# Black Sea Ecosystem Modelling

## Contents



## Data provider

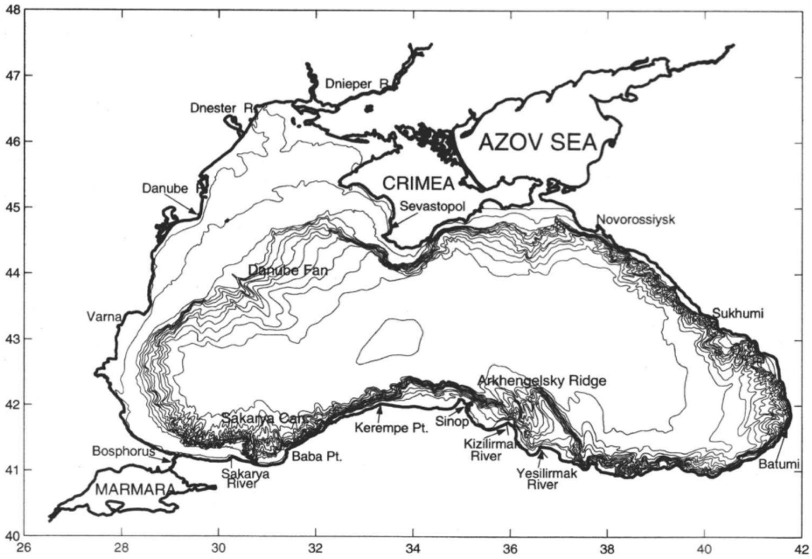
Black Sea models have been developed by the [Institute of Marine Science ]at the Middle East Technical University (METU) by Dr Baris Salihoglu and his team.

## Regional summary

The Black Sea is one of the major semi-enclosed seas of the world oceans and has experienced striking ecological changes due to impacts of climate change, intense eutrophication, population explosion of some invasive species and unsustainable fisheries with their density-dependent feedback processes. Nitrate loading increased nearly four-fold during the 1970s due to increased use of agricultural fertilizers. Rapidly intensifying eutrophication has caused comparable increases both in the subsurface nitrate concentrations and phytoplankton biomass, degradation of the classical mesozooplankton-dominated food web by flourishing of the opportunistic species *Noctiluca scintillans* and *Aurelia aurita* in the 1980s. The intense eutrophication phase was ended by a sequence of events; the collapse of total small pelagic stock (Oguz et al., 2012) and the simultaneous outburst of ctenophore *Mnemiopsis leidyi* population at 1989-1991 (Shiganova et al., 2001; Purcell et al., 2001) and the subsequent marked decline of anthropogenic nutrient loads from the River Danube and other northwestern rivers following the disintegration phase of the former Soviet Union during the early 1990s (Oguz and Velikova, 2010). The subsequent years are referred to as the post-eutrophication phase in which the nutrient reduction led to approximately a two-fold decrease in the phytoplankton and small pelagic standing stocks and *Noctiluca* and *Mnemiopsis* populations (BSC, 2008), and 30-40% decline in the subsurface nitrate and phosphate peak concentrations. Invasion of the opportunistic gelatinous species *Beroe ovata* and their predation on the *Mnemiopsis* population has introduced further changes in the food web structure by the end of 1990s.

Contrary to the relatively rich data availability and their analyses related to the eutrophication and fishery, observations concerning the carbonate system properties are scarce and limited to the total alkalinity and pH measurements. These data sets may be helpful to understand gross features of the carbonate system, but the lack of systematic time series measurements hinders exploring their seasonal to inter-annual variability and the current status of acidification and its vertical structure in the aerobic part of the interior Black Sea.

Different aspects of the structural changes observed in the Black Sea ecosystem have been studied quantitatively by modelling studies (e.g. Oguz et al., 2000, 2001a,b; Oguz and Merico, 2006; Lancelot et al., 2002; Daskalov, 2002; Gregoire and Friedrich, 2004; Gregoire and Soetaert, 2010; Staneva et al., 2010; He et al., 2012). They focussed mostly on the impacts of eutrophication, fishery and invasion of alien gelatinous species, but none of them have investigated the acidification problem in general and the processes governing atmospheric $CO_2$ uptake, temporal and spatial variability of the carbonate system properties in particular. Therefore, additional modeling studies are timely and warranted to broaden our conceptual understanding on the Black Sea carbonate structure and to analyze the synergistic effects of climate change, eutrophication, and acidification by means of sufficiently complex and fully coupled models of the physical-biogeochemical-carbonate system.



