hereafter.

The human dimension of Marine Protected Area (MPA), the steps for identifying, understanding and integrating human dimensions into MPA planning and management and the Small-Scale Fisheries (SSF) have been widely discussed by invited chairs at ToR D. This reflects two main evidences: *i)* increasingly MPAs are being recognized by scientists and stakeholders as an effective tool for the achievement of conservation, biodiversity and fisheries management objectives around the world; *ii)* increasingly, researchers, conservation planners, managers and communities are calling for a more adequate integration of the human dimension as an approach to MPA planning and management. In fact, it has been pointed out that many of the existing MPAs worldwide have been established, planned and managed with only little integration of the human dimensions and impacts. Social, cultural, economic, political and governance issues have been only rarely included, with very little attention given to how MPA planning and management affect local resource-dependent communities and other stakeholders. A missing human dimension that needs to be considered alongside ecological issues to avoid the generation of conflicts and concerns that may undermine MPA objectives and benefits. Scientific evidence based on both ecological patterns' observation and study of stakeholders' behaviour/perception, confirms that a participatory and integrated management – or rather taking into account the values, rights, needs and concerns of local communities and other stakeholders – provide a range of benefits for local communities, local economies, conservation, fisheries and the natural environment.

This was particularly underlined during the talk entitled "Marine protected areas as socio-ecological systems: case studies from the Mediterranean Sea" by Antonio Di Franco presenting the socio-economic benefits generated by MPAs to fisheries (Di Franco *et a*l. 2016; Bennet *et al*. 2019). The authors of the research collated a unique database of ecological, social and economic attributes of SSF in 25 Mediterranean MPAs from the peer-reviewed literature, grey-literature and interviews. By using random forest with Boruta algorithm they identified a set of attributes determining successful SSFs management within MPAs. Di Franco and co-authors reported that fish stocks are healthier, fishers' incomes are higher and the social acceptance of management practices is fostered if five attributes are present (i.e. high MPA enforcement, presence of a management plan, fishers' engagement in MPA management, fishers representative in the MPA board, and promotion of sustainable fishing; Figure 1.22). These findings can be defined as pivotal to Mediterranean coastal communities that can achieve conservation goals while allowing for profitable exploitation of fisheries resources.

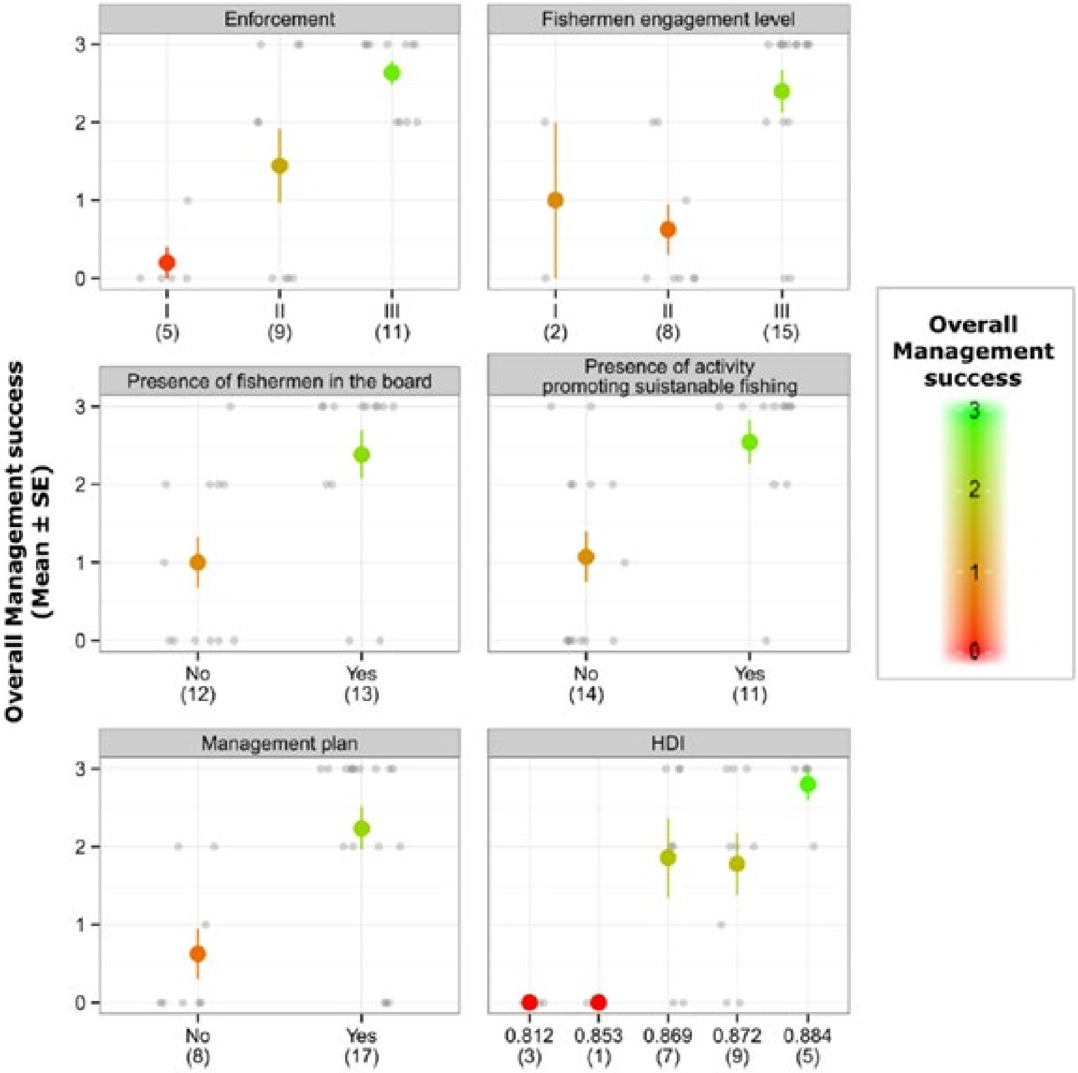


Figure 1.22. as from Figure 1 from Di Franco *et al.* 2016 reporting the "Effects of six significant attributes on overall management success (OMS). Average (± S.E.) OMS for each level of the six significant attributes. Colours denote average magnitude of success from red (null) to green (high). Sample size (number of MPAs; n) is provided under each level".

