### 4.1.3 Main S&T results/foregrounds

## Quantification of Impacts and Feedbacks in FW and BP

The core of the OCEAN-CERTAIN work in WPs (WP) 1 and 2 was to address one of the two main targeted uncertainties proposed:

*Changes in functionalities in food-web and connected feedbacks (such as link between FW and BP and the efficiency of the BP to export Carbon (C) from surface to deep water) caused by multi-stressors*

Data mining and Literature Based Knowledge Discovery (LBKD) with text mining within WP1 performed essential a role to produce knowledge about past and present states of the ecosystem structure and functionality and about the processes of change. We aimed through data mining, to establish quantitative relationships between multiple stressors, FW and BP, and through LBKD, to extract latent knowledge from scientific literature.

In WP1 Data Mining task, we have created a comprehensive bio-climate data bank that accounts for FW observations together with environmental, climate and anthropogenic forcing variables extracted from global databases and data repositories. The data base contains quantitative information and was used to investigate the effect of climatic and non-climatic stressors on pelagic FW in the study cases using state-of-the-art statistical modelling approaches. To tackle these questions, we used long term data covering several decades to understand ecosystem wide changes and the relative importance of climatic and non-climatic drivers on such patterns.

The main output of WP1's Text mining task was creation of a text mining and custom-purpose search system called Marine Variable Linker (MVL). It is an online web application that runs in any web browser. Its main function is to enable end-users (marine scientists) to easily search through a large collection of Marine science journal articles in an interactive way and to present search results in a browsable and visual way. It supports searching for related events (changes, increases, decrease of variables) where the events can be correlated (i.e., frequently occurring together in a sentence) or causally related (i.e., connected by a verb such as causes). This is one of the aspects that makes MVL different from general search engines such as Google. The system identifies "increase", "increasing", "elevating", "higher", "rising", etc…, i.e., different natural language expression of the semantically equal "increase" event as the same event.

Quantification of impacts and feedbacks in FW and BP within WP2 had the overall objective of WP2 to expand the natural science understanding necessary to model the impact of multiple stressors (e.g. climate change, overfishing, ocean acidification and pollution) on the overall functioning of the ecosystem FW and BP. We aimed to determine key ecosystem responses to theses stressors at the base of the marine FW; these potentially affect the upper trophic levels and therefore society (e.g. fisheries). We used as base an established conceptual model (**Figure. 1**) to identify key changes within the integral components of the FW across ecosystems and therefore be able to better assess potential future changes in efficiency of BP.

**The qualitative and quantitative changes of FW and BP: Effect of multi-stressors in Patagonia (Comau Fjord), Arctic (Ny-Ålesund-Kongens fjord) and Mediterranean (Crete)**

Throughout OCEAN-CERTAIN, we were able to determine the responses on more than 50 different environmental variables relevant to FW and BP in the experiments performed to study the effect of multi-stressors in the three study cases. We observed the effect of both synergistic and antagonistic responses of specific variables under the presence of two or more stressors in the experiments conducted. This draws attention to the point that combined effects of multi-stressors may have a different impact from that expected of the simple additive effect from stressors acting individually. Therefore, we highlight the need in pursuing a comprehensive and holistic approach in addressing the impacts of both climatic and non-climatic stressors on FW and BP, and its ultimate impact on global climate dynamics. The main responses of measured variables compared to reference conditions set across the three study cases is summarized in **Figure 2**, and it highlight the responses of the different ecosystems under the following stressors: **High grazing (Z), Low pH (L-pH), High Carbon (C)**. In Patagonia, the addition of surplus carbon had a fundamental role in influencing FW structure, modulating dynamics between bacteria and large phytoplankton (mainly diatoms). The results from Ny-Ålesund showed the most negative response to combined effects of multi-stressors, enhancing small phytoplankton and bacterial production. In these two ecosystems, the results obtained highlighted the potential impacts of the efficiency of BP. On the other hand, in the Mediterranean, biological responses were dominated by the observed shift in grazing pressure, rather than by chemical changes in L-pH or C input.

To better constrain the possible qualitative and quantitative changes in functionalities of the FW observed in the experiments, the conceptual model was employed to reproduce the observed scenarios in each region. The basis for testing this model has been under the stressors of Grazing pressure and Carbon supply. Under this type of forcing, the conceptual model has previously been shown to reproduce major trends of plankton dynamics, showing that top-down control by grazing pressure affects the entire food web all the way to bacterial consumption of organic carbon and viral activity. The results obtained experimentally, in contrast to the model predictions, suggested that specific responses of the system to stressors depended strongly on the food web structure studied, meaning that different initial food web structures have different consequences on the functionality of the different components in BP. Given that experimental results represent synoptic conditions, the other important source of uncertainty is the variability in food web structure over time and space. One of the main lesson drew from comparison of the conceptual model with the experimental results is existence of the key role for the FW structure in modulating the interaction between stressors. Assessing of the conceptual model under all scenarios gave an overall good reproducibility in Patagonia and Mediterranean, while model deviations in the Arctic scenario, required adjustments of the model, highlighting new gaps in our understanding of the ecological interactions and FW functionalities. By this effect, we have gained improved insight into the strengths and limitations of this model therefore reducing uncertainty.

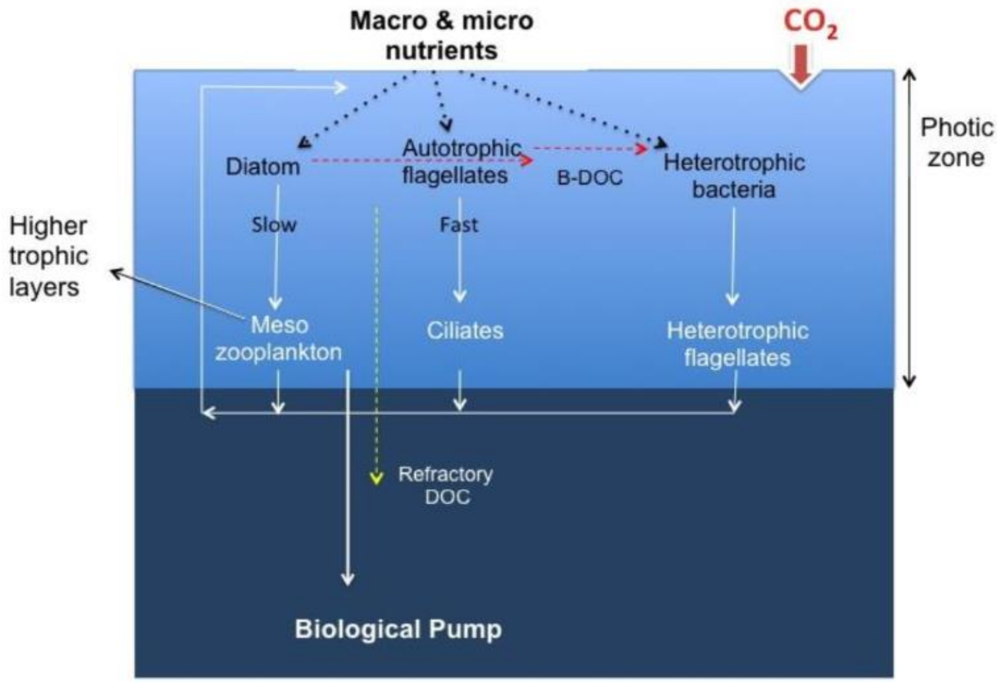

**Figure**. 1: Conceptualization of the microbial FW that will form part the basis of the mathematical model for OCEAN-CERTAIN adapted from T. Thingstad et al. (2008).

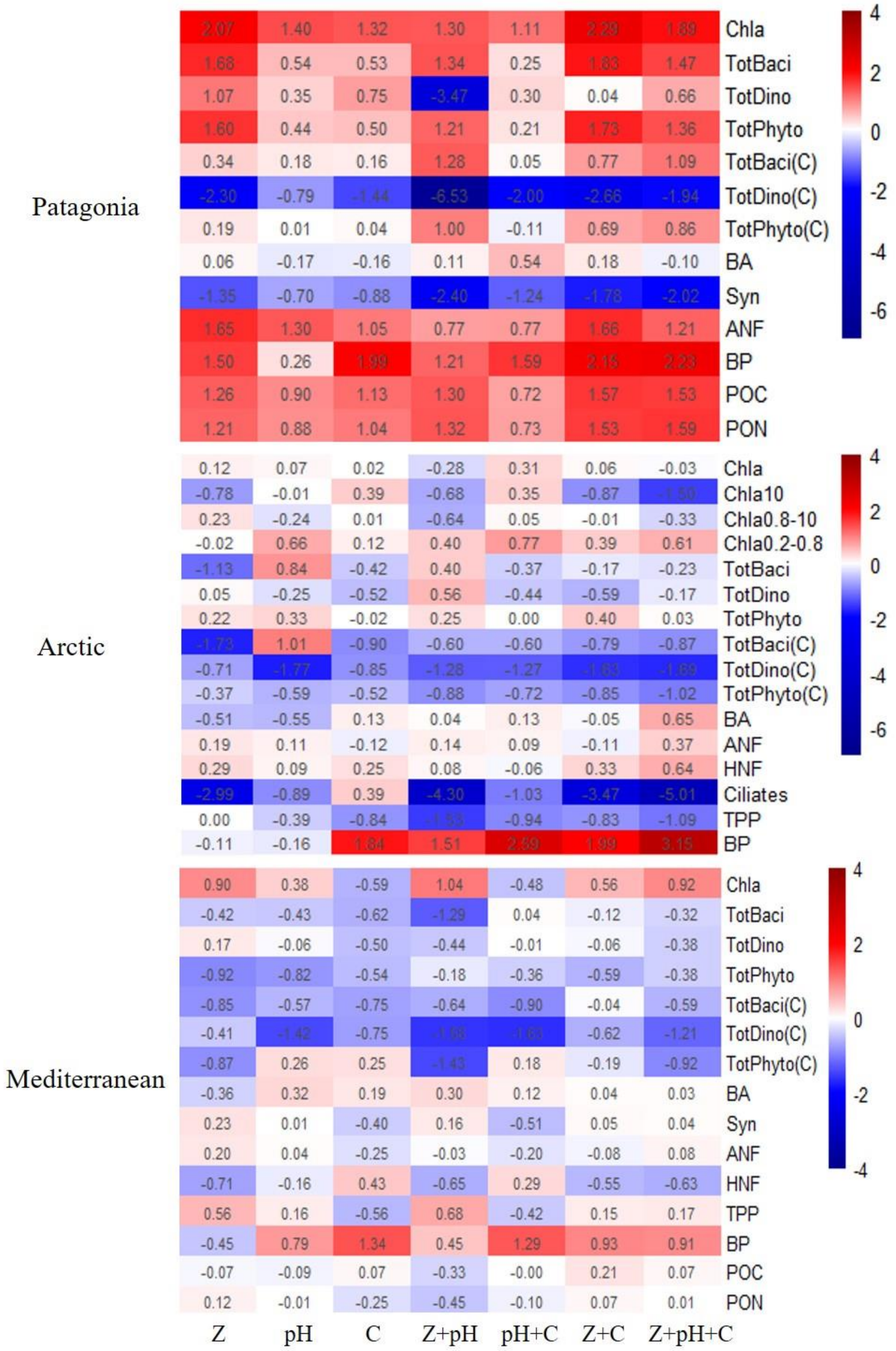


**Figure 2.** Heat maps showing the responses of main variables in multi-stressor experiments in the three study cases. The responses following the different stressors combination (Z: High grazing, L-pH: Low pH, C: High Carbon) is represented

by the comparison with the reference conditions (Low grazing, current seawater pH and no Carbon addition). Blue denotes negative (decrease), whereas red denotes positive increase in the specific variables. Values are Log 2 transformed. Chla: Chlorophyll-a; Chla-10, Chla 0.8-10, Chla0.2-0.8: Chl-a in different size fractions; TotBaci, TotDino, TotPhyto: Total abundance in diatoms, dinoflagellates, phytoplankton; TotBaci (C), TotDino (C), TotPhyto (C): Total carbon in diatoms, dinoflagellates, phytoplankton; BA: bacterial abundance; Syn: Synnecochoccus abundance; ANF and HNF: autotrophic and heterotrophic nanoflagellates; POC and PON: Particulate organic carbon and nitrogen.

