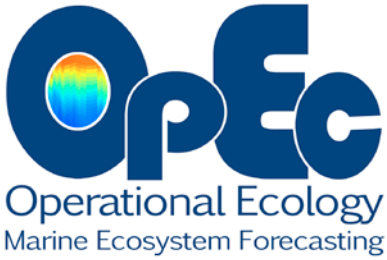

OPerational ECology

Ecosystem forecast products to enhance marine GMES applications

DG SPACE

Collaborative Project - small or medium-scale focused research project

Project Number: 283291

Deliverable No: D7.4		Workpackage: 7	
Date:	4/11/2013	Contract delivery due date	Dec 2014
Title:	Roadmap for the sustainable implementation of operational ecology		
Lead Partner for Deliverable	Danish Meteorological Institute		
Author(s):	She J. and I. Allen		
Dissemination level (PU=public, RE=restricted, CO=confidential)			PU
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OPEC Overview

"OPEC provides an enhanced capability to predict indicators of good environmental status in European regional Seas"

The OPEC project (Operational Ecology) will help develop and evaluate ecosystem forecast tools to help assess and manage the risks posed by human activities on the marine environment, thus improving the ability to predict the "health" of European marine ecosystems. The programme will focus on four European regional seas (North-East Atlantic, Baltic, Mediterranean and Black Seas) and plans to implement a prototype ecological Marine Forecast System, which will include hydrodynamics, lower and higher trophic levels (plankton to fish) and biological data assimilation.

Products and services generated by OPEC will provide tools and information for environmental managers, policymakers and other related industries, laying the foundations for the next generation of operational ecological products and identification of knowledge / data gaps.

OPEC will use the EU's Global Monitoring for Environment and Security Marine Service as a framework and feed directly into the research and development of innovative global monitoring products or applications. This in turn will advise policies such as the European Marine Strategy Framework Directive and Common Fisheries Policy, as well as the continued monitoring of climate change and assessments of mitigation and adaptation strategies.

www.marineopec.eu

Content

Executive Summary

The aim of this document is to propose a roadmap for the transitioning of OPEC research into the marine core service. There are three objectives of the roadmap;

- *To identify and work with stakeholders to determine the user requirements for the system.*
- *To transition to an operational status in the Marine Core Service, OPEC model systems and data products, in terms of both quality assurance (monitoring administrative and procedural activities) and quality control (verification of data products)*
- *To determine the future R&D requirements to deliver the full range operational ecology products.*

Relevance to Policy

OPEC services have the potential to feed into several key policy areas, such as the European Marine Strategy Framework Directive and Common Fisheries Policy. By providing information on the state of the past and current environment for key indicators related to MSFD Descriptors, regional and national stakeholders will be better able to plan, monitoring and report on their waters. Products and services generated by OPEC will provide information for environmental managers, policy makers and other related industries, laying the foundations for the next generation of operational ecological products and identification of knowledge gaps.

1. Introduction to Operational Ecology in Europe

1.1 Operational Ecology

Operational ecology (OE) aims at systematic and operational provision of quality assured data and information on the status of marine ecosystems (environment, low trophic and high trophic levels) to stakeholders through integrating research, operation and service. The OE data products are generated from remote sensing and in-situ measurements and marine ecosystem models with data assimilation for the past (reprocessed long-term observation time series and reanalysis), current and recent (analysis and updated rolling reanalysis) and future (short-term/seasonal/decadal forecast and scenario projections). The OE information products are value-added ones, such as ecological indicators and descriptors (as defined in MSFD implementation plan) and seasonal/annual marine ecosystem status reports, derived from the OE data products.

The relationship of the OE Research-Operation-Service is shown in a flowchart in Fig. 1. The objective of the OE Research module is to develop state-of-the-art OE platforms of monitoring, modelling and assessment. With inputs on the service and service data requirements from the OE Service module, the OE Research will firstly identify the corresponding scientific and technical requirements for the next generation monitoring and modeming platforms as well as a roadmap for implementing the research and development. The content of the OE research covers, but not limited to, the optimisation of monitoring platforms/networks and marine ecosystem models, efficient combination of the two

through data assimilation, technology to assess and reduce the product uncertainty, and methodology and tool development for the integrated ecosystem assessment and service.