Interestingly, Di Franco reported also on the importance of local support for the longevity of conservation initiatives (Bennet *et al*. 2019) specifically referring to a study dealing with the examination of the relationships among perceptions of ecological effectiveness, social impacts, and good governance in influencing levels of local support for conservation. By using data from a survey of small-scale fishers in 11 MPA from six countries in the Mediterranean Sea Di Franco and co-authors constructed composite scores for three categories of perceptions—ecological effectiveness, social impacts, and good governance—and tested the relationship with levels of support using ordinal regression models. While all three factors were positively correlated with support for conservation, perceptions of good governance and social impacts were stronger predictors of increasing support (Figure 1.23). These findings suggest that employing good governance processes and managing social impacts may be more important than ecological effectiveness for maintaining local support for conservation.

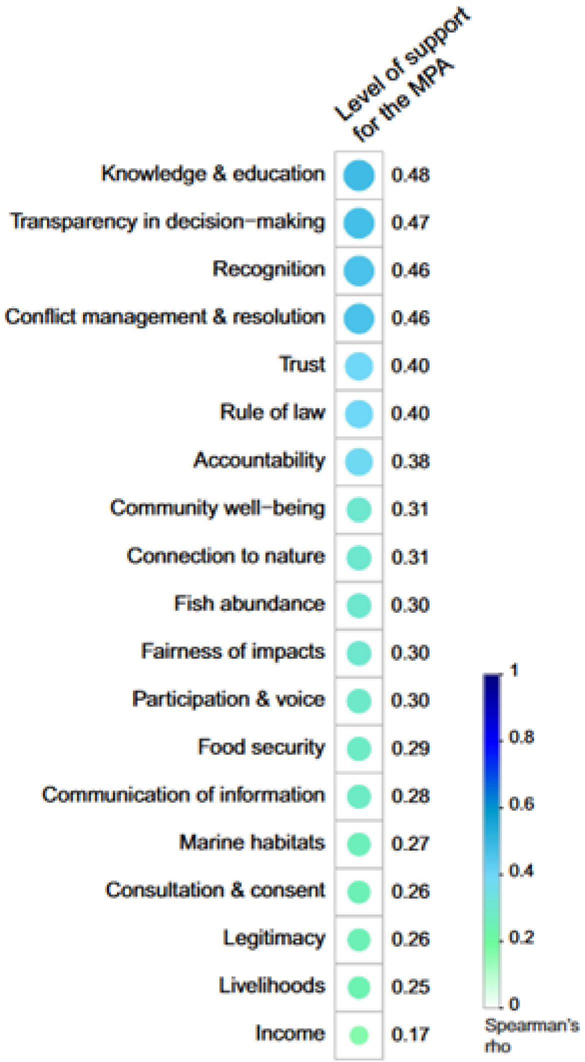


Figure 1.23. as from Figure 1 from Bennet *et al.* 2019 reporting the "Individual perceptions indicators correlated with levels of support for the marine protected area. Size of dot and colour scale both represent correlation coefficient. Survey data from 102 small-scale fishers with complete responses in survey".

In the same context the talk offered by Antonio Calò entitled "Multi--specific small--scale fisheries rely on few, locally essential, species: Evidence from a multi--area study in the Mediterranean" offered the chance to underline the relevance of ecological data collection through stakeholders (specifically small-scale fishers) in a framework of socio-ecological systems analysis (Calò *et al*. 2022). Achieving sound management of small-scale fisheries (SSFs) is globally recognized as a key priority for sustaining livelihoods, local economies, social wealth and cultural heritage in coastal areas. The paucity of information on SSFs often prevents the proper assessment of different socio-ecological aspects, potentially leading to draw inappropriate conclusions and hampering the development and adoption of effective policies to foster SSF sustainability. To respond to the growing global call to assess these fisheries, Calò and co-authors carried out a multidisciplinary and data-rich assessment of SSFs at 11 areas in 6 Mediterranean EU countries, combining the analysis of 1 292 SSF fishing operations and 149 semi-structured surveys of fishers. Specifically, the study assessed (1) landed species contribution to SSF catches and revenues and (2) the spatial variability in a set of fishery socio-ecological descriptors. Results highlighted that, despite a high species diversity, Mediterranean SSFs actually rely economically upon a very limited number of species with catch and revenues per unit of effort mostly determined by less than 5 species, that can guarantee high and stable catches and revenues over time. Moreover, some fishing communities were found to rely on a restricted number of gears. These results suggest that some SSFs' properties often assumed, but never broadly verified, should be carefully reconsidered, especially when viewed from a broader socio-ecological perspective, as in the case of the diversified portfolio or of the polyvalence of fishing gears. Taking the local scale into proper account is likely to reduce the risk of implementing management strategies potentially generating socio-ecological inequalities.