**Patagonia**

In Patagonia, the system is influenced by high freshwater inputs (high natural silicic acid) in interaction with deep high salinity oceanic waters. Combination of physical and chemical processes lead to high-seasonal primary production in spring dominated by highly silicified chain-forming diatoms and high bacterial production in winter. In a scenario such as Patagonia, where diatoms dominate the microbial food web, the model predicts that elements are channelled mainly through the "classical food chain" (diatoms-mesozooplankton), fuelling the BP, especially under Z. Therefore, the model is able to successfully reproduce the circumstances under which a strong BP can be expected. These observations are in line with the current scenario observed in the region where the spring period drives efficient export of carbon the BP.

In our experimental results, the C source was fundamental for heterotrophic microorganisms. C source and Z increased bacterial productivity and nanoflagellates. This pattern drives competition between autotrophs and heterotrophs assemblages, with bacterioplankton leading over phytoplankton (mainly big diatoms). In response to multi-stressors, we highlight that low pH induced a decrease in phytoplankton biomass (15%) compared to normal pH (**Figure 3**). So far, the annual cycle of $CO_2$ flux in northern fjords is governed by seasonal changes in biological processes that enhanced the shift from a $CO_2$ sink in late spring and summer, caused by high primary production, to a $CO_2$ source the rest of the year caused by high community respiration. It is expected that environmental changes (e.g. Climate Change) and natural variability (e.g. seasonal succession) may cause changes in the structure and function of the microbial food web, which in turn may alter BP efficiency. Up to now, it is still scarce information on how ocean acidification (OA), Z and C sources, as stressors, interactively affect carbon dynamics in phytoplankton and bacterial assemblages in the region. These results highlights, the interactive effects of OA and zooplankton grazing processes may reduce biological production in coastal waters, therefore decreasing carbon matter to higher trophic levels and increasing $p\mathrm{CO}_2$ levels in the upper layer. It is relevant to highlight that the current model description of BP functioning in Patagonian ecosystem however have not been tested under L-pH. This draws attention to the potential decrease in efficiency in BP, as observed experimentally, in which the system can eventually become more heterotrophic (net $CO_2$ source).

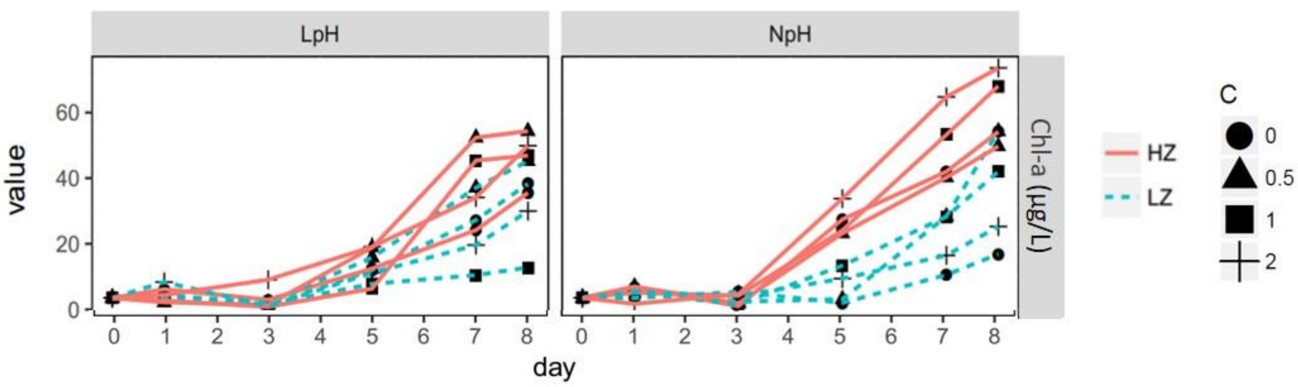


**Figure 3.** Chl-a (μg $L^{-1}$) over time under low (LpH) and normal (NpH) pH, together with high (HZ) and low (LZ) grazing conditions in the multistressor experiment in Patagonia.C: Carbon gradient.

**Arctic**

The Arctic ecosystem as well Patagonia is highly influenced by freshwater, yet on of the dominant features the strong seasonality observed in the region in term of light, sea-ice extension, nutrient inputs, all which in turn drives high-seasonal primary production in spring. It is predicted that Arctic ecosystem will be among the most affected by climate change, as freshening, warming and acidification are occurring faster there than in other regions. Ocean acidification has been found to cause a shift in phytoplankton community towards smaller organisms, leading to decrease efficiency in the export BP (Riebesell et al. 2013). In the mesocosm experiment conducted in Ny-Ålesund, the responses among most relevant variables varied, although the largest impacts observed were overall negative (**Figure 2**). The grazing effect was a strong feature and exhibited contrasting results between conditions. The consequent cascading effect, promoted overall higher phytoplankton biomass (~42%) and primary production (~39 %), yet this was comprised mostly of small phytoplankton. Specifically, within the 0.2-0.8 Chl-a fraction, it can be observed the effects of single and multi-stressors: this Chl-a fraction was negatively affected under Z and positively affected by L-pH. Yet, in the interaction of the three stressors, the antagonistic effect of Z and L-pH disappears as C effects seems to dominate, promoting higher picoplankton under Z, L-pH and C.

The experiment results in Ny-Ålesund, showed significant effect of the carbon over the bacterial production and the glucose turnover time. Different from the gradual effect of carbon in Patagonia, bacterial production in Ny-Ålesund showed a sharp change from no Carbon addition to the lowest addition. This effect was more drastic under L-pH conditions (**Figure 4**). Bacterial production was the only parameter that displayed a strong positive response. Together with bacterial abundance showed a clear effect of single and combined stressors. It was observed the expected negative impact of Z for these variables, whereas with C addition there was a compensatory effect, mitigating the negative Z effect. When looking at effect of L-pH alone, it is negative, whereas in combination of the three, the overall effect top-down control promoted by Z disappeared and the negative effect of L-pH, turned it into overall positive response caused by C. The results suggest of a quick and sharp response to C input in Ny-Ålesund, drawing attention to potential future scenarios in this kind of ecosystem with increasing DOM inputs with thawing of the permafrost in the Arctic. The observed results showed bacterial carbon consumption was higher than predicted by the model. Data obtained, confirmed a shift in the bacterial community, and therefore observed the need to add another Plankton Functional Type to the model. A manuscript, addressing how bacterial life strategy can change entire ecosystem functioning in the Arctic was submitted as part of OCEAN-CERTAIN results. This highlights how bacterial life strategy can change entire ecosystem functioning in the Arctic, with potential implications for BP efficiency.

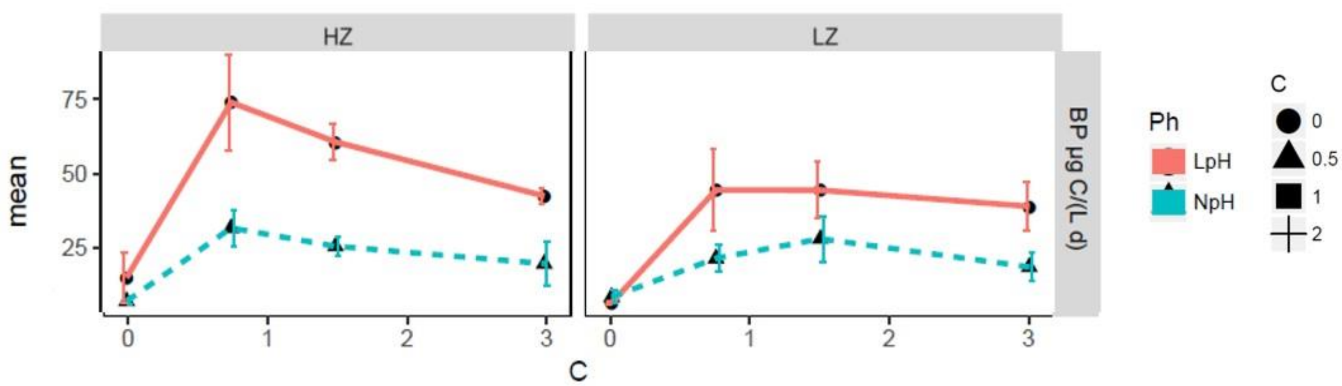

**Figure 4.** Bacterial production (µg C. $L^{-1}d^{-1}$) and under low (LpH) and high (NpH) versus Carbon gradient the mesocosm experiment in Ny-Ålesund. C: Carbon gradient.

**Mediterranean**

The Mediterranean Sea provides a unique platform for climate change research. It behaves like a miniature ocean (Bethoux et al. 1999) with a well-defined overturning circulation and time scale much shorter than for the global ocean, with a turnover of only several decades. In addition, the Mediterranean Sea has been identified as a hot spot for climatic change (Giorgi 2006), i.e., a region most affected by ongoing warming trend and decrease of precipitation. The Mediterranean is therefore a potential model for global patterns that will be experienced in the next decades worldwide not only regarding ocean circulation, but for the marine biota as well (Lejeusne et al. 2010). Warming, increased stratification, ocean acidification, are among recognized environmental stressors by which climatically driven ecosystem disturbance are generated.

The experimental response to multi-stressors effect, highlight responses in two main variables such Chl-a and bacterial production. In former, overall positive response were observed under Z and L-pH (**Figure 5).** This effect happens to be rather counterintuitive and contrary to that observed in Patagonia. Bacterial production had overall positive response under the combined effects of grazing, carbon and L-pH as observed in the other study cases. However, in the Mediterranean largest increases were under carbon (1 stressor) or L-pH and C (2 stressors) and not under the 3 stressors combined as in Patagonia and Arctic. The latter suggests that in combination of different stressors, grazing is a more important in this region in promoting indirect control over bacterial production.

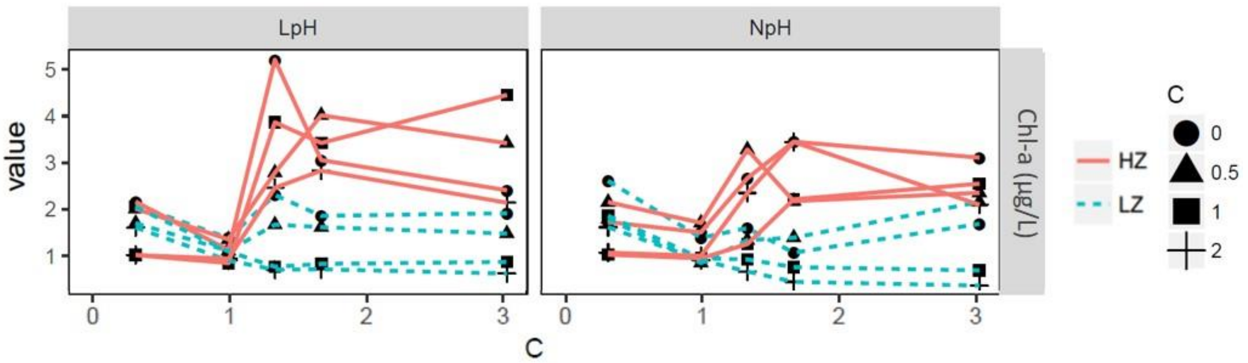


**Figure 5.** Chl-a (µg $L^{-1}$) over time under low (LpH) and normal (NpH) pH, together with high (HZ) and low (LZ) grazing conditions in the multistressor experiment in the Mediterranean. C: Carbon gradient.

Experimental results on the effect of single stressor of carbon input, did not show discernible effects in most of the response variables. Interestingly, heterotrophic bacteria remained largely unchanged while the turnover time of glucose (C source) increased at low carbon. This suggests that although bacterial abundance did not change significantly, less carbon was consumed. It is unlikely this was due to nutrient limitation since the P turnover time remained largely unchanged. Regarding a nutrient limited (phosphorus) system such as the Mediterranean, the model predictions indicate that bacteria benefit from the nutrient and carbon additions, until bacteria become co-limited by N and P (e.g. Pitta et al. (2016), OC funded) and DOC accumulates in the system. The implication of DOC accumulation in the region extends to the carbon pump, since mixing can lead to the direct export of DOC to deeper layers. It constitutes essential to reconcile experimental and model results, as to determine whether the seasonal DOC accumulation observed (Santinelli et al. 2012), is due to the recalcitrance nature of the DOC or bacteria that become nutrient limited.