The objective of the OE Operation module is to generate quality-assured data and information products on an operational basis by using the platforms developed in the OE Research. It includes implementation of the platforms, calibration and operational verification of the platforms and products and operational maintenance of the dataflow (quality control of raw data, pre-processing, historical states reconstruction, analysis, forecast and projection, value-added post-processing).

The objective of the OE Service module is to ensure a user-driven approach. It includes timely and effectively broadcast and dissemination of the data and information products generated in the OE Operation to the stakeholders, facilitation of user uptake, down-stream services, user requirements/feedbacks/verifications, specification of service evolution strategy (service and service data requirement, technical requirement) and implementation plan together with the OE Research and Operation modules.

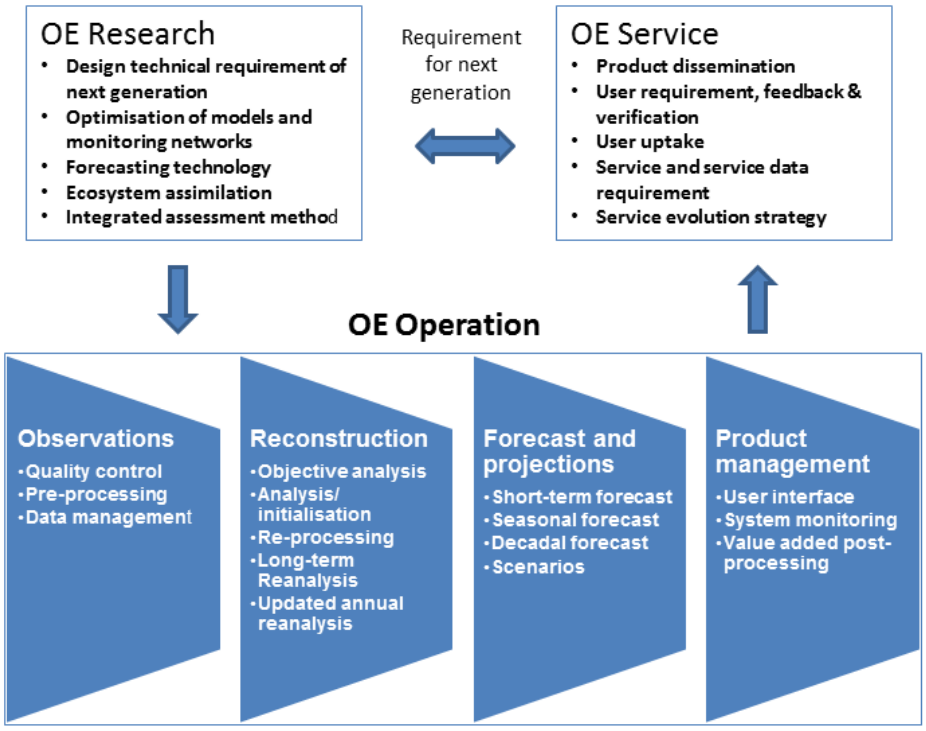

Figure 1. Flowchart of the Operational Ecology

1.2 Copernicus Marine Service – implementation of the OE

In the past decade, Europe has implemented a program of Global Monitoring for Environment and Security (GMES, currently renamed as Copernicus), aiming at a provision of operational services based on the earth monitoring. The Copernicus Marine Service is one of the three fast track services which aiming at providing quality-assured operational data and information products for both physical ocean and marine ecosystems. A pre-operational

service has been developed through EU FP6/FP7/Horizon 2020 project series of MERSEA, BOSS4GMES, MyOcean I, II and Follow On (Bahruel et al. 2009). Currently through MyOcean Follow On, the Copernicus Marine Service provides data and information services on both physical and biogeochemical parameters for the global and European regional seas (Arctic, Baltic, NW Shelf Sea, NE Shelf Sea, Mediterranean Sea and Black Sea).

