WORKING GROUP ON COMPARATIVE ANALYSES BETWEEN EUROPEAN ATLANTIC AND MEDITERRANEAN MARINE ECOSYSTEMS TO MOVE TOWARDS AN ECOSYSTEM-BASED APPROACH TO FISHERIES (WGCOMEDA)

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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) recently completed its second three-year cycle. WGCOMEDA was established in 2014 and works in cooperation with other groups within the ICES Integrated Ecosystem Assessments Steering Group (IEASG).

The working group objectives are: i) to set the analytical and data framework to develop common Integrated Ecosystem Assessments (IEA) exercises, ii) to advance several ongoing comparative studies on ecosystems stability, and iii) to frame comparative size- and traits-based approaches in both demersal and benthic ecosystems. To fulfil these objectives, the group focused on:

1. **Providing a more complete understanding of the structural and functional role of ecological stability across different types of ecosystems.** The group has made considerable progress on understanding the interplay between stability-diversity-resilience on both demersal and pelagic communities, conducting a resilience assessment to detect recent regime shifts, and examining the role of individual and species size in the stability of communities.
2. **Using functional trait information to assess the structure and functioning of demersal and benthic communities across Mediterranean and Atlantic systems and to predict their vulnerability to fishing disturbance**. Trait-based approaches (TBA) has been one of the most active topics of the group, with several Atlantic-Mediterranean comparative studies, and novel regional studies developing new approaches and methods combining trait information with methods and data beyond scientific surveys. In addition, specific trait-based approaches have been developed in the benthic realm by formulating disturbance and resistance indices on sensitive benthic habitats.
3. **Analyzing the link between ecological stability across different ecosystems types and ecosystem properties (structure and function).** Work on this topic has been initiated and will be one of the main objectives for the next cycle of the working group. This effort will evaluate the complexity of biodiversity patterns and investigate the link between ecosystem structure and stability.
4. **Identifying methods and products to support the implementation of IEA in regional ecosystems.** The group discussed pros and cons of the main IEA methods and conducted an integrated trend analysis of Atlantic and Mediterranean fish communities with the goal to identify the importance of two main global drivers: fishing vs. natural hydroclimatic variability. A user-friendly, open access shiny application and an R library were developed to apply this approach.

WG COMEDA has collected common databases, developed novel tools, revealed common patterns and mechanism between the Atlantic and the Mediterranean as well as identified important differences that need to be consider in the future development of IEAs in contrasting ecosystems. Common gaps of knowledge have been also used to define new ToRs in the next WG COMEDA cycle which include: **i)** improving the assessment of the functional biodiversity, **ii)** better undertand and integrate the complexity of marine biota, **iii)** investigating resilience an mechanisms of change, and **iv)** exploring potential options to integrate ecological and socio-economic dimensions.

ii Expert group information

Expert group name	Working Group on Comparative Analyses between European Atlantic and Mediterranean marine ecosystems to move towards an Ecosystem-based Approach to Fisheries (WGCOMEDA)
Expert group cycle	2
Year cycle started	2017
Reporting year in cycle	3/3
Chair(s)	Manuel Hidalgo, Spain
	Christian Möllmann, Germany
	Hilmar Hinz, Spain
	Marta Coll, Spain
Meeting venue(s) and dates	24–27 April 2017, Lisbon France (18 participants)
	29–31 May 2018, Sète, France (11 participants)
	8–11 April 2019, Esporles, Spain (11 participants)

Scientist attending to the WG COMEDA meeting in 2017 (Lisbon, Portugal), 2018 (Sète, France), and 2019 (Esporles, Spain). Note that in 2017 the meeting was developed back to back with WGIAB (Baltic Sea) and WGBIE (Iberian Waters), and in 2019 with WGIAB.

1 Terms of Reference (ToRs) defined

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Provide a more complete understanding of the structural and functional role of ecological stability across different types of ecosystems.	a) The scientific and applied development of this ToR is sustained by all the outcomes obtained in the previous 3-years of WG, that evidence which are the strategic and needed lines to follow up the research on this topic, and combining information from both seas (Atlantic and Mediterranean). b) The ecological and applied importance of understanding the mechanisms affecting the stability of natural systems for IAF justifies the work and research to be developed in this ToR. c) The ToR will benefit from the attendance of scientists from other WGs from IEASG such as WGIAB or WGEAWESS, and the designed back-to-back meetings with WGIAB and WGEAWESS. This guarantees a good coordination with other WGs of IEASG.	1 and 3	3	Scientific collaborative papers for several scientific questions: 1. The relative influence drivers and structural properties of communities for different type of ecosystems both in both seas (Atlantic and Mediterranean). 2. The relative contribution of different functional groups to the stability of different systems. 3. Mechanisms affecting the non-stationary pattern on stability. 4. Relationship between temporal and spatial stability. 5. Mechanisms affecting ecological stability in the pelagic realm.
b	Use of functional traits information to assess the structure and functioning of demersal and benthic communities across Mediterranean and Atlantic systems; and to predict their vulnerability to fishing disturbance.	a) This topic is directly addressing two main themes of ICES Strategic Science plan i.e. EFD Ecosystem Process and Dynamics and EPI Ecosystem pressures and Impacts. The TOR will provide further insights into the development of indicator that may help with the management of ecosystem goods and services and help to devise management strategies that may help to mitigate human impacts on these. b) The TOR is direcly related to outcomes obtained in the previous 3-years of WG, where the general ideas and work flows have been developed. Based on these previous outcomes the current TOR aims to complete a cross Mediterranean Atlantic comparison	1 and 3	3	1. Database on demersal fish and benthic invertebrate traits for species used within the analyses including where possible real data from a regional scale data e.g. median size, maturity etc. 2. Methodology to assess the resistance/resilience of demersal and benthic communities with respect to their trait composition to fishing. 3. Collaborative scientific papers comparing functional properties of demersal and benthic communities across regional seas and their vulnerability to fishing disturbance.

c	Further develop the analysis of the link between ecological stability across different ecosystems types and ecosystem properties (structure and functioning)	a) The scientific development of this ToR is sustained by the outcomes from the previous 3-years of WG with the aim to follow up in the research on this topic. It will combine information from both seas (Atlantic and Mediterranean). a) This topic is addressing several main themes of ICES Strategic Science plan i.e. EFD Ecosystem Process and Dynamics and EPI Ecosystem pressures and Impacts. The TOR will provide insights into the knowledge needed to understand ecosystem dynamics that could help with guidelines needed for the management of marine resources.	1 and 3	3	1. Database on ecosystem properties of Mediterranean and Atlantic marine ecosystems 2. Methodology to assess the links between ecological stability and ecosystem properties. 3. Collaborative scientific papers comparing ecosystem stability and ecosystem properties across regional seas and their vulnerability to fishing disturbance and environmental factors.

2 Progress towards the completion of each ToR

In this section we synthetize the most relevant work presented and developed during this three years within each ToR and presented in three consecutive meetings from 2017 to 2019.

2.1 Provide a more complete understanding of the structural and functional role of ecological stability across different types of ecosystems (ToR A, lead by Manuel Hidalgo)

Understanding the stability of marine ecosystems has been one of the main topics of research from the beginning of COMEDA in 2014. We investigated the main structural properties and drivers affecting emergent properties (e.g. properties of groups that cannot be entirely explained by their individual components) such as the stability of fish communities. To do that, the first comparative work developed within COMEDA was to develop a portfolio analytical framework to compare five types of systems across Mediterranean and Atlantic demersal communities. The Portfolio Effect (PE) is a measure of the stabilizing effect of the diversity that can be also impacted for other external (anthropogenic and environmental) drivers. PE estimates were estimated in close relation with community synchrony estimates, and both related to external drivers. The results showed that synchrony is affected negatively by the heterogeneity of Primary Production and a Global Indicator of Anthropogenic Impact (Fig. 1), while the PE effect is positively affected by the mean value of Primary Production and negatively affected by the seasonal range of the bottom temperature (Fig. 1). In addition, we investigated the partitioning of these effects for different groups of the ecosystems attending to mean life history traits: somatic growth rate, length at maturity and trophic level.

Outcome: *Hidalgo et al. (in prep). Functional traits shapes the environmental and human impacts on the stability of fish communities*. Outcome entirely associated to WG COMEDA work.

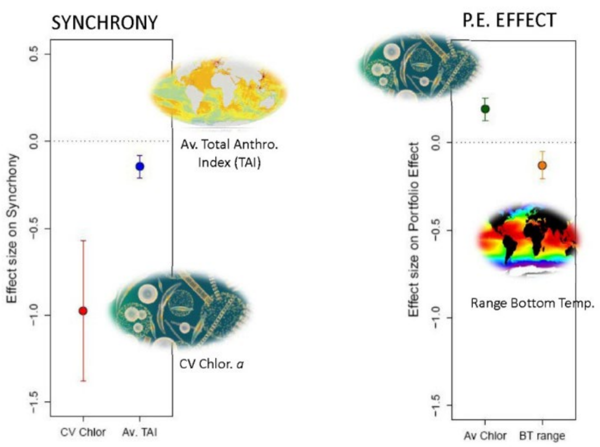

Figure 1. Relative global effects of synchrony (left) and communities' stability (PE effect, right).

