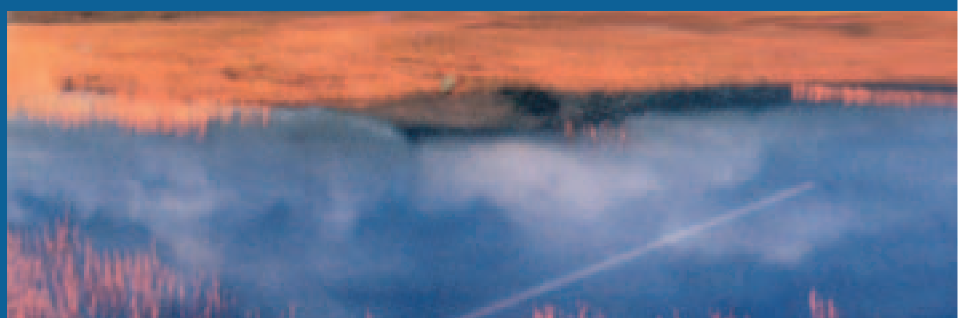
SPSD II

BALANCING IMPACTS OF HUMAN ACTIVITIES IN THE NORTH SEA (BALANS)

F. MAES, M. VINCX, C. JANSSEN, S. SCORY, H. POLET



PART 2

GLOBAL CHANGE, ECOSYSTEMS AND BIODIVERSITY

ATMOSPHERE AND CLIMATE

MARINE ECOSYSTEMS AND BIODIVERSITY

TERRESTRIAL ECOSYSTEMS AND BIODIVERSITY

NORTH SEA

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BIODIVERSITY

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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
(SPSD II)

Part 2:
Global change, Ecosystems and Biodiversity

Final report

BALANS
BALANCING IMPACTS OF HUMAN ACTIVITIES IN THE NORTH SEA

EV/21

Coordinator and promotor:
Prof. Dr. F. Maes, Maritime Institute, University Gent

Promotors:
Dr. Hans Polet, Institute for Agricultural and Fisheries Research
Prof. Dr. M. Vincx, Marine Biology Section, University Gent
Prof. Dr. Colin Janssen, Laboratory for Biological Research in Aquatic Pollution, University Gent
Ir. Serge Scory, Management Unit of the North Sea Mathematical Models
Ir. D. Leroy, Ecolas nv

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Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person:
Mr David Cox
Secretariat: +32 (0)2 238 36 13

PREFACE

Managing systems in a sustainable way has become one of the key considerations in environmental policy over the last decade. Applying sustainable management on the Belgian part of the North Sea (BPNS) is one of those challenges. It becomes clear however that a sustainable management of the BPNS faces a number of uncertainties, environmental complexity and an intense interaction between uses and their ecological impacts. Still, policy and decision makers and the users themselves, demand advice on how to manage the system in order to safeguard it and therefore themselves from deterioration in the future.

The BALANS project and the resulting report reflects a first attempt to create an instrument that allows for different policy choices to be weighed against each other. The embryonic stage of this kind of research, for the BPNS, forced us to concentrate on only two uses, hoping that this gives way for the development of a methodology to be used for and extented to more uses of the BPNS. Sand and gravel extraction was chosen because of its economic importance within the BPNS and without complex international dynamics neither jurisdictionally nor socio-economically. Fisheries however gave way to a more complex use in which international jurisdictional frameworks and regulations are much more important. Therefore, focus was on the shrimp fisheries in order to limit the complexity to a certain extent.

These uses are the central themes throughout the report. They are unravelled down to their most elementary parts in terms of what is driving them, of how they impact or are impacted by the environment, and of how they trigger a socio-economic system. It is important to emphasise that this project does not have the ambition – as many other previous projects did – to be a "data gathering project". The stress is on "systems thinking", "algorithm generation", and "simulation". Data are gathered wherever needed but only for the sake of using them in order to make the instrument run. The final aim was to create a decision support system with which decision makers and stakeholders can compare different policy options and choices against an output of ecological and socio-economic indicators. The accuracy of such a system obviously depends on the reliability of data feeding into it. The making of the framework as such however is a task on itself.

Our acknowledgements go to the Belgian Science Policy for their financial support and all the members of the "end user committee" who were involved in discussions, data exchange and many formal and informal meetings from the very beginning. We gladly present you the results of four years of BALANS. We do hope that it can be used as a first attempt to quantitavely approach the idea of sustainable management of our Belgian part of the North Sea both in an interdisciplinary as well as in a holistic way.

Prof. Dr. F. Maes, coordinator of the BALANS project
Dr. J. Schrijvers, project leader
Vanessa Sutton, successor project leader
On behalf of our partners

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www.belspo.be → publications → final reports → SPSD2 - North Sea

LIST OF CONTRIBUTORS

PARTNERS

Maritime Institute
University of Gent
Team:

- Promotor: Prof. Dr. Frank MAES
- Dr. Jan SCHRIJVERS
- Ms. Vanessa SUTTON

Marine Biology Section
University of Gent
Team:

- Promotor: Prof. Dr. Magda VINCX
- Dr. Steven DEGRAER
- Drs. Sofie DEROUS

Ecolas Environmental Consultancy & Assistance
Team:

- Promotor: Ir. Dirk LE ROY
- Dr. Bart DE WACHTER
- Mr. Karl VAN BIERVLIET
- Ms. Annemie VOLCKAERT

Laboratory for Biological Research in Aquatic Pollution
University of Gent
Team:

- Promotor: Dr. Colin JANSSEN
- Dr. Vincent DUFOUR

Institute for Agricultural and Fisheries Research
Team:

- Promotor: Dr. Hans Polet
- Dr. Hans HILLEWAERT
- Dr. Frank REDANT

Management Unit of the North Sea Mathematical Models (MUMM)
Team:

- Promotor: Ir. Serge SCORY

MEMBERS OF THE "END USERS" COMMITTEE

- Kathy BELPAEME, Centre for Integrated Coastal Zone Management
- Bernard DE PUTTER, Ministry of the Flemish Community, Administration Waterways and Coast
- Miguel BERTELOOT, Ministry of the Flemish Community, Administration Waterways and Coast
- Jan MEES, VLIZ & Jan SEYS – Flemish Institute for the Sea
- Patrick SCHOTTE, Federal Public Service of Economy, SMEs, Self-employed and Energy
- Helga VANDENREYKEN, Federal Public Service of Economy, SMEs, Self-employed and Energy
- René DESAEVER, Zeegra
- Luc VANDEKERCKHOVE, Zeegra
- Marc ASPESLAGH, Rederscentrale cv
- Luc MAERTENS, Ministry of the Flemish Community, Administration of Agriculture Dienst Zeevisserij
- Jean-François VERHEGGHEN, Ministry of the Flemish Community, Administration of Agriculture, Dienst Zeevisserij
- George PICHOT & Laurence VIGIN (MUMM)
- David COX (Belgian Science Policy)

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ABSTRACT

BALANS stands for "Balancing impacts of human activities in the Belgian part of the North Sea". The main goal of BALANS is to gain experience in correlating and balancing relevant social, economic and ecological data, through the elaboration of indicators, and weighing these indicators through the development of a conceptual policy model for "Sustainable Management of the North Sea". Partners from various disciplines (economics, biology, eco-toxicology, fisheries and modelling) cooperated over a 4 year period (2002-2006) towards this aim, focusing on sand and gravel extraction and shrimp fisheries on the BPNS.

The main focus of BALANS is to develop a first conceptual balancing model for 'Sustainable Management of the North Sea' for shrimp fisheries and sand and gravel extraction. In a fully operational phase, the policy model should be able to support arguments and directions for policy makers in order to reach a sustainable management of the North Sea. The policy model resulting from BALANS is operational in the sense that it provides the users with a tool through which they can gain a better understanding of the activities involved in sand and gravel extraction and shrimp fisheries, and the effects of policy choices on sustainable management. While the 'tool' developed from BALANS may not be a definitive decision support system, it should be seen as a tool that generates a thinking process for users.

Keywords: sustainable management, conceptual models, numerical models, algorithms, decision support systems, systems thinking environment, integrated conceptual policy, scenario development

INTRODUCTION

The final aim of the BALANS project was to create a decision support system with which decision makers and stakeholders can compare different policy options and choices against an output of ecological and socio-economic indicators. Only two uses were emphasised and described. Sand and gravel extraction was chosen because of its economic importance within the BPNS without complex international dynamics neither jurisdictionally or socio-economically. Belgian Fisheries however gave way to a more complex use in which international jurisdictional frameworks and regulations are much more important. The focus was limited to the shrimp fisheries because of the availability of data and the lack of data for other fisheries.

The report is divided along the lines of these two uses. Both uses are dealt with in the same way following a specific set of steps. The methodology that was organically shaped within the BALANS project is reflected as follows, within the 5 steps: (1) conceptual model development; (2) translation into a system-thinking environment; (3) data entry; (4) integrated conceptual policy and interface development; (5) scenario development.

(1) Each use was unravelled down to its elementary parts in terms of what is driving it, how it impacts or is impacted by the environment, and how it triggers a socio-economic system. This was then reflected in an algorithm which was discussed continuously and fine-tuned making use of experts and literature.

(2) Once decided on what elements and what interactions were most crucial in the description of the use, the resulting algorithm was translated into a systems thinking environment (Stella version 8.0, 2003)[i]. This allowed for the detection of crucial data, time steps, arrays, units etc. Each box within the resulting scheme is described with:

   a. Definition – explaining what exactly this box represents
   b. Equation – explaining how this box is mathematically described
   c. Array – what dimensions (e.g. zone, shrimp size category) are used; these dimensions are different for sand and gravel and for fisheries and will be dealt with in the introduction to the separate chapters
   d. Units
   e. Value – within what range of values the box varies and what the initial value is

[i] Stella version 8.0 is a software product of isee Systems, Inc., 2003.

f. Type – stock (state of being); flow (activity or action); variable (converter or rate); parameter (variable but as a starting point in the system)
g. Function – scenario (value can be changed by user, however, representing something beyond control); policy choice (value that can be changed by the user as it would be changed in reality); objective (calculated final output of model that is used as a measure for further policy changes); calculation (intermediate result used in calculation of 'objective')
h. Links – input (boxes leading into this box); output (boxes leading out of this box)
i. Data

(3) The generation of the most crucial boxes in the thinking system evidently asks for data delivery. The BALANS project is not a data gathering project but reliable data obviously allow the system to run and to function in an accurate way. Boxes at the starting point of the system need a data feeding that is either virtual or that makes use of existing data. Boxes in the middle of the system are calculated by the equation linking all the input boxes. If real data exist they can be used to verify this calculated value. Data gathered from reality are all represented in the annex with source and sometimes graphical presentation.

(4) The making of a conceptual policy model was to be one of the final outputs of the project. This modelling stage made use of the systems thinking output in the previous steps. The aim was the standardization, parameterisation and visualisation of a final decision support system for both sand and gravel extraction as well as for shrimp fisheries. The constant interaction and fine-tuning of the systems thinking approach and data issues were crucial during this step. This phase also included the creation of a user-friendly interface for both models with 'tuning factors' that allow users to 'play' with inputs to the model, with resulting outputs.

(5) The development of management scenarios is the final stage of this project. Through the development of economic, social and environmental scenarios the "what if" questions are examined (*e.g*. what if policy measures restrict the exploitation for the purpose of environmental protection? What if the market demand induces 10 times the current level of exploitation?). Consequences on each of the three indicators in response to a system change are explored. The purpose of running decision making models while making the input parameter vary is to assess how the system will evolve, how its behaviour will

change, when some external conditions or internal characteristics are modified.

The three first steps are dealt with for the driving force, the environment and the socio-economy for both sand and gravel extraction (Section I: Chapters 1, 2 and 3) and the shrimp fisheries (Section II: Chapters 1, 2 and 3). The final step integrates the previous chapters for both sand and gravel extraction and for shrimp fisheries separately (Section III: Chapter 1 and 2).

SECTION ONE

SAND AND GRAVEL EXTRACTION

INTRODUCTION

There is an ever growing demand for sand. Aggregate extraction of sand from the seabed provides an alternative source to existing sand quarries on land. In 2006, there are 12 exploitation vessels extracting on the BPNS, with a bin content between 877 m³ (Saeftinge) and 13700 m³ (Uilenspiegel)[1]. Three vessels are most frequently used and therefore belong to the priority Fleet A (Banjaard, Reimerswaal and Saeftinge). Generally, sand extraction takes place with a trailing suction hopper dredger.

A concession holder requests a vessel to extract a certain type of grain type. The vessel chooses a specific site in a specific concession area, within which it knows the demanded grain type can be found. The vessel departs from one of 4 possible ports, these being Nieuwpoort, Ostend, Zeebrugge and Vlissingen, with each being varying distances from extraction sites. The systems thinking exercise for sand and gravel extraction therefore works along two dimensions (the array):

(1) Concession areas and zones (8 in total)[2]

a. Concession area 1 consists of two zones 1a and 1b. Zone 1a is open for exploitation all year round. Zone 1b may only be exploited in March, April and May because of breeding of fishes and the impact on the environment.
b. Concession area 2 is divided in zones 2a, 2b and 2c. Zones 2a and 2b are open alternately for a period of 3 years. 2c is open for exploitation all year round.
c. Concession area 3 with zones 3a and 3b. 3a is open for exploitation all year round. Zone 3b is closed to exploitation as long as this site is used for a dumping site for dredged materials.
d. Exploration zone 4 allows for exploration in order to delineate new exploitation zones

(2) Grain types (3 in total)

a. "Fine sand" with a Folk classification of gravelly-muddy sand and muddy sand (gmS+mS) (Renard Center of Marine Geology); grain

[1] Ecolas nv. (2006): Environmental Impact Assessment for the extraction of marine aggregates on the BPNS. 194 pp. + Annexes

[2] Koninklijk besluit van 1 september 2004 betreffende de voorwaarden, de geografische begrenzing en de exploratie en de exploitatie van de minerale en andere niet-levende rijkdommen in de territoriale zee en op het continential plat, O.J. 7 october 2004

classification of <1000 µm with 97.5% <500 µm (based on Technical information fiche Hanson Aggregates Belgium nv.) and grain classification of 0-250 µm (Marine Biology Section, University of Ghent)

b. "Medium coarse sand" with a Folk classification of gravelly sand and sand (gS+S) (Renard Center of Marine Geology); grain classification of <2000 µm with 98% <1000 µm (based on Technical information fiche Hanson Aggregates Belgium nv.) and grain classification of 250-1000 µm (Marine Biology Section, University of Ghent)

c. "Gravel" with a Folk classification of sandy gravel (sG) (Renard Center of Marine Geology); grain classification of <4000 µm with 99% <2500 µm (based on Technical information fiche Hanson Aggregates Belgium nv.) and grain classification of >1000 µm (Marine Biology Section, University of Ghent)

As we are not able to exactly match what "fine sand" means for a biologist and what it means for a concession holder, we had to make compromises and find overlaps to define what "fine sand" means for BALANS. The Folk Classification is based on the proportions of silt/clay, sand and gravel present.

It is necessary to note that the terminology used by the sector and within the Royal Decree regarding sand and gravel extraction differs from BALANS, in that, the 3 'concession areas' above are referred to as three 'control zones' (1, 2 and 3). The 8 'zones' we have referred to above are consequently described as 'sectors', except the exploration zone 4. Within this zone new sectors will be designated based on exploration research.

Central to the sand and gravel extraction activity is the actual extraction. It is on the one hand driven by societal needs and on the other hand impacts both on the environment as well as the socio-economy. Figures 1 and 2 in Annex 9 (Sand and Gravel Conceptual Model) represent the algorithms describing the driving force, the environmental impact and the socio-economic impact linked with sand and gravel extraction.

The actual extraction of sand is ultimately driven by a demand for sand, a quotum, and infrastructural and technical specifications. A certain demand for sand will be completely extracted unless limited by a quotum ceiling, a maximal capacity of the fleet and a suitable stock of sand present.

The main goal of the socio-economic loop is to detect a profit or loss. The profit or loss is the difference between the turnover and the total costs. The turnover is a result of the entire extracted sand and the price of that sand. The total costs however are divided into variable costs, semi-fixed costs, fixed costs and fees. The variable costs only consist of fuel cost. The further the extraction area is located from the port, the higher the unit cost price will be. The semi-fixed costs consist of personnel costs and maintenance costs. Fixed costs consist of investment costs and insurance costs. The annual investment costs depend on the depreciation and interest rates. It should be noted that only within the sub-model for socio-economics there is a third array for 'vessel type'. The two types of vessels are Fleet A and Fleet B vessels, which differ in the loading capacity, extraction time, fuel consumption, number employees, etc.

The impact upon the environment is dependent on the intensity of extraction, resulting in both the extracted amount as well as the surface area impacted on the seabed and the recolonization rate afterwards. Also, the regime of extraction (continuous or discrete) is an important factor determining the recolonization rate. This exercise mainly focuses on impacts of extraction (direct and via sediment plumes) on sediment fractions and the macro-benthic density. Initially the ecotoxicological impacts originating from the release of toxic pollutants during extraction were studied, however, it was concluded that there was little to no risk to the ecological status of the study area and further model development for this component did not proceed. For more information see Annex 11 (Ecotoxicology Summary). The impact on other ecosystem components like fish or phytoplankton are not considered here since very little qualitative and quantitative information is available.

Maritime Institute
University Ghent
Vanessa Sutton and Jan Schrijvers

CHAPTER ONE

DRIVING SAND AND GRAVEL EXTRACTION

1. MAIN STOCK AND FLOW

This is the central part of the model in which the sand stock changes according to a monthly input and output of sand. The only possible input of sand is the natural sedimentation, whereas the output can be either natural erosion or human extraction. The cumulative extraction of sand leads into the total amount of extracted sand over time.