The substantial increase in poaching within the fisheries' management areas (MA) system in central Chile is likely driven by an interplay of socio-economic factors. To assess this problem, Silvia de Jaun and colleagues studied the exploitation state of an important benthic resource in the MAs (i.e. keyhole limpet) and the relationship with the socio-economic drivers of the fishery. The potential drivers of poaching included the level of formal and informal enforcement and distance to surveillance authorities, a rebound effect of fishing effort displacement by MAs, wave exposure and land-based access to the MA, and alternative economic activities in the fishing village. A Bayesian-Belief Network approach was adopted to assess the effects of potential drivers of poaching on the exploitation state of limpets, assessed by the proportion of the catch that is below the minimum legal size and by the relative median size of limpets fished within the MAs compared with neighbouring open access areas. Results showed the important role of socio-economic (e.g. alternative economic activities in the village) and context variables (e.g. fishing effort displacement or distance to surveillance authorities) as drivers of poaching in the study area. Scenario analysis explored variables that are susceptible to be managed, evidencing that an integrative ecological and socio-economic approach can offer solutions to the unsustainable exploitation of marine resources

Outcome*: de Juan, S., Subida, M. D., Ospina-Alvarez, A., Aguilar, A., & Fernández, M. (2022). Multidimensional data analysis to guide the sustainability of a small-scale fishery affected by poaching. Ocean & Coastal Management, 227, 106290.*

The use of Local Ecological Knowledge (LEK) has been confirmed as a valid tool to collect data when dealing with the inclusion of stakeholders' perception in ecosystems management and conservation as well to provide salient information on the natural environment, generating a deep understanding of the surrounding ecology. The knowledge of local, indigenous communities around the world has been recognized as a valuable and credible resource for information on how the environment, biodiversity, and local conditions are changing over time. A growing body of research is acknowledging the adaptive capacity of LEK and the ability for local stakeholders to understand fluctuating social and environmental conditions.

Climate change is driving rapid changes at global scales with significant consequences impacting on all ecological organization levels, influencing individual performance and distribution species patterns, having contrasting impacts on different biotas. Mar Bosch Belmar and co-authors observed that some benthic species such as the coral *Astroides calycularis* are repeatedly suffering mortality events potentially due to climatic extreme events (i.e. marine heat waves), while other taxa like the stinging fireworm *Hermodice carunculata* are increasing their distribution and population densities within the Mediterranean Sea. In this context, knowledge coming from citizens and specific stakeholders (i.e. scuba divers) may be crucial and may not only fill present gaps in scientific literature but also provide precious information on biodiversity, species distribution and habitat ecological status at high spatial scale. A short semi-structure questionnaire was performed to 25 diving centres along the Italian coasts to assess i) presence and perception of the orange coral and health status of the colonies in the most visited diving sites; ii) presence and perception of *H. carunculata* in the sites that scuba divers usually visit and co-habitation with *A. calycularis* in these places; iii) interviewees perception on the water temperature changes in the last years. Collected information allowed to map the distribution of both target species along the Italian coasts, highlighting the areas where the species cohabitated and sites where *A. calycularis* populations presented mortality (presence of necrotic tissue). Information on the orange coral health status allowed to relate the mortality events of the species with concurrent marine heat waves showing a potential relationship between them and suppose a baseline to consecutive experimental trials aimed to investigate *A. calycularis* thermal tolerance and thresholds. Understanding how different species will respond to warming (through the joining action of social science and mechanistic approaches) may be a key factor to developing adequate conservation and management plans aimed at enhancing the resilience of vulnerable ecosystems.

Outcome: *Mar Bosch Belmar et al. (in preparation) "Using Local Ecological Knowledge to understand the effects of climate change on Mediterranean biodiversity".*

LEK has been reported as essential for exploring co-management options, adaptation alternatives, nature conservation attitudes (Braga *et al*. 2017), and to improve socio-ecological resilience (Reid *et al*. 2006; Dìaz *et al*. 2018), integration of knowledge processes which can guide future landscape and nature management policies (Palomo 2017) and reduce conflict between stakeholders and governing entities at multiples scales (Kati *et al*. 2015).

Guillaume Marchessaux and co-authors reported the effectiveness of using LEK to expand the knowledge on invasive species patterns of distribution, spreading and level of threat on biodiversity and human activities by interviewing stakeholder's groups (Marchessaux *et al.* 2023). The recent expansion of the two invasive Portunidae blue crabs *Callinectes sapidus* and *Portunus segnis* has generated great concern in the western Mediterranean basin. Here, the authors collected perception from artisanal small-scale fishers on the socio-economic issues associated with this invasion. Professional fishers from France, Italy, and Tunisia were interviewed to survey their perception on: (i) the potential drivers of spatial expansion of blue crabs, (ii) the impact on the small-scale fisheries, and (iii) the management measures expected. The main reported impacts were the damage of fishing nets, followed by a consequent associated increase in work intensity and by physical injuries to fishers. Fishers reported to have caught less fish in presence of blue crabs, as well fish damaged by blue crabs' bite inducing a decrease in the quality and value of catches (Figure 1.24). The negative effects induced a decrease on global revenues as well despite the negative impacts of blue crabs on the fishery, the presence of these new species has been generally perceived as positive, being considered as a new revenue resource for some fishers. The majority of them (72%) proposed fishing and marketing as main management measures. Despite the interest expressed for exploitation of this new resource, many questions emerged to promote and develop management strategies.