**Climate Change transition of the Mediterranean Sea: Temporal and spatial trends**

Understanding the complex interplay of changing ocean variables and the implication for marine ecosystems, requires not only modelling but extensive monitoring. Long-term time-series are fundamental prerequisite to detect and understand climate shifts and trends; still, such time-series are seldom available for the deep ocean. Oceanographic field studies and exploitation of available long-term time series carried out during OCEAN CERTAIN contributed to overcome these gaps. Evidence of warming trend in the region has been already documented by the scientific community, in particular for the surface layer (Bethoux et al. 1990) as well as deep layer (Rixen et al. 2005). However, during OCEAN-CERTAIN it was demonstrated that thermohaline properties (i.e. temperature and salinity) of the Levantine intermediate water (layer between 300 and 600 m depth), have undergone significant changes during the 23 years of monitoring (**Figure 6**). The very stable thermohaline characteristics of the deep water have always been considered a robust reference to quantify even the smallest effect of climate change. Stressors like warming and stratification will be exacerbated in the near future, with significant deepening of isotherms that will impact thermal exposure levels of existing biota. |

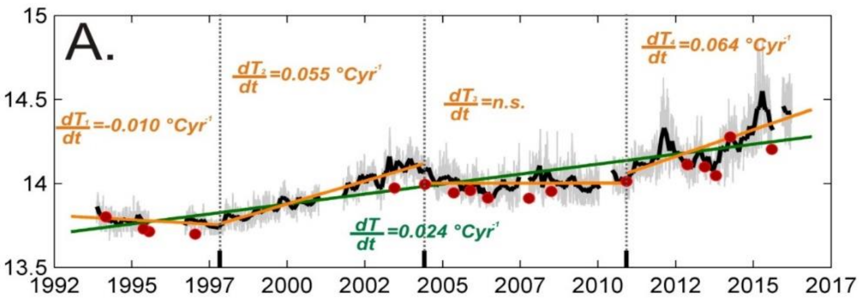


**Figure 6**. Time series of temperature at 400 m depth in the Sicily Channel. Red dots indicate CTD measurements from ship during servicing. Monthly mean time-series is shown in black. Green and orange lines represent long- and short-term trends respectively, for different periods (from Schroeder et al. (2017)).

In order to understand how these changes in physical properties and dynamics affecting biogeochemical dynamics in the Mediterranean, cruises were carried out in the Western and Eastern Mediterranean.

**Western Mediterranean Cruise**

On top of long-term warming trends, the Mediterranean region is affected by long-lasting warm-season extreme events as marine heat wave (MHW). Under climate warming scenarios, MHW are predicted to increase in frequency and intensity. In summer 2015, the western Mediterranean experiences a 30-40 days long marine heatwave (**Figure 6**), which was associated to few mass mortalities events (e.g., Rubio-Portillo et al. 2016). The impact of MHW on FW and BP is under current study through OCEAN-CERTAIN datasets collected during the field campaign in August 2015. Preliminary results from the cruise on the FW structure showed a well-defined stratification of abiotic factors in the water layers. In general, it was observed a sharp decrease of autotrophic and heterotrophic plankton abundance from the epi- to meso- pelagic layer. A similar decreasing trend was also observed in term of microbial C production and respiration. A sharp decrease of all metabolic activities and prokaryotic growth efficiency was observed at 200m depth (**Figure 7**).

Studies conducted on ecology and diversity of planktonic viruses in the deep sea, increased knowledge on a group that despite being fundamental component in microbial food webs, little is known still. OCEAN-CERTAIN data produced the first biodiversity inventory of viral assemblages in the bathypelagic Mediterranean Sea. As a result, lytic viruses from bathypelagic waters that can infect deep-sea strains of bacteria were isolated. Two of these viruses were demonstrated to be novel. Further analyses indicated that the viral genomes were recruited in surface and deep waters, suggesting a link between the photic and the dark ocean layer. The results provide new insights into ecological and evolutionary relationships between deep-sea prokaryote and its viruses, as a step forward for the better understanding of virus-host interactions and their ecological significance in the microbial food web and the ultimate effect on BP (Lara et al. 2017).

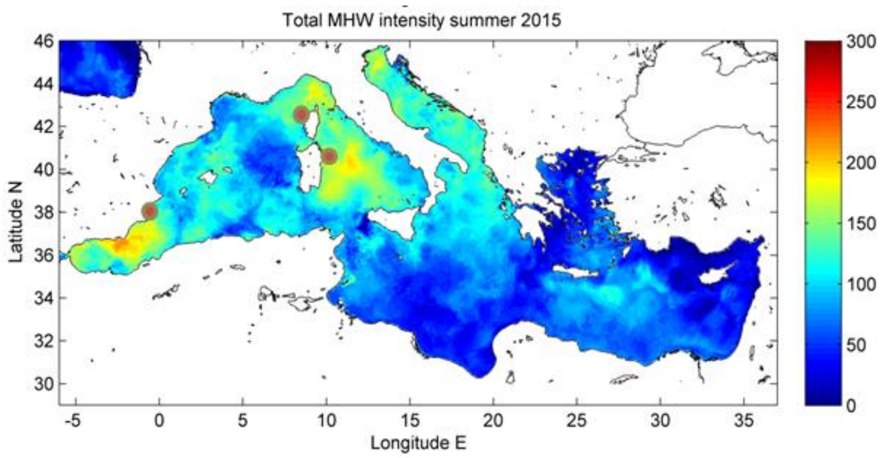


**Figure 6**. cumulated heat intensity anomaly over the baseline climatology (based on SST data courtesy of CMEMS Copernicus Marine Monitoring Service, http://marine.copernicus.eu/) for 2015. MHW parameters have been estimated following Hobday et al. (2016). Red dots highlight reported mass mortality events.

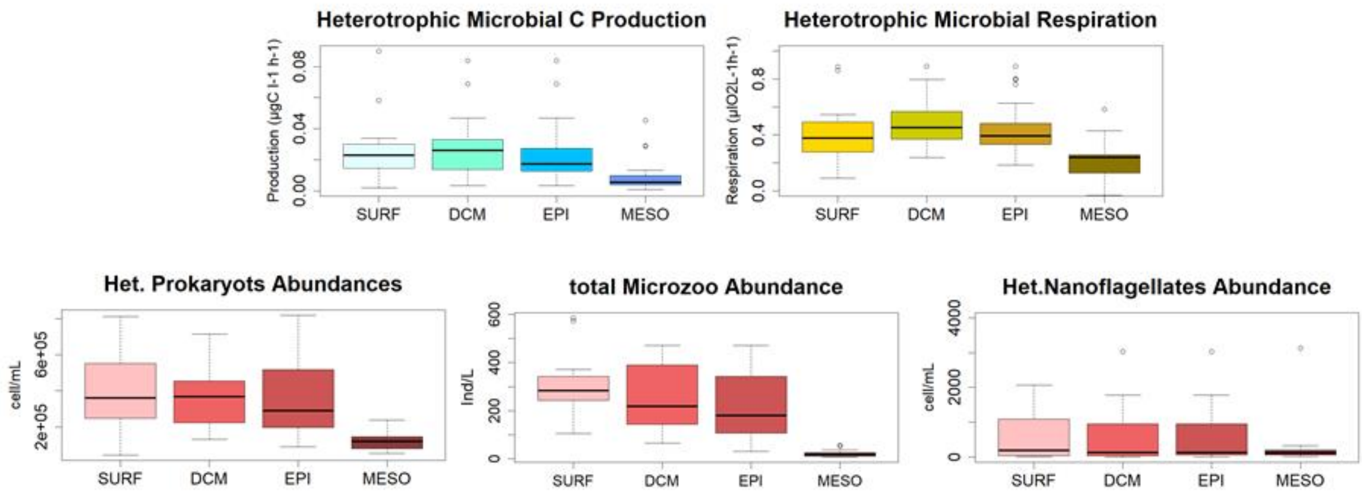


**Figure 7.** metabolic processes and abundances and of planktonic component at different water depth layer [SURF=surface, DCM=Deep Clorophyll Maximum, EPI=epipelagic, here defined from below the surface to 100m, including DCM that is counted twice, MESO=Mesopelagic, here defined from 200m to 500m).

**Eastern Mediterranean Cruise**

Climatic changes in the Mediterranean thermohaline circulation are all likely to affect the mesoscale dynamical features of the Eastern Mediterranean which consist of sub-basin-scale gyres and permanent -or quasi-permanent- cyclonic and anticyclonic structures interconnected by intense jets and meandering currents. Abrupt change in physical properties in the 90s led to large scale change in the Mediterranean, where Aegean Sea waters sunk to the bottom of the Eastern Mediterranean to form Eastern Mediterranean Deep Water (EMDW). Previously, it was known that the Adriatic Sea was the only source for EMDWs, and that Aegean Sea waters could sink only to limited depths. Formation and subsequent flow of dense water towards deep layers has direct effect on the transport of biological material from surface to deep layers. Although no studies to understand this direct effect in Aegean Sea were carried out, studies in the Adriatic within the context of the OCEAN-CERTAIN revealed importance of this mechanism. It is found that, dense water production over the Adriatic shelf plays a key role in carbon dynamics (Chiggiato et al. 2016). It grants cross shelf transport along ocean margins, directly controlling the particle flux (Langone et al. 2016), subtracting a C-enriched water mass later transferred to the deep Mediterranean (Cantoni et al. 2016) and influencing, over long distances, pico- nano- micro- plankton communities (Bernardi Aubry et al. 2017; Luna et al. 2016).

Data obtained confirm the expected depths patterns for nutricline in the downwelling and upwelling regions were confirmed by the phosphate concentration. The relatively high P-uptake rates and turn-over times for particulate phosphorus found in deeper layers were however more difficult to reconcile with the generally low bacterial production measurements. The signature difference in elemental composition between DOC samples in the are, show that DOC characterization can be used as an ideal tool in combination with TOC and POC to describe the dynamics of carbon capture in Rhodes gyre. Expected high phytoplankton biomass values were observed in the center of the gyre (**Figure 8**). New records for particularly small size diatom (mainly cyclotelloid), as dominant group in pico-nano plankton, have been observed for this region in surface waters. The recent dominance of these smaller species is significantly correlated to warming-induced strengthening of thermal stratification, reduced mixing, and notable reductions in regenerated nitrogen supplied from deeper waters to the euphotic zone. One of interesting observation in the zooplankton samples is the high abundance of doliolids at the cyclonic stations. They are key component of the zooplankton abundance during summer and autumn especially in the western Mediterranean Sea (Mazzocchi et al. 1997; Saiz et al. 1999) and in the Aegean Sea (Siokou et al. 2013). However, they have not been reported in high numbers from the most oligotrophic eastern Mediterranean.

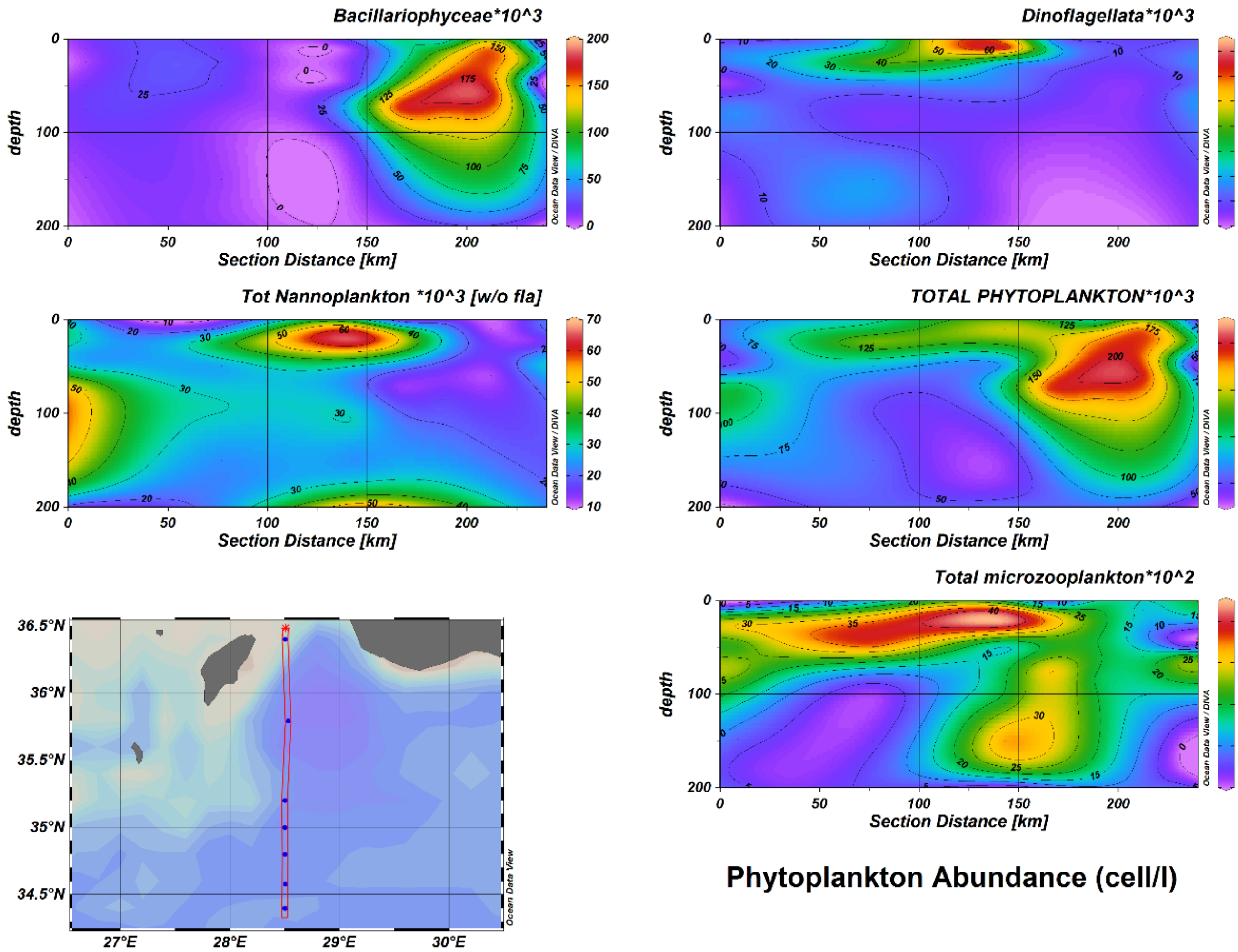


**Figure 8**. Distribution of phytoplankton across the Rhodes gyre cruise track..

**Ecosystem Modelling: Lower (LTL) and Higher (HTL) trophic levels in Patagonia (Gulf of Ancud), Arctic (Barents Sea) and Mediterranean (Rhodes Gyre)**