The work on this topic continued investigating the interplay between taxonomic and structural (size-based) stability across contrasting European marine systems. Most studies use taxonomic classifications to understand why and under what conditions the community is more stable than the sum of its parts. However, fish populations, for example, are known for their strong ontogenetic-trophic niche shift, suggesting a size-based classification of individuals that complement information on its functional role. A size-based approach to study the Diversity-Stability Relationship was presented in order to understand the influence of the size distribution on the stability of the community. The study is based on a data collection of more than 25 000 fisheries hauls covering most of the European marine ecosystems (Baltic Sea, North Sea, European Atlantic Shelf, and the Mediterranean Sea). After compiling long-term (>20 years) time-series of fish abundances in 23 distinct areas, stability indicators were calculated with both the taxonomic and size classification. The size-based approach presented provides new insights into the dynamics of communities, complementary to the view offered by taxonomic diversity. Particularly, the study shows that size structure contribute to the stability of the community dynamics, especially when few species dominate (Fig. 2). Knowing the importance of size distribution in the stability of fish communities, relevant advice for marine ecosystem based management could be provided. More areas were included for the final analysis of this study.

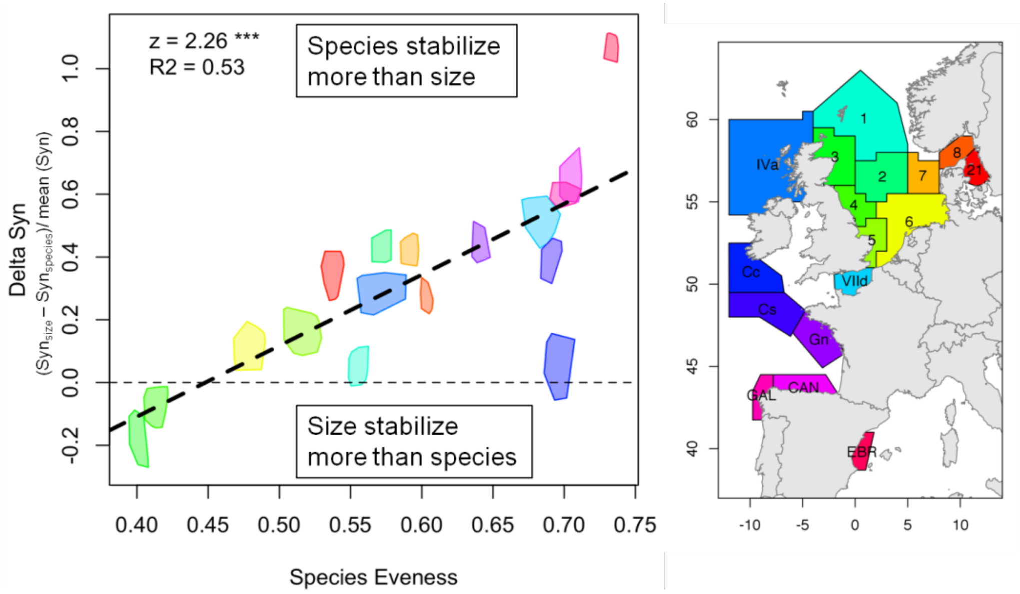

Figure 2. Relationship between species evenness and the contribution of synchrony based on taxonomic information and on size (left). Different colours code with different study areas (right).

<u>Outcome</u>: *Frelat et al. (submitted). Does size matter? Influence of size synchrony on fish community stability using big data across large marine ecosystems*. Outcome entirely associated to WG COMEDA work.

Apart of investigating stability questions on demersal ecosystems, we also challenged similar hypothesis to the pelagic fish communities worldwide. Two metrics of stability (synchrony and portfolio effect) were assessed in 43 stocks of pelagic species worldwide in order to investigate geographical segregation of stability as well as potential drivers. Preliminary analyses on the fluctuations of abundance-at-age for all these stocks show that less synchronous stocks have a higher mean-variance portfolio and a large number of age classes (Figure 6.5). This was predicted the theory but never shown empirically in the context of pelagic fish populations. The preliminary analyses also show that species with a higher von Bertalanffy growth parameter (K) display more synchronous fluctuations. Furthermore, elevated exploitation rates and higher temperatures imply more synchrony within stock fluctuations (Fig. 3). Taken together, internal and external factors seem to have an influence on the stability on community of small pelagic fish in worldwide waters (Fig. 3). For the next WG meeting, analyses will be complemented according to the comments and suggestions received.

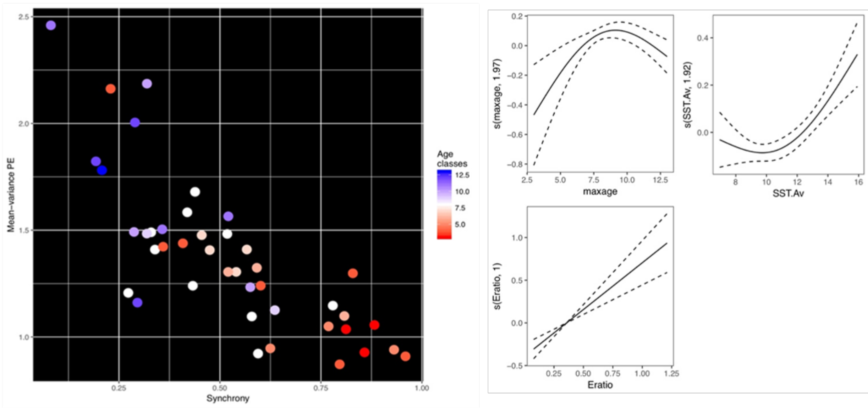

Figure 3. Relationship between mean-variance portfolio and synchrony for 43 stocks of small pelagic species in worldwide waters. Dots are coloured according to maximum assessed age for each stock. (left). Partial effects obtained from fitting a GAM model to the synchrony data as a function of maximum age, average sea sur-face temperature and exploitation rate (right).

<u>Outcome</u>: *Otero, Catalán et al. (in prep). Worldwide assessment of stability in pelagic ecosystems*. Outcome entirely associated to WG COMEDA work.

Taking advantage of Integrated Resilience Assessment (IRA) framework, developed by Paris Vasilakopoulos and applied to Barents Sea cod (Vasilakopoulos and Marshall 2015) and Mediterranean catches from FAO (Vasilakopoulos et al 2017), we have applied this method at a community level. The theory of critical transitions suggests that complex natural systems undergoing regime shifts may feature folded stability landscapes with fluctuating resilience, fold bifurcations, and alternate basins of attraction (Scheffer, 2009). However, the implementation of such features to elucidate response mechanisms in an empirical context is scarce, due to the lack of generic approaches to quantify resilience dynamics of individual systems. For this, the IRA framework was introduced: a three-step analytical process to assess resilience dynamics and construct stability landscapes of empirical complex systems. This framework involves a multivariate analysis to estimate holistic system indicator variables, non-additive modelling to estimate alternate attractors, and a quantitative resilience assessment to scale stability landscapes. We have applied this framework on empirical community complex systems in both Mediterranean and NE Atlantic ecosystems. In the Mediterranean, we are exploring recent shifts in different Western Mediterranean: Alboran Sea (GSA 1) and Spanish mainland coast (GSA 6). In the Atlantic, we have explored shifts in the Baltic and North Seas. Our preliminary results from the Mediterranean show that recent shifts observed are associated with changes in the winter climate conditions (Figure 4).

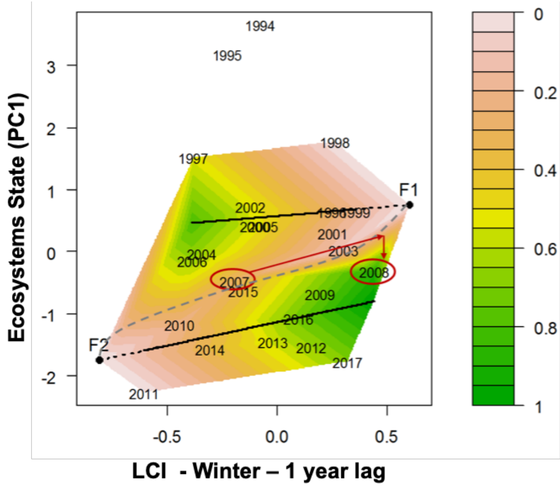

Figure 4. The folded stability landscape of the Mediterranean Iberian Peninsula (GSA 6) in 1994–2014. The x-axis is the first PC of a Local Climatic Index (LCI) calculated with winter stressors and the y-axis is the first PC of a PCA carried out on community species. Continuous black lines indicate the linear attractors, dotted black lines indicates the possible extensions of the branches, dashed grey line indicates the approximate position of the basins' border and F1, F2 indicate the tipping points. Colours represent the relative resilience contour interpolated from the relative resilience of each year. Circles and arrows indicate the 2007-2008 regime shift. Resilience was not estimated for years 1994-1995 which appear to be part of an older regime.