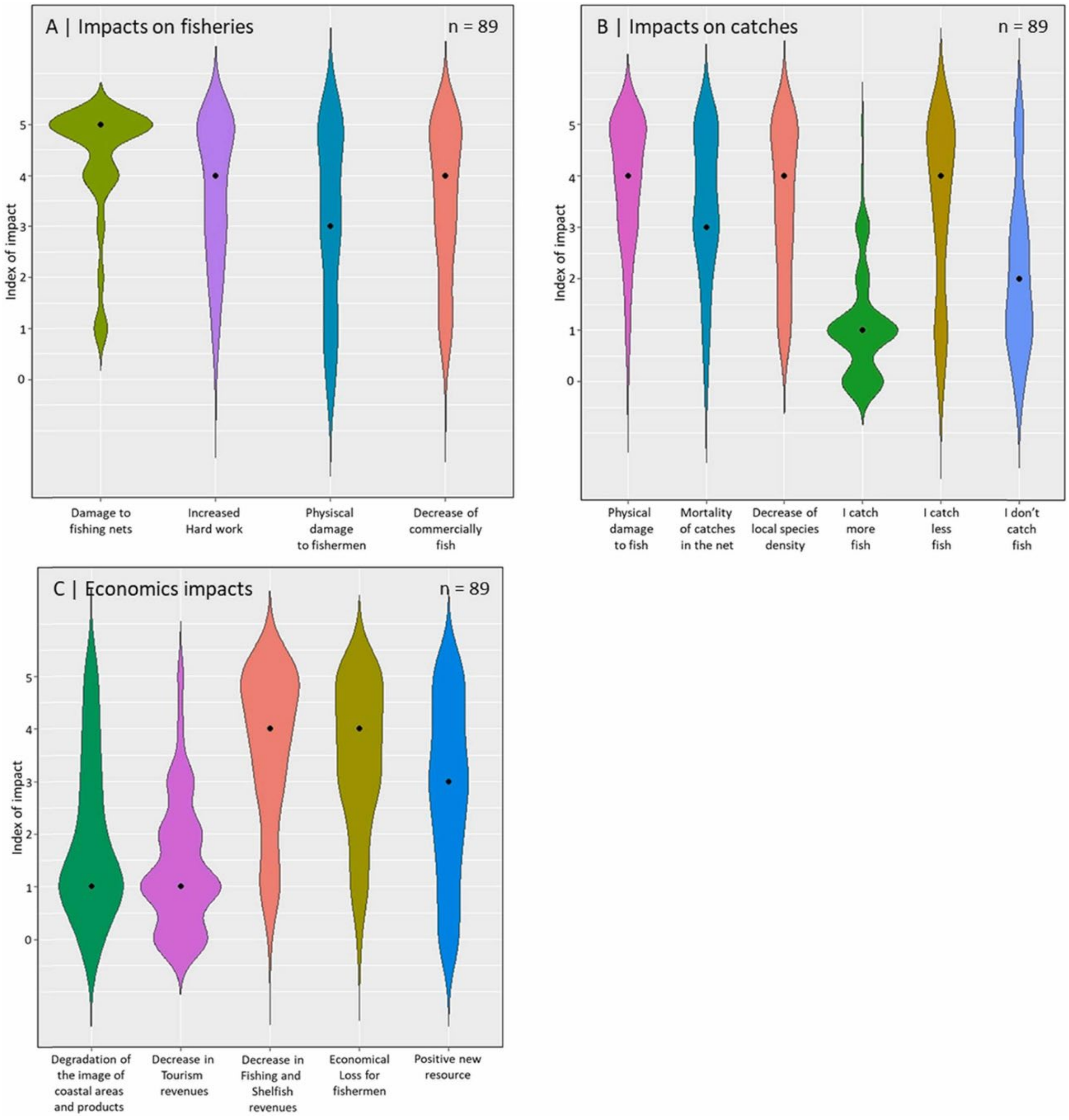


Figure 1.24. as from Figure 3 from Marchessaux *et al*. 2023 "Distribution of perceived impacts of blue crabs (*C. sapidus* and *P. segnis*) on (A) artisanal fisheries activities, (B) on catches, and (C) economics impacts. Black dots represent the median".

Outcome: *Invasive blue crabs and small-scale fisheries in the Mediterranean sea: Local ecological knowledge, impacts and future management. Marine Policy, 148, 105461. Marchessaux, G., Mangano, M. C., Bizzarri, S., M'Rabet, C., Principato, E., Lago, N., ... & Sarà, G. (2023).*

The role of social scientists in supporting, promoting, facilitating and reaching human integration into ecological assessment has been recognized as highly relevant through the 3 years cycle of ToR D. Specifically during 2022, WGCOMEDA has been joined by Maria Vittoria Marra (presentation title "Building a bridge between ocean science and society from the Atlantic to the Mediterranean"), Sebastian Villasante (presentation title "Social vulnerability of coastal communities in the EU"), Valerio Sbragaglia (presentation "Digital fisheries data in the Internet age: Emerging tools for research and monitoring using online data in recreational fisheries") and Michael Kriegl, who offered the talk "Connecting the dots between ocean and society: Using social-ecological networks to effectively manage marine resources". The latter is of particular interest due to its focus, and reported hereafter.

Natural resource management in the marine realm deals with complex interactions and interdependencies between ocean and society. In this context, the social-ecological network approach offers a promising pathway towards understanding coupled human-environment systems by capturing multifaceted relationships and bridging the gap between traditional scientific disciplines. The authors apply this approach to study small-scale fisheries management using a variety of network analysis tools focusing both on the individual resource user (ego-network approach) as well as the whole system level (complete social-ecological networks). Dynamic network models are particularly useful to study the social and ecological implications of management options, environmental disturbances and the crossing of social-ecological tipping points. With this, the authors are working towards a versatile, accessible and comprehensive decision-making tool for the sustainable management of marine resources in a changing world.

***Outcome**: Kriegl, M., Kluger, L. C., Gorris, P., Kochalski, S. (2022). Coastal livelihood resilience to abrupt environmental change: The role of social capital in a Peruvian Bay. Regional Environmental Change, 22, 103. https://doi.org/10.1007/s10113-022-01959-3*

Adaptation in a dynamic seascape: Kriegl, M., Kluger, L. C., Salazar Céspedes C. M., Barriga Rivera, E., Wolff, M., Schlüter, A. The evolution of fisheries connectivity in two contrasting Peruvian bays (in preparation).