The joint work performed within WP1 and WP2 allowed to connect changes occurring at the base of BP, connecting to HTL, which are most involved ecosystems services and society. The result was the development by CEFAS of complex end-to-end models for the three locations, in consultation with the project partners (**Figure 9**). In the same way, WP3, WP4 and WP5 have been responsible for translating the model outputs into decision frameworks and assessing their significance for human societies in the case study areas. The results provided were incorporated into the DSS to be used by policy makers, stakeholders and other interested parties.

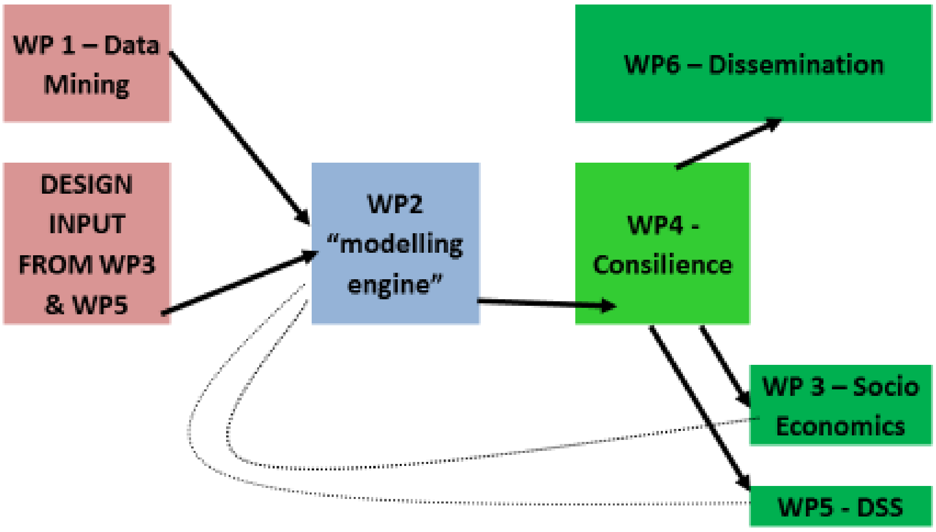


**Figure 9.** Schematic view of project structure, showing how the WP2 "modelling engine" takes input from WP1, and produces outputs for WP4-6.

Modelling allowed to scale up the scope of OCEAN-CERTAIN both on a spatial and temporal basis. From the temporal perspectives, we aimed to increase resolution on a short (annual seasonality) and long term (up to year 2099) basis based on two of the possible future scenarios proposed by the from the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report. The spatial resolution covered 1000s of square kilometre, including the area where the mesocosm experiments were conducted and where the vulnerabilities of the local communities where assessed (**Figure 10**). In the same way, we amplified the scope for climatic and in particular non-climatic stressors and the combinations of both, e.g. the role of climate change (warming) and overfishing or OA and overfishing. These could not be assessed otherwise experimentally within the fieldwork of OCEAN-CERTAIN (**Table 1**). Important caveat regarding the simulated scenarios was creation of independent scenarios for Climate Change (Warming) and Ocean Acidification (OA). It would be unrealistic to expect atmospheric $pCO_2$ values to change while the climatic conditions do not (OA1, OA2 scenarios), as both are driven by the increasing atmospheric $CO_2$ concentration. Here the OA only scenarios were performed to allow for a) identification of the single stressor response (and thus aid interpretation of the combined stressor response) and b) to allow for comparison with the single stressor L-pH mesocosms experiments. The assessment of the carbon export (considered at ~100m by convention) constituted one of the main output of the end-to-end model simulations which provided insights into possible future scenarios for BP functioning in the study cases. More details are to be found in deliverable 2.2.

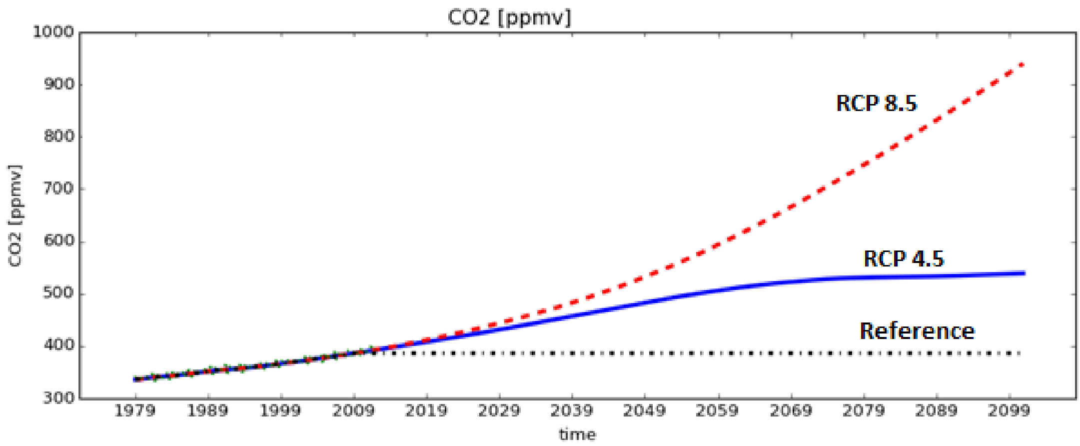


**Figure 10.** Atmospheric pCO2 projections under the different emission scenarios: RCP (representative concentration pathways) 4.5 (representing compliance with the Paris Agreement) and 8.5 (representing no additional mitigation action or "business as usual") outlined by the IPCC (http://www.ipcc.ch/report/ar5/).

| Scenario Name | Description |
|---|---|
| Reference | Repeat of the meteorology from 1979-2008, atmospheric pCO2 values constant from 2008 onwards |
| CC1 | Meteorological conditions from the RCP4.5 pathway (Paris agreement), atmospheric pCO2 values constant from 2008 onwards |
| CC2 | Meteorological conditions from the RCP8.5 pathway (business as usual), atmospheric pCO2 values constant from 2008 onwards |
| OA1 | Repeat of the meteorology from 1979-2008, atmospheric pCO2 values increasing according to the RCP4.5 pathway (Paris agreement) |
| OA2 | Repeat of the meteorology from 1979-2008, atmospheric pCO2 values increasing according to the RCP8.5 pathway (business as usual) |
| CC1OA1 | Meteorological conditions and atmospheric pCO2 values according to the RCP4.5 pathway (Paris agreement) |
| CC2OA2 | Meteorological conditions and atmospheric pCO2 values according to the RCP8.5 pathway (business as usual) |
| F1 | Fishing pressure 1 (MSY-) and repeat of the meteorology from 1979-2008, atmospheric pCO2 values constant from 2008 onwards |
| CC1F1 | CC1 scenario combined with MSY- fishing pressure |
| CC2F1 | CC2 scenario combined with MSY- fishing pressure |
| CC1OA1F1 | Full RCP4.5 pathway combined with MSY- fishing pressure |
| CC2OA2F1 | Full RCP8.5 pathway combined with MSY- fishing pressure |
| F2 | Fishing pressure 2 (MSY+) and repeat of the meteorology from 1979-2008, atmospheric pCO2 values constant from 2008 onwards |
| CC1F2 | CC1 scenario combined with MSY+ fishing pressure |
| CC2F2 | CC2 scenario combined with MSY+ fishing pressure |
| CC1OA1F2 | CC1OA1 scenario combined with MSY+ fishing pressure |
| CC2OA2F2 | CC2OA2 scenario combined with MSY+ fishing pressure |

**Table 1**: Overview of the different scenario combinations for modelling projections. Scenarios are based on climate conditions projected under emission scenarios RCP 4.5 and RCP 8.5.

In light of the model simulations and expansion of the spectre of stressors and the combinations thereof, results in LTL outputs largely the experimental observations made in the three study cases. We highlight the dominance over time of the warming effect of temperature increases (Climate Change) over those of OA in the three regions, however with different consequences for each region. In Patagonia and the Arctic (Barents Sea), net primary production is expected to increase and with it the net carbon export. Combined impacts of climate change and acidification seem additive for the pelagic components. In Patagonia**,** net primary production increases due to a decrease in estuarine waters input (weakening of stratification), allowing for more nutrients to reach the surface layer through advective processes. Changes in the climatic conditions in the system, promotes shifts to a more bacterial state although still dominated by phytoplankton. Yet within phytoplankton is expected that diatoms lose the competition for the spring bloom nutrients increasingly to flagellates. In the same way, In the Arctic**,** phytoplankton biomass decreased while net primary production, in this case due to increased higher turn-over rates of the available nutrients. Production also shifted in time with a predicted increase in spring bloom values but a sharp reduction in autumn bloom values.

In general, the responses on these two ecosystems at LTL, corresponded with the experimental observations and scenarios predicted by the conceptual model. However, it is essential to highlight that the temporal scale could only be capture by modelling. Long term simulations can show how stressor may act in different temporal scales with its relative importance varying through time. This is illustrated in the case of Patagonia, where rapid glacial melting was omitted from the model. Note that this may influence results in the short-term future: if the local glacial melt accelerates due to climate change, the estuarine fresh water lens is expected to thicken initially, decreasing nutrient supply to the euphotic zone. In similar way, in the Arctic, stratification is expected to varied, and with it affecting the timing in the autumn bloom. The latter is due to the increase in stratification strength, resulting in a longer stratified period and a later break up and remixing in autumn. Under future climate conditions the remixing of the water column in autumn occurs later in the year when light conditions are lower, causing a sharp decline in autumn bloom production due to light limitation.

For the Rhodes Gyre area, the changing climate conditions form the greatest challenge: the current high productivity system is based on occasional deep overturning of the water column in the centre of the Rhodes Gyre, caused mainly by long, cold winters, resulting in high nutrient concentrations in the euphotic zone and a highly productive area in the otherwise oligotrophic Eastern Mediterranean. As air temperatures increase by 5 °C by the year 2100 in this area, winters are not cold enough anymore to cause the surface layer density to become higher than that of the Levantine Deep Water layer at the bed. Thus, deep overturning of the water column declines with increasing air temperatures, and (in these simulations) stops from 2060 onwards under the RCP8.5 (business as usual) scenario. This causes a strong decline in surface nutrient concentrations, and thus phytoplankton biomass. Species composition shifts from microphytoplankton (diatoms, dinoflagellates) to nano- and picophytoplankton, as smaller organisms are better adapted to taking up nutrients in a low-nutrient environment (higher surface to volume ratio). Note that the process described above does not include any changes to the Levantine Deep Water composition: if the LDW characteristics change this will affect its density which will influence the frequency of overturning in the Rhodes Gyre centre. However, large changes are not expected, as mid-layer waters in the Mediterranean (< 1500m) are still becoming saltier, thus denser (Skliris 2014).