Major user application areas are Coastal environment, Marine safety, Marine resources and weather and climate forecast. The Marine resource user areas are based on the biogeochemical products provided from MyOcean which include satellite and in-situ observations at near real-time, reprocessed long-term satellite observations and forecasts of biogeochemical parameters in lower trophic level up to 10 days. Biogeochemical analysis and reanalysis by using data assimilation is currently not a practice in the operational production. This is regarded it as a state-of-the-art of operational implementation of European OE service.

Based on the quarterly service status report, MyOcean has more than 3000 users. However the usage of MyOcean biogeochemical model products is much less than the physical model products. This may be caused by many factors such as concern of uncertainty in the model products, lack of interesting ecological products in relevant time scales such as seasonal, inter-annual and decadal and value-added products such as ecological indicators.

Next phase of Copernicus Marine Service will be full operation mode from April 2015 – March 2021. Mecator Ocean is the entrusted entity of the European Commission (DG Enterprise) to implement the Service. They will undertake a tendering exercise to appoint the delivery partner for the regional production centres (Arctic, Baltic, NW Shelf, Mediterranean and Black Seas), MERCATOR Ocean will be responsible for the provision of global and SW Shelf Sea (IBI region). There will also be a separate procurement focusing on the coupled global atmosphere-ocean model system and multi-model ensemble global ocean reanalysis. The future of the Black Sea system is unclear due to political situation in the Ukraine, the lead institute being based in Sevastopol. It is also anticipated that there will be funding opportunities for R&D activities later in 2015.

Currently in MyOcean, there is a process by which new or updated products are introduced which involves a request for change going into the central service management team. It is in theory driven by the user needs, for example the recent addition of hourly products to the North West Shelf forecast and 1 nautical mile resolution Baltic Sea forecasts as the result of a user workshop. Alongside evaluating the user requirement there is also a requirement to look at system dependencies (i.e. if a change has a knock on effect to other products) and also whether the product is integrated into the system. So if the product coming from the same production chain as a present product that is straightforward but if the proposed product that isn't well integrated with other systems it may be difficult.

The mechanism for introducing a new service (product) into the operational Copernicus Marine Service as it moves into its operational mode may of course evolve, but it appears the ultimately it is but that is down to the judgment of those managing the project.

1.3 OPEC – the OE research for next generation platforms

The OPEC (the OPerational ECology project) was funded to develop and evaluate ecosystem forecast tools. To this end OPEC has developed prototype ecological marine forecast systems for European seas, which include hydrodynamics, lower and higher trophic levels (plankton to fish) and biological data assimilation. The OPEC tools will help to assess and manage the risks posed by human activities on the marine environment, thus improving the ability to predict the "health" of European marine ecosystems.

Ecosystem models have a key role to play in the development of the evidence base that underpins future policy and regulation. It is not possible to answer complex policy or regulatory questions or assess the impact of management measures without considering dynamic ecosystem feedbacks and responses to external pressures, which can only be achieved using models. Despite this need, the use of ecosystem models in policy and regulation is often limited as modellers are isolated from the decision makers that need model-derived products. The lack of dialogue between communities means that there is limited understanding of how models can be applied to policy and regulatory questions, a lack of confidence in model-derived products, no visibility of models or access to model-derived products and no assurance of quality, robustness and transparency of models. We assess how to maximise the utility of ecosystem modelling for policy and regulation, using the UK ecosystem modelling capability as an example. Europe has a broad capability in ecosystem modelling, but there are only a few good examples of use of ecosystem models in policy and regulation. Challenges for the uptake of ecosystem models include: producing the right information, building confidence in models, visibility of and access to model products, and the need for targeted development of ecosystem modelling capability. A number of policy and regulatory issues can be addressed now including attribution of change to underlying drivers, integration of models and monitoring to develop more efficient monitoring programmes, assessment of indicators and the interactions between MSFD descriptors, and the cost-benefit of legislation.

OPEC provides information on the past, present and future states of the marine ecosystems of the North East Atlantic, along with the Black, Baltic and Mediterranean Seas. Reanalysis hindcast simulations use data assimilation to blend models and observations to provide a description of past states, trends and changes and assess the effectiveness of marine observational systems. Rapid Environmental Assessment simulations again blend model and observations to provide the best available estimates of the current state of the ecosystem. Finally seasonal forecasts have the potential to provide continuous predictions of potential future states of marine ecosystems. OPEC has demonstrated that its model systems have skill at seasonal timescales. This needs to be further explored in a pre-operational mode. The aim of is document is to define the strategic rationale for transitioning the OPEC prototype operational ecosystem service to the operational centres of the marine core service.

