Annex 4: Economic model

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NIMED is a multi-species and multi-fleet bio-economic model developed within the Horizon 2020 research project "Science, Technology, and Society Initiative to minimize Unwanted Catches in European Fisheries (MINOUW)". The model was used in the project MINOUW to simulate management scenarios based on changes in selectivity and fishing effort for the demersal fisheries in GSA 9. During the EWG 18-09, additional scenarios on the reduction of fishing effort in GSA 9 demersal fisheries were simulated. During the EWG 19-01, the number of fleets and stocks was extended to be include simulation for the demersal fisheries in the GSAs 9, 10 and 11, following the requirements of the Multi-Annual Management Plan for the western Mediterranean fisheries.

The model follows a bio-economic simulation approach, where the biological module simulates the stock dynamics producing the levels of catches and landings by stock and fleet segment while the economic module simulates prices and costs dynamics. A short description of the equations is reported below.

Biological module

The population dynamics of the stock at age a is given by the following equation:

$$N_{a+1,t+1} = N_{a,t} * \exp\left(-F_{a,t} - M_{a,t}\right) \quad (1)$$

where N is the number of individuals, F and M the fishing and natural mortality respectively.

For the first age, recruitment is estimated by a geometric mean of the values registered in the last three years.

Catch at age in numbers follows the standard Baranov equation:

$$C_{a,t} = \frac{F_{a,t}}{F_{a,t}+M_{a,t}} N_{a,t} * \left(1 - \exp\left(-F_{a,t} - M_{a,t}\right)\right) \quad (2)$$

while total yield in weight is calculated as

$$Y_t = \sum W_{a,t} * C_{a,t} \quad (3)$$

Fishing mortality at age is given by the sum of the partial fishing mortality at age by fleet segment. Eq.3 applied to the fishing mortality of each fleet segment allows to calculate the total catches by fleet segment. Discards and landings by fleet segment are also calculated assuming constant percentages of discards by age class. The fishing mortality by fleet segment is assumed to be a linear function of fishing effort and selectivity:

$$F_{a,t,f} = q_f * S_{a,t,f} * E_{t,f}. \quad (4)$$

When partial fishing mortality at age by fleet segment is not available, the model estimates the total landings (or catches if data on discards is not available), which are divided among the fleet segments based on an equivalent effort measure.

Fishing effort by fleet segment, expressed in terms of days at sea (or other control variable) cannot be summed up to have a measure of the total fishing effort comparable with the fishing mortality. This is due to the different productivity and selectivity of each fleet segment. To overcome the problem of homogeneity associated to the different productivity, it is possible to calculate a measure of equivalent effort. Assuming a specific fleet segment k as a reference for the effort productivity, the equivalent effort can be estimated by the following equation:

$$Eeq_i = \frac{CPUE_i}{CPUE_k} E_i,$$

where CPUE is the catch per unit of effort, E is the effort, i is the generic fleet segment and k the specific fleet segment used as reference of productivity. Clearly, the equivalent effort of the fleet segment k is equal to its fishing effort.

The equivalent effort by fleet segment can be summed up and compared with the fishing mortality assuming a linear relationship between the two variables. Furthermore, the estimation of comparable measures of effort for each fleet segment allows the total landings or catches to be divided among the fleet segments proportionally to their quotas of equivalent effort.

Economic module

Landings by stock and fleet segment are inputs to the economic module.

Prices by stock and fleet segment are estimated through the following flexibility equation, where ε is the flexibility coefficient estimated on the time series data:

$$p_{t,s,f} = p_{t-1,s,f} \left(\frac{L_{t,s,f}}{L_{t-1,s,f}}\right)^{\varepsilon}. \quad (5)$$

Revenues by stock and fleet segment is calculated by multiplying landings by price. The total revenues are estimated as a linear function of the revenues calculated on the stocks simulated by the model:

$$R_{t,f} = rr_f * \sum_s p_{t,s,f} * L_{t,s,f}. \quad (6)$$

Other income is estimated as a linear function of total revenues:

$$OI_{t,f} = oi_f * R_{t,f}. \quad (7)$$

Total income (TI) is the sum of total revenues (R) and other income (OI).

Other inputs to the economic module are the number of vessels and the average days at sea, which are defined by the management scenario to be simulated.

Gross tonnage and engine power are estimated as a linear function of the number of vessels as follows:

$$GT_{t,f} = gt_f * N_{t,f}, \quad (8)$$

$$kW_{t,f} = kw_f * N_{t,f}. \quad (9)$$

The average days at sea are multiplied by the number of vessels to calculate the total number of days at sea (fishing effort in the model).

From a cost perspective, variable and fixed costs, labour and capital costs are included in the model. Variable costs are divided in energy costs and other variable costs; fixed costs are divided in repair cost and non-variable costs; capital costs are divided in depreciation and opportunity costs of capital.

Energy costs (EC) are based on energy consumption (En), which is estimated as a linear function of fishing effort. Energy costs are calculated by multiplying energy consumption by the average fuel price (Fp):

$$EC_{t,f} = En_{t,f} * Fp_{t,f}, \tag{10}$$

$$En_{t,f} = en_f * E_{t,f}. \tag{11}$$

Other variable costs (OVC) are estimated as a linear function of fishing effort:

$$OVC_{t,f} = ovc_f * E_{t,f}. \tag{12}$$

Both repair (RC) and non-variable costs (NVC) are estimated as linear functions of GT:

$$RC_{t,f} = rc_f * GT_{t,f}, \tag{13}$$

$$NVC_{t,f} = nvc_f * GT_{t,f}. \tag{14}$$

Labour costs are calculated by considering two different remuneration types for fishing employees, the share contract and the fixed salary. Under the share contract, labour costs (LC) are calculated as a percentage of the difference between revenues (R) and variable costs (VC), where VC is the sum of energy costs and other variable costs:

$$LC_{t,f} = cs_f\left(R_{t,f} - VC_{t,f}\right). \tag{15}$$

Under the fixed salary, labour costs are calculated as a linear function of the number of employees (EM):

$$LC_{t,f} = fs_f * EM_{t,f}. \tag{16}$$

The model allows the user to estimate labour costs by using a combination of the two remuneration types.

The total number of employees by fleet segment is estimated as a linear function of the number of vessels:

$$EM_{t,f} = em_f * N_{t,f}. \tag{17}$$

Regarding capital costs, both depreciation (D) and capital value (CV) are estimated as linear functions of GT. The opportunity costs (O) are calculated by multiplying capital value by the interest rates (r) deflated by the inflation rate (i):

$$D_{t,f} = d_f * GT_{t,f}, \tag{18}$$

$$CV_{t,f} = cv_f * GT_{t,f}, \tag{19}$$

$$O_{t,f} = ((1 + r_t)/(1 + i_t)) * CV_{t,f}. \tag{20}$$

The gross value added (GVA) is calculated as a difference between the total income and the sum of variable and fixed costs, which include energy costs, other variable costs, repair costs and non-variable costs:

$$GVA_{t,f} = TI_{t,f} - EC_{t,f} - OVC_{t,f} - RC_{t,f} - NVC_{t,f}. \quad (21)$$

The gross profit (GP) is calculated by the difference between the gross value added and the labour costs:

$$GP_{t,f} = GVA_{t,f} - LC_{t,f}. \quad (22)$$

The net profit (NP) is calculated as a difference between the gross profit and the sum of depreciation and opportunity costs:

$$NP_{t,f} = GP_{t,f} - D_{t,f} - O_{t,f}. \quad (23)$$