Regarding the carbon flow to HTL is where the effects of both climatic and non-climatic stressors exert combined effects in a bottom-up and top-down fashion. Results within WP1 Data Mining task and WP2 HTL modelling, showed that the three studied areas are experiencing multiple stressors mainly through growing anthropogenic pressures in concurrence with chancing climate conditions. Of the simulated scenarios, most striking effects are observed with the combined effects of Climate Change (warming) and overfishing. This is supported by the literature findings, where the synergies of the multiple stressors, seems to have promoted structural shifts mainly driven by increased abundance of opportunistic populations, such as jellyfish. The combination of warmer temperatures that enhance jellyfish reproduction (Purcell 2012), and overfishing that enhances prey availability and reduces competition pressure for jellyfish (Lynam et al. 2006) are most relevant. Regardless the ecosystem, the compound effects of climate shifts and overfishing promoting a shift in jellyfish dynamics pointing towards enhanced frequency of blooms events. The observed food webs changes suggest an overall altered fish to jellyfish biomass ratio, potentially triggering a non-linear response in these ecosystems. The influence of Climate Change (warming) and fishing stressors varied throughout the time, warning a potential magnification of climate influence in scenarios of higher removal of fish biomass.

Product of the observed and predicted changes in all study cases, it is expected diverse consequences for carbon flow to higher trophic levels and therefore likely negative impacts on ecosystems services. It can be highlighted that in the case of the Arctic (Barents Sea) region, the predicted higher productivity by small phytoplankton in LTL is expected to make the HTL components more variable and more prone to shocks but no less productive. On the other hand, in the Mediterranean (Rhodes Gyre), the combination of climate change and fishing pressure causes bottom up higher trophic level changes of the order of 30 to 50 % by the end of the 21st century. These projected changes are greater than for the other case study areas. They represent a serious and sustained pressure, which will interact with other economic and sociological pressures, potentially in an extremely negative way.

Increase presence of jellyfish in European seas on the other hand, may imply increase in BCE (Lebrato et al. 2013; Sweetman et al. 2016). There are reports (Sweetman and Chapman 2015) suggesting that flux rate of jellyfish carcasses (jelly-falls) contributing to the biological pump as “jelly – pump” and it will potentially increase in future if the current trends continue. Yet, while jellyfish boost BCE and BCP, the fate of jellyfish biomass in the benthic system may indicate different outcome: jellyfish biomass reach to the benthic system may cause a rapid and significant shift in C-uptake path; while bacterial C uptake increasing, Jellyfish carbon cannot be used effectively by benthic macrofaunal organism (Sweetman et al. 2016). That is, C path in the benthic will be much shorter and CO2 production rather than C sequestration might be expected. Since the focus on “Jelly-pump” is very new, there is not enough data to conclude the net contribution of Jellyfish to both BCE, BCP and C sequestration.

Our results showed that the massive jellyfish blooms observed in recent decades have portended substantial impacts on ecosystem functioning. These findings are of relevance as the Mediterranean Sea is one of the most threatened hotspots of marine biodiversity, while the Barents Sea and the northern Patagonian marine ecosystem are highly productive and important fishery grounds for harvested species. Hence, our quantitative assessment simultaneously examined drivers of jellyfish proliferation, the implications of which may have profound consequences on pelagic food webs. In the European Seas, Mediterranean and Barents, the continuously rising temperatures, fishing pressure and the expansion of invasive jellyfish species stress that the observed changes are likely to be enhanced in the future, increasing the uncertainty with regard to resource use. In addition, our results highlight an additional threat that is, the replacement of high-economic-value exploited resources by low-economic-value species with rapid turnover, such as jellyfish, which may have effects on resources use, i.e. fisheries, and economic industries, i.e. tourism, that will be particularly costly.

## Socio-Economic Analyses

The work conducted by OCEAN-CERTAIN within WP3 and WP5 focused on address the second targeted uncertainty proposed:

*Feedbacks from the socio-economic system generated by human response to changes in food-web that result from the effects of climatic and non-climatic stressors*

WP 3 focused on the human elements of the socio-ecological system (SES) studied by OCEAN-CERTAIN, as both impacted by and in turn affecting the marine food web (including the organic elements of the biological pump), with particular reference to selected climatic and non-climatic stressors.

The WP sought to address these objectives by working directly with stakeholders in three communities adjacent to the marine areas in which OCEAN-CERTAIN's marine scientists were working. It sought to capture stakeholder perceptions of specific socio-economic systems that would provide insights about the key marine goods and services upon which these stakeholders rely and what the most important factors affecting their decisions relating to the utilization of marine resources were. The WP produced assessments of "**vulnerability**" of the three communities to changes in their marine resource base. This required, first, understanding the exposure of these communities to changes in the resource base; second, the sensitivity of the community to such changes and third, an assessment of adaptive capacity.

**The study case of vulnerability in coastal communities in Patagonia (Cochamo, Chile), Arctic (Senja, Norway) and Mediterranean (Çeşme, Turkey)**

In each of the selected three coastal communities, stakeholders from three economic sectors were sought: tourism, fishing and aquaculture. Stakeholders were consulted primarily through stakeholder workshops. Initial contact with stakeholders took place through a series of workshop that employed the participatory modeling methods of systems thinking and Bayesian Belief Networks (BBNs), described detail in many of the project deliverables (see especially Ds3.4-3.6). The research design called for workshops specific to each economic sector, as well as workshops for managers (an ingredient for the adaptive capacity assessment, described below). WP3 researchers (especially TALCA) created a general vulnerability model (D 3.2) that was used as the common vantage point for all workshops. These workshops produced mental models of socio-ecological resources as seen by each group and an analysis of the sensitivity of the factors identified as important by the stakeholders (as reported in Ds 3.4-3.6). These models subsequently served as input for the construction Fuzzy Cognitive Maps and then the **Decision Support System** produced in WP5 (Decision Support System).

The initial workshops and addition work provided insights for the improvement of the participatory model building. GRIFFITH produced a tablet application for the BBN (D.3-11); TALCA created a Game Theory application that built on the initially employed Systems Thinking and Bayesian Belief Network methodologies relying on choice experiments in order to better understand the preferences of specific stakeholder groups. This methodology was tested in a second round of Chilean workshops.

In assessing adaptive capacity, OCEAN-CERTAIN drew upon existing studies (national reports and international indices) of adaptive capacity of the countries in which the three communities were located (Chile, Norway and Turkey), but also did research with respect to adaptive capacity at the local and regional levels. WP3 researchers also examined existing public opinion polls for each country (and where available, relevant regional and local areas) to assess whether attitudes towards climate change could affect responses to climate change) (reported in D3.9). At the regional and local level, use was made of media mining to understand which marine resources issues were creating divisions in the communities that might impede effective cooperative action (included in D3.10). Governance issues were also explored in workshops with public authorities responsible for the management of marine resources, including those from the national, regional and local levels. The results of these workshops are reported in D.3.7. The overall results of the vulnerability assessments are reported in D3.10.

**Significant results to highlight**

- Comprehensive vulnerability studies of three communities not previously studied (Cochamó, Chile; Senja, Norway; Çeşme, Turkey)
    - Mental maps of socio-ecological systems, identification of key factors affecting stakeholder decision-making for 3 sectors in each of three communities;
    - New and unexpected findings in all three cases (see below);
    - Incorporation of wide (and novel) range of data/information in final vulnerability study
- New tablet application that will make the BBN methodology easier to use and produce better results;
- New game theoretical/choice experiment addition to Bayesian Belief Network (BBN-GT) methodology improved participatory modeling by strengthening the analysis of stakeholder preference structure.
- Supported development of way to convert Systems Thinking models to Fuzzy Cognitive Maps, contributing to the development of the DSS by WP5.
- Contribution to the production of model that integrates marine ecosystem and socio-economic information, and provides a generic platform for application of the scientific outcomes to other case studies, surviving the project's lifetime (WP 5)

**Chile (Patagonia)**

Many of the results of the case study confirmed the general picture of vulnerability expected from reviews of the literature (general theoretical literature or analyses at the national level). However, the local Cochamó community has displayed a level of adaptive capacity in recent years that was unexpected given the local level of socio-economic factors. Community cohesion has apparently played a role in fostering adaptive capacity. In addition, most literature ranks Chile generally high on governance, but OCEAN-CERTAIN workshops indicate issues relating to marine management that can work against adaptive capacity, particularly due to recent experiences of the salmon aquaculture industry. These aspects have been improved in the recent years as a response to important sanitary crisis in the industry. In particular stakeholders have expressed a lack of faith in the necessary political will of Chilean politicians and the monitoring and enforcement capacity of Chilean management authorities with respect to aquaculture companies. The aquaculture sector was identified by the Cochamó community as having the greatest individual impact on local ecosystems, but the local community had adapted to the presence of the Atlantic salmon aquaculture industry. The salmon aquaculture proved in general bring both advantages and disadvantages: the area, including Cochamó, benefited from industry-related infrastructure improvements, an expanded economy and increased support for social needs, but, as noted, faced challenges relating to the environmental impact of the industry.
Significant Results:

- Case study (vulnerability assessment) of a specific community in the Reloncaví fjord in Los Lagos region;
- Confirmation of many aspects of previous general vulnerability assessments;
- Finding that Cochamó has greater adaptive capacity than socio-economic factors would suggest; community cohesion has apparently played an important role in fostering adaptive capacity;
- More complete understanding of governance issues with respect to marine management produced, revealing newly-identified marine management challenges;

- Identification of challenges and benefits produced by the aquaculture industry:
- Extensive survey of residents of Cochamó to supplement workshops and other sources.

**Norway (Artic)**

The Norwegian case study, the island of Senja, is located in Troms Country. Workshops were held in the nearest large city (Tromsø) and on the island of Senja. The region hosts all three economic sectors (fishing, aquaculture and tourism) and is adjacent to the Barents Sea, one of the three areas where the natural science researchers in OCEAN-CERTAIN researchers were studying. Norway as a whole is ranked having relatively low vulnerability to climate change. It relies on marine ecological goods and services, but it is anticipated that is marine resources are likely to be only moderately affected. Norwegian fishers do not anticipate a decline in resources because of global warming; Instead, they anticipate a net gain in resources (or perhaps a shift in species) as fish move to the north in response to warming waters in the south. However, warming waters may also push aquaculture to the north, which has the potential for increasing conflict with other sectors. Norway also scores high in adaptive capacity. The case study indicated that what is true at the general level is also largely true at the level of the smaller community. Findings of the study suggest that Norwegian fishers are very adaptable, although the coastal fleet is less so than the off-shore fleet. The tourist industry proved to be less sensitive to changes in the marine resource base than anticipated, but more vulnerable to changes in general climatic conditions than anticipated: representatives were very concerned that cloud cover could increase and obscure the northern lights or affect air and sea travel to the region. The case study revealed issues relating to managerial capacity and rules and regulations not previously highlighted and which may negatively affect adaptive capacity. It also identified the divisions in the community that could impede adaptive capacity. Norwegians at the national and local level are aware of and accept the human dimension of climate change but they do not anticipate the need for much adaptation and the issues is not divisive in the community.

Significant results

- Case study (vulnerability assessment) for Senja, Norway with iterative workshop with commercial fishers one and a half year after the first workshop;
- The perceptions of the tourism sector are that they are flexible and robust and relatively non-sensitive to changes in marine resource base; they are vulnerable to changes that would affect cloud cover and hinder northern lights from being visible;
- Potential capacity issues in Norwegian coastal/marine management as well as regulatory hindrances to fishers' adaption to climate change because of the quota system in Norway;
- Fishers display long-term adaptive capacity, though not in the coastal fleets;
- Confirmation of community division over aquaculture (particularly given a scenario of an increase in aquaculture over time because of warming waters further south that moves the industry northwards) and between inshore/offshore fleets; new issues identified (net fishing); and
- Attitudes towards climate change not a divisive issue for the community.

**Turkey (Mediterranean)**

The Mediterranean is highly vulnerable to climate change, and its marine ecosystems are expected to be profoundly affected. Climate change factors are interacting with non-climate stressors, such as over-fishing and pollution to magnify the anticipated impacts of climate-change-related ocean stressors. The three marine-oriented sectors are highly important for the country as a whole, with tourism of particular importance (8.5% of GDP); fisheries and aquaculture provides 4.5% of GDP); all are vulnerable to the anticipated effects of climate change.

The adaptive capacity of the country as a whole is ranked as medium. The major problems identified in comprehensive studies lie in the realm of governance. Issues relating to political stability and political violence; voice and accountability and regulatory quality are highlighted in these studies. At the national level, climate change is not an issue that divides Turks: most Turks acknowledge the occurrence and seriousness of climate change, accept that human activity has a large role in causing climate change and are willing to take action to both mitigate and adapt to climate change.