1.4 Capacities developed by OPEC

The vision for the OPEC project is to provide a range of data products describing the past (historical reanalysis simulations), present (Rapid Environmental Assessment (REA) of the current state of the system) and future (seasonal forecast) states of European marine

Ecosystems. The emphasis is on providing information which describes the environmental status of marine ecosystems (e.g. Indicators, habitat descriptions), intermediate services (e.g. Nutrient budgets, primary production) and final services (e.g. fish stocks).

The OPEC project has developed 4 new services with the potential to be implemented in the Marine Core Service. A prototype of each of these products has been implemented in the NE Atlantic, Baltic Sea, Mediterranean Sea and Black Sea regions as follows;

Reanalsysis hindcast for the period (1990-2020). These simulations provide a baseline estimate of the state of European marine ecosystems, allowing the determination of climatological seasonal cycles, inter-annual variability and trends for a range of key ecosystem variables.

- **NE Atlantic**: Coupled hydrodynamic (POLCOMS) ecosystem model (ERSEM), with data assimilation of satellite ocean colour (EnKF) and offline simulation of off line HTL / fisheries using Ecopath with Ecosim and a size spectra model *(PML, Cefas).*
- **Baltic Sea**: Coupled hydrodynamic (HBM) ecosystem model (ERGOM), with data assimilation of in-situ optics and nutrient profiles (nudging method) and offline simulation of off line key fish commercial species (Cod, Sprat, Herring) using SMS. *(DMI, DTU)*
- **Mediterranean Sea**:
    a. Coupled hydrodynamic (POM) ecosystem model (ERSEM), with data assimilation of ocean colour (SEIK) and offline simulation of anchovy in the N. Aegean Sea using an IBM. *(HCMR)*
    b. Offline hydrodynamic (NEMO, My ocean operational model), ecosystem model (BFM), with data assimilation of satellite ocean colour (4D var)) and offline simulation of off line HTL / fisheries in the Adriatic Sea using Ecopath *(OGS)*.
- **Black Sea**: Coupled hydrodynamic (POM) ecosystem model (BIMS_ECO) and offline simulation and offline simulation of off line HTL / fisheries in the Adriatic Sea using Ecopath *(METU)*.

Rapid Environmental Assessment (rolling hindcast or reanalysis of recent past); the integration of operational observation networks and operational ecological model provides a valuable and efficient, method of adding value to the monitoring of ecosystem properties. The OPEC REA experiments have demonstrated that coupled oceanographic/marine ecology models can be operationalized combining model with observations to interpolate and/extrapolate experimental observations to areas and time periods not covered by existing observational networks. In addition REA's provide an indication of ecosystem properties which cannot be measured in near real time (e.g. phytoplankton species) or are difficult to observe (e.g. foodweb structure). Such estimates can be update in quasi real time, by exploiting the causal relationships which constrain the dynamic of those properties to those of measured properties (e.g. a model which produce skilled assessment of nutrients and chlorophyll is likely to produce reasonable estimates of primary production and,

possibly, of secondary production). The REA can be undertaken with all the regional model system.

Monitoring system assessment; OPEC has developed tools to assess the effectiveness of current operational marine biogeochemical monitoring network in European Seas for the purpose of operational ecology. The methodology of quantitative assessment of physical monitoring networks, which was developed in EU projects ODON and ECOOP, is effectively applied to assess the biogeochemical monitoring networks in Baltic, NE Atlantic, Mediterranean and Black Sea. The technique allows the assessment of the adequacy for operational forecasting and rapid environment assessment of monitoring networks.