Outcome: *Hidalgo, Vasilakopoulos et al. (in prep) Winners and losers in recent regime shits in Western Mediterranean induced by changes in the winter hydroclimate*. Outcome entirely associated to WG COMEDA work.

In addition, after obtaining some preliminary evidence of changes in the community structure and spatial patterns of stability in the Galicia-Cantabric Sea in the Atlantic (Figure 5, WG COMEDA 2018), the IRA approach will be applied to this system to investigate causes and consequences of the observed shift in 1997–1998 (Fig. 5). These results implied that in the first period the community was more unstable, most likely due to the high impact of fishing at that time, which is consistent with species-specific estimates (Modica *et al.*, 2014). However, from 1998 onwards, the community shifted to a more stable state with larger de-correlation scale, likely due to the decrease of the fishing impact that led to increase the abundance of larger fish (Modica *et al.*, 2014, Hidalgo *et al.*, 2017). Also, there was an increase of spatial occurrence of several species and of diversity towards the last decades (Punzón *et al.*, 2016).

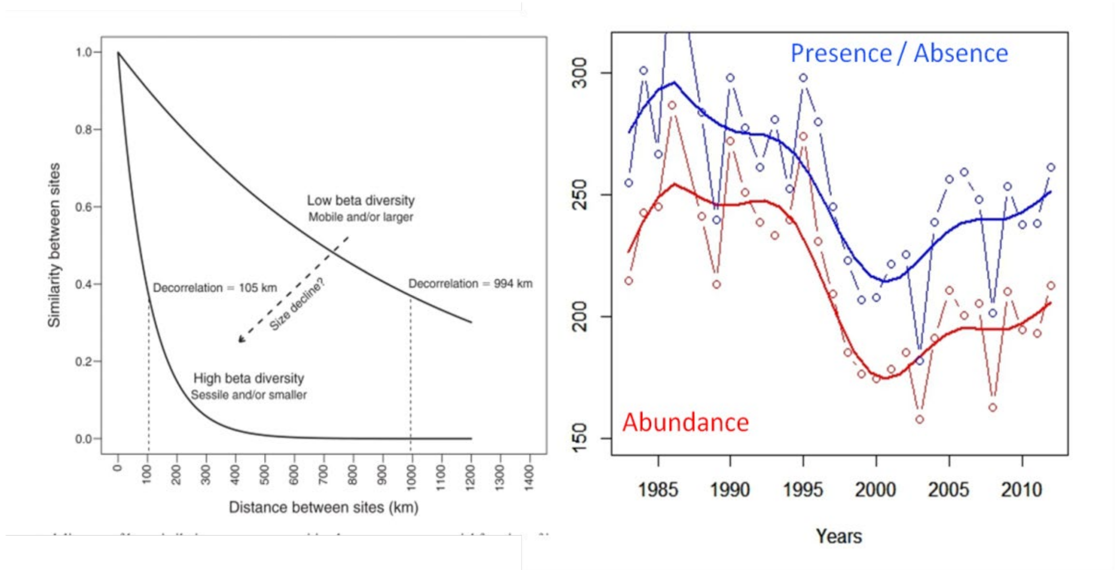

Fig. 5. Schematic representation of the de-correlation scale calculated based on the relation-ship between similarity matrix and the geographic distance between sampling stations (left, from Shackell et al. (2014). Temporal pattern of the de-correlation scale for the Galician-Cantabric Sea using abundance and presence/absence data (right).

Outcome: *Polo, Punzón et al. (in prep.) Causes and consequences of a structural and functional regime shift in the Iberian coast*. Outcome entirely associated to WG COMEDA work.

2.2 Use of functional traits information to assess the structure and functioning of demersal and benthic communities across Mediterranean and Atlantic systems; and to predict their vulnerability to fishing disturbance (ToR B)

1.2.1. Traits-based approaches in contrasting Mediterranean ecosystems (Lead by Vangelis Tzanatos).

Within the framework of the Ecosystem Approach to Fisheries, the project 'Biological traits analysis of fisheries resources: From populations to the Ecosystem Approach to Fisheries Management' (BATFISH) aims to evaluate fish community assembly and dynamics and how it may affect ecosystem functioning using biological traits (Figure 6), and has been strongly connected to the work developed in WG COMEDA. In this context and based on an already assembled dataset of 23 traits for 205 species, WGCOMEDA work will attempt to answer two questions: (a) What is the quantitative distribution of traits in different habitat types and across environmental variables and (b) Whether a temporal change in traits composition has occurred and (if yes) to determine if it followed a continuous or a discontinuous pattern. Combining traits-based approaches and Integrated Resilience Assessment (see above Section 6.1.2) will allow the identification of traits distribution patterns in space and the determination of taxonomic and/or functional changes in time providing insights to comprehend fish community resilience (structural, functional) using empirical data. Adopting this approach in analyses of data from multiple areas can allow comparative works between European Atlantic and Mediterranean marine ecosystems as framed within WGCOMEDA.

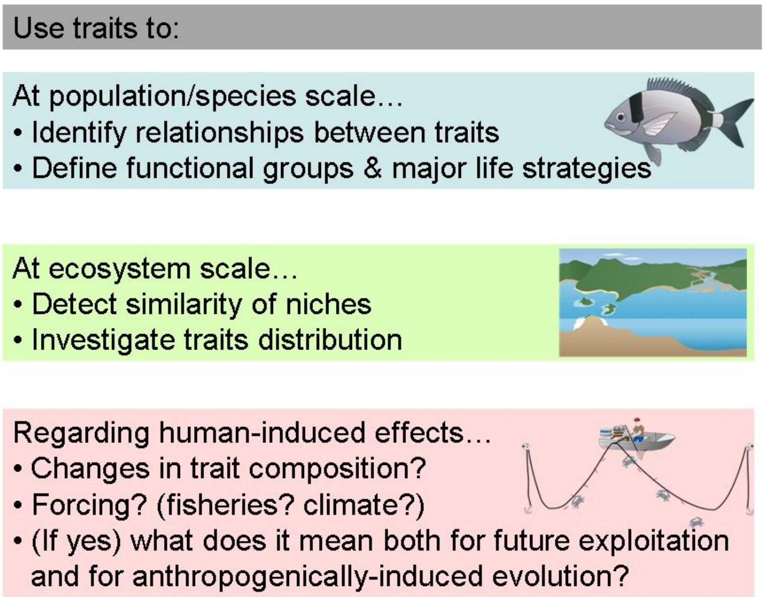

Figure 6. General framework for the already performed and future traits-based analyses within the BATFISH project. Within the Ecosystem Approach to Fisheries traits will be used across three scales (population, ecosystem, landscape/human-induced) to provide a functional aspect of the ecology of fisheries resources.

Part of this work focus on analysing of population traits can provide insights of how life-history strategies will improve the management under an integrated approach. Within the framework of the project 'Biological traits analysis of fisheries resources: From populations to the Ecosystem Approach to Fisheries Management' (BATFISH) mentioned above the present study aims at detecting relationships between fisheries resources traits and life-history patterns. Regarding traits relationships, correlation and non-linear/linear regressions were used to detect continuous traits relationships. Patterns between continuous and categorical traits were examined with ANOVA/t-test (or their non-parametric equivalents), while trait category co-occurrence was employed to detect relationships among categorical traits. For all relationships mentioned above, the effects of anthropogenic stressors (e.g. fisheries, climate change) on the trait composition of fish communities were explored. Life histories were examined with Archetypal Analysis and Multiple Correspondence Analysis (MCA), indicating in both cases three main life histories (Figure 7). Decision Tree analysis described species niches by the creation of terminal nodes (niches), occupied or vacant, combining hierarchically, using four niche descriptors (distribution, ecology, biology, and behaviour) gave an insight into the shaping of ecological niches in the fish community and provided empty (unoccupied niches). Specifically, it used four niche descriptors (distribution, ecology, biology, and behaviour), combining them in a hierarchical fashion, and determined species niches with species appearing in terminal nodes of descriptor combinations. Apart from showing species in their (occupied) niche, it also indicated vacant niches. Together with the results of MCA, they helped identify species occupying similar niches, giving important information for management like the absence of potential competitors for lessepsian species or competitors for species occurring in important habitats.