The ToR was concluded with a talk from the Chair, M. Cristina Mangano, who reported on the topic: "The aquaculture supply chain in the time of COVID-19 pandemic: Vulnerability, resilience, solutions and priorities at the global scale". Aquaculture plays a vital and rapidly expanding role in food security, in some cases overtaking wild-caught fisheries in the production of high-quality animal protein in this PFSC, and the Authors have reported the COVID-19 global pandemic severe, unpredictable and synchronous impacts on all levels of perishable food supply chains (PFSC), across multiple sectors and spatial scales. Mangano and co-authors performed a rapid global assessment to evaluate the effects of the COVID-19 pandemic and related emerging control measures on the aquaculture supply chain. Socio-economic effects of the pandemic were analysed by surveying the perceptions of stakeholders, who were asked to describe potential supply-side disruption, vulnerabilities and resilience patterns along the production pipeline with four main supply chain components: a) hatchery, b) production/processing, c) distribution/logistics and d) market. Different farming strategies have been assessed, comparing land- *vs.* sea-based systems; extensive *vs.* intensive methods; and with and without integrated multi-trophic aquaculture, IMTA. In addition to evaluating levels and sources of economic distress, interviewees were asked to identify mitigation solutions adopted at local / internal (*i.e.* farm-site) scales, and to express their preference on national / external scale mitigation measures among a set of *a priori* options. Survey responses identified the potential causes of disruption, ripple effects, sources of food insecurity, and socio-economic conflicts. They also pointed to various levels of mitigation strategies. The collated evidence represents a first baseline useful to address future disaster-driven responses, to reinforce the resilience of the sector and to facilitate the design reconstruction plans and mitigation measures, such as financial aid strategies.

***Outcome**: Mangano, M. C., Berlino, M., Corbari, L., Milisenda, G., Lucchese, M., Terzo, S., ... & Sarà, G. (2022). The aquaculture supply chain in the time of COVID-19 pandemic: Vulnerability, resilience, solutions and priorities at the global scale. Environmental science & policy, 127, 98-110.*

References

Bennett, N. J., Di Franco, A., Calò, A., Nethery, E., Niccolini, F., Milazzo, M., & Guidetti, P. (2019). Local support for conservation is associated with perceptions of good governance, social impacts, and ecological effectiveness. *Conservation letters, 12(4), e12640.*

Braga HO, Azeiteiro UM, Oliveira HMF, Pardal MA (2017) Evaluating fishermen's conservation attitudes and local ecological knowledge of the European sardine (Sardina pilchardus), Peniche, Portugal. J Ethnobiol Ethnomed.

Calò, A., Di Franco, A., Quattrocchi, F., Dimitriadis, C., Ventura, P., Milazzo, M., & Guidetti, P. (2022). Multi-specific small-scale fisheries rely on few, locally essential, species: Evidence from a multi-area study in the Mediterranean. *Fish and Fisheries, 23(6), 1299-1312.*

Dìaz S, Pascual U, Stenseke M, Martìn-Lòpez B, Watson RT, Molnàr Z, Hill R, Chan KMA, Baste IA, Brauman KA, Polasky S, Church A, Lonsdale M, Larigauderie A, Leadley PW, Van Oudenhoven APE, Van Der Plaat F, Schroter M, Lavorel S, Aumeeruddy-Thomas Y. Bukvareva E, Davies K, Demissew S, Erpul G, Failler P, Guerra CA, Hewitt CL, Keune H, Lindley S, Shirayama Y (2018) Assessing nature's contributions to people: recognizing culture, and diverse sources of knowledge, can improve assessments. Science 359:270–272.

Di Franco, A., Thiriet, P., Di Carlo, G., Dimitriadis, C., Francour, P., Gutiérrez, N. L., ... & Guidetti, P. (2016). Five key attributes can increase marine protected areas performance for small-scale fisheries management. *Scientific reports, 6(1), 1-9.*

Fath, B. D., Asmus, H., Asmus, R., Baird, D., Borrett, S. R., De Jonge, V. N., … Wolff, M. (2019). Ecological network analysis metrics: The need for an entire ecosystem approach in management and policy. Ocean and Coastal Management, 174, 1–14. https://doi.org/10.1016/j.ocecoaman.2019.03.007

Hidalgo M, Vasilakopoulos P, García-Ruiz C, Esteban A, López-López L, García-Gorriz E (2022). Resilience dynamics and productivity-driven shifts in the marine communities of the Western Mediterranean Sea. Journal of Animal Ecology, 91(2), 470-483.

Kati V, Hovardas T, Dieterich M, Ibisch PL, Mihok B, Selva N (2015) The challenge of implementing the European network of protected areas Natura 2000. Conserv Biol 29:260–270.

Kittinger, J., Finkbeiner, E., Glazier, E., and Crowder, L. (2012). Human dimensions of coral reef social-ecological systems. Ecol. Soc. 17:17.

Kortsch S., Frelat R., *et al*. (2021). Disentangling temporal food web dynamics facilitates understanding of ecosystem functioning. Journal of Animal Ecology 90: 1205–16 https://doi.org/10.1111/1365-2656.13447

Koutsidi M., Moukas C., Tzanatos E. (2019): Koutsidi, Moukas, Tzanatos: 23 biological traits of 235 species. figshare. Dataset. https://doi.org/10.6084/m9.figshare.11347406.v1

Koutsidi M., Moukas C., Tzanatos E. (2020). Trait-based life strategies, ecological niches, and niche overlap in the nekton of the data-poor Mediterranean Sea. Ecology and Evolution 10: 7129– 7144. https://doi.org/10.1002/ece3.6414

Kriegl, M., Kluger, L. C., Gorris, P., Kochalski, S. (2022). Coastal livelihood resilience to abrupt environmental change: The role of social capital in a Peruvian Bay. Regional Environmental Change, 22, 103. https://doi.org/10.1007/s10113-022-01959-3

Levin, P. S., Breslow, S. J., Harvey, C. J., Norman, K. C., Poe, M. R.,Williams, G. D., *et al*. (2016). Conceptualization of social-ecological systems of the California current: an examination of interdisciplinary science supporting ecosystem based management. Coastal Manag. 44, 397–408. https://doi.org/10.1080/08920753.2016.1208036

Mangano, M. C., Berlino, M., Corbari, L., Milisenda, G., Lucchese, M., Terzo, S., ... & Sarà, G. (2022). The aquaculture supply chain in the time of COVID-19 pandemic: Vulnerability, resilience, solutions and priorities at the global scale. Environmental science & policy, 127, 98-110.

Marchessaux, G., Mangano, M. C., Bizzarri, S., M'Rabet, C., Principato, E., Lago, N., ... & Sarà, G. (2023). Invasive blue crabs and small-scale fisheries in the Mediterranean sea: Local ecological knowledge, impacts and future management. Marine Policy, 148, 105461.