1.1 netto sand stock

DEFINITION: The actual stock of a grain type present in a zone
EQUATION: Netto_sand_stock[*,*](t - dt) + (Natural_flux[*,*] - Extraction_per_zone_and_type[*,*]) * dt
ARRAY: zone vs. grain type
UNITS: m^3
VALUE: initial value = Surface_of_pockets*10 (*i.e*. an initial exploitable depth of 10 m is assumed; range between 0 and unlimited; +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Natural_flux_of_sediment
- Output: Extraction_per_zone_and_type; Mean_bottom_level

DATA: calculated but not verifiable

1.2 extracted per zone and type

DEFINITION: The accumulation over time of the extracted sediment per grain type for each zone
EQUATION: Extracted_per_zone_and_type[*,*](t - dt) + (Extraction_per_zone_and_type[*,*] - Reset_for_quota[*,*]) * dt
ARRAY: zone vs. grain type
UNITS: m^3

VALUE: initial value = 0; range between 0 and unlimited unless limits set by policy; only +; is reset to zero when the quota is reached
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Extraction_per_zone_and_type
- Output: Quota_reset; IND_ratio_extraction_per_type_to_quota

DATA: calculated but not verifiable

1.3 mean bottom level

DEFINITION: The bottom depth as it evolves under the influence of extraction and natural flux.
EQUATION: IF ((Surface_of_pockets[*,*] > 0) AND NOT(Regime_of_the_zones[*] = 0))THEN(Netto_sand_stock[*,*]-INIT(Netto_sand_stock[*, *]))/Surface_of_pockets[*,*] ELSE (Effective_critical_depth)
ARRAY: zone vs. grain type
UNITS: m
VALUE: initial value = 0; range from unlimited (positive) and Effective_critical_depth; +/-
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Netto_sand_stock; Surface_of_pockets, Effective_critical_depth; Regime_of_the_zones
- Output: Critical_depth_flag, IND_Depth_ratio

DATA: calculated but not verifiable

1.4 extraction per zone and type

DEFINITION: The actual extracted sediment of a grain type which is removed from a zone in one month
EQUATION:
Surface_to_be_extracted_per_zone_and_type[*,*]*Extraction_depth_of_gear
ARRAY: zone vs. grain type
UNITS: m^3/month
VALUE: range between 0 and unlimited unless limits set by policy; only +
TYPE: flow
FUNCTION: calculation

LINKS:

- Input: Surface_to_be_extracted_per_zone_and_type; Extraction_depth_of_gear
- Output: Extracted_per_zone_and_type; Extraction_per_zone; Extraction_by_fleet_A, Extraction_by_fleet_B; Input to Socio-economy and Environmental sub-models

DATA: calculated but not verifiable

1.5 natural rate

DEFINITION: The rate with which sediment of a grain type is deposited on or eroded from a zone over months
EQUATION: time
ARRAY: zone vs. grain type
UNITS: $m^3/m^2*month$
VALUE: range unlimited; positive (deposition) or negative (erosion); default value is 0
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Natural_flux

DATA:

- Source: Management Unit of the North Sea Mathematical Models, Royal Belgian Institute of Natural Sciences
- Dataset: sedimentory balance on the Flemish banks is zero on a yearly basis (see annex)

1.6 natural flux

DEFINITION: The quantity of sediment of a grain type which is deposited or eroded on a zone in one month
EQUATION: Natural_rate[*,*]*Surface_of_pockets[*,*]
ARRAY: zone vs. grain type
UNITS: $m^3/month$
VALUE: unlimited, negative or positive
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Unlimited_stock; Natural_rate; Surface_of_pockets
- Output: Netto_sand_stock

DATA: calculated

1.7 quota reset

DEFINITION: Mechanism that allows to reset the system after a period of five years
EQUATION: if(ABS(TIME-60)<(DT/2)) OR (ABS(TIME-120)<(DT/2))
THEN (Extracted_per_zone_and_type[*,*]/DT)ELSE (0)
ARRAY: zone vs. grain type
UNITS: dimenionless
VALUE: unlimited; always +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Extracted_per_zone_and_type
- Output: Unlimited_stock

DATA: calculated

2. DEMAND FOR EXTRACTION

The extraction of sand is a demand driven economy. The actual monthly demand for a grain type is the result of a comparison between the initial demand and the extraction level against the quotum. If the quotum is reached the demand drops to zero.

2.1 total demand

DEFINITION: The quantity of aggregates that is demanded by the concession holders of extraction permits on a monthly basis
EQUATION: time
ARRAY: none
UNITS: m^3 / month
VALUE: range between 0 and unlimited; only +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Demand per type

DATA:

- Source: FOD Economie, KMO, Middenstand en Energie
- Dataset: (see annex)

2.2 demand per type

DEFINITION: The quantity of a given grain type that is demanded on a monthly basis
EQUATION: Total_demand*Demand_intensity*Fraction[*]
ARRAY: grain type

UNITS: m³ /month
VALUE: range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Total_demand; Demand_intensity; Fraction
- Output: Allowed_demand_per_type

DATA: calculated but not verifiable

2.3 fraction

DEFINITION: The percentage of a given grain type in the monthly demand
EQUATION: constant
ARRAY: grain type
UNITS: dimensionless
VALUE: range between 0 and 1; only +; sum of the three fractions must be equal to 1
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Demand_per_type

DATA: virtual (see annex)

2.4 demand intensity

DEFINITION: Tuning parameter that allows the user to assess the effect of a general increase or decrease of the demand for aggregates
EQUATION: constant
ARRAY: none
UNITS: dimensionless
VALUE: range between 0.5 and 10; only +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Demand_per_type

DATA: virtual

2.5 total extracted sand over all types

DEFINITION: The accumulation over time of the extracted sediment
EQUATION: ARRAYSUM(Extracted_per_zone_and_type[*,*])
ARRAY: none
UNITS: m³

VALUE: 0 to Quota
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Extracted_per_zone_and_type
- Output: Allowed_demand_per_type; ratio_total_to_quota

DATA: calculated but not verifiable

2.6 quotum over 5 years

DEFINITION: A value set by policy makers to restrict the total extracted sediment over a period of five years
EQUATION: constant
ARRAY: none
UNITS: m^3
VALUE: 15,000,000 for 5 years but variable according to policy
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Allowed_demand_per_type; Ratio_total_to_quota; IND Ratio_Extraction_per_type_to_quota

DATA:

- Source: Koninklijk besluit van 1 september 2004, *O.J.* 7 october 2004
- Dataset: available as one set value = 15,000,000 m^3 for 5 years (see annex)

2.7 allowed demand per type

DEFINITION: The monthly demand of aggregates, possibly corrected by the quotum status
EQUATION: IF(Total_extracted_sand_over_all_types<Quotum_over_5_years) THEN (Demand_per_type[*])ELSE (0)
ARRAY: grain type
UNITS: m^3
VALUE: range between 0 and maximum monthly demand (unlimited) and drops to 0 when quotum reached
TYPE: variable
FUNCTION: calculation

LINKS:

- Input: Quotum_over_5_years; Total_extracted_sand_over_all_types; Demand_per_type

- Output: To_be_extracted_nominal_surface_per_type

DATA: calculated but not verifiable

3. EXTRACTION

The aim of this subsection is to find out the depth resulting from the exploitation (demand) under a 'specific policy regime' (percentage of overlap) and, hence, the surfaces in each zone, for each grain type, affected by the exploitation. Note below, that under 'FUNCTION' some variables are categorized as 'potential policy choices' as these are not currently existing policy restrictions.

3.1 percentage of overlap

DEFINITION: When no overlap is permitted, the activity is performed extensively. Extractors are supposed to pass only once over a given place. When full overlap is permitted, the activity is performed intensively. Extractors are supposed to always go to the same place until they reach the critical depth

EQUATION: constant

ARRAY: none

UNITS: dimensionless (%)

VALUE: range between 0 and 100

TYPE: parameter

FUNCTION: potential policy choice

LINKS:

- Output: Effective_critical_depth

DATA: virtual

3.2 absolute critical depth

DEFINITION: The depth up to which extraction is allowed in case of intensive activity

EQUATION: constant

ARRAY: none

UNITS: m

VALUE: range between 0 and -10

DEFAULT VALUE: - 4 m

TYPE: parameter

FUNCTION: potential policy choice

LINKS:

- Output: Effective_critical_depth

DATA: virtual

3.3 effective critical depth

DEFINITION: A translation into depth of the extraction strategy defined by "Percentage of Overlap"

EQUATION: –Extraction_depth_of_gear+ (Absolute_critical_depth+Extraction_depth_of_gear)*Percentage_of_overlap/100

ARRAY: none

UNITS: m

VALUE: range between (–)Extraction_depth_of_gear and Absolute_critical_depth; always negative

TYPE: variable

FUNCTION: calculation

LINKS:

- Output: Mean_bottom_level; Critical_depth_flag; Effectively_extracted_surface per_zone_and_type

DATA: calculated but not verifiable

3.4 critical depth flag

DEFINITION: A flag indicating whether the depth limit is reached in each pocket.

EQUATION: IF(Mean_bottom_level[*,*]<=(Effective_critical_depth)) then (0) else (1)

ARRAY: none

UNITS: dimensionless

VALUE: 0 (critical depth is reached) or 1

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Mean_bottom_level; Effective_critical_depth
- Output: Status_of_the_zones; Surface_to_be_extracted_per_zone_and_type

DATA: calculated

3.5 regime of the zones

DEFINITION: A flag indicating whether a zone is open for exploitation according to policy in force

EQUATION: constant

ARRAY: zone

UNITS: dimensionless

VALUE: 0 (closed) or 1 (open)

TYPE: parameter

FUNCTION: potential policy choice

LINKS:

- Output: Mean_bottom_level; Status_of_the_zones

DATA: virtual

3.6 status of the zones

DEFINITION: A flag indicating whether the zone is open or closed for any of the two possible reasons (policy and/or critical depth)
EQUATION: Regime_of_the_zones[*]*Critical_depth_flag[*,*]
ARRAY: zone vs. grain
UNITS: dimensionless
VALUE: 0 (closed) or 1 (open)
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Regime _of_the_zones; Critical_depth_flag

DATA: calculated

3.7 surface of pockets

DEFINITION: The surface of the 24 different pockets being the 8 zones and within each of these the pockets of grain types ('fine sand', 'medium-coarse sand' and 'gravel')
EQUATION: constant
ARRAY: zone vs. grain type
UNITS: m²
VALUE: theoretical range between 0 and the surface of the Belgian part of the North Sea but limited by environment and policy
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Natural_flux; Mean_bottom_level; Sum_of_surfaces

DATA:

- Source: Renard Center of Marine Geology, University of Gent
- Dataset: see annex (24 set values)

3.8 extraction depth of gear

DEFINITION: The depth with which a suction dredger dredges during one cycle of extraction
EQUATION: constant
ARRAY: none
UNITS: m
VALUE: range between a minimum value and unlimited but within limits of infrastructure and policy; 0.5 m at present

TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: To_be_extracted_nominal_surface_per_type; Extraction_per_zone_and_type; Effectively_extracted_surface_per_zone_and_per_type

DATA:

- Source: Reimerswaal, personal communication
- Dataset: available as one set value = 0.5m (see annex)

3.9 sum of surfaces

DEFINITION: The sum of the surface for a given grain size over all zones
EQUATION: ARRAYSUM(Surface_of_pockets[*,*])
ARRAY: Grain
UNITS: m²
VALUE: range between 0 and the surface of the Belgian part of the North Sea but limited by policy
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Surface_of_pockets

DATA: calculated and verifiable (see annex 3.7)

3.10 to be extracted nominal surface per type

DEFINITION: The nominal surface to be affected by extraction, as a function of the demand and of the extraction depth, assuming no overlap
EQUATION: Allowed_demand_per_type[*]/Extraction_depth_of_gear
ARRAY: grain type
UNITS: m²
VALUE: range between 0 and unlimited
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Allowed_demand_per_type; Extraction_depth_of_gear
- Output: Surface_to_be_extracted_per_zone_and_type

DATA: calculated but not verifiable

3.11 surface to be extracted per zone and type

DEFINITION: With this variable, we distribute the monthly demand for a given grain size over the zones. When the first zone is closed (either by policy or because the critical depth is reached) we go to the next one, in order of increasing distance of the zones to the shore. It is a "virtual" surface as it does not take into account the actual extraction depth. (shown for fine sand in zone 1a only)

EQUATION:

Surface_to_be_extracted_per_zone_and_type[Zone1a,Fine_Sand]=
IF ((Critical_depth_flag[Zone3a,Fine_Sand]+
Critical_depth_flag[Zone3b,Fine_Sand]+
Critical_depth_flag[Zone2a,Fine_Sand]+
Critical_depth_flag[Zone2b,Fine_Sand]+
Critical_depth_flag[Zone1b,Fine_Sand])=0 AND
Critical_depth_flag[Zone1a,Fine_Sand]=1)
THEN To_be_extracted_nominal_surface_per_type[Fine_Sand]
ELSE (0)

ARRAY: zone vs. grain type

UNITS: m²

VALUE: range between 0 (when/if the pocket is closed) and the value of the surface of the pockets

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Critical_depth_flag; To_be_extracted_nominal_surface_per_type
- Output: Effectively_extracted_surface_per_zone_and_type; Extraction_per_zone_and_type

DATA: calculated but not verifiable

NOTE: see annex for complete set of equations

3.12 effectively extracted surface per zone and type

DEFINITION: The actual surface that is extracted, on a monthly basis, per grain type per zone.

EQUATION:

Surface_to_be_extracted_per_zone_and_type[*,*]*
Extraction_depth_of_gear/abs(Effective_critical_depth)

ARRAY: zone vs. grain type

UNITS: m²

VALUE: range between 0 (when/if the pocket is closed) and the value of the surface of the pockets

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Surface_to_be_extracted_per_zone_and_type; Extraction_depth_of_gear; Effective_critical_depth
- Output: Used in environmental sub-model

DATA: calculated but not verifiable

4. FLEET AND TRIPS

This subsection aims at modelling the number of trips required by Fleet A and Fleet B vessels in order to extract specific grain types from the zones. Fleet A will first be used to its maximum monthly loading capacity. It will then be followed by Fleet B. The actual volume extracted by a fleet and the average loading capacity of that fleet's vessels render the amount of trips made by that fleet per grain type and per zone.

4.1 average loading capacity of fleet A

DEFINITION: The volume of sediment a vessel in Fleet A can extract during one extraction trip
EQUATION: constant
ARRAY: none
UNITS: m^3
VALUE: 1266 but variable according to policy and infrastructure
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Trips_made_by_Fleet_A_per_zone_and_type; Maximum_monthly_capacity_of_Fleet_A; Input to Socio-economic and Environmental sub-models

DATA:

- Source: Ecolas nv.
- Dataset: see annex (maximum loading capacity of each fleet A vessel with an average as one set value)

4.2 number of fleet A vessels

DEFINITION: The total number of vessels that occur in Fleet A
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 3 but variable according to policy and infrastructure
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Maximum_monthly_capacity_of_Fleet_A; Input to Socio-economy sub-model

DATA:

- Source: Reimerswaal (2004)
- Dataset: see annex

4.3 maximum number of trips per day and per vessel

DEFINITION: The maximum number of trips that can be made by one vessel per day
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 2 but variable according to policy, infrastructure and environment
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Maximum_monthly_capacity_of_Fleet_A; Maximum_monthly_capacity_of_Fleet_B

DATA:

- Source: Reimerswaal, personal communication
- Dataset: available as one set value = 2 (see annex)

4.4 maximum number of extraction days per month

DEFINITION: The maximum number of days per month on which extraction can be carried out
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 30 but variable according to policy, infrastructure and environment
TYPE: parameter
FUNCTION: scenario

LINKS:

- Output: Maximum_monthly_capacity_of_Fleet_A; Maximum_monthly_capacity_of_fleet_B

DATA: available as one set value = 30

4.5 number of fleet B vessels

DEFINITION: The total number of vessels that occur in Fleet B
EQUATION: constant

ARRAY: none
UNITS: numeric
VALUE: 9 but variable according to policy and infrastructure
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Maximum_monthly_capacity_of_Fleet_B

DATA:

- Source: Ecolas nv. (2006)
- Dataset: see annex

4.6 average loading capacity of fleet B

DEFINITION: The volume of sediment a vessel in Fleet B can extract during one extraction trip
EQUATION: constant
ARRAY: none
UNITS: m³
VALUE: 3903 but variable according to policy and infrastructure
TYPE: parameter
FUNCTION: policy
LINKS:

- Output: Trips_made_by_Fleet_B_per_zone_and_type; Maximum_monthly_capacity_of_Fleet_B; Input to Socio-economic and Environmental sub-models

DATA:

- Source: Ecolas nv. (2006)
- Dataset: see annex (maximum loading capacity of each Fleet B vessel with an average as one set value)

4.7 maximum monthly capacity of fleet A

DEFINITION: The maximum volume of sediment that can be extracted per month by Fleet A
EQUATION:
Average_loading_capacity_of__fleet_A*Maximum_number_of_extraction_days_per_month*Maximum_number_of_trips_per_day_per_vessel*Number_of_fleet_A_vessels
ARRAY: none
UNITS: m³
VALUE: 0 to unlimited only by input variables
TYPE: variable
FUNCTION: calculation

LINKS:

- Input: Average_loading_capacity_of_Fleet_A; Number_of_Fleet_A_vessels; Maximum_number_of_trips_per_day_per_vessel; Maximum_number_of_extraction_days_per_month
- Output: Extraction_by_Fleet_B

DATA: calculated but not verifiable

4.8 maximum monthly capacity of fleet B

DEFINITION: The maximum volume of sediment that can be extracted per month by Fleet B

EQUATION:

Average_loading_capacity_of_fleet_B*Maximum_number_of_extraction_days_per_month*Maximum_number_of_trips_per_day_per_vessel*Number_of_fleet_B_vessels

ARRAY: none

UNITS: m^3

VALUE: 0 to unlimited only by input variables

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Average_loading_capacity_of_Fleet_B; Number_of_Fleet_B_vessels; Maximum_number_of_trips_per_day_per_vessel; Maximum_number_of_extraction_days_per_month

DATA: calculated but not verifiable

4.9 extraction by fleet A

DEFINITION: The total sediment extracted by Fleet A over one month and not exceeding the maximum loading capacity of this fleet (shown for Zone1a and fine sand only)

EQUATION:

```
Extraction_by_fleet_A[Zone1a,Fine_Sand]=
IF(     Maximum_monthly_capacity_of_fleet_A
        -Extraction_per_zone_and_type[Zone3a,Fine_Sand]
        -Extraction_per_zone_and_type[Zone3b,Fine_Sand]
        -Extraction_per_zone_and_type[Zone2a,Fine_Sand]
        -Extraction_per_zone_and_type[Zone2b,Fine_Sand]
        -Extraction_per_zone_and_type[Zone1b,Fine_Sand])> 0
THEN
        (MIN(Extraction_per_zone_and_type[Zone1a,Fine_Sand],Maximum_monthly_
capacity_of_fleet_A
        -Extraction_per_zone_and_type[Zone3a,Fine_Sand]
```

-Extraction_per_zone_and_type[Zone3b,Fine_Sand]
-Extraction_per_zone_and_type[Zone2a,Fine_Sand]
-Extraction_per_zone_and_type[Zone2b,Fine_Sand]
-Extraction_per_zone_and_type[Zone1b,Fine_Sand]))
ELSE (0)
ARRAY: zone vs. grain
UNITS: m³
VALUE: range between 0 and the maximum monthly capacity of Fleet A
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Maximum_monthly_capacity_of_Fleet_A; Extraction_by_zone_and_type_
- Output: Trips_made_by_Fleet_A_per_zone_per_type; Extraction_by_Fleet_B

DATA: calculated but not verifiable
NOTE: see annex for complete set of equations

4.10 extraction by fleet B

DEFINITION: The total sediment extracted by Fleet B over one month and not exceeding the maximum loading capacity of this fleet
EQUATION: MAX(0,Extraction_per_zone_and_type[*,*]-Extraction_by_fleet_A[*,*])
ARRAY: zone vs. grain
UNITS: m³
VALUE: range between 0 and the maximum monthly capacity of Fleet B
TYPE: variable
FUNCTION: calculation

LINKS:

- Input: Extraction_per_zone_and_type; Extraction_by_fleet_A
- Output: Trips made by Fleet B per zone per type

DATA: calculated but not verifiable

4.11 trips made by fleet A per zone and per type

DEFINITION: The number of trips made per month by fleet A vessels to a grain type pocket within a zone
EQUATION: INT(Extraction_by_fleet_A[*,*]/Average_loading_capacity_of_fleet_A-0.0001)+1
ARRAY: zone vs. grain type
UNITS: unit less

VALUE: range between 0 and unlimited but within limits of extracted volume and average loading capacity for Fleet A
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Average_loading_capacity_of_Fleet_A; Extraction_by_Fleet_A
- Output:Total_distance_travelled_per_zone_and_type; Input to Socio-economic and Environmental sub-models

DATA: calculated but not verifiable

4.12 trips made by fleet B per zone and per type

DEFINITION: The number of trips made per month by fleet B vessels to a grain type pocket in a zone
EQUATION: INT**(**Extraction_by_fleet_B[*,*]/Average_loading_capacity_of_fleet_B-0.0001)+1
ARRAY: zone vs. grain type
UNITS: unit less
VALUE: range between 0 and unlimited but within limits of extracted volume and average loading capacity for Fleet B
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Average_loading_capacity_of_Fleet_B; Extraction_by_Fleet_B
- Output: Total_distance_travelled_per_zone_and_type; Input to Socio-economic and Environmental sub-models

DATA: calculated but not verifiable

5. DISTANCES TRAVELLED

A major output from this subsection is the total distance travelled. It can be modelled by making use of the known distances between the zones and the different ports, and the number of trips made.