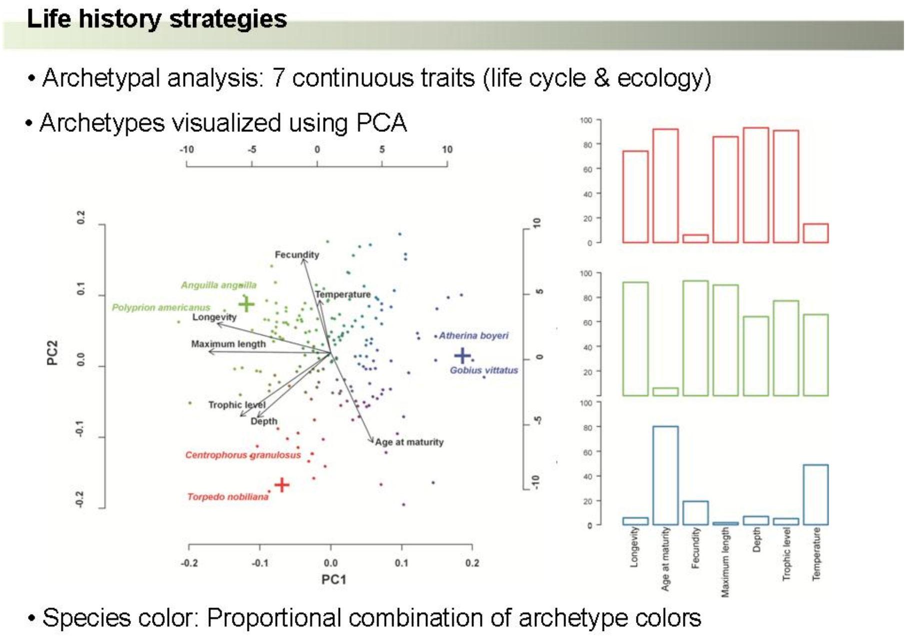

Figure 7. General framework for the already performed and future traits-based analyses within the BATFISH project. Within the Ecosystem Approach to Fisheries traits will be used across three scales (population, ecosystem, landscape/human-induced) to provide a functional aspect of the ecology of fisheries resources.

Outcome: *Martha Koutsidi, Catherine Moukas, Evangelos Tzanatos (in preparation): Trait-based ecological niches and potential inter-specific competition in Mediterranean nekton.* Outcome associated to WG COMEDA research topics.

Previous works have already documented discontinuous changes-regime shifts in the quantities landed both at the level of individual taxa (Tzanatos et al. 2014) and at the community level (Vasilakopoulos et al. 2017). It is important to investigate whether these changes appear also regarding biological traits since, in the case that the traits composition remains stable, species with similar characteristics are interchanged in fish catches, while in the opposite case fisheries could be causing changes in the distribution and abundance of traits in the ecosystem. This may alter the flow of energy possibly altering ecosystem functioning. In this context, a biological traits analysis of the Mediterranean FAO landings of 101 species for the years 1985-2015 created a traits composition dataset. The dynamics of the individual traits were investigated indicating changes in traits' relative abundance (e.g. Figure 8). Furthermore, an Integrated Resilience Assessment (Vasilakopoulos et al. 2017) using combinations of traits indicated that indeed there has been a discontinuous shift in the mid-90's: From higher abundances of species of higher longevity, winter spawning, low optimal temperature and high fecundity landed previous to the shift, there has been a transition to species of lower longevity, summer spawning, high optimal temperature and lower fecundity. These changes were linked to increasing sea temperature (SST) and have significant implications regarding the effects of fisheries and climate change on fish stocks.

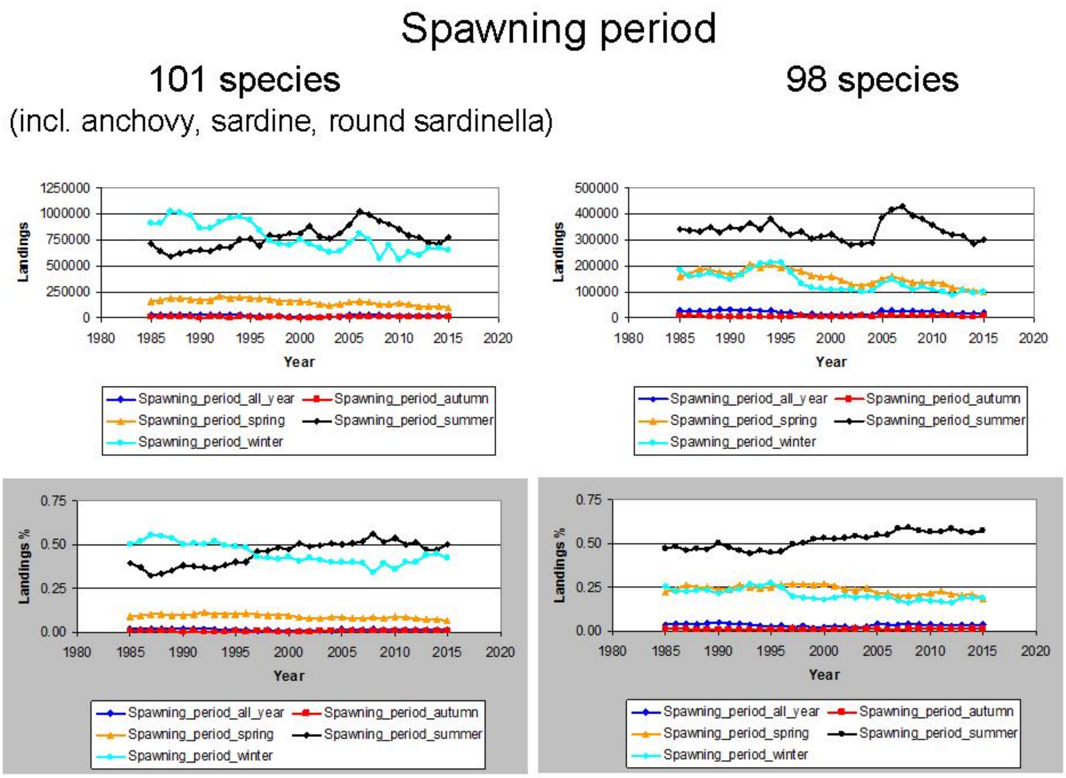

Figure 8. Top: Landings biomass fluctuations assigned to the categories of the spawning period biological trait including all species (left) and excluding small pelagic species that have high fluctuations: anchovy, sardine and round sardinella (right). Bottom: Percent fluctuations of the trait categories of these datasets.

Outcome: *Eleni Tsimara, Paraskevas Vasilakopoulos, Martha Koutsidi, Dionysios E. Raitsos, Evangelos Tzanatos (under preparation). Traits-based analysis of Mediterranean FAO landings over the last 30 years*. Outcome associated to WG COMEDA research topics.

Finally, the mass-balance-trophic-model Ecopath and its extension Ecopath with Ecosim is very popular for modelling marine ecosystems (Pauly et al. 2000, Coll et al. 2008). A model of the marine ecosystem of the North Aegean Sea (eastern Mediterranean) was created, incorporating the use of biological traits in (a) building the model, where biological traits data were used for the definition of fish functional groups (the final model built in Ecopath is presented in Figure 6.12) and (b) and explaining the model as results were not only analyzed in the functional groups level but also regarding the composition of the resulting biological traits. Six different fisheries management scenario of fishing effort changes for the period 2018-2033 were simulated with Ecosim. The simulations indicated a reduction of pelagic species and biological traits and a concurrent increase in the biomass of deep-living species and of relevant traits. Significant findings pertain to the decrease of thermophilic traits like high optimal temperature and summer spawning in all management scenario simulated; these could mitigate the opposite trend expected to be favoured by climate change. Also, a decrease of characteristics associated with the r-life strategy was observed, possibly resulting in less resilient future fish communities. In addition, the negative trends of the biological traits that are anyway rare (e.g. low trophic level and small lifespan) may impact ecosystem functioning. The approach used here could be adopted to model other marine communities (possibly also using traits for other ecosystem components) to provide interesting insights regarding anthropogenic effects on marine ecosystem functioning.

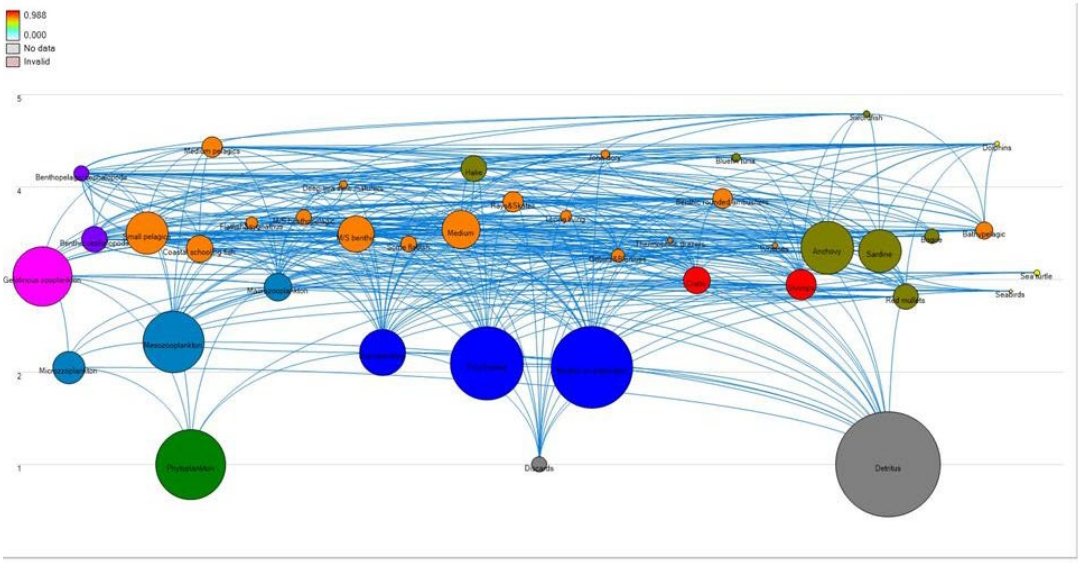

Figure 9. An overview of the Ecopath model created.