Çeşme is located in a region (the Aegean) with a relatively high GDP and other socio-economic indicators (including good infrastructure); it is also a region where tourism, aquaculture and fishing are important components of the economy. Çeşme ranks high in its exposure and sensitivity to climate change: it hosts a large artisanal fleet and important aquaculture sites and experiences a ten-fold increase in its population during tourist season (marinas and beach-oriented hotels are particularly important). In addition, because the marine environment of the Mediterranean as a whole will be affected, the range of adaptive strategies in the marine sector is reduced, reducing overall adaptive capacity. Workshops with stakeholders indicate a number of issues that divide the community, with divisions among the three sectors in evidence (fishermen and aquaculture have the most direct conflicts of interest). Stakeholders expressed a clear need for greater synchronization in the management of the three sectors, but, research suggests that the dominant economic sector, tourism sector, has refrained from cooperating actively with the artisanal and aquaculture sectors, which are working to mitigate their conflicting issues. Stakeholders identified other factors that reduce adaptive capacity: the ability to adjust to international rules, regulations and laws; lack of investment in infrastructure and coastline management; the quality of marine and coastal planning capacity; and issues relating to monitoring and enforcement of rules, regulations and laws. Some public opinion polls on climate change show that public opinion in the Aegean region is largely in line with national attitudes and not a cause of division. It proved difficult to access and gather management authorities in Turkey, an experience that supported other findings that governance issues impede adaptive capacity in Turkey.

Significant results:

- Case study (vulnerability assessment) for Çeşme, Turkey.
- Identification of impediments to adaptive capacity with respect to divisions in the community, governance, and the wide-spread character of changes to the marine systems in the Mediterranean.
- Identification of coordination and cooperation issues among the three economic sectors
- Confirmation of literature assessments of exposure and sensitivity of the region and locality.

## Assessment, Iteration, Consilience, Integration

The main aim for WP4 was to support the exchange of knowledge and information between the different WPs. The knowledge and information exchange was to be facilitated between scientists, stakeholders and policy makers with the ambition to link together the information and data collected throughout the different target areas. With respect to the aims outlined WP4 had a central role in the project and the successful achievement of the goals set out was heavily dependent on the success of individual WPs. Workshops for knowledge and information exchange were an important component of WP4, and these took place on an as needed basis.

In order to develop key components of the socioeconomic feedback and the vulnerability assessment at NTNU, the game theory approach at TALCA and ultimately the DSS development, input from stakeholders was pivotal. WP4 engaged with the stakeholder and decision maker community at the world Ocean Council meeting in September 2014. Participants from VITO, NTNU and UiB organized a workshop entitled: Changing Oceans and industry futures. OC partners presented the rationale and main components of the project and upon completion of the presentations stakeholders engaged in participatory mapping and scenario construction run by partners from NTNU and TALCA. The workshop provided WP3 and 5 with material used in the socioeconomic analysis and the DSS. In conjunction with facilitating the collection of information and knowledge exchange within the project WP4 should also contribute to knowledge integration and scenario building. This process had the ultimate goal of feeding the relevant information into the DSS and included the integration of both experimental and modelling data. The first step of the process was to identify who the potential end users of the DSS would be, a key stakeholder profile was set up for the three target areas, the database consisted of stakeholders in the scientific community, experts from member state competent authorities, industry and business representatives, regional authorities, environmental managers and NGOs. The same individuals are potential DSS users and thus its development should include scenarios that are relevant to the stakeholders.

On the other end, it was necessary a lot of information to go into the DSS for it to be informed appropriately, which meant integrating the modelling component of OC. Partner UG was developing a chemical speciation model, partner CEFAS was working with a 3D biogeochemical model and partner UiB was using a conceptual lower trophic food web model. The conceptual model predicts that in changed conditions, also referred to as stressors, the ability of the lower trophic food web to degrade and recycle material will be modified. This in turn can alter the way in which particles are produced and exported and, depending on whether the effects are more top down (changes in predation) or bottom up (changes in nutrient availability), can also significantly influence resource allocation in the microbial food web. The experimental work was designed and carried out to explore this control of resource allocation and experiments took place in the three study areas, within WP2. The overview of the planning process and the main aims of the experimental work were included in WP4 activities, as there had to be close links between the experimental set up, the modelling work and the corresponding scenarios to be tested with the DSS. The DSS is the platform where the natural and social sciences were ultimately integrated. The natural sciences described the stressors and the changes these induce in the system which the social sciences analyzed the potential socio economic impacts response and adaptive capacity of the stakeholders. Upon completion of the project, in the framework of WP5, the DSS is operational.

## Decision Support System

The design objectives for the OC-DSS were to:

- provide a platform for science-policy integration: to capture and combine scientific expertise and local knowledge (of stakeholders and administrators) on the positive and negative impacts of climate change on the ocean food web and the socio-economic system.
- provide a generic platform for analysing and demonstrating the role of system feedback on the interactions between the natural and social subsystem.
- support the analysis and comparison of different policy alternatives aimed at reducing the negative impact of the interactions identified during stakeholder exchanges in the project.
- support the communication and dissemination activities related to objectives 1-3 and science-policy exchanges related to the project overall theme.

The OC-DSS general user interface (**Figure 1**) has been designed to provide quick access to the settings of stressor scenarios (climate change, ocean acidification, and fishing pressure), policy alternatives (for example investment in tourism), and the selection of which social-economic and environmental indicator time series to generate for the combinations of scenarios and policy options. The scenario and indicator settings are read from database tables and are easily adapted, replaced, extended, or custom-defined.

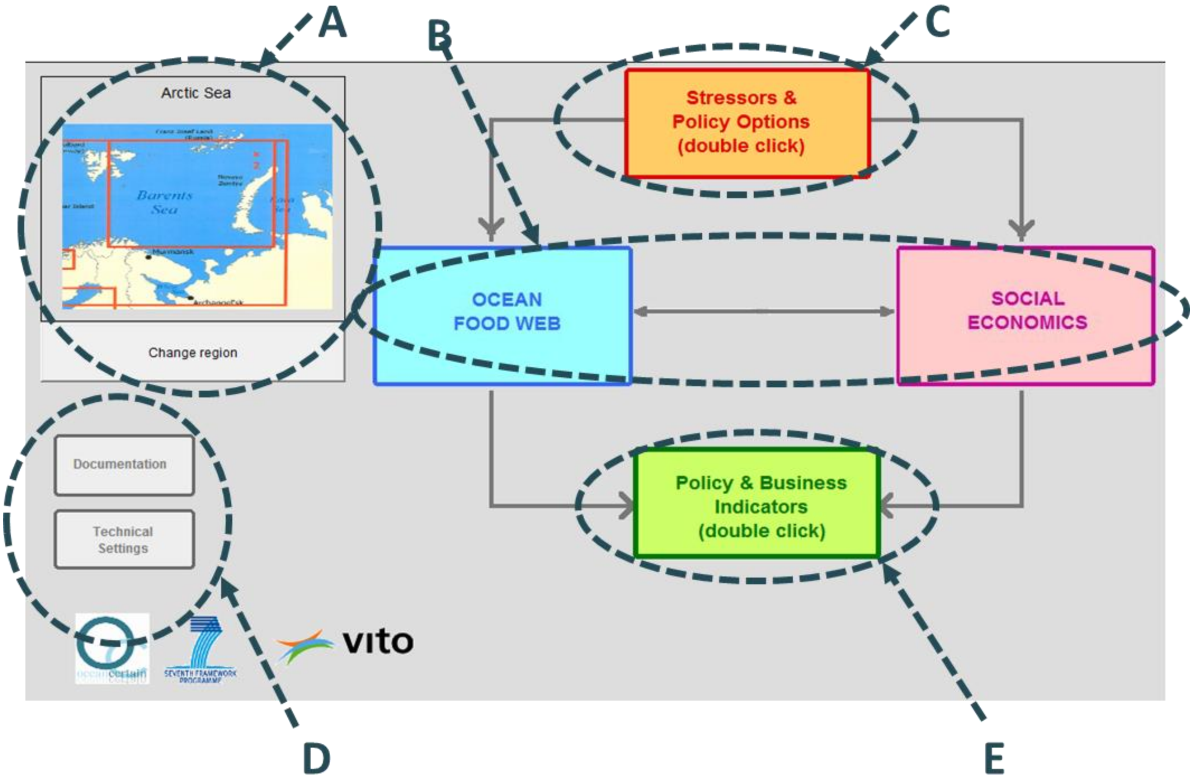


**Figure 11** Front-end interface of the OC-DSS with control options for selecting the case study area (A); access to the model (B); scenario and policy settings (C); technical settings and documentation (D); and the policy indicators (E).

The OC-DSS works with a time step of one month and a simulation period for the years 2000-2100. The time step and period can be changed by replacement of the table contents as these correspond to the time step and simulation time frame of the input data used. So if higher resolution data with a daily or hourly time step are available for a different simulation period these can still be used without problems provided the relevant tables using time series of data are correctly redimensioned. However, a time step of one month or even a year seems reasonable for typical end users in view of the typical time horizon for climate change impacts (50-100 years). Scenarios, models and indicators are managed through **database** tables. These provide the input used by the model, and can be used to store results: a general database, and three case-specific databases one for each of the OCEAN-CERTAIN case study areas ("DBArctic", "DBPatagonia" and "DBMediterranean"). The structure (number and type of tables) of the region specific databases is identical but the contents of the tables is region specific. More case studies can easily be added to the system provided because the internal database structure for all regions is identical. The database GENERAL contains the information common to all case studies and is only used by the DSS component that selects the case study/region. Hierarchical "H-blocks" are used to structure the DSS with a multi-layer design.

A combination of three techniques is used the findings and knowledge of the behavioral and natural sciences in the DSS: a **component-based architecture** (de Kok et al. 2015), **meta-modelling** to represent the biophysical processes described by the components, and **System Dynamics** (SD) modelling to represent narrative scenarios derived from local knowledge (Figure ).

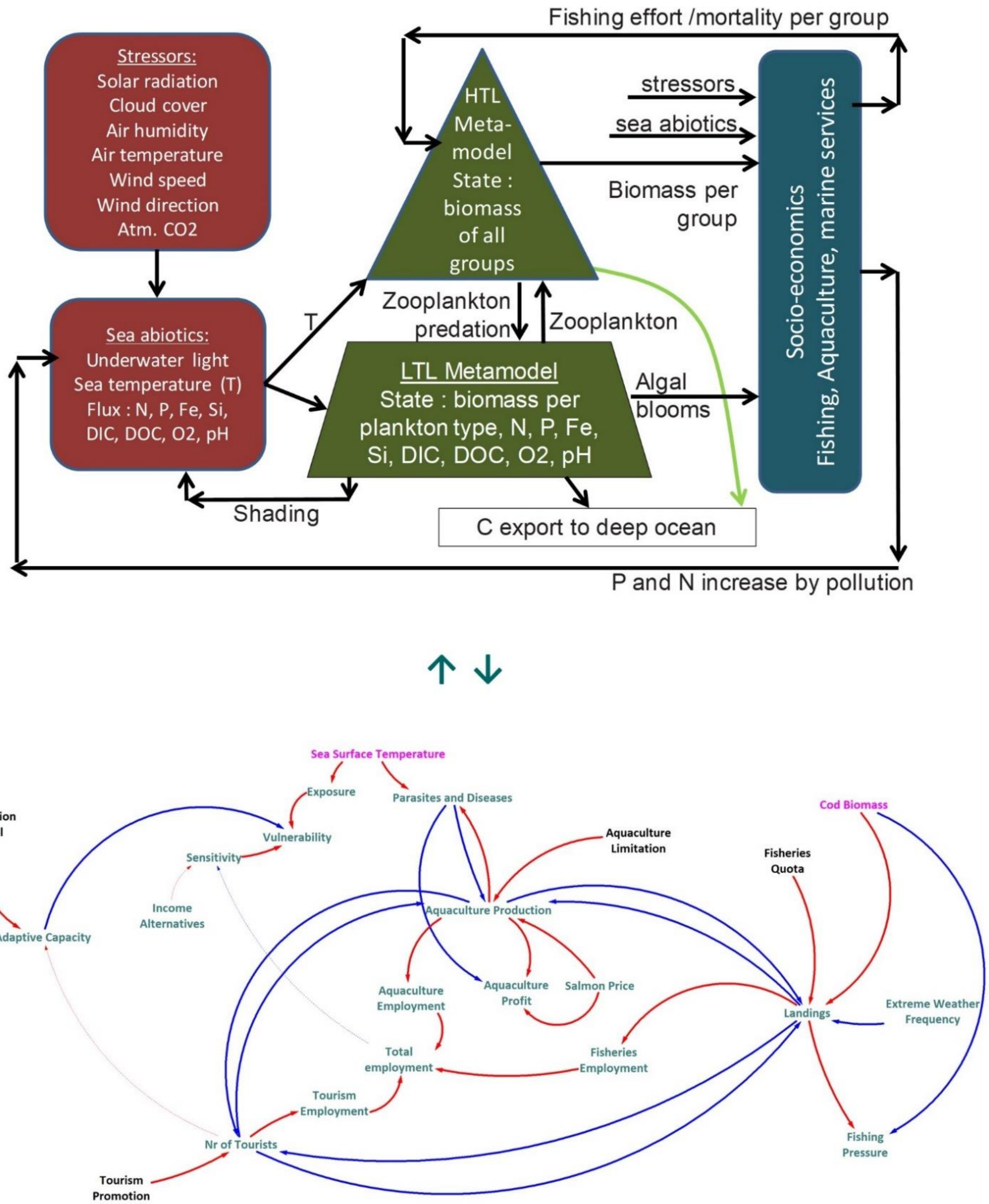


**Figure 12.** Integration of scientific and local knowledge in the OC-DSS.

Together, the combination of a meta-model for the Ocean Food Web, a system dynamics model for the social-economic system and a custom-designed graphical user interface based on ExtendSim® make the OC-DSS a powerful and generic tool for the evaluation and demonstration of policy alternatives under different climate and social-economic conditions. The OC-DSS is mainly intended for policymakers rather than the marine industry. Four types of use are envisaged for the instrument:

- **demonstration** of the impacts of climate change and human-induced stressors such as ocean acidification and overfishing on of key environmental and social-economic indicators
- evaluation, comparison and **ranking of policy alternatives** to mitigate these changes
- **support exchanges** and discussions between natural and social scientists who collaborate in the domain of climate change, the coastal environment, and coastal economy
- applications with similar objectives, but for **new case studies**, not included in OCEAN-CERTAIN or in different problem contexts (generic use)

The **computational efficiency** of the OC-DSS is large due to the hybrid combination of meta-modelling and System Dynamics: typical simulations take less than a second. This makes the tool useful for interactive use and participatory modelling exercises (Tiller and Richards 2015; Tiller et al. 2016; Voinov et al. 2016) provided these are well prepared and lead by experienced moderators. Stakeholders are brought together to compare and discuss different policy alternatives and examine the impacts of economic activities on the ocean food web and vice versa. A second strength of the tool is the generic **flexibility** of the design. The outcomes of workshops focusing on the qualitative feedback structure of the system can be combined with scientific models and data with moderate effort. End users are not confronted with the full complexity and detail of models and data, but have indirect control of the modelled scenarios (custom-defined interpolations) by the use of metamodeling.

At a second level of hierarchy the DSS users are given quick access to the settings for various scenarios, consisting of different combinations of stressors and policy options (**Figure 13.**) and the biophysical and social-economic indicators (**Figure 14.** ) resulting from the choices made for the DSS simulation period (2000-2100).

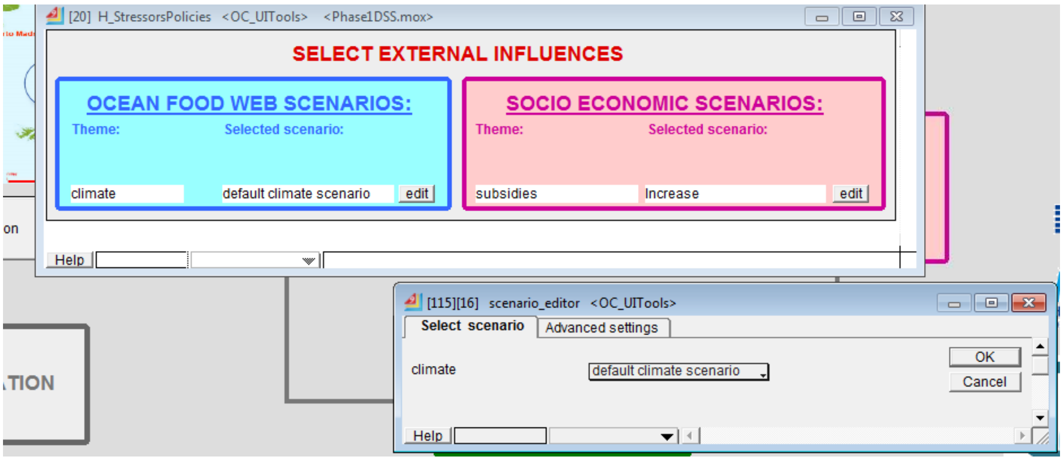


**Figure 13.** Selecting stressor-policy combinations (scenarios).

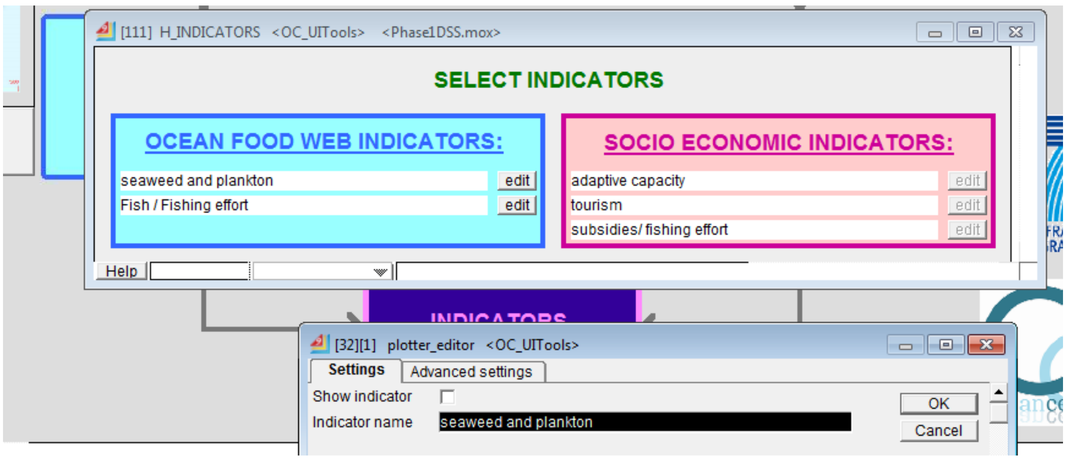


**Figure 14.** Selecting policy indicators.

As an example changes in tourism promotion directly translate to the number of tourists and the employment in the tourism sector. As tourism is more labour intensive than fishery and aquaculture, an increase in employment in tourism will increase total income for the region and therefore adaptive capacity. The latter will decrease vulnerability of the region. As we assume in the model that the sectors have a negative impact on each other, an increase in tourism will result in a decrease of aquaculture production and therefore employment. **Figure 15**. shows more examples policy indicator time series produced with and available in the DSS.

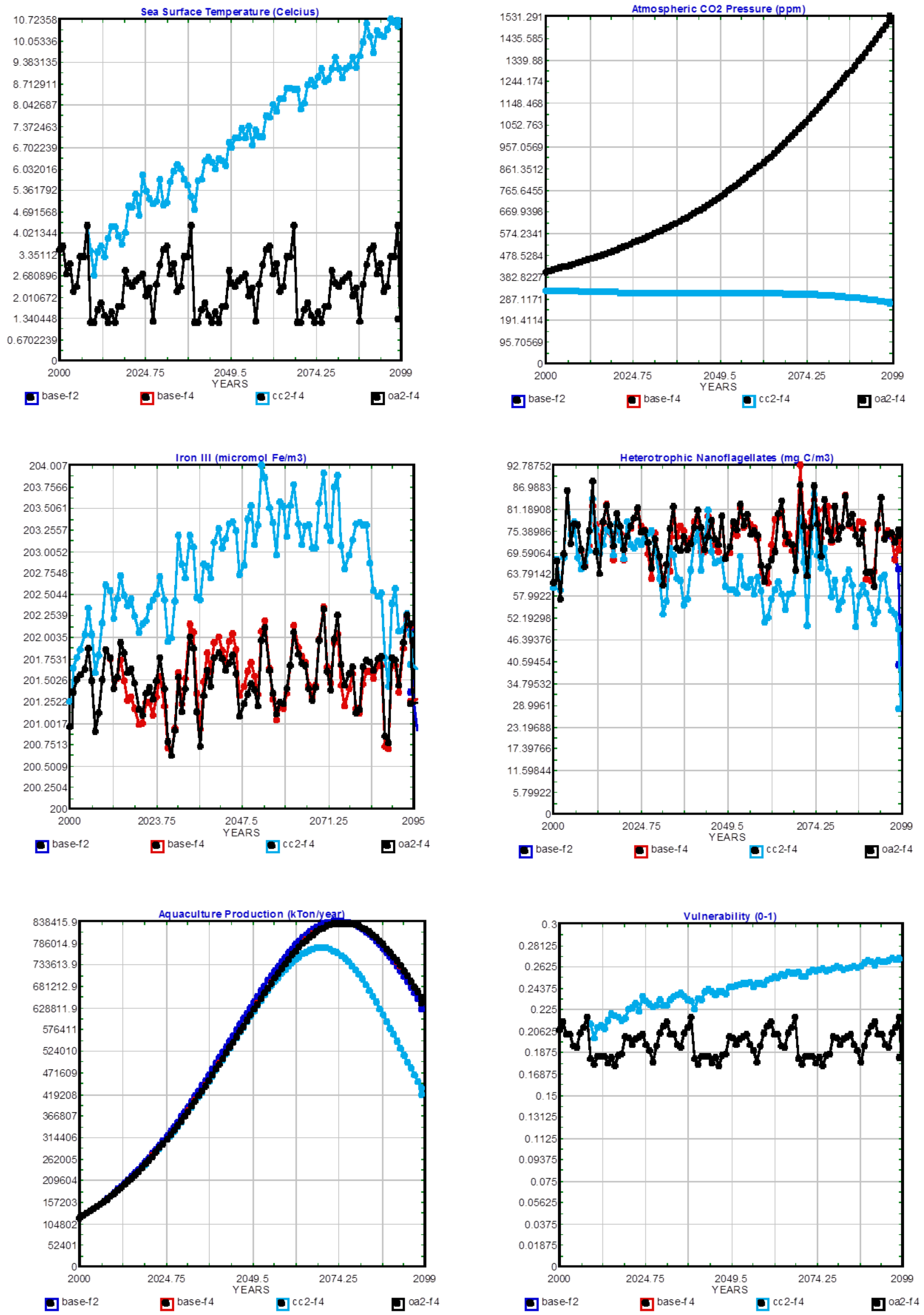

**Figure 15.** Examples of scientific and policy indicators for different social-environmental scenarios: Business-As-Usual (BAU) and low fishing pressure (F2), BAU and moderate fishing pressure (F4), accelerated Climate Change (CC2) and moderate fishing pressure (F4), and Ocean Acidification (OA) and moderate fishing pressure (F4).

Finally, software components are independent units which can perform tasks, and can be replaced or updated if necessary (de Kok et al. 2015; Rizzoli et al. 2008). The components are fitted with an interface allowing exchange with other components through, in- and outgoing connectors or, indirectly, through a database. **Figure** shows the example of the Metablock component which is, to a certain extent, generic: it can be used to represent the different modules. A single component for the LTL, HTL and abiotic submodule is used in the tool; the functionality changes depending on the selected option in the user dialogue of this generic component. The exchange with other components is handled with so-called array connectors, combining vectors of data to be exchanged. The type of information exchanged through these connectors is defined by the structure and contents of tables defining variables and the numerical data exchanged. The advantage is that the component does not require adaptations such as the relabelling of existing connectors, or adding or replacement of connectors when the number or type of variables, which are not clear or even unknown at the time of development of the component, changes.