5.1 total distance travelled per zone and per type

DEFINITION: The total distance travelled per month for the trips extracting a grain type in a zone
EQUATION:
(Trips_made_by_fleet_A_per_zone_and_type[*,*]+Trips_made_by_fleet_B_per_zone_and_type[*,*])*Distance_between_zone_and_port[*]
ARRAY: zone vs. grain type

UNITS: m
VALUE: range between 0 and unlimited but within limits of number of trips
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Trips_made_by_Fleet_A_per_zone_and_type; Trips_made_by_Fleet_B_per_zone_and_type; Distance_between_zone_and_port
- Output: Total_distance_travelled_per_zone

DATA: calculated but not verifiable

5.2 distance between zone and port

DEFINITION: The average distances from each of the four ports (Nieuwpoort, Oostende, Zeebrugge and Vlissingen) to the centre of each of the 8 zones
EQUATION: constant
ARRAY: none
UNITS: m
VALUE: range between 0 and the length of the Belgian part of the North Sea but limited by environment and policy
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Total_distance_travelled_per_zone_and_type; Input to Socio-economic sub-model

DATA:

- Source: Management Unit of the North Sea Mathematical Models (BMDC), Royal Belgian Institute of Natural Sciences
- Dataset: see annex (distances to 4 different ports with an average as 8 set values for the 8 zones)

5.3 total distance travelled per month

DEFINITION: The total distance travelled per month to meet the final demand for sand per month
EQUATION: ARRAYSUM(Total_distance_travelled_per_zone [*])
ARRAY: none
UNITS: m
VALUE: range between 0 and unlimited but within limits of number of trips
TYPE: variable

FUNCTION: calculation
LINKS:

- Input: Total_distance_travelled_per_zone

DATA: calculated but not verifiable

5.4 total distance travelled per zone

DEFINITION: The total distance travelled per month back and forth to the various zones.
EQUATION: ARRAYSUM(Total_distance_travelled_per_zone_and_type[*])
ARRAY: zone
UNITS: m
VALUE: range between 0 and unlimited but within limits of number of trips
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Total_distance_travelled_per_zone_and_type

DATA: calculated but not verifiable

Fig. I.1.1 is the Stella diagram for the Sand and Gravel Driving Force model. The above text describes the crucial elements. Elements in the figure that are not described in this text are characteristic of the modelling process and are used to allow the model run.

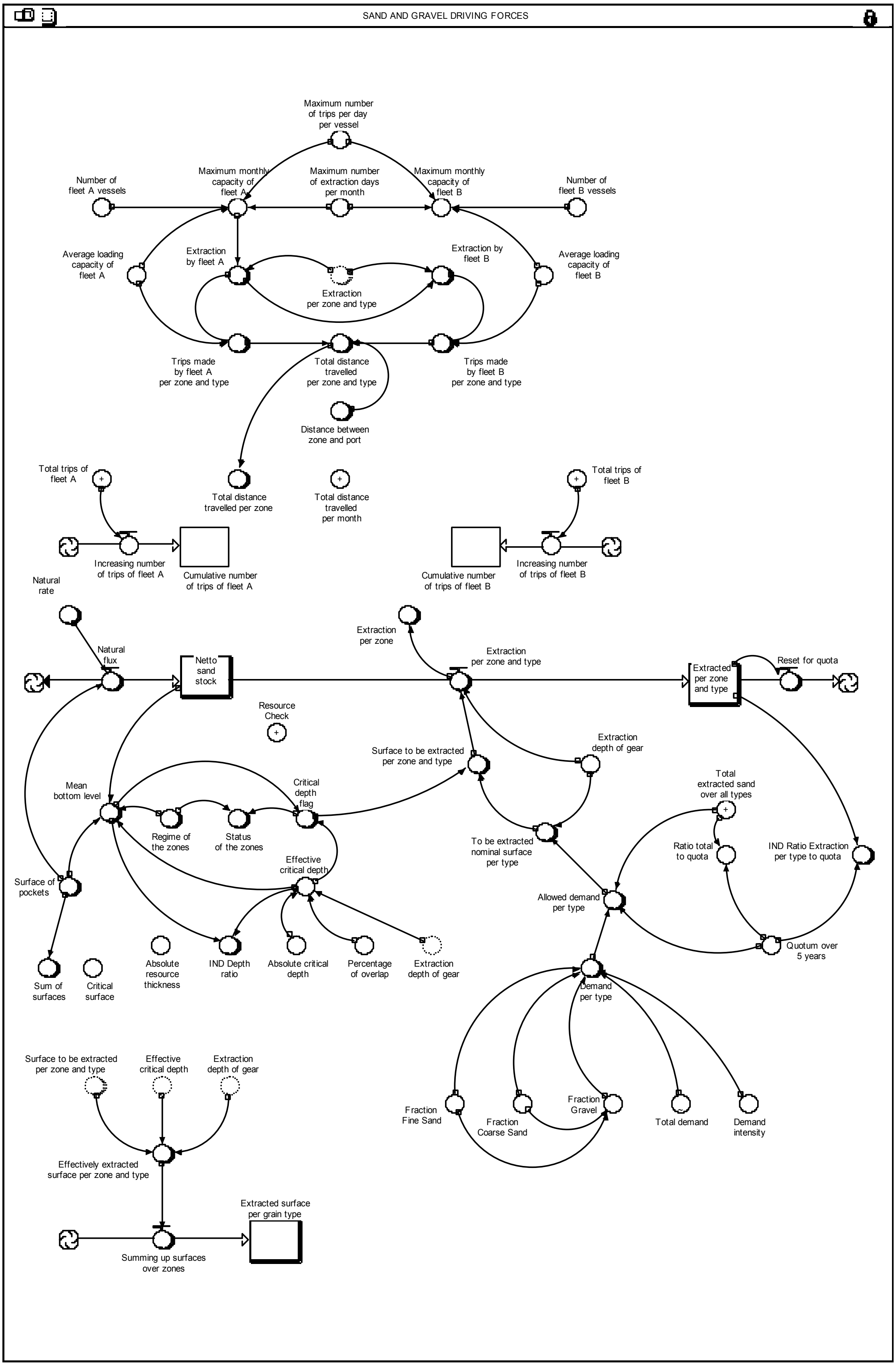


Figure I.1.1 STELLA sub-model for Sand and Gravel Driving Forces

Marine Biology Section
University Ghent
Sofie Derous

CHAPTER TWO

ENVIRONMENT OF SAND AND GRAVEL EXTRACTION

1. MACROBENTHIC DENSITY AT EXTRACTION SITE: STOCK AND FLOWS

For sand and gravel extraction the average macrobenthic density occurring on the top side of the sandbanks is considered. These communities (e.g. *Ophelia limacine-Glycera lapidum* community) are characterized by relative low densities (averages ranging between 135-450 ind/m²) and low species richness (averages between 5-8 sp/m²). An initial value of 300 ind/m² is chosen for the macrobenthic density.

1.1 density extraction site

DEFINITION: The amount of macrobenthic individuals that are present in a zone
EQUATION:density_extraction_site[*,*](t-dt)+(recruiting[*,*]+recolonizing[*,*]-dying_off[*,*]-losing_by_extraction[*,*]-competition[*,*])*dt
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: initial value = 300; range between 0 and 1000 (= density at which competition becomes too high ➔ see Density for competition)
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Recolonizing; Recruiting
- Output: Dying_off; Competition; Losing_by_extraction

DATA:

- Source: MACRODAT database (Section Marine Biology), Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

1.2 dying off

DEFINITION: The amount of macrobenthic individuals that die off naturally
EQUATION: density_extraction_site[*,*]*mortality_rate
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Density_extraction_site; Mortality_rate

DATA: calculated but not verifiable

1.3 mortality rate

DEFINITION: The rate with which macrobenthic individuals die off

EQUATION: constant

ARRAY: none

UNITS: numerical

VALUE: 0.05

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Dying_off

DATA:

- Source: Blackford (1997); Duplisea (1998)
- Dataset: see annex

1.4 competition

DEFINITION: The amount of macrobenthic individuals that die off or leave due to competition effects

EQUATION: IF(density_extraction_site[*,*]>density_for_competition[*,*])T HEN(density_extraction_site[*,*]-density_for_competition[*,*])/DTELSE 0

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range between 0 and unlimited, only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Density_extraction_site; Density_for_competition

DATA: calculated but not verifiable

1.5 density for competition

DEFINITION: The maximum macrobenthic density which can be sustained in a zone of the BCS

EQUATION: constant

ARRAY: none

UNITS: ind/m²

VALUE: 1000 (maximum macrobenthic density found on sandbank tops of BCS)

TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Competition

DATA:

- Source: MACRODAT database (Section Marine Biology)
- Dataset: available at Section Marine Biology, University of Ghent

1.6 losing by extraction

DEFINITION: The amount of macrobenthic individuals that die off or are lost due to the extraction of aggregates
EQUATION: ABS(effect_of_amount_on_density[*,*])*density_extraction_site[*,*]
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Density_extraction_site; Effect_of_amount_density

DATA: calculated but not verifiable

1.7 recruiting

DEFINITION: The amount of macrobenthic individuals that are being born
EQUATION: density_extraction_site[*,*]*birth_rate
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Density_extraction_site; Birth_rate

DATA: calculated but not verifiable

1.8 birth rate

DEFINITION: The rate with which macrobenthic individuals are being born
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 0.36
TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Recruiting

DATA:

- Source: Sohma et al. (2001); Duplisea (1998); Ortiz & Wolff (2002)
- Dataset: see annex

1.9 recolonizing

DEFINITION: The amount of macrobenthic individuals that recolonize a patch in a zone that is disturbed by the extraction of aggregates

EQUATION:IF(sum_of_effects_surface[zone,gr]=0)THEN(0)
ELSE(-sum_of_effects_surface[zone,gr]) *density_extraction_site[zone,gr])

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range from 0 to unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Density_extraction_site; Effect_surface
- Output: Density_extraction_site

DATA: calculated but not verifiable

2. EFFECT OF AMOUNT OF EXTRACTION

The effect on density of the amount of extraction differed for each of the 3 grain types. In the following descriptions only the equation for fine sand is presented. The equations for medium-coarse sand and gravel can be found in the annex (subsection 2.1).

2.1 effect of amount on density

DEFINITION: The amount of macrobenthic individuals that recolonize a patch in a zone that is disturbed by the extraction of aggregates

EQUATION: IF (Extraction_per_zone_and_type[Zone1a,Fine_Sand]<10) THEN 0
ELSE ((10^(((-
0.0731*LOGN(Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000))+0.180
7)+2.004))-101)/100

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range from 0 to unlimited; only +

TYPE: variable

FUNCTION: calculation
LINKS:

- Input: Extraction_per_zone_and_type (input from Driving Forces sub-model)
- Output: Losing_by_extraction

DATA: Calculated in meta-analysis (see Annex)

2.2 regime

DEFINITION: The cumulative amount of days between two extraction events
EQUATION: regime[*,*](t–dt)+(increasing[*,*] - decreasing[*,*])*dt
ARRAY: zone vs. grain type
UNITS: days
VALUE: initial value = 0; range between 0 and unlimited unless limits set by policy, only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Increasing
- Output: Decreasing; R1; R2; R3; R_continuous; R1_2; R2_2; R3_2; R_continuous_2; R1_3; R2_3; R3_3; R_continuous_3

DATA: calculated but not verifiable

2.3 increasing

DEFINITION: The mean number of days between 2 extraction trips, which yields an increase of the regime (~ discrete regime)
EQUATION:IF(Mean_number_of_days_between_2_trips[*,*]=15.00)THEN(Mean_number_of_days_between_2_trips[*,*]) ELSE 0
ARRAY: zone vs. grain type
UNITS: days
VALUE: range between 0 and value of regime; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Mean_number_of_days_between_2_trips

DATA: calculated but not verifiable

2.4 decreasing

DEFINITION: The amount of days which decrease the regime when the mean number of days between 2 extraction trips is less than 15 (~ continuous regime), resulting in a regime that equals 0 days
EQUATION: IF (Mean_number_of_days_between_2_trips[Zone,Grain]<15.00)

THEN (regime[Zone,Grain]/dt) ELSE (0)
ARRAY: zone vs. grain type
UNITS: days
VALUE: range between 15 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Mean_number_of_days_between_2_trips; Regime

DATA: calculated but not verifiable

2.5 mean number of days between 2 trips

DEFINITION: The amount of days which decrease the regime when the number of days between 2 extraction trips is less than 15 (~ continuous regime), resulting in a regime that equals 0 days
EQUATION:IF(Number_of_trips_per_zone_and_type_per_day[*,*]>0.068)THEN(1/Number_of_trips_per_zone_and_type_per_day[*,*])ELSE(15)
ARRAY: zone vs. grain type
UNITS: days
VALUE: range between 15 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Number_of_trips_per_and_type_per_day
- Output: Increasing; Decreasing; R_continuous; R_continuous_2; R_continuous_3

DATA: calculated but not verifiable

2.6 number of trips per zone and type per day

DEFINITION: The number of extraction trips that are made per grain size type, per concession zone and per day
EQUATION: Total_number_of_trips_per_zone_and_type_per_month[*,*]/30
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Total_number_of_trips_per_zone_and_type_per_month
- Output: Mean_number_days_between_2_trips

DATA: calculated but not verifiable

2.7 total number of trips per zone and type per month

DEFINITION: The number of extraction trips that are made per GR size type, per concession zone and per month

EQUATION: Trips_made_by_fleet_A_per_zone_and_type[*,*]+Trips_made_by_fleet_B_per_zone_and_type[*,*]

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; only +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Trips_by_fleet_A_per_zone_and_type; Trips_made_fleet_B_per_zone_and_type (both are input from Driving Forces sub-model)
- Output: Number_of_trips_per_zone_type_per_day

DATA: calculated but not verifiable

3. EFFECT OF SURFACE AREA OF EXTRACTION

The effect on density of the surface area of extraction differed for each of the 3 grain types and is explained in the Decision Process Diamond "Effect surface" and "Effect of surface sediment". In the following descriptions only the equation for fine sand is presented. The equations for medium-coarse sand and gravel can be found in Annex 2 (subsection 3.1-3.7).

3.1 r1

DEFINITION: Regime 1, which is different for the different grain size types

EQUATION:IF(regime[*,*]>15)AND(regime[*,*]<101)THEN1ELSE0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and 1; only +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Regime
- Output: Effect surface_1

DATA: calculated from meta-analysis (see Annex)

3.2 r2

DEFINITION: Regime 2, which is different for the different grain size types
EQUATION:IF(regime[*,*]>100) AND(regime[*,*]<6 01)THEN1ELSE0
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Regime
- Output: Effect_surface_2

DATA: calculated from meta-analysis (see Annex)

3.3 r3

DEFINITION: Regime 3, which is different for the different grain size types
EQUATION: IF(regime[*,*]>600THEN1ELSE0
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Regime
- Output: Effect_surface_3

DATA: calculated from meta-analysis (see Annex)

3.4 r continuous

DEFINITION: Continuous regime (when the mean number of days between two trips is less than 15), which is similar for all grain size types
EQUATION:IF(Mean_number_of_days_between_2_trips[*,*]<15)OR(regime[*,*]=0)THEN1ELSE0
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Regime; Mean_number_of_days_between_2_trips
- Output: Sum_of_effects_surface

DATA: calculated from meta-analysis (see Annex)

3.5 effect surface 1

DEFINITION: Effect of the extraction of a certain surface area on the macrobenthic density when regime 1 is valid

EQUATION:IF(R1[Zone1a,Fine_Sand]=1)THEN(((10^(((-6.9997*((Effectively_extracted_surface_perzone_and_type[*,*]/1000000)^2))+(6.7046*(Effectively_extracted_surface per zone_and_type[*,*]/1000000))-0.694)+2.004))-101)/100)ELSE0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: R1; Effectively_extracted_surface_ zone_and_type
- Output: Sum_of_effects_surface

DATA: calculated in meta-analysis (see Annex)

3.6 effect surface 2

DEFINITION: Effect of the extraction of a certain surface area on the macrobenthic density when regime 2 is valid

EQUATION:IF(R2[*,*]=1)THEN(((10^(((-152.86*((Effectively_extracted_surface_per_zone_and_type[*,*]/1000000)^6))-(705.03*((Effectively_extracted_surface_per_zone_and_type[*,*]/1000000)^5))+(1200.4*((Effectively_extracted_surface_per_zone_and_type[*,*]/1000000)^4))-(912.8*((Effectively_extracted_surface_per_zone_and_type[*,*]/1000000)^3))+(293.38*((Effectively_extracted_surface per_zone_and_type[*,*]/1000000)^2))-(29.757*((Effectively_extracted_surface per _zone_and_type[*,*]/1000000))+0.3803)+2.004))-101)/100))ELSE0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: R2; Effectively_extracted_surface_per_zone_and_type
- Output: Sum_of_effects_surface

DATA: calculated in meta-analysis (see Annex)

3.7 effect surface 3

DEFINITION: Effect of the extraction of a certain surface area on the macrobenthic density when regime 3 is valid

EQUATION: IF(R3[*,*]=1 AND Effectively_extracted_surface_per_zone_and_type[*,*]>100) THEN(((10^((-0.1323*LOGN((Effectively_extracted_surface_per_zone_and_type[*,*] /1000000))-0.3102)+2.004))-101)/100)ELSE 0

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: R3; Effectively_extracted_surface_per_zone_and_type
- Output: Sum_of_effects_surface

DATA: calculated in meta-analysis (see Annex)

3.8 sum of effects of surface

DEFINITION: Sum of the effects of the extraction of a certain surface area for all regimes on the macrobenthic density

EQUATION:IF(R_continuous[*,*]=1)THEN0ELSE(SUM(effect_surface_1[*,*]+effect_surface_2[*,*]+effect_surface_3[*,*]))

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: R_continuous; Effect_surface_1; Effect_surface_2; Effect_surface_3
- Output: Recolonizing

DATA: calculated but not verifiable

4. MACROBENTHIC DENSITY AT DEPOSITION SITE: STOCK AND FLOWS

For deposition after sand and gravel extraction again the effects on the *Ophelia limacine-Glycera lapidum* community are considered.