Potential for seasonal forecast; The predictability of a model is influenced by various factors, including initial conditions, external forcing functions (e.g. meteorological forcing, open boundary conditions, freshwater and nutrient inputs) and model process descriptions and parameterisations. Five model systems have been assessed; two in the Mediterranean, one in the NE Atlantic, one in the Black Sea and one in the Baltic Sea. A common experimental approach was followed in each of the systems to assess the skill of seasonal forecast on a time scale of months/seasons and examine the sensitivity to initial conditions. In the common experiment, the skill of three-month seasonal forecast simulations over 2007, initialised from the re-analysis, was assessed against the re-analysis climatology. Additional experiments were defined, as appropriate per region, to explore the impact of changes in meteorological forcing, the sensitivity to winter nutrients and large-scale climatic indicators, such as the NAO signal. Predictability experiments showed that initial conditions provided from the assimilation experiments and used for the initialization of the seasonal forecasts, produce an improvement in model projection but information on spatial patterns is lost quite quickly, evidencing the need of assimilating surface chlorophyll data at a time frequency higher than monthly. To represent model uncertainties, ECMWF downscaled forecast ensembles were used in the Baltic Sea, while for the Mediterranean, an ensemble of atmospheric perturbations was generated using data assimilation techniques.

The downscaled ocean and ecosystem forecast ensemble showed a better prediction skill than the climatology on a seasonal scale, although this decayed with time. A multi-model ensemble approach is foreseen as a final solution for forecasting pan-European regional sea ecosystems in seasonal or longer time scales.

In addition OPEC has developed the following tools which should be of benefit to the COPERNICUS MARINE SERVICE;

- An open source webGIS Data portal, which allows users to visualize, plot and download large spatial-temporal data sets.
- A model benchmarking tool, for the automated validation of numerical simulations available as open source python scripts.

The OPEC project has provided a robust evaluation of the regional ecosystem forecast models, demonstrating their ability to provide information of past and present ecosystem states. We have also demonstrated the potential to make seasonal ecosystem forecasts. Our aspiration is to maintain transition these systems into the operational suites of the Copernicus Marine Core Service.

2. Development of the strategy

The OPEC consortium prepared a draft strategy in autumn 2013, based on internal consultation and consultation with the OPEC PI who was also a MyOcean Board Member Jun She (DMI). This document was provided for discussion at the 2nd project review (Athens 2013). The reviewer commented that "It gives a roadmap towards a sustainable system, but for the final version it should also include some thoughts indicating responsibility and funding through the three stages suggested". The document was then sent to the MyOcean for consultation. We were promised that it would be presented to the MyOcean board and feedback provided. However due to circumstance this did not occur. The original plans for the delivery of the Copernicus Marine Service via a European Centre for Ocean Monitoring and Forecasting (ECOMF), being superseded by the awarding of a contract to MERCATOR Ocean.

2.1 Strategic Objectives

The aim is to define a roadmap for the transitioning of OPEC research into the marine core service.

There are three key objectives of the roadmap:

- *To identify and work with stakeholders to determine the user requirements for the system.*
- *To transition to an operational status in the Marine Core Service, OPEC model systems and data products, in terms of both quality assurance (monitoring administrative and procedural activities) and quality control (verification of data products)*
- *To determine the future R&D requirements to deliver the full range operational ecology products.*

A schematic of the Operational Ecology service is given in Figure 2. The regional ecosystem model system would be implemented in the appropriate Copernicus Marine Service regional centre. We envisage producing three sets of core products a) reanalysis products, b) REA and c) seasonal forecast from plankton to fish. These products complement current MyOcean product portfolio in terms of ecosystem products in user interested long-term temporal scales (seasonal/Inter-annual /decadal), high trophic level products and information products (ecological indicators). The model systems developed in OPEC would exploit operational products from the Marine Core Service (e.g. met forcing, ocean circulation, EO) as driving forces. Underpinning this is a requirement for rigorous QA and QC procedures. The data products will be disseminated to the user community via a webserver. Improved communication with the user community is crucial to the success of such a system.