Murillo, F. J., Weigel, B., Bouchard Marmen, M., Kenchington, E. (2020) Marine epibenthic functional diversity on Flemish Cap (northwest Atlantic) – identifying trait responses to the environment and mapping ecosystem functions. Diversity and Distributions 26: 460– 478.

Ovaskainen, O., Tikhonov, G., Norberg, A., Guillaume Blanchet, F., Duan, L., Dunson, D., Roslin, T., *et al*. 2017. How to make more out of community data? A conceptual framework and its implementation as models and software. Ecology Letters, 20: 561–576.

Ovaskainen, O., and Abrego, N. 2020. Joint Species Distribution Modelling. Cambridge University Press.

Palomo I (2017) Climate change impacts on ecosystem services in high mountain areas: a literature review. Mt Res Dev 37:179–187.

Papantoniou, G., Giannoulaki, M., Stoumboudi, M.T., Lefkaditou, E. and Tsagarakis, K. (2021). Food web interactions in a human dominated Mediterranean coastal ecosystem. *Marine Environmental Research*, *172*, p.105507.https://doi.org/10.1016/j.marenvres.2021.105507

Pecuchet L., *et al*. (2020). Novel feeding interactions amplify the impact of species redistribution on an Arctic food web. Global Change Biology, 26, 4894 – 4906. https://doi.org/10.1111/gcb.15196

Polo J, Punzon P, Vasilakopoulos P, Somavilla R, Hidalgo M (2022). Environmental and anthropogenic driven transitions in the demersal ecosystem of Cantabrian Sea. *ICES Journal of Marine Science* 79, 2017-2031.

Reid WV, Berkes F, Wilbanks TJ, Capistrano D (2006) Bridging scales and knowledge systems: concepts and applications in ecosystem assessments. Island Press, Washington DC.

Szymkowiak, M. (2021). A conceptual framework for incorporating human dimensions into integrated ecosystem assessments. *Frontiers in Marine Science, 8, 617054.*

Tikhonov, G., Opedal, Ø. H., Abrego, N., Lehikoinen, A., de Jonge, M. M. J., Oksanen, J., and Ovaskainen, O. 2020. Joint species distribution modelling with the r-package Hmsc. *Methods in Ecology and Evolution*, 11: 442–447.

Vasilakopoulos, P., Raitsos, D. E., Tzanatos, E., & Maravelias, C. D. (2017). Resilience and regime shifts in a marine biodiversity hotspot. *Scientific Reports*, 7(1), 1–11. https://doi.org/10.1038/s4159 8-017-13852 -9

Weigel, B., Kotamäki, N., Malve, O., Vuorio, K., & Ovaskainen, O. (2023). Macrosystem community change in lake phytoplankton and its implications for diversity and function. Global Ecology and Biogeography, 32, 295–309. https://doi.org/10.1111/geb.13626

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2020

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Annex 2: Resolutions

2019/FT/IEASG03 The **Working Group on Comparative Ecosystem-based Analyses of Atlantic and Mediterranean marine systems** (WGCOMEDA), chaired by Sofia Henriques, Portugal, Maria Cristina Mangano, Italy, Paris Vasilakopoulos, EU and Romain Frelat, Netherlands, will work on ToRs and generate deliverables as listed in the Table below.

YEAR	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2020	21-25 September	by correspondence	No reporting	Four new co-chairs to pursue the development of WGCOMEDA activities
Year 2021	4–7 October	Online meeting	No reporting	
Year 2022	3–6 October	University of Palermo (Distem), Palermo, Italy	Final ICES Scientific report by December 2022	Romain Frelat (outgoing chair)

Tor descriptors

TOR	DESCRIPTION	BACKGROUND	SCIENCE PLAN CODES	DURATION	EXPECTED DELIVERABLES
a	Assess the **functional biodiversity** of demersal and benthic assemblages across Mediterranean and Atlantic systems	A) The topic is a follow up from the work in the previous cycles aiming to improve: (1) the use of functional traits to assess the structure and functioning of marine assemblages (integrating different taxonomic groups) and (2) the assessment of functional biodiversity patterns across Mediterranean and Atlantic systems B) The tor will provide better understanding of ecosystems functioning and improve our ability to predict the impact of environmental and human-induced changes.	1.4; 1.9; 2.2	3 years	1. Define the **core functional traits** across different taxonomic groups in order to integrate the current approaches 2. **Compile trait data** for phytoplankton, zooplankton, fish and invertebrate species to standardize the use of traits 3. Identify possible methods to deal with **dynamic traits on space and time**, i.e. Those which are demographic (e.g. Fecundity) or ontogenetic (e.g. Diet) dependent 4. Understand spatio-temporal dynamics and patterns of **functional diversity and respective drivers** (trait biogeography; co-occurrence of traits) 5. Understand functional changes to different human