4.1 density deposition site

DEFINITION: The amount of macrobenthic individuals that is present in an area where the extracted sediment is deposited

EQUATION:density_deposition_site[*,*](t-dt)+(recruiting_2[*,*]+depositing_alive[*,*]+increasing_by_conditions[*,*]-dying_off_2[*,*]-smothering[*,*]–competition_2[*,*])*dt
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: initial value = 300; range between 0 and 1000 (= density at which competition becomes too high ➔ see Density for competition)
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Increasing_by_conditions; Depositing_alive; Recruiting_2
- Output: Dying_off_2; Competition_2; Smothering; Depositing_alive; Increasing_by_condition; Recruiting_2

DATA:

- Source: MACRODAT database (Section Marine Biology), Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

The 'Dying off 2' and 'Competition 2' outflows, the 'Recruiting 2' and the 'Density for competition', 'birth rate' 'mortality rate' parameters are identical to the ones described for 'density extraction site' (see 1.2, 1.4, 1.7, 1.5, 1.8 and 1.3). The actual descriptions of these flows and parameters can be found in Annex 2 (subsections 4.11-4.16).

4.2 smothering

DEFINITION: The amount of macrobenthic individuals which are smothered due to the overflow material that is deposited on them
EQUATION: ABS(effect_of_amount_on_smothering[*,*])
density_deposition_site[,*]
ARRAY: zone vs. grain type
UNITS: ind/m²
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Density_deposition_site; Effect_of_amount_on_smothering

DATA: calculated but not verifiable

4.3 effect of amount on smothering

DEFINITION: The effect of the extraction of a certain amount of sand on the amount of macrobenthic individuals which are smothered (different for the different grain size types)

EQUATION:((10^(((-3*(10^(-5))*Extraction_per_zone_and_type[*,*] /1000000)+0.4006)+2.004))-101)/100

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Extraction_per_zone_and_type (input from Driving Forces sub-model)
- Output: Smothering

DATA: calculated from meta-analysis (see Annex)

4.4 depositing alive

DEFINITION: The amount of macrobenthic individuals which are present in the overflowing material and are deposited alive on the deposition area

EQUATION:
effect_of_amount__on_depositing[Zone,Grain]*density_deposition_site[Zone,Grain]

ARRAY: zone vs. grain type

UNITS: ind/m²

VALUE: range from 0 to unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Density_deposition_site; Effect_of_amount_on_depositing
- Output: Density_deposition_site

DATA: calculated but not verifiable

4.5 effect of amount on depositing

DEFINITION: The effect of the extraction of a certain amount of sand on the amount of macrobenthic individuals which are smothered (different for the different grain size types)

EQUATION:((10^(((-7*(10^(-7))*Extraction_per_zone_and_type[Zone1a,Fine_Sand]/1000000)+0.4042)+2.004))-101)/100

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Extraction_per_zone_and_type
- Output: Depositing_alive

DATA: calculated from meta-analysis (see Annex)

4.6 increasing by conditions

DEFINITION: The amount of macrobenthic individuals that benefit from the enhanced growth conditions at the deposition site due to organic material in the sediment plume
EQUATION:
ABS(effect_of_organic_matter_on_density[*,*])*density_deposition_site[*,*]
ARRAY: zone vs. grain type
UNITS: ind/m^2
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Density_deposition_site; Effect_of_organic_matter_on_density
- Output: Density_deposition_site

DATA: calculated but not verifiable

4.7 effect of organic matter on density

DEFINITION: The effect of the depositing of organic matter present in the sediment plume on the amount of macrobenthic individuals at the deposition site
EQUATION ((10^(((-91.625*((Difference_in_organic_matter[*,*] /1000000)^3))-(84.84*((Difference_in_organic_matter[*,*]/1000000)^2))-(17.338*Difference_in_organic_matter[*,*]/1000000)-0.4019)+2.004))-101)/100
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Difference_in_organic_matter
- Output: Increasing_by_conditions

DATA: calculated from meta-analysis (see Annex)

4.8 difference in organic matter

DEFINITION: The difference of the organic matter concentration after and before deposition in function of the total organic matter enrichment in the sediment plume

EQUATION:((-1E-8)*(Organic_matter_enrichment[zone,gr]^3))+(4 *(10^(-6))*(Organic_matter_enrichment[zone,gr]^2))+(0.0022*Organic_matter_enrichment[zone,gr])-0.6342

ARRAY: zone vs. grain type

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Organic_matter_enrichment
- Output: Effect_of_organic_matter_on_density

DATA: calculated from meta-analysis (see Annex)

4.9 organic matter enrichment

DEFINITION: The difference of the organic matter concentration before and after deposition in function of the total organic matter enrichment in the sediment plume

EQUATION: 0.0004402*Total_amount_of_sediment_removed[zone,gr]

ARRAY: zone vs. grain type

UNITS: m^3

VALUE: range between 0 and unlimited; only +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Total_amount_of_sediment_removed
- Output: Difference_in_organic_matter

DATA:

- Source: Newell et al. (1999)
- Dataset: see annex

4.10 total amount of sediment removed

DEFINITION: The total amount of sediment which is removed by fleet A and fleet B

EQUATION: (Average_loading_capacity_of_fleet_A*Trips_made_by_fleet_A_per_zone_and_type[*,*])+(Average_loading__capacity_of_fleet_B*Trips_made_by_fleet_B_per_zone_and_type[*,*])

ARRAY: zone vs. grain type

UNITS: m^3

VALUE: range between 0 and unlimited; only +

TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Average_loading_capacity_of_fleet_A_vessel; Trips_made_by_fleet_A_per_zone_and_type; Average_loading_capacity_of_fleet_B_vessel; Trips_made_by_fleet_B_per_zone_and_type (all variables input from Driving Forces sub-model)
- Output: Organic_matter_enrichment

DATA: Calculated but not verifiable

5. SEDIMENT COMPOSITION AT THE EXTRACTION SITE

Although the Stella model uses an array for different extraction license areas and different sediment types, it is still needed to differentiate the sediment fractions further. An area which is roughly characterized as "fine sand" always consists of a mixture of different sediment fractions (with the dominant sediment fraction being the "fine sand" fraction). The percentages of different sediment fractions are therefore visualized as stocks (which use the same array 'zone', 'grain' as used in the driving force compartment). The sediment fractions chosen are 'fine sand-FS', 'medium-coarse sand-MCS' and 'gravel'. In the following section only the descriptions for the fine sand fraction is given. The descriptions for the other sand fraction can be found in the annex (subsections 5.8-5.21).

5.1 sediment extraction site fs

DEFINITION: The percentage of the fine sand grain size fraction that is present in a zone (different for all grain types)
EQUATION: sediment_extraction_site_FS[Zone1a,Fine_Sand](t-dt)+(natural_input_FS[Zone1a,Fine_Sand]+infilling_FS[Zone1a,Fine_Sand]-decrease_by_extraction_FS[Zone1 a,Fine_Sand]-natural_decrease_by_transport_FS[Zone1a,Fine_Sand])*dt
ARRAY: zone vs. grain type
UNITS: %
VALUE: initial value = 60.37; range between 0 and unlimited
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Sediment_extraction_site_FS; Natural_input_FS; Infilling_FS
- Output: Decrease_by_extraction_FS; Decrease_by_natural_transport_FS

DATA: Calculated from meta-analysis (see Annex)

5.2 natural input fs

DEFINITION: The percentage of the fine sand grain size fraction that is coming in the zone due to natural sediment transport processes
EQUATION: infilling_rate_FS[zone,gr]*sediment_extraction_site_FS[zone,gr]
ARRAY: zone vs. grain type
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Infilling_rate_FS; Sediment_extraction_site_FS
- Output: Sediment_extraction_site_FS

DATA: calculated but not verifiable

5.3 infilling rate fs

DEFINITION: The rate at which the fine sand grain size fraction is transported to an area
EQUATION: Constant
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: 1.0129 (for gr=Fine Sand), 1.0104 (for gr= Medium Coarse Sand), 1.0106 (for gr=gravel) for zone 1A
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Natural_input_FS

DATA: Calculated from meta-analysis (see Annex)

5.4 infilling fs

DEFINITION: The percentage of the fine sand grain size fraction that fills in the extraction tracks
EQUATION:IF(sum_of_effects_surface_FS[*,*]=0)THEN(0)ELSE((sum_of_effects_surface_FS[*,*]+1)*sediment_extraction_site_FS[*,*])-((sum_of_effects_surface_FS[*,*]+1)*sediment_extraction_site_FS[*,*])
ARRAY: zone vs. grain type
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: scenario result
LINKS:

- Input: Sum_of_effects_surface_FS; Sediment_extraction_site_FS
- Output: Sediment_extraction_site_FS

DATA: calculated but not verifiable

→ The variables mentioned in the decision process diamonds "Effect of surface sediment" and "Effect of amount sediment" are analogue to the ones in the decision process diamond "Effect surface" (for details, see Annex 2 subsections 6 and 7).

5.5 natural decrease by transport fs

DEFINITION: The percentage of the fine sand grain size fraction that leaves the zone due to natural sediment transport processes
EQUATION: sand_transport_FS[*,*]*sediment_extraction_site_FS[*,*]
ARRAY: zone vs. grain type
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Sand_transport_FS; Sediment_extraction_site_FS

DATA: calculated but not verifiable

5.6 sand transport fs

DEFINITION: The rate at which the fine sand grain size fraction is transported away from an area
EQUATION: constant
ARRAY: zone vs. grain type
UNITS: numerical
VALUE: 1.0071 (for gr=Fine Sand), 1.0084 (for gr= Medium Coarse Sand), 1.0095 (for gr=gravel) for zone 1A
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Natural_decrease_by_transport_FS

DATA: Calculated from meta-analysis (see Annex)

5.7 decrease by extraction fs

DEFINITION: The percentage of the fine sand grain size fraction that is removed from the zone due to the extraction activities
EQUATION:IF(sum_of_effects_amount_FS[*,*]<0)THEN(sediment_extraction_site_FS[*,*]-(sum_of_effects_amount_FS[*,*]+1)*sediment__extraction_site _FS[*,*])ELSE0

ARRAY: zone vs. grain type
UNITS: %
VALUE: range from 0 to unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Sum_of_effects_amount_FS; Sediment_extraction_site_FS

DATA: calculated but not verifiable

Fig. I.2.1 is the Stella printout for the Sand and Gravel environmental sub-model. The above text describes the crucial elements. Elements in the figure that are not described in this text are characteristic of the modelling process and are used to allow the model run.

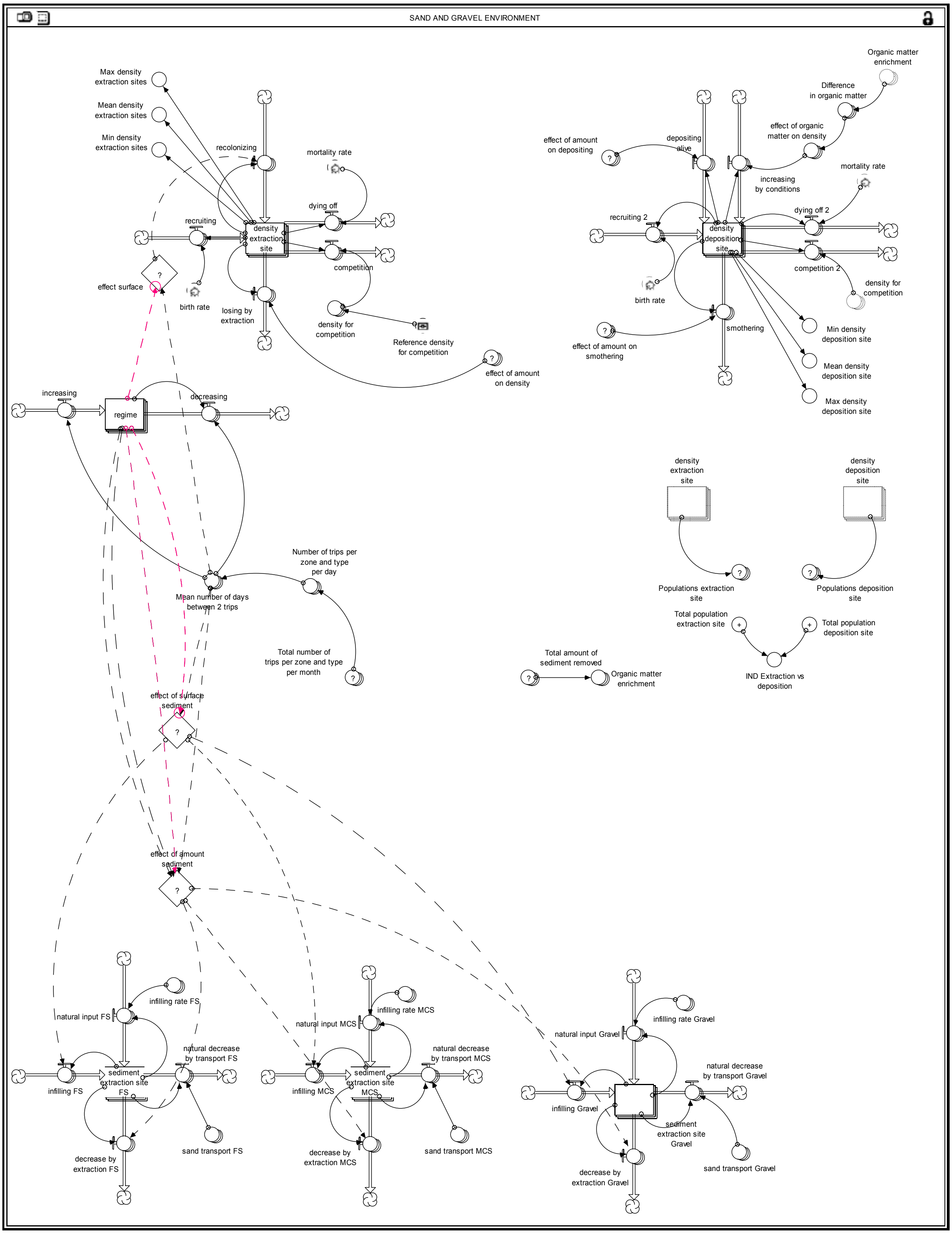


Fig I.2.1 STELLA sub-model for Sand and Gravel Environment

ECOLAS
Environmental Consultancy & Assistance
Annemie Volckaert

CHAPTER THREE

SOCIO-ECONOMY OF SAND AND GRAVEL EXTRACTION

1. ECONOMIC RESULT

From an economic perspective the calculation of the economical result is the main purpose of the model. The economic result can be positive (profit) or negative (loss). The profit or loss is calculated by decreasing the total turnover of the aggregate sector with the total costs made by the sector and the fees.

1.1 economic result

DEFINITION : the return of the aggregate sector over time
EQUATION: Economic_result(t) = Economic_result(t - dt) + (Calculation_economic_result) * dt
ARRAY: none
UNITS: EUR
VALUE: initial value = 0; range between 0 and unlimited; +/-
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Calculation_economic_result

DATA : calculated but not verifiable

1.2 calculation economic result

DEFINITION: the monthly return for the aggregate sector
EQUATION: ARRAYSUM(Calculation_turnover_per_type[*]) -Calculation_costs-ARRAYSUM(Fee[*,*])
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +/-
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Calculation_turnover_per_type; Calculation_costs; Fee

- Output: Economic_result

DATA: calculated but not verifiable

1.3 turnover per grain type

DEFINITION: the total turnover per grain type over the different concession zones over time

EQUATION: Turnover_per_grain_type[*](t - dt) + (Calculation_turnover_per_type[*]) * dt

ARRAY: grain type

UNITS: EUR

VALUE: initial value = 0; range between 0 and unlimited; +

TYPE: stock

FUNCTION: objective

LINKS:

- Input: Calculation_turnover_per_type

DATA: calculated but not verifiable

1.4 calculation turnover per type

DEFINITION: the total monthly turnover per grain type over the different concession zones

EQUATION: ARRAYSUM(Turnover_per_zone_per_type[*])

ARRAY: grain type

UNITS: EUR

VALUE: range between 0 and unlimited; +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Turnover_per_zone_per_type
- Output: Turnover_per_grain_type; Calculation_economic_result

DATA: calculated but not verifiable

1.5 turnover per zone per type

DEFINITION: the monthly turnover of the extraction activities defined per concession zone and grain type

EQUATION: Extraction_per_zone_and_type[*,*]*Aggregate_price[*,*]

ARRAY: zone vs. grain type

UNITS: EUR

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Extraction_per_zone_and_type (input from Driving Forces sub-model); Aggregate_price
- Output: Calculation_turnover_per_type

DATA: calculated but not verifiable

1.6 aggregate price

DEFINITION: Unit price of the extracted aggregates defined per concession zone and grain type that the extractors receive
EQUATION: constant
ARRAY: zone vs. grain type
UNITS: EUR/m³
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Turnover_per_zone_per_type

DATA:

- Source: Communication L. Vandekerckhove (August 2006)
- Dataset: See Annex

1.7 total cost

DEFINITION: the total cost for the aggregate sector over time
EQUATION: Total_cost(t - dt) + (Calculation_costs) * dt
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Calculation_costs

DATA: calculated but not verifiable

1.8 calculation costs

DEFINITION: the total monthly cost for the aggregate sector
EQUATION: Overall_monthly_fixed_cost_total_fleet+Overall_monthly_semi_ fixed_cost_total_fleet+Overall_monthly_variable_cost_total_fleet
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +

TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Overall_monthly_variable_cost_total_fleet; Overall_monthly_semi-fixed_cost_total_fleet; Overall_monthly_fixed_cost_total_fleet
- Output: Total_cost

DATA: calculated but not verifiable

1.9 fee

DEFINITION: the monthly compensation that has to be paid to the "Sand & Gravel fund" for the exploration and exploitation of the marine environment, calculated per concession zone and type
EQUATION:
Extraction_per_zone_and_type [*, *] *Current_fee_rate[*, *]
ARRAY: zone vs. grain type
UNITS: EUR/m³
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: policy choice
LINKS:

- Input: Extraction_per_zone_and_type (input from Driving Forces sub-model); Current_fee_rate
- Output: Calculation_economic_result

DATA: calculated but not verifiable

1.10 fee rate

DEFINITION: Basis (2005) unit fee defined per concession zone and grain type, necessary for the calculation of compensation to be paid to the "Sand & Gravel fund" for the exploration and exploitation of the marine environment
EQUATION: constant
ARRAY: zone vs. grain type
UNITS: EUR/m³
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: policy choice

LINKS:

- Output: Current_fee_rate

DATA:

- Source: Royal Decree of 01/09/2004 concerning the conditions, the geographical delimitation and the allocation procedure of the concessions for the exploration and the exploitation of mineral and other non-living resources in the territorial sea and on the continental shelf (RD 01/09/2004)
- Data: See annex

1.11 adaptation coefficient

DEFINITION: a yearly revised coefficient, determined on the basis of a yearly average of the index NACE 10-14 for the production in extraction industries per working day
EQUATION: 4.8046*(INT(TIME/12)+2005)-9508.6911
ARRAY: grain type
UNITS: unspecified
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Current_fee_rate

DATA: calculated but not verifiable

- Source: Ministry of Economy, SME's, Self-employed and Energy, National Institute of Statistics, Fund for Sand extraction
- Data: (see annex)

1.12 current fee rate

DEFINITION: Actual unit fee defined per concession zone and grain type taking into account the yearly adaptation of the basis fee
EQUATION: Fee_rate[*, *] *Adaptation_coefficient
ARRAY: zone vs. grain type
UNITS: EUR/m³
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Fee_rate; Adaptation_coefficient
- Output: Fee

DATA: calculated but not verifiable

2. VARIABLE COST

The variable costs of aggregate extraction will mainly depend upon the fuel cost. Several parameters play a role in the calculation of the fuel cost:

- The type of activity: sailing to the extraction zone versus the extraction activity;
- The distance: number of kilometres to the extraction zone (variable per zone) versus the distance of dredging per trip (non-variable);
- The fuel consumption per activity and per vessel type;
- The fuel price.