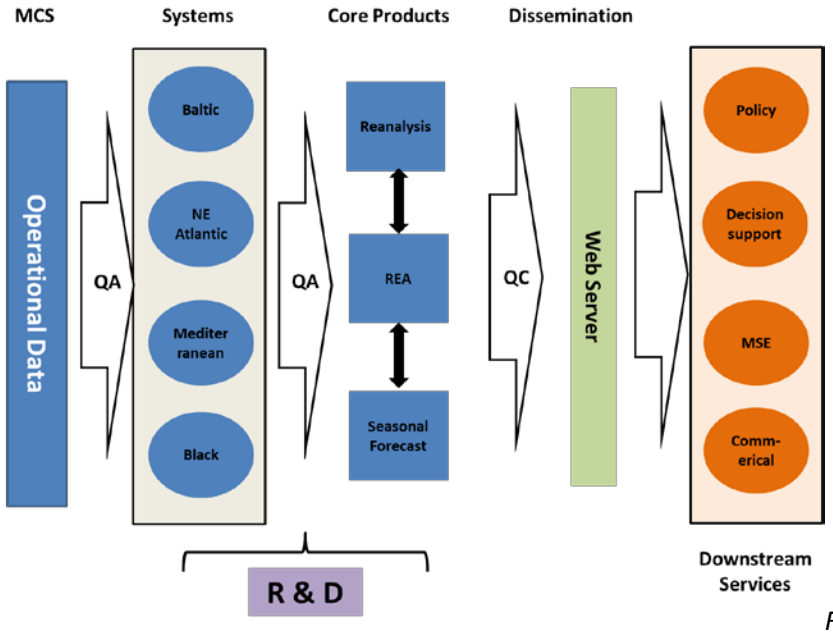

Figure 2. Schematic of the Operational Ecology Service. QA refers to Quality Assurance, QC refers to Quality Control.

2.2 Stakeholder requirements

A primary requirement for the marine operational ecosystem core service, is to have a clear idea of its stakeholders in the user community and their requirements. At the heart of this is the provision of an evidence base which demonstrates to the management teams of the operational centres that the prosed product(s) are a genuine user requirement. A major challenge is communication to resolve the tension between research driven products and user defined products.

Key issues include:

- Demonstrating user requirements to the operational centres.
- Identification of new and existing stakeholders and their requirements
- Which products are required?
- How should they be delivered – in what formats?
- How to communicate metric of product skill.
- How to manage the relationships between individual customers and groups of customers.

2.3 Implementing systems and evaluation of OPEC products

Once the user requirements have been established and potential new products have been accepted by the operational centres, then OPEC regional systems and products can be transitioned to operational status. The key challenges include:

- Feasibility of integrating the new products into the existing forecast system.
- Establishing the data feeds from the COPERNICUS MARINE SERVICE (met data, EO for data assimilation, open ocean boundary conditions)

- Establishing the QA procedure for OPEC services
- Developing the QC procedure for OPEC services
- Data delivery systems

2.4 Future R&D

Operational ecology is a new and developing field. For the moment, none of the countries in the world has provided quality assured ecology service of seasonal forecasting, annual assessment, decadal reanalysis and scenario projections of marine ecosystems on an operational basis. Significant knowledge gaps exist in:

- understanding and modelling biogeochemical cycle in the regional seas
- understanding and modelling interaction between low trophic level and high trophic level
- data assimilation techniques for biogeochemical parameters and with focus on improving long-term forecasts and statistics
- forecasting technology in seasonal and longer time scales
- More accurate modelling and estimation of river nutrient load their fate in the sea
- High trophic level modelling and forecasting technology
- End 2 End ecosystem modelling for operational scenario projections

The knowledge gaps, monitoring gaps and product quality are inter-dependent. Among them, the availability of the observations is the basis for filling the knowledge gaps and quantifying and improving the product quality. In OPEC Deliverable 5.2, the efficiency of the current biogeochemical monitoring networks in European Seas has been quantitatively assessed. Significant monitoring gaps exist in Mediterranean and Black Sea. The gaps in the Baltic and North Sea are smaller than the southern European Sea. However, the data availability still cannot fit for the purpose of operational seasonal forecast and rapid environment assessment on an annual basis.

Without timely and sufficient observations, the OE product quality cannot be verified in the basin scales, not mentioning further optimisation of the modelling systems which needs observations for calibration and process studies. On the other hand, rational sampling schemes (sampling frequency and locations) are essential for making better forecasts. It was found that optimal re-location of the existing North Sea buoys can increase the explained North Sea temperature variability by a factor of two (She et al., ODON final report). In OPEC D5.2, we also found that changing sampling frequency from weekly to daily of a ferrybox line in Aegean Sea can increase the explained chl-a variability from 35% to 96.5%.