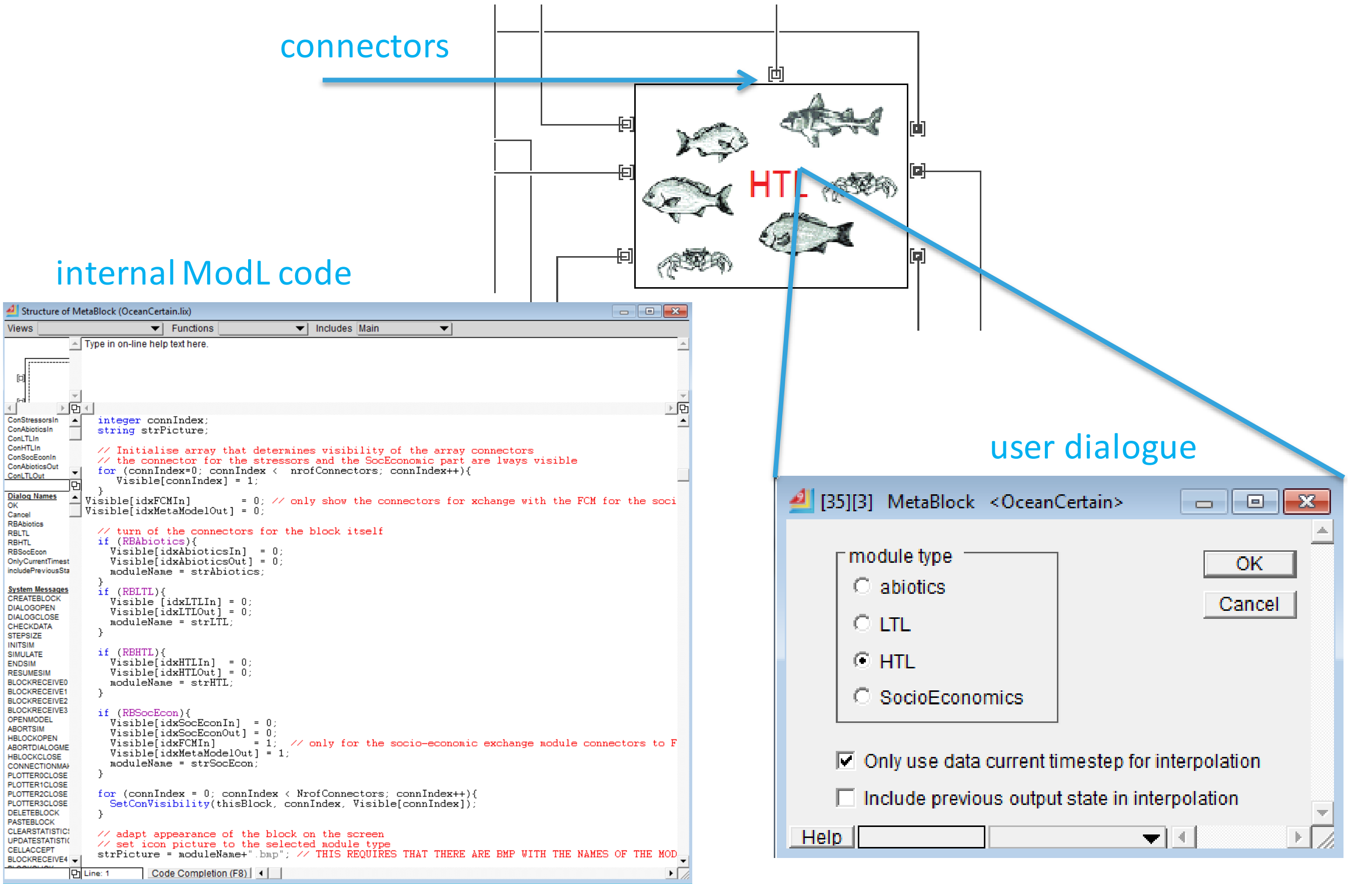


**Figure 16.** Example of a generic Metablock component used in the OCEAN-CERTAIN DSS.

Here, the exchange of data primarily takes place through the in- and out-going connectors. The components, or modules have been designed to fulfil particular functions in the tool. For this example, the component is designed to translate combinations of stressors (weather conditions, …), abiotics (N, P, …) and Higher Trophic Level (HTL) conditions (for example predation by fish) into LTL-related variables used by the other components. Ideally, changes inside well-designed and well-documented generic software components will not result in the need to change other components that are using or dependent on the component that is modified, a feature referred to as *encapsulation.*

## Potential impact, main dissemination activities and exploitation of results

WP3 has produced three case studies of vulnerability (Cochamó, Chile; Senja, Norway; and Çeşme, Turkey) in distinctive socio-ecological systems. Case studies are depth studies that allow the researcher to gather specific knowledge about the importance of causal mechanisms, path dependency and critical junctures. They yield detailed information about individual instances of a given phenomenon, but also contribute to general theory building and theory building, much in the same way that studying selected marine systems draws upon and contributes to the general understanding of ocean systems and processing, while capturing and responding to the unique configurations of a local system. The work of WP3 accordingly provides portraits of communities that should assist decision-makers and stakeholder in assessing the potential strengths and weaknesses of these communities in the face of change to the marine resource base upon which they rely. The findings of the Chilean case in particular -- highlighting the potential of strong community cohesion to drive adaptation – can contribute to more general theory-building regarding adaptive capacity. The Norwegian case suggests that some of the biggest hindrance to local adaptation can be rules imposed from above. Research done into all cases indicates that stakeholders are very aware of climate change and they anticipate changes in marine and other resources. However, they have very practical approaches with respect to responding to it: their responses are directly impacted by their assessments regarding the degree to which they will be affected and by their sense of agency (whether they can do anything about it).

WP3 relied heavily upon stakeholder workshops, as do an increasing number of research projects and management schemes. Because these are both increasingly common and increasingly important, the two innovations with respect to workshop methodology should have an impact beyond the OCEAN-CERTAIN project. The first innovation is TALCA's game theoretical addition to the Systems Thinking and Bayesian Belief Network methodology as developed by GRIFFITH. This addition, in the form of a choice experiment, can add significant dimensions to our understanding of the preference structure of local stakeholders. This in turn assists decision-makers in understanding how to better respond to stakeholder's needs. It also helps decision-makers, scientists and those modeling marine and other natural systems to anticipate how humans are likely respond to change in the marine resource base; this in turn provides insights into feedback loops from human to natural systems.

The work of WP3 provided substantial input to the work WP 5, which had the task of creating a decision-support system. The development of such a system, which could be used by both management and stakeholders, can help both visualize the results of management decisions for key resources.

WP3 researchers kicked off the project by holding a workshop issues affecting the three sectors at the annual meeting of the World Ocean Council, in New York City in October 2014. This provided an international venue to inform researchers and industry about the project. The work of WP 3 relied heavily upon workshops held with both researchers and with authorities responsible for marine and coastal management for the areas of study (Cochamó, Chile; Senja, Norway; and Çeşme, Turkey). These workshops produced much of the data for the WP's analyses, but they also provided opportunities to tell stakeholder groups about the project. Dissemination of information to stakeholders typically took place, first, as OCEAN-CERTAIN researchers made contact with potential stakeholders, stakeholder groups and local, regional and sometimes national marine and coastal management authorities. In order to convince people to participate, researchers had to describe the project and its objectives, which served to spread word about the project. Second, when workshops took place, workshop facilitators explained the project in more depth. Several workshops were held in the three countries. Six "first round" workshops were held in Norway, three in Chile and three in Turkey. In Chile and Norway, researchers returned to the communities in order to report back on the findings of the project and also to apply the new choice experiment addition to the methodology. In Chile, researchers also carried out an extensive survey of the locality (Cochamó) which required researchers to inform potential participants about the project.

WP3 researchers have also presented papers and posters at international conferences and seminars, and have published some results. Among the conferences attended are: International Studies Association (several years); IMBER (Integrated Marine Biogeochemistry and Ecosystem Research, in Bergen in 2014); the North American Association of Fisheries Economists (Baja, Mexico, 2017); the International the Henningsvær seminar, in Henningsvær, Norway in 2017; and the 8th International Congress on Environmental Modelling and Software, July 10-14, Toulouse, France (published in conference proceedings). Journals include *Frontiers in Marine Science.* Results are also published in conference proceedings of the 8th International Congress on Environmental Modelling and Software. Future work is planned; articles will be submitted to journals such as *Marine Policy, Ocean and Coastal Management and Global Environmental Politics*.

The app OceanCPT has, over the period of the project, been developed for iPad (iOS O/S) using Apple's Xcode software development kit. It is limited to use on iPad devices. OceanCPT underwent alpha-level and beta-level testing in meetings and workshops external to the OCEAN-CERTAIN project. Feedback on its design and performance were used to refine the app to its current state. Currently, the App is still under review on the Apple's App Store (iTunes Connect) but the IPA file is available for uploading to provisioned tablets. The accompanying report (D3.12) was submitted in April 2017.

Upon completion of the project the options from extracting knowledge from different sources has been explored primarily in WP1. The conceptual model has been improved with the outputs having been presented in scientific conferences and published in peer reviewed journals connected to WP2. The ecosystem model has been applied to the different ecosystems underlining the sensitivity of each study area to changes. All the necessary knowledge exchange throughout the course of the project was facilitated through WP4 which ultimately led to the successful completion of tasks in WPs 1-3 and 5. In a project as interdisciplinary as OCEAN-CERTAIN there was most assuredly a need for a WP with the functions of WP4. The concept was new and navigating all the exchanges between work packages was a challenge for all involved parties. However, this WP contributed to improving our integrative capacity and provides insights as to how to conduct these integrative activities in future multi-disciplinary projects.

**The Ocean-Certain Decision Support System (OC-DSS)**

Together, the combination of a meta-model for the Ocean Food Web, a system dynamics model for the social-economic system and a custom-designed graphical user interface based on ExtendSim® make the OC-DSS a powerful and generic tool for the evaluation and demonstration of policy alternatives under different climate and social-economic conditions. Four types of use are available with the instrument:

- **demonstration** of the impacts of climate change and human-induced stressors such as ocean acidification and overfishing on of key environmental and social-economic indicators
- evaluation, comparison and quick **ranking of policy alternatives** to mitigate these changes
- **supporting exchanges** and discussions between natural and social scientists who collaborate in the domain of climate change, the coastal environment, and coastal economy
- applications with similar objectives, but for **new case studies**, not included in OCEAN-CERTAIN or in different problem contexts (generic use)

The usefulness of post-project access to the OC knowledge (Project Task 5.7) for the identified target groups (tourism, aquaculture, and fisheries sector) and dissemination/promotion of the OC-DSS depends on a number conditions, all of which need to be fulfilled:

a. The target groups should be familiar with the objectives of the OCEAN-CERTAIN project and Consilience methodology for science-policy and natural-social science integration.

b. The project methodology, generic design concept and architecture of the OC-DSS should be made clear. Where relevant, used can be made of references to presentations, newsletters, conference papers etc.

c. Convincing tutorial examples and simulations to demonstrate the potential of the tool are needed. A proper scientific and policy interpretation should be added to these examples. These scenarios should be available for different types of DSS users: scientific and non-scientific users will find different control options and performance indicators relevant

d. The design of the OC-DSS should be transparent and user-friendly, hiding of technical aspects for advanced use (such as replacing the underlying biophysical model data) without limiting the key functionalities.

e. The user manual should be self-explaining and end-users should be able to ask for support in case of scientific or technical questions.

f. Last, but not least, resources for adaptations and improvement of the DSS (resulting from feedback of users or not) should be made available. Some central coordination of these changes is to be preferred.

Existing presentations and project deliverables are useful in this respect, but should be completed with a clear dissemination strategy to explain how the OC web site can be used to meet these conditions (see project deliverable D5.8). To ensure a durable and growing interest in the OC-DSS as a generic tool for analysing the climate-driven interactions between the ocean food web and coastal communities the dissemination can be organised in three steps:

1. The Final Project Meeting served as starting point; the design and functionalities of the final DSS tool were demonstrated and discussed by the project partners. The user-friendliness and generic applicability to other problem contexts were highly appreciated. The general recommendation was to add tutorial examples, upgrade the DSS for the second case study (Patagonia) and identify more potential target groups. In addition, the OC consortium will publish a book, with a chapter dedicated to the DSS. A peer-reviewed SCI paper will be published with the WP5 coordinator as main author, based on the iEMSS2016 conference proceedings.

2. An open registration system will be set up to control the access to well chosen, documented and validated examples on the project website, together with the DSS installation files. This is best done following the meeting, so that the feedback can be used for fine tuning of the functional design of the DSS. Both the DSS and source code will be made available for registered users through the project web site.

3. Selected scientific and other dissemination channels such as conferences, public meetings, online channels etc. are used for broader promotion of the OC-DSS and project. This activity can be supported with online and hardcopy flyers, based on the design used for the poster. Here it is relevant to mention that the WP5 coordinator has been invited as guest speaker at the Gordon Research Conference on Ocean Biochemistry, which will be held in Hong Kong in July 2018. The focus of the invited presentation will be on the challenge of bridging the gap between science and policy, and the translation of scientific results into practical and flexible instruments to support communication and decision making.

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