2.1 overall monthly variable cost total fleet

DEFINITION: the total variable cost per month (including fleet A + B) taken over all concession zones and all grain types, therefore the whole aggregate sector
EQUATION:
ARRAYSUM(Fuel_cost_per_zone_per_grain_type_for_fleet_A[*,*])
+ARRAYSUM(Fuel_cost_per_zone_per_grain_type_for_fleet_B[*,*])
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Fuel_cost_per_zone_per_grain_type_for_fleet_A; Fuel_cost_per_zone_per_grain_type_for_fleet_B
- Output: Calculation_costs

DATA: Calculated result not verifiable

2.2 fuel cost per zone per grain type for fleet A

DEFINITION: the total variable cost (fuel cost) per month for Fleet A, defined per concession zone and grain type
EQUATION: (Fuel_cost_per_m3_per_zone_per_vessel_type[*,*]*
Extraction_per_zone_per_type_for_fleet_A[*,*])
ARRAY: zone vs grain type; zone vs vessel type
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation

LINKS:

- Input: Fuel_cost_per_m³_per_zone_per_vessel_type; Extraction_per_zone_per_type_for_fleet_A
- Output: Overall_monthly_variable_cost_total_fleet

DATA: Calculated result not verifiable

2.3 fuel cost per zone per grain type for fleet B

DEFINITION: the total variable cost (fuel cost) per month for Fleet B, defined per concession zone and grain type

EQUATION: (Fuel_cost_per_m3_per_zone_per_vessel_type[*,*]
Extraction_per_zone_per_type_for_fleet_B[,*])

ARRAY: zone vs grain type; zone vs vessel type

UNITS: EUR

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Fuel_cost_per_m³_per_zone_per_vessel_type; Extraction_per_zone_per_type_for_fleet_B
- Output: Overall_monthly_variable_cost_total_fleet

DATA: Calculated result not verifiable

2.4 fuel cost per m³ per zone per vessel type

DEFINITION: the total fuel cost per m³ extracted sand (unit cost price) defined per concession zone and per vessel type

EQUATION: Fuel_cost_extraction_per_m3_per_vessel_type[*]+
Fuel_cost_sailing_per_m3_per_zone_per_vessel_type[*,*]

ARRAY: zone vs vessel type

UNITS: EUR/m³

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Fuel_cost_extraction_per_m³; Fuel_cost_sailing_per_m³_per_zone_per_vessel_type
- Output: Fuel_cost_per_zone_per_grain_type_for_fleet_A; Fuel_cost_per_zone_per_grain_type_for_fleet_B

DATA: Calculated result not verifiable

2.5 extraction per zone per type for fleet A

DEFINITION: the total amount of extracted sand per month by Fleet A, defined per zone and grain type

EQUATION: Average_loading_capacity_per_fleet_type[*]
Trips_made_by_fleet_A_per_zone_and_type[,*]

ARRAY: zone vs grain type

UNITS: m³

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Average_loading_capacity_for_fleet_A; Trips_made_by_fleet_A_per_zone_and_type (input from Driving Forces sub-model)
- Output: Fuel_cost_per_zone_per_grain_type_for_fleet_A

DATA: Calculated result not verifiable

2.6 extraction per zone per type for fleet B

DEFINITION: the total amount of extracted sand per month by Fleet B, defined per zone and grain type

EQUATION: Average_loading_capacity_per_fleet_type[*]*
Trips_made_by_fleet_B_per_zone_and_type[*,*]

ARRAY: zone vs grain type

UNITS: m³

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Average_loading_capacity_for_fleet_B; Trips_made_by_fleet_B_per_zone_and_type (input from Driving Forces sub-model)
- Output: Fuel_cost_per_zone_per_grain_type_for_fleet_B

DATA: Calculated result not verifiable

2.7 average loading capacity per fleet type

DEFINITION: the average loading capacity per vessel type.

Fleet A: Based on the average loading capacity of the Reimerswael (1600 m³), Banjaard (1320 m³) and Saeftinge (877 m³), that together account for approximately 90% of extraction activities at BCP.

Fleet B: Based on the average loading capacity of the ships occasionally used for extraction activities at the BCP, in general characterised by larger loading capacity (Charlemagne, Delta, Orisant, Swalinge, Uilenspiegel).

EQUATION: constant

ARRAY: vessel type

UNITS: m^3

VALUE: range between 0 and unlimited but within limits of the average loading capacity of a vessel; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Input: input from Driving Forces sub-model
- Output: Fuel_cost_sailing_per_m³_per_vessel; Fuel_cost_extraction_per_m³_per_vessel

DATA:

- Source: Ecolas (2006): Environmental Impact Assessment for the extraction of marine aggregates on the BPNS. 194 pp. + Annexes
- Dataset: Fleet A (1266 m^3); Fleet B (3903 m^3) (See Annex)

2.8 fuel cost extraction per m³ per vessel

DEFINITION: the total fuel cost of extraction per m^3 extracted sand (unit cost price) defined per vessel type

EQUATION: Fuel_consumption_extraction_per_vessel_type[*]
*Fuel_price*Time_extraction_per_trip_per_vessel_type[*]/
Average_loading_capacity per_vessel_type[*]

ARRAY: vessel type

UNITS: EUR/m^3

VALUE: range between 0 and unlimited; +

TYPE: parameter

FUNCTION: calculation

LINKS:

- Input: Fuel_consumption_extraction_per_vessel_type; Fuel_price; Time_extraction_per_trip_per_vessel_type; Average_loading_capacity_per_vessel_type
- Output: Fuel_cost_per_m³_per_zone_per_vessel_type

DATA: calculated but not verifiable

2.9 fuel consumption extraction per vessel type

DEFINITION: the amount of fuel consumed per hour during extraction activity per vessel type

EQUATION: constant
ARRAY: vessel type
UNITS: l/h
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_extraction_per_m³_per_vessel

DATA:

- Source: Zeegra Vzw (2005)
- Dataset: Fleet A (350 l/h); Fleet B (400 l/h) (See Annex)

2.10 time extraction per trip per vessel type

DEFINITION: the hours of extraction per trip per vessel type
EQUATION: constant
ARRAY: vessel type
UNITS: hr
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_extraction_per_m³_per_vessel

DATA:

- Source: Reimerswaal (May 2004); Zeegra vzw (2005)
- Dataset: Fleet A (1hr); Fleet B (1.5 hr) (See Annex)

2.11 fuel cost sailing per m³ per zone per vessel

DEFINITION: the total fuel cost of sailing per m³ extracted sand (unit cost price) defined per concession zone and vessel type
EQUATION: (Distance_between_zone_and_port[*]*2)*
Fuel_consumption_sailing_per_vessel_type[*] * Fuel_price/
Average_loading_capacity per_vessel_type[*]
ARRAY: vessel type vs zone
UNITS: EUR/m³
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: calculation
LINKS:

- Input: Distance_between_zone_and_port (input from Driving Forces sub-model); Fuel_consumption_sailing_per_vessel_type; Fuel_price; Average_loading_capacity_per_vessel_type
- Output: Fuel_cost_per_m³_per_zone_per_vessel_type

DATA: calculated but not verifiable

2.12 fuel consumption sailing per vessel type

DEFINITION: the amount of fuel consumed per meter sailing per vessel type
EQUATION: constant
ARRAY: vessel type
UNITS: l/m
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_sailing_per_m³_per_zone_per_vessel_type

DATA:

- Source: Zeegra Vzw (2005)
- Dataset: Fleet A (0.05 l/m); Fleet B (0.075 l/m) (See Annex)

2.13 fuel price

DEFINITION: the average price for gasoil used for vessels in the extraction activities
EQUATION: constant
ARRAY: none
UNITS: EUR/l
VALUE: range between 0 and unlimited
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_sailing_per_m³_per_zone_per_vessel; Fuel_cost_extraction_per_m³_per_vessel_type

DATA:

- Source: FPS Economy, SMEs, Self-employed and Energy: Ecodata. Official maximum prices of petroleum products (incl. BTW) (1999-2005).
- Dataset: 0.54 €/l (last update from 20/12/2005) (see Annex)

3. SEMI-FIXED COST

The semi-fixed costs of aggregate extraction consist of personnel costs and maintenance costs.

3.1 overall monthly semi fixed cost total fleet

DEFINITION: the total semi fixed cost calculated for the whole fleet (A+B) per month
EQUATION: Overall_monthly_semi_fixed_cost_fleet_A + Overall_monthly_semi_fixed_cost_fleet_B
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Overall_monthly_semi-fixed_cost_for_fleet_A_and_fleet_B

DATA: calculated but not verifiable

3.2 overall monthly semi fixed cost fleet A

DEFINITION: the total monthly semi fixed cost (maintenance, personnel) for the total Fleet A.
EQUATION: Number_of_fleet_A_vessels* Monthly_semi_fixed_cost_per_vessel_per_vessel_type[*]
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Number_of_fleet_A_vessels (input from Driving Forces sub-model); Monthly_semi-fixed_cost_per_vessel_per_vessel_type
- Output: Overall_monthly_semi-fixed_cost_total_fleet; Calculation_costs

DATA: calculated but not verifiable

3.3 overall monthly semi fixed cost fleet B

DEFINITION: the total monthly semi fixed cost (maintenance, personnel) for the total active Fleet B. Only the active Fleet B vessels are considered in the calculation, together with a certain percentage of semi-fixed costs (maintenance ratio) as Fleet B's main task is not the extraction of aggregates at the BCP.
EQUATION: Maintenance_ratio_fleet_B*Number_of_active_fleet_B_vessels* Monthly_semi_fixed_cost_per_vessel_per_vessel_type[*]
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Maintenance_ratio_fleet_B; Number_of_active_fleet_B_vessels; Monthly_semi-fixed_cost_per_vessel_per_vessel_type
- Output: Overall_monthly_semi-fixed_cost_total_fleet

DATA: calculated but not verifiable

3.4 monthly semi fixed cost per vessel per vessel type

DEFINITION: the total monthly semi-fixed cost combining the personnel and maintenance cost per month for one ship, defined per vessel type

EQUATION: Monthly_maintenance_cost_per_vessel_type[Vessel]+ Monthly_personel_cost_per_vessel_type[Vessel]

ARRAY: vessel type

UNITS: EUR/vessels

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Monthly_maintenance_cost_per_vessel_per_vessel_type; Monthly_personnel_cost_per_vessel_per_vessel_type
- Output: Overall_monthly_semi-fixed_cost_fleet_A_and_B

DATA: calculated but not verifiable

3.5 number of active fleet B vessels

DEFINITION: the number of actively involved Fleet B vessels. This depends on the demand for extraction and the total capacity of Fleet A. It is calculated based on the extra volume that has to be extracted by the Fleet B vessels divided by the average loading capacity of a Fleet B vessel.

EQUATION: ARRAYSUM(Extraction_by_fleet_B[*,*]/ Average_loading_capacity_of_fleet_B

ARRAY: none

UNITS: vessels

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Extraction_by_fleet_B; Average_loading_capacity_of_fleet_B
- Output: Overall_monthly_semi_fixed_cost_fleet_B

DATA: Calculated result (see fixed cost)

3.6 maintenance ratio fleet B

DEFINITION: the percentage of involvement in the semi fixed costs of the active Fleet B vessels. As the main task of Fleet B is not the extraction of sand at the BCP, the semi fixed cost (maintenance, personnel) should not be allocated 100% to this additional activity.
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Overall_monthly_semi-fixed_cost_fleet_B

DATA:

- Source: Expert judgement Ecolas
- Dataset: 0.02 (=2%) (See Annex)

3.7 monthly maintenance cost per vessel per vessel type

DEFINITION: the monthly cost needed to maintain a vessel for a specific vessel type
EQUATION: constant
ARRAY: vessel type
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Overall_monthly_semi_fixed_cost_per_vessel_per_vessel_type

DATA:

- Source: Estimation by Ecolas based on interview Reimerswael (2004)
- Dataset: Fleet A (37,500 EUR/vessel); Fleet B (50,000 EUR/Vessel) (See Annex)

3.8 monthly personnel cost per vessel per vessel type

DEFINITION: the total monthly cost for personnel directly (fixed) working in the aggregate extraction sector, defined per vessel type.
EQUATION:
Cost_per_employee*Number_of_employees_per_vessel_per_vessel_type[Vessel]
ARRAY: vessel type
UNITS: EUR/vessel
VALUE: range between 0 and unlimited; +

TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Cost_per_employee; Number_of_employees_per_vessel_per_vessel_type
- Output: Monthly_semi_fixed_cost_per_vessel_per_vessel_type

DATA: calculated but not verifiable

3.9 cost per employee

DEFINITION: the monthly gross cost per employee on board vessel (gross pay)
EQUATION: constant
ARRAY: none
UNITS: EUR/employee
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_personnel_cost_per_vessel_per_vessel_type

DATA:

- Source: Bel-First (database of financial data from Belgian corporations), Average cost per employee for the year 2002 for the following companies: ALGEMENE ZAND- EN GRINTHANDELMAATSCHAPPIJ ALZAGRI, BELMAGRI, CAMBEL AGREGATS, CHARLES KESTELEYN ZAND EN GRINTHANDEL, DEME BUILDING MATERIALS, GHENT DREDGING, HANSON AGGREGATES BELGIUM and INTERNATIONAL SAND AND GRAVEL
- Dataset: 4583 EUR/employee (See Annex)

3.10 number of employees per vessel type

DEFINITION: the number of (fixed) employees per vessel defined per vessel type
EQUATION: constant
ARRAY: vessel type
UNITS: Employee/vessels
VALUE: range between 0 and 20; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_personnel_cost_per_vessel_per_vessel_type

DATA:

- Source: Interview Reimerswael (2004)

- Dataset: Fleet A (4 Employee/vessel); Fleet B (6 Employee/Vessel) (See Annex)

4. FIXED COST

The fixed costs of aggregate extraction consist of insurance and investment costs.

4.1 overall monthly fixed cost total fleet

DEFINITION: the total fixed cost calculated for the whole fleet (A+B) per month
EQUATION:
Overall_monthly_fixed_cost_fleet_A+Overall_monthly_fixed_cost_fleet_B
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Overall_monthly_fixed_cost_for_fleet_A_and_fleet_B

DATA: calculated but not verifiable

4.2 overall monthly fixed cost fleet A

DEFINITION: the total fixed cost (insurance and maintenance) for total Fleet A.
All vessels of Fleet A are taken into account in the calculation as they are considered 100% operational
EQUATION:
Number_of_fleet_A_vessels*Monthly_fixed_cost_per_vessel_per_vessel_type[*]
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Number_of_fleet_A_vessels (input from Driving Forces sub-model); Monthly_fixed_cost_per_vessel_for_fleet_A
- Output: Overall_monthly_fixed_cost_total_fleet

DATA: calculated but not verifiable

4.3 overall monthly fixed cost fleet B

DEFINITION: the total fixed cost (insurance and maintenance) for total Fleet B. Only the active vessels of Fleet B are taken into account in the calculation as Fleet B will only get into action if the capacity of Fleet A is exceeded. Therefore this figure can range from 0 to all Fleet B vessels (100% operational).

EQUATION: Investment_ratio_fleet_B*Monthly_fixed_cost_per_vessel_per_vessel_type[*]*Number_of_active_fleet_B_vessels

ARRAY: none

UNITS: EUR

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Investment_ratio_fleet; Number_of_active_fleet_B_vessels; Monthly_fixed_cost_per_vessel_for_fleet_B
- Output: Overall_monthly_fixed_cost_total_fleet

DATA: calculated but not verifiable

4.4 monthly fixed cost per vessel per vessel type

DEFINITION: the monthly fixed cost per ship due to investment and insurance defined per vessel type

EQUATION: Monthly_investment_cost_per_vessel_per_vessel_type[*] +Monthly_insurance_cost_per_vessel_per_vessel_type[*]

ARRAY: vessel type

UNITS: EUR/vessels

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Monthly_investment_cost_per_vessel_per_vessel_type; Monthly_insurance_cost_per_vessel_per_vessel_type
- Output: Overall_monthly_fixed_cost_fleet_A_and_B

DATA: calculated but not verifiable

4.5 number of active fleet B vessels

Reference is made to paragraph 3.5

4.6 investment ratio fleet B

DEFINITION: the percentage of involvement in the investment costs of the active Fleet B vessels. As the main task of Fleet B is not the extraction of sand at the BCP, the fixed cost (insurance, investment) should not be written 100% to this additional activity.