<u>Outcome</u>: *George Papapanagiotou, Konstantinos Tsagarakis, Martha Koutsidi, Evangelos Tzanatos (submitted). A trait-based approach to an ecosystem model. Journal of Marine Systems*. Outcome associated to WG COMEDA research topics.

1.2.2. Use of functional traits information to assess the structure and functioning of demersal and benthic communities across Mediterranean and Atlantic systems; and to predict their vulnerability to fishing disturbance (Lead by Hilmar Hinz).

Resistance and resilience index of benthic communities. Traits based studies often investigate the effect of anthropogenic stressors on individual traits weighted by abundance or biomass aiming to identify individual traits that respond to a stressor. By dissembling species and pooling traits information in this way there is the danger of introducing considerable noise into the traits-based analysis. The responds of a species to a stressor does often not depend on one single traits but on a combination of traits some of which may be related in opposing direction to the stressor. Taking fishing disturbance as an example, generally species living on the surface of the seabed are highly likely to be affected, however if these species at the same time have a highly resistant shell they may survive trawling impacts. If "living position – surface" is now used as a single explanatory trait, the species will contribute little towards an effect. If we have several species with a similar traits combination, it could be concluded that trawling had little or no effect on organisms that inhabit the seabed surface. While this may be true for the particular area analysed due its species composition other areas may show different responses. Thus, analysing the responses of single traits has the potential to introduce bias and lead to spurious conclusions about the impact of stressor on any singular trait. Furthermore, due to these confounding traits, the conclusions drawn from these types of studies cannot easily be generalized to other areas with different species compositions and thus the predictive power of results is limited and at large specific to only the respective study area.

To overcome some of the shortcomings of the traits-based approach it has been suggested to use more directed subsets of traits that are *a priori* logically linked to a stressor or an ecological function instead of using all or a single trait. Within a paper presently in perpetration paper, we introduce a traits-based approach to investigate the effects of trawling on ecosystem function through a more directed set of trait combinations. Based on the observations that the vulnerability of a species to trawling is not random but related to the habitus and the behaviour of a species we developed a physical "Resistance index" for benthic species using traits related to this aspect. Furthermore, we developed a "Resilience (Recovery) Potential index" considering traits related to the reproductive strategies and growth. These two indices were subsequently combined into an overarching vulnerability ranking index that we named Resistance and Resilience index or RRI (Resilience – within this paper is used as a synonym for the potential to recover after trawling impact). This index can subsequently serve to group species into different vulnerably categories and the responses of these to trawling can be investigated (see Figure 10). Furthermore, the RRI opens up the possibility of community stress tests or simulation scenarios that link vulnerability directly to ecosystem function indices. Within this paper, we explore both the idea of stress scenario modelling and the use of RRI as a descriptive index using data from two fishing grounds, one located in the Irish Sea (Atlantic) and the other in the Catalan Sea (Mediterranean) as case studies.

The concept and approach of this new method has been presented at the World Conference on Marine Biodiversity in May 2018, Montreal (Canada). Furthermore, the work was presented to the ICES working group FBIT (Fisheries Benthic Impact and Trade-offs) during their first meeting and was of evident interest to this working group. The work is now in a prepublication stage and will hopefully be submitted for publication in autumn 2019. The indices developed will subsequently be adopted for other regional seas for an interregional comparison.

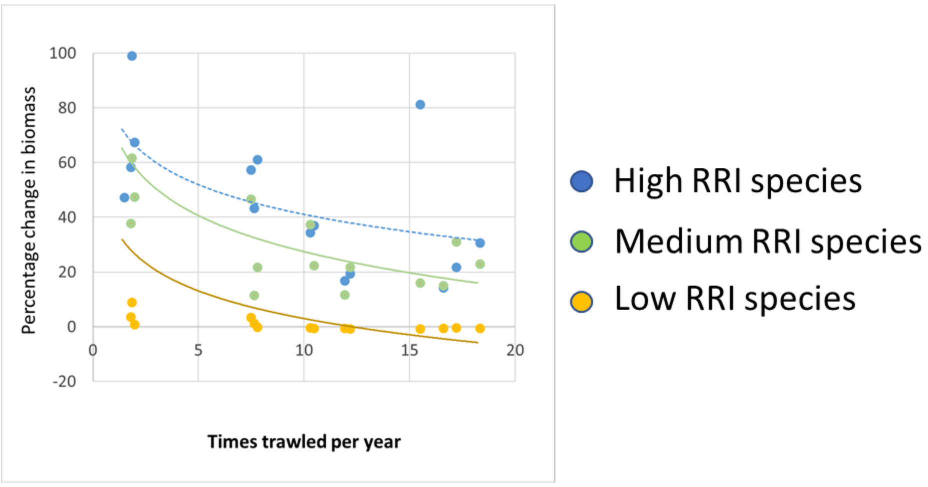

Figure 10. Percentage change in biomass with increasing trawling intensity of species pooled within different RRI index groups (Benthic data from the Irish Sea). Organisms with a low RRI index are the most vulnerable tor trawling as they have low resistance and reproductive potential.

Outcome: *Hilmar Hinz, Anna Törnross and Silvia de Juan: Linking benthic resistance and recovery potential to ecosystem functions: An ecological traits-based approach (under preparation). Resistance and resilience index of benthic communities*. Outcome associated to WG COMEDA research topic.

Traits-based approaches in marine ecology: Dead ends and new paths. Due to the intense discussion about the traits-based approach members of the working group are now engaged in writing a critical review of this approach as a comment paper to highlight its strength but also its weaknesses. Furthermore, this work is aimed at providing new solutions and ideas to increase its scope beyond its current limitations.

There is an increasing amount of scientific studies using the trait-based approach attempting to investigate A) the ecological functional composition of marine communities in response to external stressors such as eutrophication, non-indigenous species invasions, fishing impacts and climate change, and B) the links between diversity and ecosystem functioning. Essentially there are two different “types” of trait-based approaches i) the BTA-type and ii) the more "mechanistic trait approach” with a firm focus on fitness linked to reproduction, survival and feeding (e.g. Litchman et al. 2013, Verberk et al. 2013). For the paper, we will introduce both approaches but mainly focus on BTA. Some of the issues we point out here concerns both types of approaches (1 and 4), but some (2 and 3) concerns specifically the BTA, which is the one that has been applied generally to fish and benthos. The BTA approach is attractive as it is easily applied to past and present datasets. In the early 2000, it became a popular approach in marine studies as, it allowed assessing community patterns, beyond species composition, which evidenced changes caused by external stressors (response traits) often difficult to assess with traditional metrics like density and diversity. Also, these approaches allowed inter-regional comparisons. More recently, emphasis has been on the link between biological traits (effect traits) and ecosystem functions, and lately on the provision of ecosystem services, as a way to advance on the implications of community structure for the wider ecosystem (including humans). Furthermore, including this functional aspect of communities facilitates the understanding of complex (ecosystem responses and patterns?) by non-experts when presenting results. Nevertheless, there are several problems with this approach which we would like to highlight within this paper. These will need to be addressed by the scientific community if we want to further the adoption of this approach and advance the field of functional ecology of marine communities.

We have summarized the main critical points that we would like to cover with this paper in four bullet points. We envision a manuscript structure where we first intend to present the importance of this approach, i.e. why it is needed, highlighting its strength and its wide application. After that we would like to show the current state and describe the current critical issues related to the approach (listed below).

i) Dilemma of expert knowledge and the lack of standardized reporting

Due to the lack of a central database and standardized protocols for the use of traits data (from data collection to integration) most studies are not strictly comparable, and results may be difficult to reproduce. To attempt any type of analysis many studies relay on expert classifications due to lack of data on traits for specific species or the difficult of attaining them from the literature. Thus, most traits analyses have an inherent element of bias depending on the judgement of the researcher. Often the source of the information on traits is not being provided on a species level and the reader is not able to distinguish which information has been added as expert opinion and which information is based on data resulting from scientific studies. Our solution and argument must be that there is a need for a centralized database, which is actively managed by the scientific community. Furthermore, we need to standardize the way of reporting on traits and the source of the information (guidelines for data collection and reporting). What is expert opinion needs to be clearly identifiable, similarly the foundation of this expert opinion (e.g. traits allocated based on similar species, trait allocated based on morphological characteristics, traits allocated due to observer’s experience). Providing this information enables sensitivity assessments of the trait data, i.e. analysis of the effect of expert opinion/lack of data (this could also be formally tested within a subsection of the manuscript). Within this section, we will point out that there have been useful efforts to create such databases (e.g. EMODNET, BIOTIC, FISHBASE etc and the indices papers, e.g. Degen et al.2018) nevertheless the issues raised here are still unresolved! Past projects could form the foundation of a new international efforts to collate existing data in a standardized way.