In order to build up quality assured European capacity on the OE service, which shall also be world-leading, EuroGOOS Scientific Advisory Working Group has proposed a roadmap through an “Operational Ecology European Experiment - OEEE” (She et al, EuroGOOS Scientific Strategy White Paper, in preparation). The above analysis in OPEC is consistent with the OEEE concept. The OEEE is supposed to service as the mid- to long-term research

element of European OE while the implementation of the OE in the next section covers short-term research, Cal/Val, operationalisation and service.

COPERNICUS MARINE SERVICE. The OEEE will build up quality assured, state-of-the-art next generation monitoring and modelling platforms for the European OE through Integrated monitoring, modelling and research to fill the gaps, pave the way and reach an operational status which meets the stakeholder needs.

The OEEE has four modules: monitoring, modelling, research and integration.

The monitoring module aims at establishing necessary monitoring basis for the OE. It includes monitoring network optimisation (based on statistical methods, Observing System (Simulation) Experiments) and new monitoring activities as necessary for model optimization, better forecast, Rapid Environment Assessment and reanalysis and satellite-in situ cross Calibration and validation.

The modelling module aims at optimizing and developing as necessary the operational modelling technology for the OE. It includes full-scale model calibration and validation, data assimilation and coupled model development;

The research module aims at improving the OE forecasting technology. It focuses on improvements of key processes for optimizing the models, forecasting technology such as single/multi-model ensemble methods and end2end modelling for scenarios.

Integration or Operational demonstration module aims at integrating results from all the above 3 modules and transferring them into a pre-operational system. It performs operational production, i.e., reanalysis, Rapid Environment Assessment, seasonal forecasting and scenarios, and value-added information ecological indicators.

The OEEE is one of the four EuroGOOS Scientific focus area. It is recommended that it should be implemented through Horizon 2020. The final outcome of OEEE will contribute to Copernicus/GEOSS.

In addition to the aforementioned tasks, there are a number of generic issues which also need to be considered.

- Fully costing the service – implementation, running costs, business development costs
- Establishing funding streams for the transitional phase and the R&D (national and European)
- IPR policy
- Marketing strategy for data products
- Lobbying strategy

3. Implementation Plan

The implementation plan is envisaged to run from the end of OPEC (Jan 2015) to December 2020. It should be aware of that the research plan for European OE – OEEE which aims at mid- and long-term capacity is not part of implementation in this section. We envisage a 3 stage process leading to a fully operational system providing a range of data products

describing the past (historical reanalysis simulations), present (Rapid Environmental Assessment REA of the current state of the system) and future (seasonal forecast) states of European marine Ecosystems.

Stage 1. 2015-2017

The first phase step of the implementation plan will involve two main strands of activity. The first will be engagement with the regional operational centres to identify, and lobby for the inclusion of OPEC products into the marine core service. Candidate activities include the implementation of regional LTL reanalysis and REA into a trial operational system with appropriate QA and QC procedures and monitoring system assessment. This will need to be backed up evidence of stakeholder requirements. Building on work done in OPEC, the partners will need to establish the evidence base for the implementation of OPEC products into the COPERNICUS MARINE SERVICE. The OPEC products related to higher trophic levels and seasonal forecast require further R&D before they are ready for transition to the COPERNICUS MARINE SERVICE. Further funding will be sought form a variety of sources, include COPERNICUS MARINE SERVICE R&D funds, H2020 and national funding.

Stage 2. 2018-2019

The second phase is contingent on the success of the first. Assuming successful further R&D development we would anticipate making the case for;

- COPERNICUS MARINE SERVICE Implementation of regional HTL reanalysis and REA into pre operational system with appropriate QA and QC procedures.
- Implementation of regional seasonal forecast into a pre operational system with appropriate QA and QC procedures.

This requires further understanding of stakeholder requirements and an expansion of user base. In particular linkages with social and economic systems are central to delivering the maximum benefit from Operational Ecology.

Stage 3 2020

By 2020 OPEC would aim for the HTL and seasonal forecast services to be fully operational in the Copernicus Marine Service.

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