EQUATIO: constant

ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Overall_monthly_fixed_cost_fleet_B

DATA:

- Source: Expert judgement Ecolas
- Dataset: 0.02 (=2%) (See Annex)

4.7 monthly insurance cost per vessel per vessel type

DEFINITION: the monthly insurance cost per vessel in use defined per vessel type
EQUATION: Investment_cost_per_vessel_per_vessel_type[*]*(Insurance_rate/12)
ARRAY: vessel type
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Investment_cost_per_vessel_per_vessel_type; Insurance_rate
- Output: Monthly_fixed_cost_per_vessel_per_vessel_type

DATA: calculated but not verifiable

4.8 monthly investment cost per vessel per vessel type

DEFINITION: the monthly investment cost (part depreciation, part interest) for a newly invested vessel defined per vessel type
EQUATION: Investment_cost_per_vessel_per_vessel_type[*] * (Monthly_interest_rate*((1+Monthly_interest_rate)^(Economic_lifetime_ship*12))) / (((1+Monthly_interest_rate)^(Economic_lifetime_ship*12))-1)
ARRAY: vessel type
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Investment_cost_per_vessel_per_vessel_type; Monthly_interest_rate; Economic_lifetime_ship
- Output: Monthly_fixed_cost_per_vessel_per_vessel_type

DATA: calculated but not verifiable

4.9 investment cost per vessel per vessel type

DEFINITION: the total investment cost per ship per vessel type, excluding the needed (un)loading facilities, the quay's, etc.
EQUATION: constant
ARRAY: vessel type
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_insurance_cost_per_vessel_per_vessel_type; Monthly_investment_cost_per_vessel_per_vessel_type

DATA:

- Source: WES (2004). The economical importance of the aggregate sector at sea in Belgium [Dutch: Het economische belang van de sector van zandwinning op zee in België]. By order of Zeegra vzw. December 2004.
- Dataset: Fleet A (10,000,000 EUR); Fleet B (13,000,000 EUR) (See Annex)

4.10 insurance rate

DEFINITION: the unit insurance rate expressed in terms of a percentage of the investment cost per vessel
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_insurance_cost_per_vessel_per_vessel_type

DATA:

- Source: Expert judgement Ecolas
- Dataset: 0.075 (=7.5%) (See Annex)

4.11 economic lifetime

DEFINITION: the total time the vessel will be used for extraction activities (operational, this is, distinct from depreciation period (account) estimated on 15 years)
EQUATION: constant
ARRAY: none

UNITS: unspecified
VALUE: range between 0 and 50; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_investment_cost_per_vessel_per_vessel_type

DATA:

- Source: Expert judgement Ecolas
- Dataset: 30 years (See Annex)

4.12 monthly interest rate

DEFINITION: the interest rate that can be used on a monthly basis
EQUATION: (((1+(Yearly_real_interest_rate/12))^12)-1)/12
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Output: Monthly_investment_cost_per_vessel_per_vessel_type

DATA: calculated but not verifiable (See Annex)

4.13 yearly real interest rate

DEFINITION: the annual interest rate
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_interest_rate

DATA:

- Source: Vito (2003) Background document of environmental cost model. [Dutch: Achtergronddocument milieukostenmodel]: private real interest rate, p. 47 http://www.emis.vito.be/EMIS/Media/BBT_rapport_milieukostenmodel.pdf
- Dataset: 0.1 (= 10%) (See Annex)

Fig. I.3.1 and Fig. I.3.2 are the Stella model components for the Socio-Economy Sand and Gravel. They represent 'base economy', 'variable costs', 'semi-fixed costs' and 'fixed costs' respectively. Elements in the figures that are not described in this text are characteristic of the modelling process and are used to allow the model run.

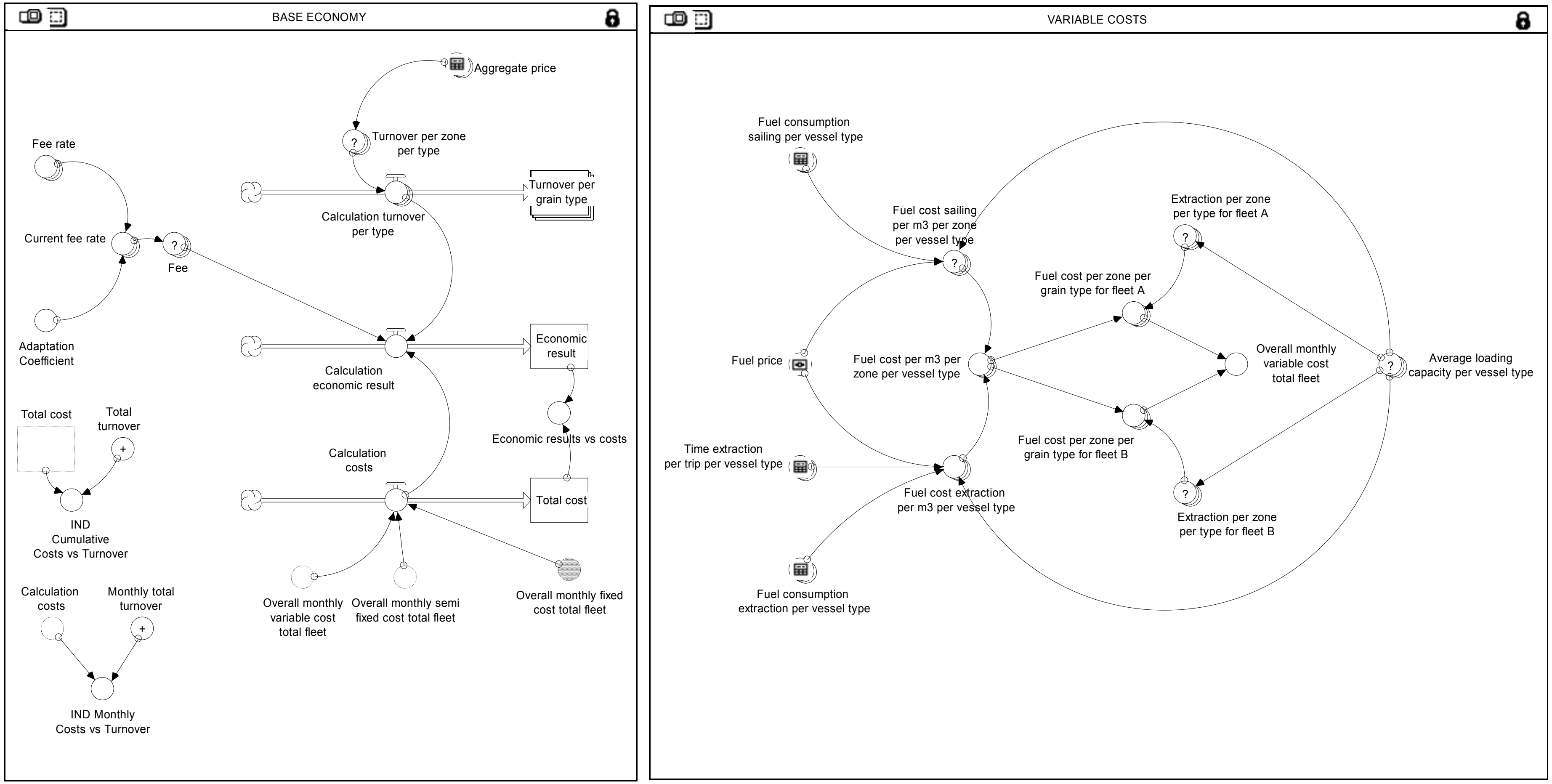
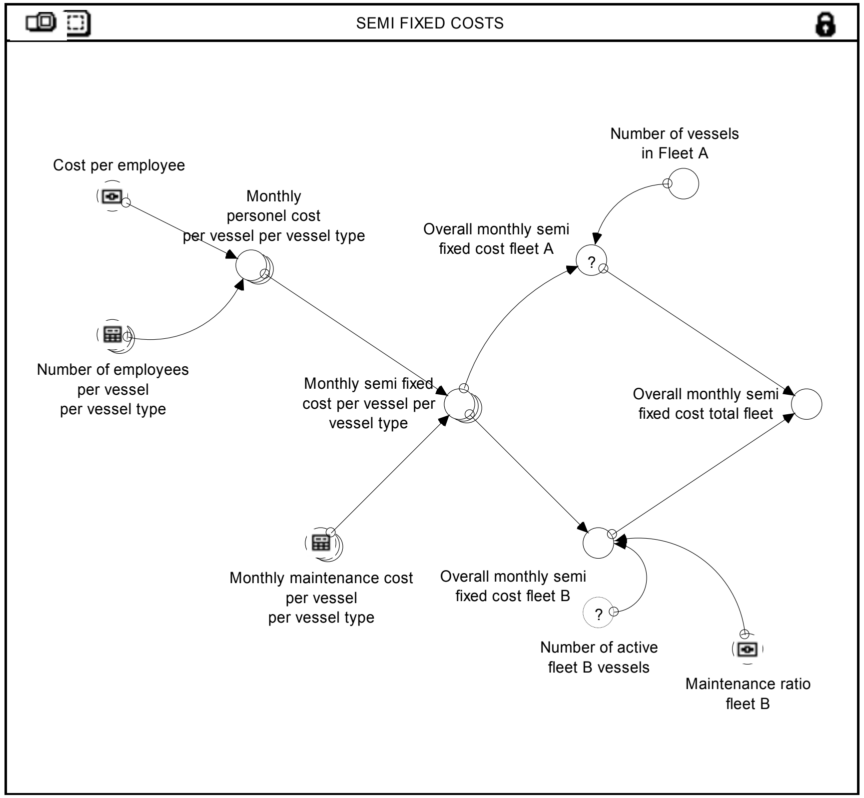


Fig. I.3.1 STELLA sub-model for Socio-economy Sand and Gravel



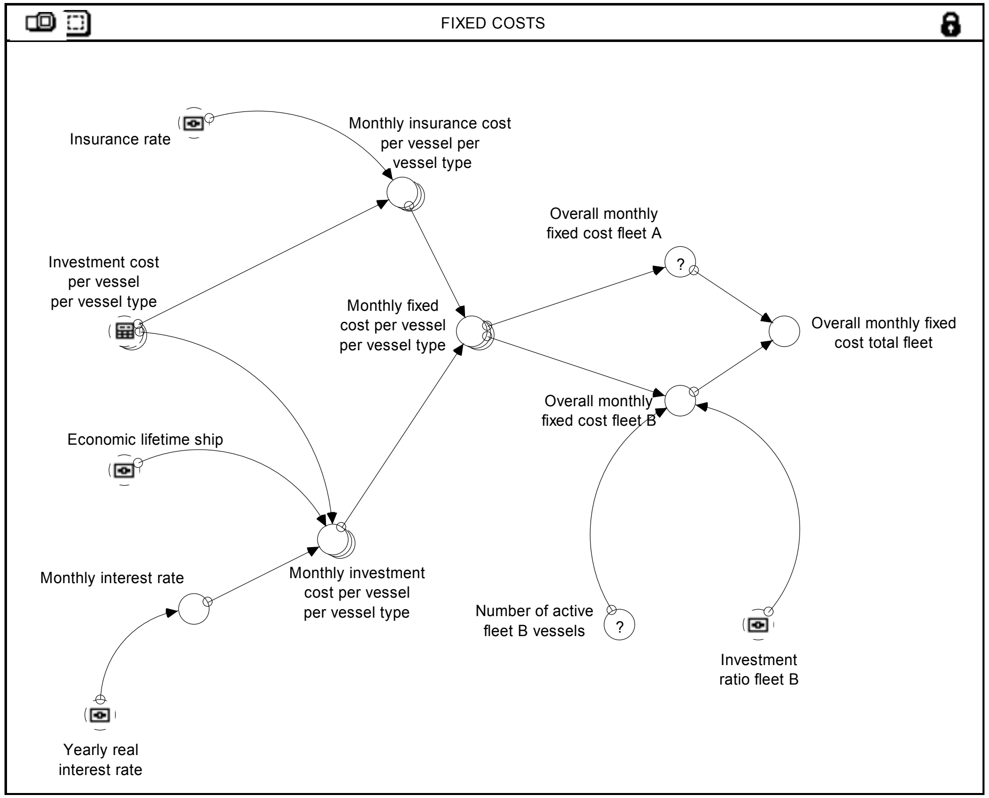


Fig. I.3.2 STELLA sub-model for socio-economy Sand and Gravel

SECTION TWO

SHRIMP FISHERIES

INTRODUCTION[1]

In order to limit the complexity to a certain extent, and due to lack of data for other fisheries, the fisheries section were reduced to the Belgian coastal shrimp fisheries for the sake of this project. Within BALANS we look at 7 vessels that predominantly catch shrimp in the Belgian part of the North Sea and all belonging to the small-scale fleet with an average capacity of 52 GT and 200 kW. These 7 vessels are a subset of the total small fleet in the Belgian shrimp fishery. These vessels stay at sea for a maximum of 24 hours. Usually, three persons are on board. In 2003, each vessel had the right to stay 169 days at sea for fishing activities (both sailing and fishing).

A shrimp vessel spends a certain number of hours at sea (effort) of which part is steaming time (going to and leaving from the fishing ground) and part is actual fishing time. The choice of a certain shrimp ground depends mainly on the time of the year. During most months shrimp are caught onshore (between 0 and 10 nm) whereas during the months of December, January and February, stocks are searched for further offshore (between 20 and 30 nm). Once back in the port, the shrimp are landed and either auctioned or sold outside the auction. Data on landings, effort and shrimp price used in this study are all derived from the official auction datasets. Fuel price is derived from the Ministry for Economy.

The systems thinking exercise for shrimp fisheries works along one dimension (the array):

(1) Shrimp size: Eight classes of shrimp size are classified (1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 7.5, 8.5 cm). The entire exercise is carried out for each one of these classes.

Central to the shrimp fisheries activity is the actual catch and landing. It is driven by societal needs and impacts both on the environment as well as on the socio-economy. Figures 1 and 2 in Annex 10 (Shrimp Fisheries Conceptual Model) represent the algorithms describing the driving force, the environmental impact and the socio-economic impact linked with shrimp fisheries.

[1] Douvere, F. & Maes, F. 2005. Commercial fisheries. In Maes, F., Schrijvers, J., Van Lancker, V., Verfaillie, E., Degraer, S., Derous, S., De Wachter, B., Volckaert, A., Vanhulle, A., Vandenabeele, P., Cliquet, A., Douvere, F., Lambrecht, J. and Makgill, R., 2005. Towards a spatial structure plan for sustainable management of the sea. Research in the framework of the BSP programme "Sustainable Management of the Sea" – PODO II, June 2005, p 136-147.

The final landing is driven and impacted by an array of factors of which effort, speed, net width, shrimp density, fuel price and shrimp price are believed to be most important. The swept area combined with the total number of shrimp in that area, delivers a total number of swept animals. The technical constraints of the fishing technique and processing eventually lead into a certain number and weight of landed animals. However, with the shrimp fishery there is no processing.

The main goal of the socio-economic loop is to detect a profit or loss. The profit or loss is the difference between the turnover and the total costs. The turnover is calculated by simply multiplying the fish landings with the price. The shrimp price on the local market is determined by the fish landings (offer) at auction. Secondly, the fish price can be externally determined, depending on a scenario.

The total costs however should be divided into variable costs and fixed costs. The variable costs consist of fuel cost, wage cost and other cost. The fuel cost is determined by the steamed distance and the fuel price. The further the shrimp ground is located from the port, the higher the unit cost price will be. Other cost are linked with accountancy, administration, transport, literature, clothing, rental,… Fixed costs consist of investment costs, maintenance costs and insurance costs. The annual investment cost depends on the depreciation and interest rates. Throughout the process of model development a subsidy on fuel price, fish price and investment were implemented (see Section III: Chapter 1).

The impact upon the environment is dependent upon the intensity of fishing (surface area fished) and the regime of fishing (continuous or discrete). This exercise mainly focuses on impacts of shrimp fisheries on sediment fractions and the macrobenthic density. The impact on other ecosystem components, such as fish or phytoplankton, is not considered here to make the result comparable with that of sand and gravel extraction. Initially the ecotoxicological impacts originating from the release of toxic pollutants during fishing were studied, however, it was concluded that there was little to no risk to the ecological status of the study area and further model development for this component did not proceed. For more information see Annex 11 (Ecotoxicology Summary).

ILVO
Institute for Agricultural and Fisheries Research
Hans Polet

CHAPTER ONE

DRIVING FORCE OF SHRIMP FISHERIES

1. SWEEPING

This is the starting point of the fishing operation. It depends on the shrimp stock present on the fishing ground on the one hand and the fishing effort to exploit the shrimp stock on the other hand. After each passage of a beam trawl on the fishing ground, a certain amount of the shrimps present in the trawl path will be caught and enter the gear and the rest will escape, of which a certain amount will die from injuries.

1.1 effort

DEFINITION: The total amount of hours the shrimp beam trawl is used on the fishing grounds over a given unit of time.
EQUATION: N/A
ARRAY: none
UNITS: hours per month
VALUE: range between 0 and unlimited unless limits set by policy; only +
TYPE: parameter
FUNCTION: policy
LINKS:

- Output: Swept_area; Input to Fisheries Environmental sub-model

DATA:

- Source: Ministry of the Flemish Community
- Data: see annex

1.2 effort intensity

DEFINITION: A multiplying factor of the nominal fishing effort.
EQUATION: N/A
ARRAY: none
UNITS: dimensionless
VALUE: range between 0 and 2; only +
TYPE: parameter
FUNCTION: scenario

LINKS:

- Output: Swept_area; Input to Fisheries Environmental sub-model

DATA: virtual

1.3 swept area

DEFINITION: The area of the sea floor over which the gear is dragged during its operation.
EQUATION: Effort*Speed*Width*Effort_Intensity
ARRAY: none
UNITS: m² per month
VALUE: range between 0 and unlimited unless limits set by policy; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Effort; Speed; Width; Effort_Intensity
- Output: Being_swept; Input to Fisheries Environmental sub-model

DATA: calculated but not verifiable

1.4 speed

DEFINITION: The speed at which a trawl is towed, relative to the seafloor or to the water column.
EQUATION: constant
ARRAY: none
UNITS: m/h
VALUE: 5093 m/h
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Swept_area

DATA:

- Source: Polet, 2003
- Dataset: see annex

1.5 width

DEFINITION: The opening of the net perpendicular to the towing direction and parallel to the seafloor. For a beam trawl this is equal to the beam length (sum of the two trawls).
EQUATION: constant
ARRAY: none
UNITS: m

VALUE: 7.65 m
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Swept area

DATA:

- Source: Polet, 2003
- Dataset: see annex

1.6 shrimp density submodel

DEFINITION: Numbers of shrimp per m², split up in length classes and grouped by quarter.
EQUATION: NA
ARRAY: shrimp size
UNITS: numbers / m²
VALUE: A given value depending on shrimp size and time of the year (quarter)
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Being_swept

DATA:

- Source: ILVO-Fisheries
- Dataset: see annex

1.7 density intensity

DEFINITION: A multiplying factor of the shrimp densities.
EQUATION: N/A
ARRAY: none
UNITS: dimensionless
VALUE: range between 0 and 2; only +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Being_swept

DATA: virtual

1.8 being swept

DEFINITION: The density or number of shrimps on a certain surface trawled by the fishing gear in a given time period
EQUATION: Number_of_animals_per_area[*]*Swept_area*Density_intensity

ARRAY: shrimp size
UNITS: numbers of animals per month
VALUE: initial value = 0; range between 0 and unlimited
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Swept_area; Shrimp_density_submodel; Density_intensity
- Output: Netto_catch_animals; Escaping_sweeping; Escaping_gear; Escaping_cod_end; Being_discarded

DATA: calculated but not verifiable

1.9 netto catch animals

DEFINITION: The accumulation of animals swept but not escaped for any of the possible reasons.
EQUATION: Netto catch animals (TIME-DT)+ (Being_swept-Escaping_sweeping-Escaping_gear-Escaping_Cod_End-Being_discarded)*DT
ARRAY: shrimp size
UNITS: numbers per month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Being_swept
- Output: Escaping_sweeping; Escaping_gear; Escaping_cod_end; Being_discarded

DATA: calculated but not verifiable

1.10 gs

DEFINITION: This process is described by the selectivity at the entrance of the gear, i.e. the net mouth. It is the percentage of animals escaping from the net mouth.
EQUATION: PEsc[*] = 0.0014 LC + 0.0298 (PEsc = percentage escaping, LC = shrimp size)
ARRAY: shrimp size
UNITS: dimensionless
VALUE: between 5 and 15%
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Shrimp_sizes_per_class

- Output: Escaping_sweeping; Escaping_gear; Escaping_cod_end; Being_discarded

DATA:

- Source: Polet, 2003
- Dataset: see annex

1.11 escaping sweeping

DEFINITION: The amount of shrimps escaping from the beam trawl per unit of time
EQUATION: Being_swept[*]*GS[*]
ARRAY: shrimp size
UNITS: numbers of animals per month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: GS; Being_swept
- Output: Swept_escape_but_dead; Escaped_sweeping

DATA: calculated but not verifiable

1.12 mrate swept escape

DEFINITION: The percentage of animals dying after escape from the net mouth
EQUATION: N/A
ARRAY: none
UNITS: dimensionless
VALUE: between 0% and 100% but for the time being fixed at 1%
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Swept_escape_but_dead

DATA: virtual (see annex)

1.13 escaped sweeping

DEFINITION: The accumulation of animals swept but that escaped the net.
EQUATION: Escaped sweeping(TIME-DT)+ Escaping_sweeping*DT
ARRAY: shrimp size
UNITS: numbers per month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Escaping_sweeping

DATA: calculated but not verifiable

1.14 swept escape but dead

DEFINITION: Total number of shrimps dead after escape from the net mouth
EQUATION: Escaping_sweeping[*]*MRate_swept_escape
ARRAY: shrimp size
UNITS: numbers per month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: MRate_swept_escape; Escaping_sweeping
- Output: Total_dead_numbers_per_month

DATA: calculated but not verifiable

2. GEAR

The fishing operation causes a certain amount of shrimps present in the trawl path to enter the trawl mouth. Part of the catch will escape from the trawl mouth and through the meshes of the net. Part of these will die of injury. Another part of the catch will stay in the net and be lead to the cod-end. This process is described below.