ii) Functional diversity indices - fishing for function

Functional diversity indexes have become popular, however, these are often difficult to interpret and reproduce. The outcome of the indices depends on the traits included in the analysis and our allocation of traits to species per say (see above point). Through this we introduce a variability to the index which make it difficult to compare across studies. While within study comparisons are possible, the essence of a diversity index to easily compare it across various scales and regions, is being lost. Comparisons across studies are furthermore complicated as the index is based on multivariate statics which would require the exact replication of traits to be used to be comparable between studies. It is thus not universally applicable like traditional biodiversity indices. The naming of this index as "functional diversity" is also viewed critically. We assume that trait diversity is equal to functional diversity. However, this may in most cases not be true, as not all traits may code for functions. It is often a specific combination of traits that code for functions and therefore having many traits does not necessarily reflect functional diversity. There may be many traits that are unrelated to functions but still contribute to traits diversity. Furthermore, there is an additional point with respect to functional diversity that need raising. These indexes do not provide a comparable measure with respect to functionality that is present within a community. The presence of a trait alone does not necessarily code for the presence of "ecosystem function". For example the presence of a burrowing bivalve on its own its not enough to verify that bioturbation function is present. Also, studies indifferently work with abundance or biomass indices; are these really equivalent? For example, habitat provision, might it be better to have a few large habitat structuring species, than numerous small individuals (while bioturbation might be otherwise). There might be a need to establish thresholds of presence of traits related with functions (probably only achieved through experiments) to develop better functional diversity indexes. Due to these shortfalls of past indices we propose the development of new indices of clearly defined functions based on trait combinations. From these at a later point we could develop a functional diversity index that truly reflects its name. Examples are the bioturbation or irrigation indices or our habitat provisioning index as single functional indices. We also suggest a name change form functional diversity to traits diversity.

iii) Investigating the effect of anthropogenic stressors on individual traits and why loosing species identity may be the wrong idea

Traits based studies often investigate the effect of anthropogenic stressors on individual traits weighted by abundance or biomass aiming to identify individual traits that respond to a stressor. By dissembling species and pooling traits information in this way there is the danger of introducing considerable noise into the traits-based analysis. The responds of a species to a stressor does often not depend on one single traits but on a combination of traits, some of which may be related in opposing direction to the stressor. Taking fishing disturbance as an example, generally species living on the surface of the seabed are highly likely to be impacted, however if these species at the same time have a highly resistant shell they may survive trawling impacts. If "living position – surface" is now used as a single explanatory trait the species will contribute little towards an effect. If we have several species with a similar traits combination it could be conclude that trawling had little or no effect on organisms that inhabit the seabed surface. While this may be true for the particular area analysed due its species composition other areas may show different responses (see for conceptual idea Figure 11). Thus, analysing the responses of single traits has the potential to introduce bias and lead to spurious conclusions about the impact of stressor on a single trait. Furthermore, due to these confounding traits the conclusions drawn from these types of studies cannot easily be generalized to other areas with different species compositions and thus the predictive power of results is limited and at large specific to only the respective study area. In this context, there is also a need to work with standardised functional groups, in relation with specific stressors, to minimise subjectivity in the definition of set of traits. There are, however, also example studies that have adopted a different approach based on functional groups or organisms' types that are a combination of biological traits with an expected response direction to a stressor (the existing examples will be given here). But there is also a lack of consistency across studies and the selection of traits that form a group is rather subjective (could also provide a fig/table comparing functional groups across studies).

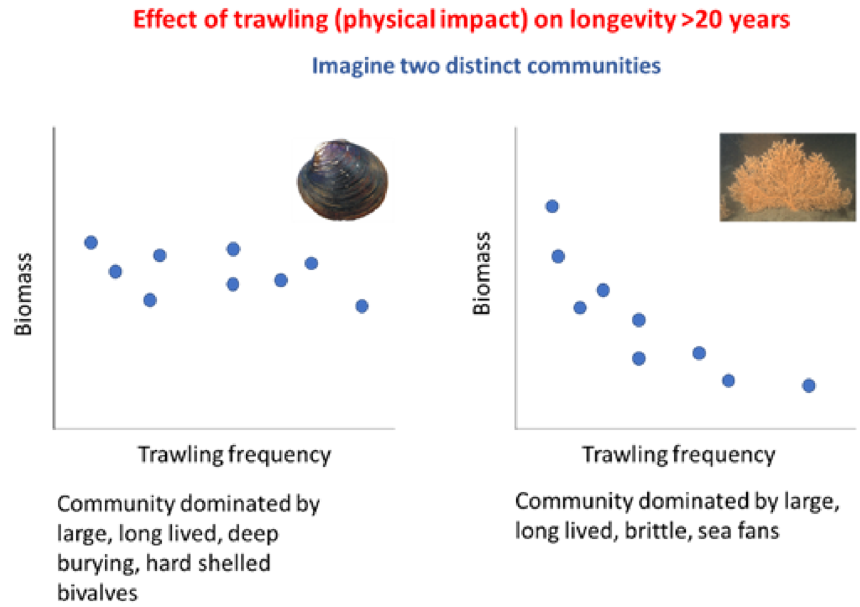

Figure 11. Impact of fishing on a single trait may vary depending on the traits characteristics of the dominant species. The conclusions drawn from pooled weighted traits data need to be viewed with this limitation in mind (source: H. Hinz, *Pers. Comm.*).

Moving from trait categories to continuous variables- time to rethink the importance of baseline observational studies: Besides the acute lack of data on specific traits for species as highlighted in point 1 we also need to move forward from dividing traits into categories or modalities to measurements of continuous parameters. Traits categories often have wide arbitrary levels that are reflecting our lack of knowledge over the precise nature or behaviour of a species. Movement is a simple example. Often, we classify mobility in large categories such as sessile or mobile. However, mobility is a trait that, with respect to for example benthic infauna, is related to function i.e. bioturbation. Thus, the speed of movement is essential to estimate the contribution of a species to this function. Considering animals of a similar size and habitus we can assume that very slow-moving animals may contribute less to this function compared to fast moving animals. To be able to model the contribution of a species to a specific function knowing the precise values of a parameter would increase the capabilities of modelling specific ecosystem functions. There is an acute lack of such data not only for rare but also for common species. While for some common species data on the mean traits may be available, we have little knowledge of the variance of trait modalities which is highly relevant for some functions or stressors. Similarly, traits modalities may change during the life history of a species. Currently most BTA use average adult size organism as the reference organism which may introduce bias and hide the true variability within a dataset. The collection of this type of data would mean a return to baseline observational studies for which there are currently limited funding opportunities. However, if we want to move this approach forward exactly this type of data will be needed. While collecting this data for entire communities would be an enormous task a start may be to focus on the common dominant species which commonly also hold a great part of the functionality of a community. Against the backdrop of new technologies that have become available using small sensors that can detect movement patterns, animal electronic tagging and the use of small inexpensive cameras we now have the tools to collect this type of data in an efficient precise and cost-effective way. Here we would like to give examples of the various technologies available to monitor specific functions i.e. a type of toolkit review.

Finally, as a concluding remark we want to highlight that we are only at the beginning of the traits-based approach. However, we need to come out of some dead ends and walk on new paths (or maybe better said revisiting old ones – return to baseline ecology). These ideas will need support by funders, requiring a rethink about their disposition towards baseline observational studies. We all want to be able to model the marine environment and the importance of models cannot be overstated, however, to have good models we need good baseline data on traits. Thus, to move the traits base approach forward we do need to reengage with the collection of baseline data within the context of a traits-based approach making use of new technologies.

Outcome: *Hilmar Hinz, Anna Törnroos, Maria Cristina Mangano, Julie Bremner, Simon Thrush, Joana R. Xavier, Judi Hewitt, Silvia de Juan (under preparation). Traits-based approaches in marine ecology: Dead ends and new paths.* Outcome associated to WG COMEDA research topics.

Benthic community functional reference points. The need of functional reference points was discussed during the meeting. Currently impacts and recovery trajectories from fishing disturbances are measured using abundance and biomass as an indicator. Compositional changes in species are often reported but rarely are the linked functional changes investigated. Recent research has shown that recovery times in already disturbed areas are much faster compared to disturbances in relatively pristine sites. This indicates that species composition does not necessarily return to their original states but may stabilize with respect to abundance and biomass in an alternative state. This state of recovered abundance or biomass may however be functionally very different to the undisturbed bassline state e.g. the bioturbation potential may not have recovered while overall abundance and biomass have (see Figure 12).