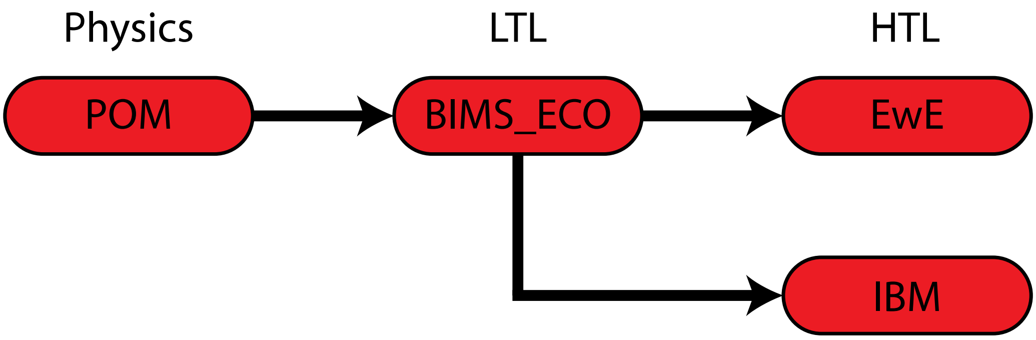

*The Black Sea: geographic setting, main rivers and bathymetric features (from Besiktepe et. al., 2001)*

## Justification of model selection

The peculiar characteristics of the Black Sea that include strong stratification, anoxia below 150m, water and nutrient influx from a high number of major rivers and recent invasion events by alien species make it difficult to model effectively using standard off-the-shelf models. As a result, models that take into account the properties peculiar to the Black Sea were developed at the Institute of Marine Science of the Middle East Technical University (IMS-METU) in previous EU funded projects. The physical, lower-trophic-level and higher-trophic level models were tested and validated extensively during the MEECE project and their capacity for prediction was duly demonstrated.

## Technical overview of models used in this region

Black Sea model is an end-to-end coupled model that includes a physical model (POM), a lower-trophic-level model (BIMS_ECO), a higher-trophic-level box-type model (EwE) and an individual based model larvae model (Anchovy IBM). The physical model is run in a standalone mode to produce the fluid velocity, vertical diffusivity, temperature and salinity fields, which are stored in a NetCDF file that is read by BIMS_ECO to force the biogeochemical dynamics. The biogeochemical fields produced by BIMS_ECO are stored in another NetCDF file that is used in EwE and IBM models as input. All of the couplings in our modelling framework are therefore offline and make use of file I/O for coupling.




*The coupling between POM, BIMS_ECO, EwE and Anchovy IBM. The arrows indicate one-way coupling in which the output of one module is stored in a file that is used as input in the other module.*

### Hydrodynamic model

The hydrodynamic model applied in this study is the Princeton Ocean Model using the Mellor-Yamada level 2.5 turbulence parameterization (POM; Blumberg and Mellor, 1987). The model domain encompasses the entire Black Sea (41°S - 46°N, 28°E - 41.5°E), although excludes the Azov Sea and consists of a (4km x 4km) resolution, Arakawa C, horizontal grid and a 26 level, sigma-coordinate, vertical grid. The sigma-levels are compressed towards the surface and bottom. The maximum depth of the model domain is 220 m.

### Lower Trophic level model

The biogeochemical model resolves all the major processes within the strongly stratified upper layer water column that overlies the deep (~2000 m) sulfide-rich anoxic pool. It describes the dynamics of phytoplankton (diatoms, dinoflagellates, small phytoplankton and coccolithophores); bacterioplankton; zooplankton (micro- and mesozooplankton, gelatinous carnivorous zooplankton *Mnemiopsis leidyi* and the heterotrophic dinoflagellate *Noctiluca scintillans*); particulate organic nitrogen and phosphorus; inorganic nutrients ($NO_3$, $NH_4$, $PO_4$); nitrogen gas ($N_2$); dissolved oxygen and hydrogen sulphide; $CaCO_3$ produced by coccolithophores; and detritus both in nitrogen and phosphorus currencies. Dissolved $CO_2$ and total alkalinity (TA) are additional state variables that couple the model to the carbonate module.

### Higher trophic level models

*Ecosim with Ecopath*

The Black Sea HTL model was built to represent the general prevailing food web structure of the Black Sea in the inner basin, prudently avoiding the extremely variable conditions of the Northwestern Shelf (NWS). The model covers an area of 150 000 km2 where fisheries operate intensively (Oguz et al., 2008). The geographical representation of the model does not include continental shelf areas and depths greater than 150 m at which anoxia prevails. The mass-balance Ecopath model of the Black Sea was based on Akoglu et al. (in prep.) and further developed by disaggregating the functional groups of small pelagic fish, pelagic piscivorous fish and demersal fish, which were aggregated guilds of multiple species in the earlier study, into individual species. Further, new state variables were introduced; i.e. two new jellyfish species (*Pleurobrachia spp*. and *Beroe ovata*) and another detritus compartment; particulate organic matter (POM). The model was extended to include 23 functional groups, which comprised of 11 fish groups; Black Sea anchovy (*Engraulis encrasicolus ponticus*), Black Sea sprat (*Sprattus sprattus phalaericus*), Pontic shad (*Alosa kessleri pontica*), Black Sea horse mackerel (*Trachurus mediterraneaus ponticus*), bonito (*Sarda sarda*), bluefish (*Pomatomus saltator*), Atlantic mackerel (*Scomber scombrus*), turbot (*Psetta maeotica*), spiny dogfish (*Squalus acanthias*), Black Sea whiting (*Merlangius merlangus euxinus*) and red mullet (*Mullus barbatus ponticus*), four jellyfish; *Mnemiopsi leidyi*, *Aurelia*, *Pleurobrachia spp*. and *Beroe ovate*; two detritus groups; one group representing sediment and one representing particulate organic matter in the water column (POM); one phytoplankton (diatoms and flagellates) and one zooplankton (non-gelatinous, fodder zooplankton) group; one heterotrophic dinoflagellate *Noctiluca scintillans* and one dolphin group to represent the Black Sea marine mammals, which are composed of short-beaked common dolphin (*Delpinus delphis*), bottlenose dolphin (*Tursiops truncates* and harbor porpoise (*Phocoena phocoena*). Anchovy was defined as a multi-stanza group separated into “eggs and larvae (0 to 3-month old)” and “juveniles and adults (3 months and above)” stanzas. Three fishing types were identified; trawlers, purse seiners and gill-netters to represent the fishery impact on the ecosystem. The mass-balance model was setup and balanced for the quasi-pristine conditions of the early 1980s. The diet composition matrix of the model was largely based on data available by stomach content analysis and compiled from FishBase .