2.1 ns standard

DEFINITION: This process is described by the selectivity of the net body. It is the percentage of animals escaping from the net.
EQUATION: N/A
ARRAY: shrimp size
UNITS: dimensionless
VALUE: between 0% and 100%
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Escaping_gear ; Being_discarded; Escaping_cod_end

DATA:

- Source: ILVO- Fisheries
- Dataset: see annex

2.2 escaping gear

DEFINITION: The amount of shrimps escaping from the net after entering, per unit of time

EQUATION: (1-GS[*])*NSStandard[*]*Being_swept[*]

ARRAY: shrimp size

UNITS: numbers/month

VALUE: initial value = 0; range between 0 and unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: GS; Being_swept; NSStandard
- Output: Gear_escape_but_dead; Escaped_gear

DATA: calculated but not verifiable

2.3 mrate gear escape

DEFINITION: The percentage of animals dying after escape from the net

EQUATION: N/A

ARRAY: none

UNITS: %

VALUE: between 0% and 100% but for the time being fixed at 1%

TYPE: parameter

FUNCTION: scenario

LINKS

- Input: Gear_escape_but_dead

DATA: virtual (see annex)

2.4 gear escape but dead

DEFINITION: Total number of shrimps dead after escape from the net

EQUATION: Escaping_gear[*]*MRate_gear_escape[*]

ARRAY: shrimp size

UNITS: numbers

VALUE: initial value = 0; range between 0 and unlimited; only +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: MRate_gear_escape; Escaping_gear
- Output: Total_dead_numbers_per_month

DATA: calculated but not verifiable

2.5 escaped gear

DEFINITION: The accumulation of animals swept but that escaped the gear.
EQUATION: Escaped_gear(TIME-DT)+ Escaping_gear*DT
ARRAY: shrimp size
UNITS: numbers per month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Escaping_gear

DATA: calculated but not verifiable

3. COD END

Animals ending up in the cod-end will partly escape and partly stay in the net to be hauled to the surface. Of the escapees, part will die of injury. This process is described below.

3.1 cs

DEFINITION: This process is described by the selectivity of the cod-end. It is the percentage of animals escaping from the cod-end.
EQUATION: 1-EXP(A+B*Shrimp_size_per_class[*])/
(1+EXP(A+B*Shrimp_size_per_class[*]))
ARRAY: shrimp size
UNITS: dimensionless
VALUE: between 0% and 100%
TYPE: variable
FUNCTION: calculated
LINKS:

- Output: Escaping_cod_end ; Being_discarded

DATA:

- Source: ILVO- Fisheries
- Dataset: see annex

3.2 escaping cod end

DEFINITION: The amount of shrimps escaping from the cod-end after entering, per unit of time
EQUATION: (1-GS[*])*(1-NSStandard[*])*CS[*]*Being_swept[*]
ARRAY: shrimp size
UNITS: numbers/month

VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: GS, NSStandard; CS; Being_swept
- Output: Cod_end_escape_but_dead; Escaped_cod_end

DATA: calculated but not verifiable

3.3 mrate cod end escape

DEFINITION: The percentage of animals dying after escape from the cod-end
EQUATION: N/A
ARRAY: none
UNITS: dimensionless
VALUE: between 0% and 100% but for the time being fixed at 1%
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Cod_end_escape_but_dead

DATA: virtual (see annex)

3.4 cod end escape but dead

DEFINITION: Total number of shrimps dead after escape from the cod-end
EQUATION: Escaping_cod_end[*]*MRate_cod_end_escape[*]
ARRAY: shrimp size
UNITS: numbers
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Escaping_cod_end; MRate_cod_end_escape
- Output: Total_dead_numbers_per_month

DATA: calculated but not verifiable

3.5 escaped cod end

DEFINITION: The accumulation of animals swept but that escaped the cod end.
EQUATION: Escaped_cod_end(TIME)= Escaped_cod_end(TIME-DT)+ Escaping_cod_end*DT
ARRAY: shrimp size
UNITS: numbers
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: stock

FUNCTION: calculation
LINKS:

- Input: Escaping_cod_end

DATA: calculated but not verifiable

4. FINAL CATCH

The cod-end catch will be hauled to the surface and will be processed by the fishermen on board.

4.1 fs: fishermen's selection

DEFINITION: It describes the selectivity by the fishermen on board. It is the percentage of animals thrown over board, in this case depending on the properties of the shrimp sieve.
EQUATION: 1-EXP(C+D*Shrimp_size_per_class[*])/
(1+EXP(C+D*Shrimp_size_per_class[*]))
ARRAY: shrimp size
UNITS: dimensionless
VALUE: between 0% and 100%
TYPE: variable
FUNCTION: calculated
LINKS:

- Input: C; D; Shrimp_size_per_class
- Output: Being_discarded

DATA:

- Source: ILVO- Fisheries
- Dataset: see annex

4.2 being discarded

DEFINITION: The amount of shrimps discarded over a period of time
EQUATION: (1-GS[*])*(1-NSStandard[*])*(1-CS[*])*FS[*]*Being_swept[*]
ARRAY: shrimp size
UNITS: numbers/month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Being_swept; GS; NSStandard; CS;FS
- Output: Discard_and_dead; Discarded

DATA: calculated but not verifiable

4.3 mrate discard

DEFINITION: The percentage of animals dying after discarding
EQUATION: N/A
ARRAY: none
UNITS: dimensionless
VALUE: between 0% and 100% but for the time being fixed at 25%
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Discard_and_dead

DATA: from the literature (see annex)

4.4 discard and dead

DEFINITION: Total number of shrimps dead after discarding
EQUATION: Being_discard[*]*MRate_discard[*]
ARRAY: shrimp size
UNITS: numbers
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Being_discard; MRate_discard
- Output: Total_dead_animals_per_month

DATA: calculated but not verifiable

4.5 discarded

DEFINITION: The accumulation of animals swept but that were finally discarded.
EQUATION: Discarded(TIME-DT)+ Being_discarded*DT
ARRAY: shrimp size
UNITS: numbers
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Being_discarded

DATA: calculated but not verifiable

5. LANDINGS

Mainly a conversion of numbers of shrimps to biomass, *i.e*. landed marketable shrimps in metric tonnes.

5.1 weight per class

DEFINITION: The weight of a shrimp given its size
EQUATION: (Shrimp_size_per_class[*]^3.178)*3.212E-06
ARRAY: shrimp size
UNITS: gram
VALUE: range between 0 and ~5 grams
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Shrimp_size_per_class
- Output: Landed_biomass; Total_dead_biomass_per_size_per_month

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division, PhD thesis F. Redant (1978)
- Dataset: see annex

5.2 landed biomass per month

DEFINITION: The weight of shrimps landed, on a monthly basis
EQUATION: (Being_swept[*]-Escaping_sweeping[*]-Escaping_gear[*]-Escaping_Cod_End[*]-Being_discarded[*])*Weight_per_class[*]/1.0E+06
ARRAY: shrimp size
UNITS: metric tons/month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: Variable
FUNCTION: calculation
LINKS:

- Input: Being_swept, Escaping_sweeping, Escaping_gear, Escaping_Cod_End, Being_discarded, Weight_per_class
- Output: Commercial_biomass_per_month; Wasted_landed_biomass_per_month

DATA: calculated but not verifiable

5.3 landed biomass

DEFINITION: The weight of shrimps landed
EQUATION: Netto_catch_animals[*]*Weight_per_class[*]/1.0E+06
ARRAY: shrimp size

UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: Variable
FUNCTION: calculation
LINKS:

- Input: Netto_catch_animals; Weight_per_class
- Output: Commercial_biomass; Wasted_landed_biomass

DATA: calculated but not verifiable

5.4 processing

DEFINITION: This is the percentage of weight that is taken as waste from the actual commercial shrimp that is retained after discard
EQUATION: N/A
ARRAY: none
UNITS: Dimensionless
VALUE: 0 (Not applicable for shrimps)
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Wasted_landed_biomass; Wasted_landed_biomass_per_month

DATA: virtual (see annex)

5.5 wasted landed biomass per month

DEFINITION: Biomass discarded after gutting and cleaning operation on a monthly basis. Applicable to fish, not shrimp (see Processing)
EQUATION: Landed_biomass_per_month[*]*Processing
ARRAY: Shrimp size
UNITS: Metric tons/month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Landed_biomass_per_month; Processing
- Output: Commercial_biomass_per_month

DATA: calculated but not verifiable

NOTE: Biomass discarded after gutting and cleaning operations are discarded at sea and not landed on shore.

5.6 wasted landed biomass

DEFINITION: Biomass discarded after gutting and cleaning operation. Applicable to fish, not shrimp (see Processing)
EQUATION: Landed_biomass[*]*Processing
ARRAY: Shrimp size
UNITS: Metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Landed_biomass; Processing
- Output: Commercial_biomass; Total_waste

DATA: calculated but not verifiable

5.7 commercial biomass per month

DEFINITION: Weight of landings ready for market on a monthly basis.
EQUATION: Landed_biomass_per_month[*]-Wasted_landed_biomass_per_month[*]
ARRAY: shrimp size
UNITS: Metric tons/month
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Landed_biomass_per_month; Wasted_landed_biomass_per_month
- Output: Total_commercial_biomass_per_month

DATA: calculated but not verifiable

5.8 commercial biomass

DEFINITION: Weight of landings ready for market.
EQUATION: Landed_biomass[*]-Wasted_landed_biomass[*]
ARRAY: shrimp size
UNITS: Metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Landed_biomass; Wasted_landed_biomass
- Output: Total_commercial_biomass

DATA: calculated but not verifiable

5.9 total commercial biomass per month

DEFINITION: Total weight of landings, ready for the market, on a monthly basis
EQUATION: ARRAYSUM(Commercial_biomass_per_month[*])
ARRAY: none
UNITS: metric tons/month
VALUE: initial value = 0; range between 0 and unlimited unless limited by policy; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Commercial_biomass_per_month
- Output: Fish_landings_per_unit_of_effort; Input to Socio-economic sub-model

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division (Period 2003-2005)
- Dataset: see annex

5.10 total commercial biomass

DEFINITION: Total weight of landings, ready for the market
EQUATION: ARRAYSUM(Commercial_biomass[*])
ARRAY: none
UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited unless limited by policy; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Commercial_biomass

DATA: see annex 5.9 Total_commerical_biomass_per_month

5.11 fish landings per unit effort

DEFINITION: the weight of landed shrimp per unit of effort (small fleet)
EQUATION: Total_commerical_biomass_per_month*1000/(Effort_Intensity*Effort)
ARRAY: none
UNITS: kg/hr
VALUE: range between 0 and unlimited unless limits set by policy; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Effort_Intensity, Effort, Total_commerical_biomass_per_month

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division (Period 1999-2005)
- Dataset: see annex

5.12 shrimp size per class

DEFINITION: the reference size for each of the classes defining the "shrimp size" index of the arrays
EQUATION: N/A
ARRAY: shrimp size
UNITS: mm
VALUE: 15, 25, 35, 45, 55, 65, 75, 85
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Weight_per_class

DATA:

- Source: ILVO- Fisheries
- Dataset: see annex

6. DEAD DISCHARGE

Aggregation of all animals dying due to the fishing operation.

6.1 total dead numbers per month

DEFINITION: Total numbers of shrimps dead after passage of the beam trawl
EQUATION: Cod_end_escape_but_dead[*]+Discard_and_dead[*]+ Gear_escape_but_dead[*]+Swept_escape_but_dead[*]
ARRAY: shrimp size
UNITS: numbers
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Swept_escape_but_dead; Gear_escape_but_dead; Cod_end_escape_but_dead; Discard_and_dead
- Output: Total_dead_biomass_per_size_per_month

DATA: calculated but not verifiable

6.2 total dead biomass per size per month

DEFINITION: Total biomass by length class of shrimps dead after passage of the beam trawl
EQUATION: Total_dead_numbers_per_month[*]*Weight_per_class[*]/1.0E+06
ARRAY: shrimp size
UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Total_dead_numbers_per_month; Weight_per_class

DATA: calculated but not verifiable

6.3 total dead biomass over all sizes

DEFINITION: Total biomass of shrimps dead after passage of the beam trawl.
EQUATION: ARRAYSUM(Total_dead_biomass_per_size_per_month[*])
ARRAY: none
UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Output: Total_wasted_biomass

DATA: calculated but not verifiable

6.4 total waste

DEFINITION: Biomass weight lost during processing
EQUATION: ARRAYSUM(Wasted_landed_biomass [*])
ARRAY: none
UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Wasted_landed_biomass
- Output: Total_wasted_biomass

DATA: calculated but not verifiable

6.5 total wasted biomass

DEFINITION: Total dead biomass during fishing operations and processing
EQUATION: Total_dead_biomass_over_all_sizes+Total_waste

ARRAY: none
UNITS: metric tons
VALUE: initial value = 0; range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Total_dead_biomass_over_all_sizes; Total_waste

DATA: calculated but not verifiable

Fig. II.1.1 is the Stella printout for the Shrimp Fisheries Driving Force model. The above text describes the crucial elements. Elements in the figure that are not described in this text are characteristic of the modelling process and are used to allow the model run.

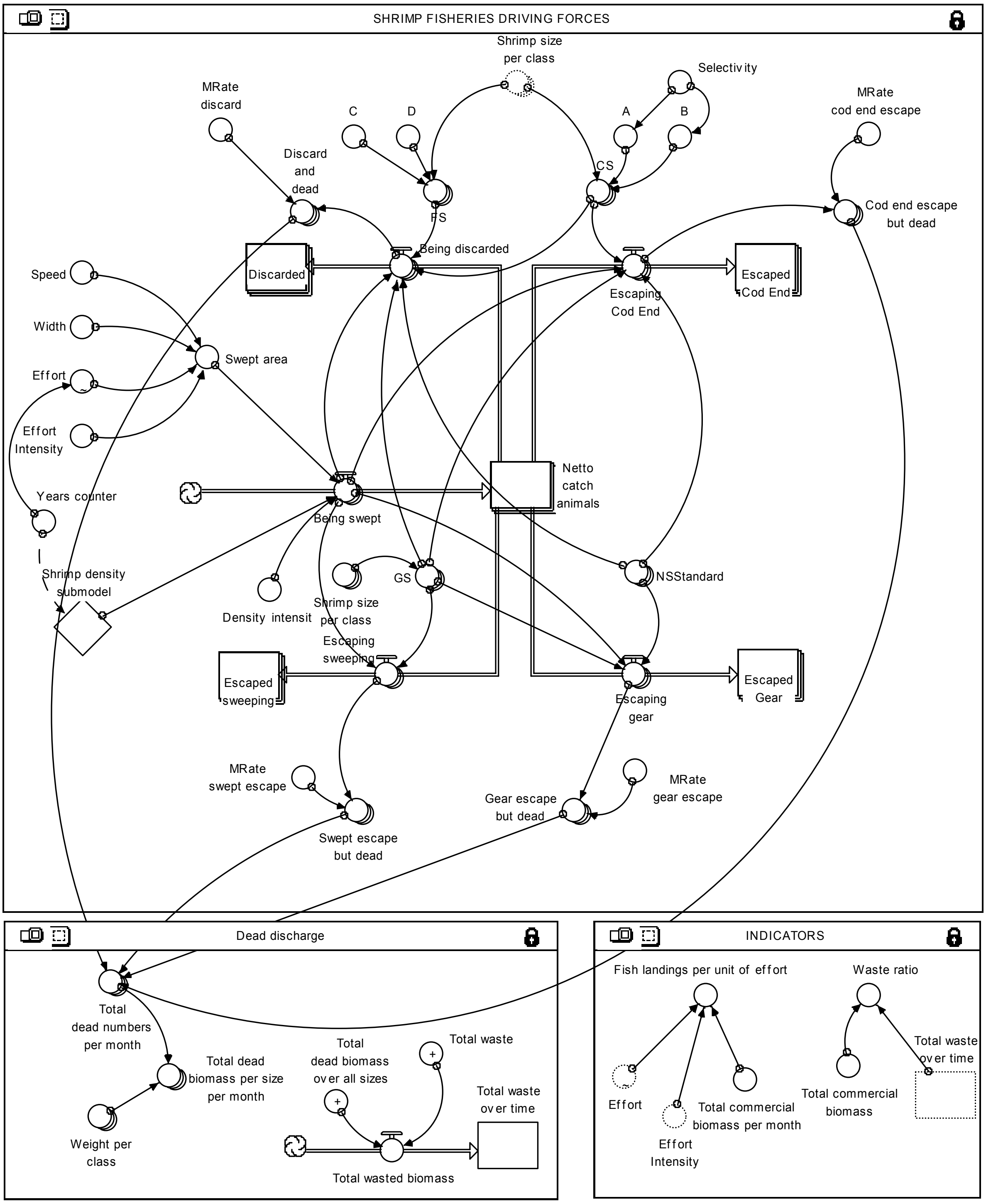


Fig. II.1.1 STELLA sub-model of the Shrimp Fisheries Driving Forces

Marine Biology Section
University of Ghent
Sofie Derous

CHAPTER TWO

ENVIRONMENT OF SHRIMP FISHERIES

1. MACROBENTHIC DENSITY AT THE FISHED SITE: STOCK AND FLOWS

The Belgian Continental Shelf (BCS) is characterized by many macrobenthic communities and it would therefore be unrealistic to determine the impact of shrimp fisheries on the total macrobenthic density (densities can vary a lot between communities). In this case, the richest benthic community (*Abra alba*) was selected with high likelihood that shrimp will occupy the same spots as these communities due to the fact they provide the most food for shrimp. The *Abra alba* community is characterized by the highest density (average value of 6400 ind/m² - maximum value of 22000 ind/m²) and the highest species richness (30 sp/m²) found on the BCS.