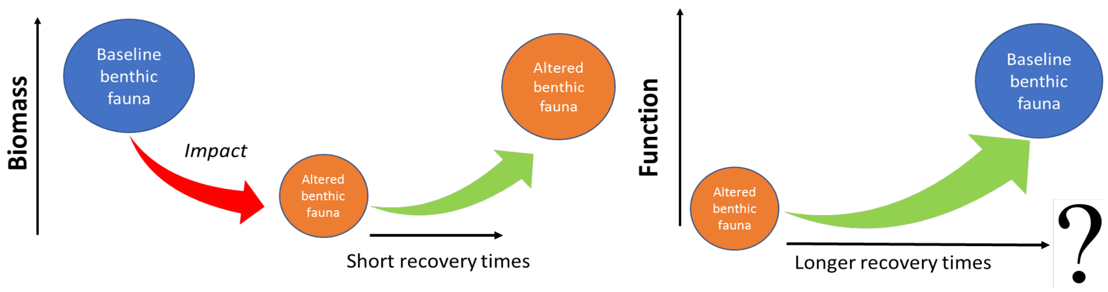

Figure 12. Benthic recovery from fishing impacts considering biomass may be relatively short. However mostly community composition and thus functions will have been altered. The recovery of functions towards some pristine reference point may take considerably longer (source: H. Hinz, *Pers. Comm.*).

To date there are no studies that focuses on finding community functional reference point. We currently do not have a good understanding of how low or undisturbed communities are structured and if there are communalities in their functional structure between different locations and habitats. For example, are there more or less constant ratios between predators, scavengers, filter feeders and deposit feeders in undisturbed areas representing baseline communities. Also, we do not yet have a clear understanding of how much functionality we would expect as a baseline for different types of habitats. One objective of this research lines would be to study these functional reference points of benthic communities. This research would use both existing data as well as collect new benthic data to establish baseline functional indices. For the estimation of functionality, the biological traits-based approach would be used that is currently widely adopted in benthic ecology. In northern Europe various studies exist that are sufficiently detailed to allow for the suggested analysis. As a first step, existing meta-databases on experimental fishing impacts can be used to investigate how much functionality has been regained after abundance and biomass levels have recovered. Furthermore, it is planned to collect new data especially for the Mediterranean on trawling impacts and functional reference points sampling low or non-impacted areas comparing them intensively trawled fishing grounds. To date the data density and understanding of benthic systems in the Mediterranean is still low compared to northern Europe.

Outcome: *Hinz et al. (under preparation). Benthic community functional reference points.* Outcome associated to WG COMEDA research topics.

New benthic surveys and fishing impacts studies in the Mediterranean. The need for a review paper on fishing impacts was discussed by the group and it was decided that a systematic review of the subject would be needed to highlight the need for Mediterranean countries to engage with fishing impact studies.

While in northern Europe large scale benthic surveys e.g. 33 and fishing impact studies have led to the capabilities to model fishing impacts and its consequences at sea scales in-cooperating different habitat and environmental conditions these capabilities do not to date exist in the Mediterranean out of two distinct reasons A) One is the lack of large-scale benthic datasets to describing the relationship between environmental drivers and benthic communities B) a lack of studies of fishing impacts on different habitats and depth strata. There is an acute lack of both fishing experiments and gradient studies in the Mediterranean. In total there are approx. studies with a limited spatial scope. Represent observational studies without a strict experimental design. While some aspects of fishing impacts studies can be easily adapted from Northern European studies e.g. the relative impact of different gears and penetration depth ideas etc. other aspects will need their own appropriate studies with respect to the very different environmental conditions and species compositions that exist in the Mediterranean. The Mediterranean is very distinct form the productive shelf sea environments shelfs where fishing impacts have generally been studied. The Mediterranean faunal communities are likely to response distinct to fishing impacts compared to northern European studies due to the oligotrophic environment and the steep depth gradient that exists on many fishing grounds with their very distinct faunal communities. Due to the oligotrophic nature and lower densities of fauna recovery times may be considerably longer in the Mediterranean compared to northern European shelf seas thus limiting the applicability of model outputs from northern Europe. Thus, a line of research that was suggested is to a) increase general benthic surveys to investigate which environmental relationships b) increase gradient and experimental fishing impacts studies. Both of these initiatives need to be integrated into international coordinated efforts to keep down costs and to standardize the approaches of these studies. Only through joint coordination will Mediterranean researchers capture EU funding and deliver solutions that are applicable over larger spatial scales. We therefore suggest the founding of a benthic working group focused on an ecosystem approach to fisheries management for the Mediterranean associated to both ICES, CIESM and GCFM. The working group COMEDA will aim to spearhead the creation of such a group with individual researchers dedicated to this field of research. Fishing impact studies could be financed besides large national and international programs also through the bid for ship time through the EUROFLEET and ASSEMBLE calls of the EU by this group. The group will aim to push for this type of work with a close link to WG-FBIT.

2.3 Develop the analysis of the link between ecological stability across different ecosystems types and ecosystem properties (structure and functioning) (ToR C).

Although this ToR has been initiated, no output has been produced during this cycle. It will be indeed one of the main objectives for the next cycle of the WG (see section '3. Degree of success and future of the WG'), considering important research topics such as describing the complexity of biodiversity patterns, investigating the link between ecosystem, structure and stability. Particularly, ongoing work is being leaded by Lucía López-Lópe on the **structural stability and functional sensitivity as the basis to assess ecosystems vulnerability to cumulative stressors.** As a follow-up from previous work from the COMEDA working group on fish functional attributes and ecosystem sensitivity, we propose an approach to evaluate ecosystem vulnerability under the impact of anthropogenic stressors (i.e. fishing and climate change) aiming to disentangle the effect of both impacts. We are carrying out this study simultaneously in two temperate ecosystems, the Cantabrian Sea in the Southern Bay of Biscay and the Iberian Shelf Sea in the North-Western Mediterranean.

To this aim, we identified a set of biological and ecological attributes (Table 1) of the species which have been related with fishing, with environmental change or with both. These attributes are being scaled according to a degree of sensitivity which allows computing a vulnerability indicator for the community, which weighted by the community composition can be used to explore spatial changes in ecosystem vulnerability. The spatial modelling of the vulnerability indicator and its dependency on fishing effort and warming will define to which extent community vulnerability depends on each impact and allow to identify the possible synergies among them. In addition, our comparative approach between Atlantic and Mediterranean ecosystems will be useful to study how subtle differences in the ecological, fishing and management context translate into different vulnerabilities to anthropogenic impacts and require distinct adaptation measurements.

Climate Change		BOTH		Fishing	
Environmental niche	Spatial distribution	Life-history	Trophic networks	Morphology	Habitat
Mean temperature Temp range Mean salinity Salinity range	Area occuppied Latitudinal range	Edad max. Talla max. Size at maturity (Lm) Max fecundity. Growth rate (K) Egg size Spawning period Larval phase duration Parental care	Trophic level Generality Vulnerability Clustering coefficient Connectivity	Fragility/Flexibility/ Morphometry	Vertical position (ref. bottom) Mobility Trophic guild

Table 1. Biological and ecological attributes potentially sensitive to fishing, climate change or both impacts.

2.4 Use of functional traits information to assess the structure and functioning of demersal and benthic communities across Mediterranean and Atlantic systems; and to predict their vulnerability to fishing disturbance (ToR D)

In this second WG COMEDA cycle, we have specifically focussed on fostering the transfer of knowledge between fundamental and applied research. ToR D has particularly focussed and succeed on that. To do that two main activities have been accomplished. First, **common Integrated ecosystem assessments (IEA) exercises in regional systems of the Atlantic Ocean and the Mediterranean Sea.** (IEA) aim to understand the dynamics of a wide range of ecosystem components in order to inform decisions for ecosystem-based management. At present, a number of methods for IEA exist or are being developed in parallel. Amongst these approaches integrated trend analyses (ITA) are commonly applied to summarize changes that have occurred in recent decades in ecosystems and highlight the possible connections between physical, biological and anthropogenic components of socio-ecological systems. Currently there is a debate on which method to use for ITA, especially given the nature of time series datasets with possible issue arising from temporal autocorrelation and non-stationarity.

We compared a suite of dimension reduction techniques (Principal Component Analysis, Forecasting Component Analysis, Dynamic Factor Analysis, Min/max autocorrelation factor analysis or Local Linear Embedding) with the aim to extract the main trends (i.e. dimensions) inherent in the dataset. We applied this suite of methods to study the dynamics of Atlantic and Mediterranean fish communities using a collection of bottom trawl surveys data. The comparison of methods confirmed that, in most regions, the main dynamics was picked up correctly by all the dimension reduction techniques. Additionally, we could reveal the main dynamics across ecosystems and found that fast and abrupt changes have recently happen in fish communities across many regions. Further analysis will compare these dynamics and identify possible natural or anthropogenic drivers for such synchronous dynamics (Figure 13).