The initial EwE model of the Black Sea was run 1-way and offline coupled with BIMS-Eco (Oguz et al., 2001a) model. The lower trophic level variables; i.e. phytoplankton, zooplankton, Aurelia and M. leidyi were forced with the simulated biomasses by BIMS-Eco model. The higher trophic level groups; i.e. fish species and dolphins as well as some lower trophic groups; i.e. Peurobrachia spp. which were not included in the BIMS-Eco model, were also simulated by the EwE Black Sea model.

The Ecosim dynamic model was run between 1980 and 2000 for hindcast validation, up until the most recent date at which adequate fisheries biology data were available. The dynamics of the fish compartments were forced using exploitation rates, i.e. fishing mortalities, where available. For groups/species without any fishing mortality estimates and stock assessment values; i.e. red mullet, bluefish and bonito, the catches were forced. Since no catch or stranding statistics were available for marine mammals, i.e. dolphins, in the Black Sea, the fishing mortality for this group was set to an estimated fixed value of 0.5 in order to represent the significant effect of by-catches due to fishery operations. The jellyfish compartments were forced by observed biomass values since they do not have natural predators within the system prior to the introduction of *B. ovata* in 1992. The primary producers were forced with time-series of non-linear production estimates from phytoplankton biomass during the simulation period. The time series of catch data and stock assessments of other models like VPA were used as a measure for the model fitting. The model was calibrated using vulnerabilities of the functional groups as well as Monte Carlo style parameter searching for the mass-balance Ecopath model.

## Data Assimilation

Eight-day composites of Chl-a obtained from the OceanColor product are assimilated into BIMS_ECO every eight days using the Singular Fixed Extended Kalman Filter (SFEK) and the localized Ensemble Transform Kalman Filter (ETKF). Parallel Data Assimilation Framework (PDAF), which is an open-source and freely available software package (http://pdaf.awi.de/trac/wiki), is used to implement the aforementioned filters. During the restructuring of BIMS_ECO, the prerequisites for the use of PDAF were considered to ensure compatibility.

## Forcing and Boundary Conditions

Hydrodynamic Model

Because the Black Sea is a semi-enclosed basin, the lateral boundary conditions are no-slip and zero heat flux and salt fluxes everywhere except at the mouths of the Bosphorous and Kerch strait, and the 8 largest rivers surrounding the Black Sea (Danube, Dniester, Dnieper, Inguri, Rioni, Yesilirmak, Kizilirmak and Sakarya). At the mouths of the rivers and straits, temperature and salinity boundary conditions are specified as inflow conditions. Diffusive heat and salt fluxes are set to zero in the straits outflow points. Surface forcing is prescribed using 6-hourly fields of wind stress, fresh water fluxes (evaporation, convective precipitation and large-scale precipitation), and radiation fields (surface shortwave radiation, surface long-wave radiation, evaporative heat flux, and convective heat flux) extracted from the DMI HIRHAM regional climate model. All simulations will be augmented by a 5 year spin-up period allowing the model to adjust to the prevalent conditions. Initial conditions are defined using monthly mean climatology for January from the World Ocean Atlas (WOA; Garcia et al., 2006).

Lower Trophic Level Model

**Initial conditions.** The initial conditions are chosen to reproduce the observed characteristics of the interior Black Sea ecosystem during its post-eutrophication phase. Nitrate concentration is set to 3.0 mmol $m^{-3}$ within the upper 65 m, 9.0 mmol $m^{-3}$ between 65m and 85 m depths and decreasing linearly to zero at 110 m. Phosphate has the same form but its concentrations are an order of magnitude lower. Dissolved oxygen is set to 50 μM within the first 60 m, 1 μM within the next 40 m (including the SOL) and zero further below. All the other state variables of the biogeochemical model are set to small and vertically uniform values over the entire water column because their equilibrium structures do not depend on the initial conditions and are emergent properties of the model dynamics. A spinup with 10 cycles is performed with these initial conditions and using physical and atmospheric forcing for the year 1990.

**For full details on models used in this region please refer to http://marine-opec.eu/downloads/OPEC_D2.4.pdf**

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