					pressures and **predict the vulnerability and stability of Mediterranean and Atlantic ecosystems** (resilience indicators).
b	Integrate the complexity of marine biota to understand how **ecosystem structure and connectivity** support the stability of communities	A) The topic is a follow up from the work in the previous cycles and addresses issues on integrating multi-trophic interactions for IEA B) Ecosystem structure and connectivity is known to affect community stability, but empirical evidences are still weak. Embracing the complexity of marine ecosystems (e.g. By integrating trophic interactions) will strengthen the input and guidance for ecosystem-based management.	1.4; 1.9; 5.2	3 years	1. Review existing **food webs models** across Mediterranean and Atlantic systems 2. Identify possible methods to **predict species interactions from traits** and extend multi-trophic interaction network in data-poor regions 3. Understand spatio-temporal dynamics of food webs and identify the **link between structure and stability** across ecosystems 4. Understand past and **predict future vulnerabilities** of communities to fishing disturbances or biological invasions.
c	Investigate **resilience and mechanisms of change** in complex marine systems impacted by anthropogenic and environmental drivers	A) The topic is a follow up from the work in the previous cycles and aims to study systems undergoing changes in the NE Atlantic and the Mediterranean to uncover synchronies and analogies across them. B) Several complex marine systems have been shown to respond to environmental and/or anthropogenic drivers with abrupt regime shifts. Comparative analysis of different systems will elucidate the exact role of different drivers in eroding or reinforcing the resilience of specific system states and help anticipate future tipping points. The impact to both ecosystems and fisheries can then be evaluated.	1.3; 1.9; 6.5	3 years	1. Review and update existing information on the **temporal development of ecosystems** in the NE Atlantic and the Mediterranean. 2. Develop and test different types of **Integrated Assessments**: e.g. Ecosystem-based, traits-based, population-based etc. 3. Quantify the **resilience of different system states** and elucidate the specific role of different stressors. 4. Compare the system dynamics and **temporal occurrence of shifts** in different ecosystems of the NE Atlantic and the Mediterranean Sea.

					5. Improve our **prediction capability on future shifts** in complex marine systems through a better understanding of the past dynamics.
d	Explore options to integrate ecological and socio-economic dimensions to support integrated fisheries advice and marine management	A) New topic incorporating social and cultural aspects in order to support the implementation of IEA in regional ecosystems. B) The tor will be organised around 3 main activities and expected deliverables: scooping and systematic review, evidence mapping and synthesis, comparative analysis of case studies.	6.6; 7.1; 7.2;	3 years	1. Scoping exercise mostly focused in the Mediterranean Sea to check for existing literature and to ensure coordination of activities with other international bodies and existing wgs within and outside ICES (e.g. ICES wgsocial, JRC, GFCM). 2. Evidence mapping to highlight the current work and identify future needs and gaps for social science in Med. 3. Case studies assessing and reporting the social and cultural significance of commercial fishing (coastal regions in both the Med and Atlantic). Selection and provision of relevant indicators and analysis with economic and ecological information. 4. Framework for collective reporting (database) to support future potential data collection, data analysis and advice development in a context of integrated ecosystem assessments. 5. Trade-off exploration to assess the socio-cultural and economic significance of commercial fishing (work with other relevant ICES wgs).

Summary of the Work Plan

Year 1	1.1 Definition of the core functional traits across different taxonomic groups. This activity will be developed in order to integrate the current approaches among trophic levels (i.e. What traits should we use to understand linkages between plankton, fish and benthic invertebrates) - Deliverable tor a1. Then, we will start the collection and compilation of standardized trait data for phytoplankton, zooplankton, fish and invertebrate species in order to create a common trait database – toward Deliverable tor a2.

	1.2 Reviews and update databases of (i) existing food webs models, (ii) temporal development of ecosystems and (iii) socio ecological systems approaches across Mediterranean and Atlantic systems - Deliverables tor b1, tor c1 and tor d1. All the 3 tors (b, c and d) start with a revision activity of data from the scientific and grey literature as well as a survey of current work from participants of the working group. Temporal dynamics of ecosystems could be informed by time-series of the abundance of different taxa (e.g. From scientific surveys) and/or fisheries-related data (e.g. Fisheries landings) - Deliverables tor c1. The scoping exercise of socio-ecological systems is followed by an evidence mapping (data analysis from the systematic review - Deliverables tor d1) that will depict the current work and identify future needs and gaps for social science when dealing with ecosystem-based approach - Deliverable tor d2. 1.3 Networking activities to ensure coordination with other international bodies and existing wgs within and outside ICES.
Year 2	**2.1 Completion of the common trait database** - deliverable tor a2 - and identification of methods to deal with dynamic traits on space and time, i.e. Those which are demographic (e.g. Fecundity) or ontogenetic (e.g. Diet) dependent - deliverable tor a3 - and to predict species interactions from traits and extend multi-trophic interaction network in data-poor regions - deliverable tor b2. **2.2 Development and testing of different types of Integrated Assessments** (e.g. Traits-based linking to tor a2, ecosystem-based, population-based) - deliverable tor c2, in order to quantify the resilience of different system states and elucidate the specific role of stressors - deliverable tor c3. **2.3. Case studies assessing and selecting relevant indicators dealing with socio-ecological systems** - Deliverable tor d3, e.g. The social and cultural significance of commercial fishing (coastal regions in both the Mediterranean and the Atlantic).
Year 3	**3.1 Spatio-temporal analysis of functional diversity dynamics** - deliverables tor a4 - **and of food webs structure** - deliverables tor b3 – in order to understand past dynamics and identify drivers of change across ecosystems in NE Atlantic and the Mediterranean Sea. **3.2 Assessment of future vulnerability and stability of Mediterranean and Atlantic ecosystems to different human pressures**, through looking at functional changes and developing resilience indicators - deliverables tor a5 – and by using food web structure to indicate the ecosystem resilience to disturbances (e.g. Fishing disturbances or biological invasions) - deliverables tor b4. **3.3 Comparison of the temporal occurrence of shifts in different ecosystems of the NE Atlantic and the Mediterranean Sea** to improve our prediction capability on future shifts in complex marine systems through a better understanding of the past dynamics - Deliverables tor c4 and c5. **3.4 Collective reporting (database) to assess the socio-cultural and economic significance of commercial fisheries** and support future potential data collection, data analysis, trade-off elaboration and advice development in a context of integrated ecosystem assessments of commercial fishing - Deliverables tor d4 and 5.