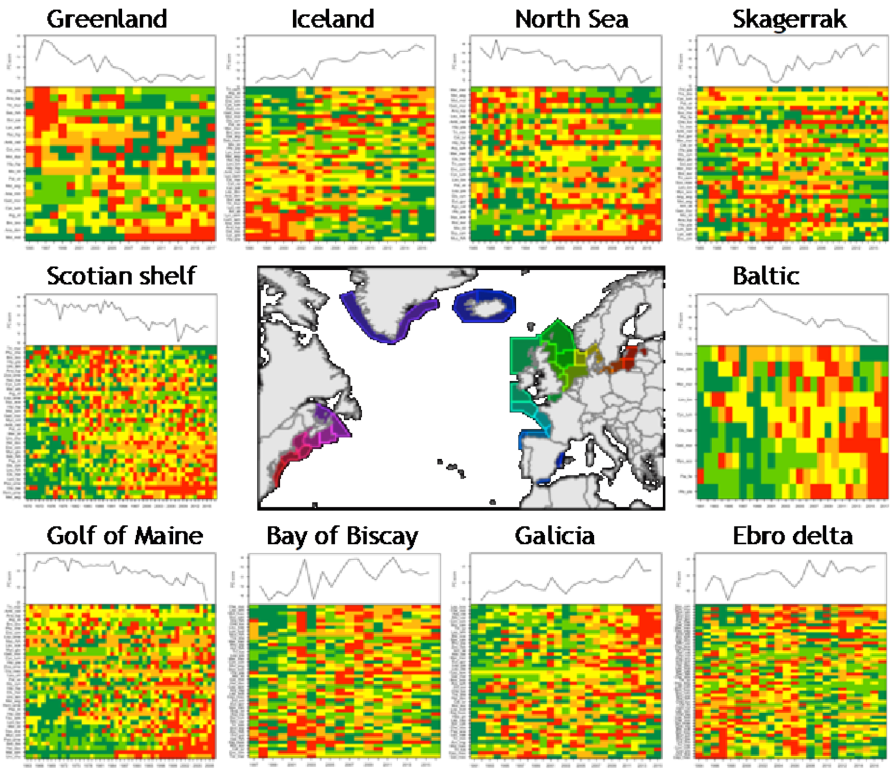

Figure 13. Principal dynamics of fish communities across Atlantic and Mediterranean ecosystems. The heatmap represent the time-series of fish assemblages, with individual fish species in rows, and time in columns. Values are transformed into quintiles and color coded (red = low values; green = high values). Fish species are sorted into numerically descending order according to their loadings on the first principal component.

Outcome: *Romain Frelat, Christian Möllmann et al (under preparation). Comparative ecosystem integrated assessments (IEA) across Atlantic Ocean and Mediterranean ecosystems.* Outcome entirely associated to WG COMEDA work.

In addition, the Group has also developed an **open source (shiny) application to develop Integrated trend analyses** (ITA). ITA are commonly applied to summarize changes that have occurred in recent decades in ecosystems and highlight the possible connections between physical, biological and anthropogenic components of socio-ecological systems. Currently there is a debate among marine scientist from ICES on which method to use for ITA (e.g. Diekmann et al. 2012, Planque et al. 2017).

The goal of the "shiny application" is to provide a simple tool for marine biologists to compare different dimension reduction techniques. The software can load user's dataset, and automatically compute a multiple suite of dimension reduction techniques (e.g. Principal Component Analysis, Forecasting Component Analysis, Dynamic Factor Analysis, Min/max autocorrelation factor analysis or Local Linear Embedding) (Figure 14). Therefore, scientists interested in Integrated ecosystem assessments can test the adequacy of different methods and the robustness of the results of ITA. The methodological comparison tool will be complemented with practical guidelines on how to select and pre-process data; and how to choose the best method according to the characteristics of the dataset. The software, available online, contribute to the homogenization of tools and methods, a first step toward a better communication between Atlantic and Mediterranean marine scientists.

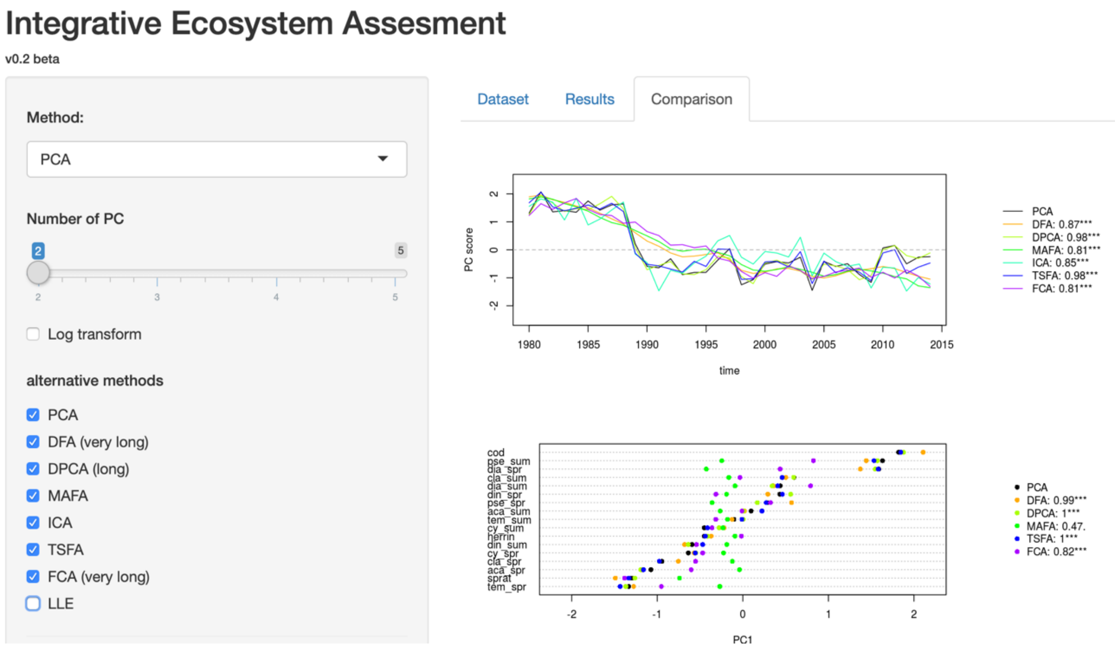

Figure 14. Screenshot of the shiny app, with three tabs for (1) loading the dataset and selecting the pre-processing methods; (2) calculating single dimension reduction techniques; and (3) comparing the results of multiple dimension reduction techniques.

Outcome: *Romain Frelat, Christian Möllmann,* 'comita': an R-package and shiny app to compare integrative trend analysis methods (*in development on Github:* https://github.com/rfrelat/comita*)*, Shiny app available on : https://rfrelat.shinyapps.io/comita/ . Outcome entirely associated to WG COMEDA work.

3 Degree of success and future of the WG

3.1 Degree of success

All ToRs with the exception of ToR C ('Develop the analysis of the link between ecological stability across different ecosystems types and ecosystem properties (structure and functioning)') can be considered completed with all outcomes in process of publication. Some of the research topics developed during this period will be further extended and will continue in the next WG 3-year cycle (see below).

In terms of collaboration with other WGs, WG COMEDA has established solid links of collaboration with other WGs devoted to work on Integrated Ecosystem Assessments such as ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) and the ICES Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS). This close relationship is ensured in the future as part the future co-chairs are also involved the work of the afore mentioned WGs.

One of main difficulty the WG faces is the lack of proper financing to attract young scientist to the meetings, which may have no official means to finance their trips. As in other WGs, many WG members while enthusiastic have limited time they can dedicate toward work group topics slowing the progress towards tangible results. Some of the research topics that have been completed faster are those that are inherent part of the PhD or postdoc projects. One of the complications detected in the first COMEDA cycle (2014-2016) was the poor translating of the scientific results into firm management advice since the group was new. In this second cycle, we have succeed on that through the development of open access tools ready to use, having thus established and consolidated communication exchange platforms.

Finally, other limitation was the medium to low success in the commitment of Mediterranean scientist to come and being involved in the word of the WGs. Since some of the colleagues interested are also involved in fisheries assessment in the context of GFCM, the overload of work associated towards fisheries assessment and the lack (to the moment) interest by GFCM on IEA tool, methods and indicators, has limited the commitment of interested but overcommitted of some Mediterranean colleagues.

3.2 Future plans

WG COMEDA will continue (pending of final approval at SCIOM) with four new co-chairs: Sofia Henriques (University of Lisbon, Portugal), Maria Cristina Mangano (University of Palermo, Italy), Paris Vasilakopoulos (European Commission - Joint Research Centre, Italy) and Romain Frelat (Wageningen University, Netherlands). The tentative ToR for the third 3-year cycle of the WG COMEDA (2020-2022) are:

i) Assess the **functional biodiversity** of demersal and benthic assemblages across Mediterranean and Atlantic systems (ToR A).

ii) Integrate the **complexity** of marine biota to understand the relationship between ecosystem structure and connectivity with the stability of communities (ToR B).

iii) Investigate **resilience** and mechanisms of change in complex marine systems impacted by anthropogenic and environmental drivers (ToR C).

iv) Explore potential options to integrate **ecological and socio-economic** dimension's to support integrated fisheries advice and marine management (ToR D).

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Annex 2: Resolution notes

Besides peer-reviewed publications, we suggest to disseminate the shiny application tools and R library developed under the framework of COMEDA to, at least, **all IEA WGs**: '*Romain Frelat, Christian Möllmann,* 'comita': an R-package and shiny app to compare integrative trend analysis methods. Beta version of the package available on Github*:* https://github.com/rfrelat/comita, Shiny app available on : https://rfrelat.shinyapps.io/comita/.

We encourage ICES DATA CENTER to embrace effort to develop a **life history traits database** for marine biota, including fish but also other benthic species (invertebrates and algae).