Supporting information

Priority	The aim of this working group (WG) is to investigate both cross-systems and system-specific key questions to guide research and improve the ecosystem approach to management of living marine resources of the European Seas. To this end, we use existing data and analysis from regional systems of the North East Atlantic Ocean and Mediterranean Sea. A **comparative approach of marine ecosystems** is essential to learn how Mediterranean and Atlantic ecosystems are structured, how they function, and also to identify which are the more sensitive species or ecological processes to be managed within the ecosystem dynamics. Therefore, this WG aims at strengthening the scientific basis for regional and integrated ecosystem approach of coastal and marine living resources through a comparative platform of research. During the previous two cycles, WG COMEDA established a strong network of collaboration that will continue contributing to the comparative knowledge of Atlantic and Mediterranean systems. The new tors build up on past research of the group and propose to use novel approaches to assess the **functional diversity, resilience, connectivity and complexity of marine assemblages**, both across biological groups and between Mediterranean and Atlantic systems. Additionally, a new topic (tor d), related with ecosystem services, aims to **integrate the socio-economic dimension** with the advanced biological knowledge in order to better understand the effects of both anthropogenic changes and management options in the ecosystems. Close collaboration with other wgs of the SCICOM/ACOM Integrated Ecosystem Assessments Steering Group (IEASG) such as WGIAB, WGEAWESS, WGSOCIAL and WGMARS will provide a solid basis to develop the research topics and tor d of this new COMEDA cycle. Furthermore, during this new cycle we will invite colleagues working on ecosystem services and on linking socio-economic and ecological dimensions to the meetings to develop and improve COMEDA's current knowledge. The new tor d shows the commitment of the group to develop applied research to support integrated fisheries advice and marine management.
Resource requirements	Information from ICES, GFCM, and JRC – STECF WG databases are the main input for this group. No additional resources are identified, although participation of some experts (especially early career scientists) to working group meetings depends on funding availability.
Participants	The Group is normally attended by some 20–25 members and guests. The preliminary list of possible participants is the following: - Romain Frelat (University of Hamburg, Germany) – Chair and expert on Atlantic ecosystems (North Sea and Baltic Sea). - Sofia Henriques (University of Lisbon, MARE, Portugal) – Chair and expert on Atlantic ecosystems, global meta-analysis and functional diversity. - Paris Vasilakopoulos (European Commission - JRC, Italy) – Chair and expert on Mediterranean ecosystems and resilience. - Maria Cristina Magano (distem,, University of Palermo, Italy) – Chair and expert on Mediterranean ecosystems. - Marta Coll (ICM-CSIC, Spain) – Expert on Mediterranean ecosystems and food webs. - Manuel Hidalgo (IEO, Spain) – Expert on Atlantic and Mediterranean ecosystems. - Hilmar Hinz (IMEDEA-CSIC, Spain) – Expert on Atlantic ecosystems and invertebrates´ biodiversity and assemblages. - Christian Möllmann (Univ. Of Hamburg, Germany) – Expert on Atlantic ecosystems. - Evangelos Tzanatos (University of Patras, Greece) – expert on Mediterranean ecosystems. - Bastian Merigot (University of Montpellier, France) – expert on Atlantic and Mediterranean ecosystems. - Francoise Le Loch (IRD, France) – Expert on Atlantic and Mediterranean ecosystems. - Konstantinos Tsagarakis (Greece) – Expert on Mediterranean ecosystems (Aegean Sea).

	- Martin Lindegrem (DYU-AQUA, Denmark) – Expert on Atlantic ecosystems (Baltic Sea). - Rita Vasconcelos (IPMA, MARE, Portugal) – Expert on Atlantic ecosystems, fisheries management and global meta-analysis. - Silvia de Juan (IMEDEA-CSIC, Spain) – Expert on Atlantic ecosystems and invertebrates´ biodiversity and assemblages. - Lucia López (IEO, Spain) – Expert on Mediterranean ecosystems and food webs. - Michele Casini (Swedish University of Agricultural Science, Sweden) – expert on Atlantic ecosystems (Baltic Sea). - Thorsten Bleckner (Stockholm Resilience Center, Stockholm University, Sweden) – expert on Atlantic ecosystems (Baltic Sea). - Henn Ojaveer (University of Tartu, Estonia) – expert on Atlantic ecosystems (Baltic Sea). - Sheila Heymans (SAMS, UK) – expert on Atlantic ecosystems (Western Scotland). - Marian Torres (University of Algarve , Portugal) – expert on Atlantic ecosystems. - Eider Andonegi (AZTI, Spain) – expert on Atlantic ecosystems (Cantabric Sea). - Joachim Claudet (CRIOBE, France) – expert on Pacific and Mediterranean ecosystems. - Heino Fock (Thuenen, Germany) - expert on Atlantic and Arctic ecosystems (Greenland). - Ignacio Catalàn (IMEDEA, Spain) – expert on Atlantic and Mediterranean ecosystems. - Jaime Otero (IIM, CSIC, Spain) – expert on Atlantic and Arctic ecosystems. - Laurène Pécuchet (DTU-AQUA,Denmark) – expert on Atlantic and Mediterranean ecosystems. - Mariano Koen-Alonso (DFO, Canada) – expert on Atlantic ecosystems (West Canada). - Raul Primicerio (University of Tromsø, Norway) – expert on Arctic ecosystems (Barents Sea). - Marcos Llope (IEO, Spain) – expert on Atlantic ecosystems
Secretariat facilities	None
Financial	No financial implications for ICES. To facilitate the participation of early-career scientists, WG chairs will apply to marine research consortiums to find financial support for early-career researchers who need travel funding.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages.
Linkages to other committees or group	There is a very close working relationship with all the groups IEASG, and especially – Working Group on Integrated Assessments of the Baltic Sea (WGIAB) – Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS) – Working Group on SOCIAL indicators (WGSOCIAL) (especially tor d) – Working Group on Maritime Systems (WGMARS) (especially tor d) It is also very relevant to the Working Groups: – Working Group on the Integrated Assessments of the Barents Sea (WGIBAR) – Working Group on Integrated Assessments of the North Sea (WGINOSE) – Working Group on Integrated Ecosystem Assessment for the Central Arctic Ocean (WGICA) – Working Group on the Northwest Atlantic Regional Sea (WGNARS) – Working Group on Biodiversity Science (WGBIODIV) (especially tor b) –

Linkages to other organizations	None