1.1 macrobenthos density

DEFINITION: The amount of macrobenthic individuals that is present in the fished areas (which are the areas with highest species richness and densities – typical for the occurrence of the *Abra alba* community)

EQUATION:macrobenthos_density(t - dt)+(recruiting_macrobenthos+being_ influenced_by_fishing-dying_macrobenthos-competition)*dt

ARRAY: none

UNITS: ind/m²

VALUE: initial value = 6400; range between 0 and 22000 (= density at which competition becomes too high ➔ see Density for competition); only +

TYPE: stock

FUNCTION: objective

LINKS:

- Input: Recruiting_macrobenthos; Being_influenced_by_fishing
- Output: Dying_macrobenthos; Being_influenced_by_fishing; recruiting_macrobenthos; Actual_mortality_rate

DATA:

- Source: MACRODAT database (Section Marine Biology); Van Hoey et al. (2004)
- Dataset: available at Section Marine Biology, University of Ghent

1.2 dying macrobenthos

DEFINITION: The amount of macrobenthic individuals that die off naturally
EQUATION: macrobenthos density*actual mortality_rate
ARRAY: none
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Macrobenthos_density; Actual_mortality_rate

DATA: calculated but not verifiable

1.3 mortality rate

DEFINITION: The rate with which macrobenthic individuals die off
EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 0.05
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Actual_mortality_rate

DATA:

- Source: Blackford (1997); Duplisea (1998)
- Dataset: see annex

1.4 recruiting macrobenthos

DEFINITION: The amount of macrobenthic individuals that are being born
EQUATION: macrobenthos_density*birth_rate
ARRAY: none
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Macrobenthos_density; Birth_rate

DATA: calculated but not verifiable

1.5 birth rate

DEFINITION: The rate with which macrobenthic individuals are being born

EQUATION: constant
ARRAY: none
UNITS: numerical
VALUE: 0.36
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Recruiting_macrobenthos; Actual_mortality_rate

DATA:

- Source: Sohma et al. (2001); Duplisea (1998); Ortiz & Wolff (2002)
- Dataset: see annex

1.6 density for competition

DEFINITION: The maximum macrobenthic density which can be sustained on the BCS
EQUATION: constant
ARRAY: none
UNITS: ind/m²
VALUE: 22000 (estimated highest density found in the macrobenthic *Abra alba* communities occurring in the Belgian sea)
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Actual_mortality_rate

DATA:

- Source: MACRODAT database (Section Marine Biology)
- Dataset: available at Section Marine Biology, University of Ghent

1.7 being influenced by fishing

DEFINITION: Net effect of the fishing activity on the benthos density
EQUATION: ABS(effect_of_surface_area_fished)*macrobenthos_density
ARRAY: none
UNITS: ind/m²
VALUE: range between 0 and unlimited; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Macrobenthos_density; Effect_of_surface_area_fished

DATA: calculated but not verifiable

1.8 actual mortality rate

DEFINITION: The mortality rate to be applied, depending whether there is competition or not.
EQUATION: IF(macrobenthos_density < Density_for_competition)
THEN Mortality_rate ELSE
max(Mortality_rate,birth_rate+effect_of_surface_area_fished)
ARRAY: none
UNITS:
VALUE: range between 0 and unlimited; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Macrobenthos_density; Birth_rate; Effect_of_surface_area_fished; Mortality_rate; Density_for_competition
- Output: Dying_macrobenthos

DATA: calculated but not verifiable

2. EFFECT OF FISHING

The effect of shrimp fishing on macrobenthic density is dependent on the surface area which is fished and on the regime of fishing.

2.1 effect of surface area fished

DEFINITION: Sum of the effects of fishing for all regimes on the macrobenthic density
EQUATION: MIN(effect_surface_area_CR,effect_surface_area_R,0)
ARRAY: none
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Effect_surface_area_CR; Effect_surface_area_R
- Output: Being_influenced_by_fishing; Actual_mortality_rate

DATA: Calculated but not verifiable

2.2 regime

DEFINITION: The cumulative amount of days between two fishing events
EQUATION: regime(t - dt) + (increasing - decreasing) * dt
ARRAY: none

UNITS: days
VALUE: initial value = 0; range between 0 and unlimited unless limits set by policy, only +
TYPE: stock
FUNCTION: calculation
LINKS:

- Input: Increasing
- Output: Decreasing; Effect_surface_area_R

DATA: calculated but not verifiable

2.3 increasing

DEFINITION: The mean number of days between 2 fishing trips which yields an increase of the regime (~ discrete regime)
EQUATION:IF(days_fished_per_month<30)THEN(30-days_fished_per_month) ELSE 0
ARRAY: none
UNITS: days
VALUE: range between 0 and value of regime; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Days_fished_per_month

DATA: calculated but not verifiable

2.4 decreasing

DEFINITION: When a given regime level is reached, the regime is reset
EQUATION: IF (days_fished_per_month>=30)THEN(regime/dt) ELSE 0
ARRAY: none
UNITS: days
VALUE: range between 0 and value of regime; only +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Days_fished_per_month; Regime

DATA: calculated but not verifiable

2.5 days fished per month

DEFINITION: The amount of days per month that fishing occurs
EQUATION: Effort*Effort_Intensity/Time_fishing_per_trip_over_the_year
ARRAY: none
UNITS: days

VALUE: range between 0 and 30; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Effort; Effort_intensity; Time_fishing_per_trip_over_the_year from Socio-economy sub-model
- Output: Increasing; Decreasing; Continuous_regime

DATA: calculated but not verifiable

2.6 continuous regime

DEFINITION: Continuous regime, when the mean number of days between two fishing events is 0
EQUATION: IF (days_fished_per_month=30) THEN 1 ELSE 0
ARRAY: none
UNITS: numerical
VALUE: range between 0 and 1; only +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Days_fished_per_month
- Output: Effect_surface_area_CR

DATA: calculated but not verifiable

2.7 effect surface area cr

DEFINITION: Effect of fishing a certain surface area on the macrobenthic density when the continuous regime (CR) is valid
EQUATION: IF(continuous_regime=1)THEN(((10^(((0.0006*((Swept_area)^2))-(0.0309*(Swept_area))-0.0639)+2.004))-101)/100)ELSE 0
ARRAY: none
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Continuous_regime; Swept_area (from Driving Forces sub-model)
- Output: Effect_of_surface_area_fished

DATA: calculated in meta-analysis (see Annex)

2.8 effect of surface area r

DEFINITION: Effect of fishing a certain surface area on the macrobenthic density when regime 1 or 2 are valid

EQUATION: IF(Regime >=1 AND Regime < 30)
THEN (10^(-0.0134*Swept_area-0.0134+2.004)-101)/100
ELSE IF (REGIME > 30) THEN (10^(-8.25841E-5*Swept_area-0.13+2.004)-101)/100
ELSE -0.35

ARRAY: none
UNITS: numerical
VALUE: range between 0 and unlimited; +/-
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Regime; Swept_area from Driving Forces sub-model
- Output: Effect_of_surface_area_fished

DATA: calculated in meta-analysis (see Annex)

3. SEDIMENT COMPOSITION AT THE FISHED SITE

The percentages of the different sediment fractions are visualized as stocks. The sediment fractions chosen are 'fine sand-FS', 'medium-coarse sand-MCS' and 'gravel'. Below only the equations for the fine sand fraction are given. The other equations can be found in the annex (subsections 3.8-3.21).

3.1 sediment extraction site fs

DEFINITION: The percentage of the fine sand grain size fraction that is present in a fished area

EQUATION: sediment_extraction_site_FS(t-dt)+(natural_input_3+increase_due_to_fishing_3-natural_decrease_by_transport_3-decrease_due_to_fishing_3)*dt

ARRAY: none
UNITS: %
VALUE: initial value = 45.75; range between 0 and unlimited; only +
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Natural_input_FS
- Output: Natural_decrease_by_transport_FS; Being_influenced_by_fishing_FS; natural input FS

DATA: Calculated from meta-analysis (see Annex)

3.2 natural input fs

DEFINITION: The percentage of the fine sand grain size fraction that is coming in the zone due to natural sediment transport processes

EQUATION: infilling_rate_FS * sediment_extraction_site_FS

ARRAY: none

UNITS: %

VALUE: range from 0 to unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Infilling_rate_FS; Sediment_extraction_site_FS
- Output: Sediment_extraction_site_FS

DATA: calculated but not verifiable

3.3 infilling rate fs

DEFINITION: The rate at which the fine sand grain size fraction is transported to an area

EQUATION: Constant

ARRAY: none

UNITS: numerical

VALUE: 1.0113

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Natural_input_FS

DATA: Calculated from meta-analysis (see Annex)

3.4 sand transport fs

DEFINITION: The rate at which the fine sand grain size fraction is transported away from an area

EQUATION: constant

ARRAY: none

UNITS: numerical

VALUE: 1.0083

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Natural_decrease_by_transport_FS

DATA: Calculated from meta-analysis (see Annex)

3.5 natural decrease by transport fs

DEFINITION: The percentage of the fine sand grain size fraction that leaves the zone due to natural sediment transport processes

EQUATION: sand_transport_FS*sediment_extraction_site_FS

ARRAY: none

UNITS: %

VALUE: range from 0 to unlimited; only +

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Sand_transport_FS; Sediment_extraction_site_FS

DATA: calculated but not verifiable

3.6 effect of fishing fs

DEFINITION: Effect of fishing a certain surface area on the percentage of the fine sand grain size type.

EQUATION:((10^(((0.0058*Swept_area)-0.2765)+2.004))-101)/100

ARRAY: none

UNITS: numerical

VALUE: range between 0 and unlimited; +/-

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Swept_area (from Driving Forces sub-model)
- Output: Being_influenced_by_fishing_FS

DATA: calculated in meta-analysis (see Annex)

3.7 being influenced by fishing fs

DEFINITION: The percentage of the fine sand grain size fraction that fills in or is removed from the fished area

EQUATION: (effect_of_fishing_FS)*sediment_extraction_site_FS

ARRAY: none

UNITS: %

VALUE: range from 0 to unlimited; +/-

TYPE: flow

FUNCTION: calculation

LINKS:

- Input: Effect_of_fishing_FS; Sediment_extraction_site_FS

DATA: calculated but not verifiable

Fig. II.2.1 is the Stella printout for the Fisheries environmental sub-model. The above text describes the crucial elements. Elements in the figure that are not described in this text are characteristic of the modelling process and are used to allow the model run.

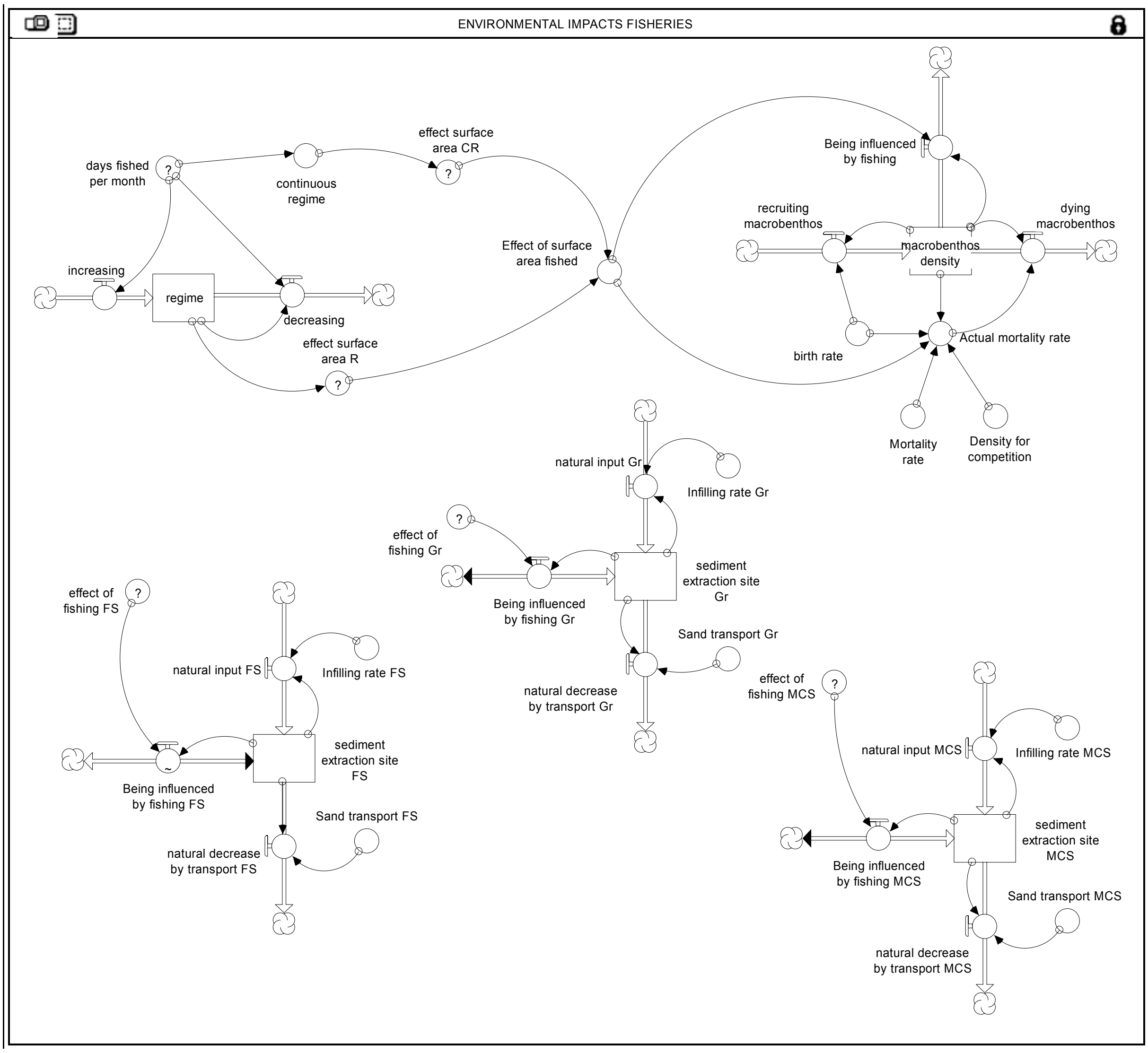


Fig. II.2.1 STELLA sub-model for Shrimp Fisheries Environment

ECOLAS
Environmental Consultancy & Assistance
Annemie Volckaert

CHAPTER THREE

SOCIO-ECONOMY OF SHRIMP FISHERIES

1. ECONOMIC RESULT

The socio-economic impact should be seen in terms of changing costs or change in turnover. These two parameters will determine the economic result. The economic result can be positive (profit) or negative (loss). The profit or loss is calculated by decreasing the total turnover of fishery with the total costs made by the sector (variable and fixed costs).

1.1 economic result

DEFINITION: the return of the shrimp fishery sector over time (small fleet)
EQUATION: Economic_result(t - dt) + (Calculation_economic_result) * dt
ARRAY: none
UNITS: EUR
VALUE: initial value = 0; range between 0 and unlimited; +/-
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Calculation_economic_result

DATA: calculated but not verifiable

1.2 calculation economic result

DEFINITION: the monthly return of the shrimp fishery sector (small fleet)
EQUATION: (Calculation_turnover)-(Calculation_costs)
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +/-
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Calculation_turnover; Calculation_costs
- Output: Economic_result

DATA: calculated but not verifiable

1.3 turnover

DEFINITION: the total turnover for shrimp over time by the small fleet segment
EQUATION: Turnover(t - dt) + (Calculation_turnover) * dt
ARRAY: none
UNITS: EUR
VALUE: initial value = 0; range between 0 and unlimited; +
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Calculation_turnover

DATA: calculated but not verifiable

1.4 calculation turnover

DEFINITION: the total turnover for shrimp by the small fleet segment per month.
EQUATION: Total_commercial_biomass_per_month*1000*(Fish_price+Public_help_on_fish_price)
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Total_commercial_biomass_per_month (from Driving Forces Fisheries sub-model), Fish_price; Public_help_on_fish_price
- Output: Turnover

DATA: calculated but not verifiable

1.5 fish price

DEFINITION: the average price per kg shrimp paid to the fishermen at auction
EQUATION: constant
ARRAY: none
UNITS: EUR/kg
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Calculation_turnover

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

1.6 total cost

DEFINITION: the total cost for the shrimp fishery sector (small fleet) over time
EQUATION: Total_cost(t - dt) + (Calculation_costs) * dt
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: stock
FUNCTION: objective
LINKS:

- Input: Calculation_costs

DATA: calculated but not verifiable

1.7 calculation costs

DEFINITION: the total monthly cost for the shrimp fishery sector (small fleet)
EQUATION:
total_monthly_fixed_cost_small_fleet+Total_monthly_variable_cost_small_fleet
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: flow
FUNCTION: calculation
LINKS:

- Input: Total_monthly_fixed)_cost_small_fleet; Total_monthly_variable_cost_small_fleet
- Output: Total_cost

DATA: calculated but not verifiable

2. VARIABLE COST

The variable costs of the shrimp fishery sector (small fleet segment) are subdivided into fuel cost and personnel cost. Several parameters play a role in the calculation of the fuel cost:

- The type of activity: sailing to the fish ground versus the fishing activity;
- The duration of the activity: number of kilometres to the fish ground versus the hours of fishing;

- The fuel consumption per activity;
- The fuel price.

2.1 total monthly variable cost small fleet

DEFINITION: the total variable cost per month for the shrimp fishery sector (small fleet)
EQUATION: Total_monthly_fuel_cost+Total_monthly_other_costs_small_fleet +Total_monthly_personnel_cost_small_fleet
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Total_monthly_fuel_cost; Total_monthly_personnel cost_small_fleet; Total_monthly_other_costs_small_fleet

DATA: Calculated result not verifiable

2.2 total monthly fuel cost small fleet

DEFINITION: the total fuel cost per month for the shrimp fishery sector (small fleet)
EQUATION: Fuel_cost_per_trip*Monthly_trips_over_the_year
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Fuel_cost_per_trip; Monthly_trips_over_the_year
- Output: Total_monthly_variable_cost_small_fleet

DATA: Calculated result not verifiable

2.3 trips to inshore fish ground

DEFINITION: the number of sea journeys (trips) per month for the inshore fish ground for the shrimp fishery sector (small fleet)
EQUATION: constant
ARRAY: none
UNITS: trips
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario

LINKS:

- Output: Monthly_trips_over_the_year

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

2.4 trips to offshore fish ground

DEFINITION: the number of sea journeys (trips) per month for the offshore fish ground for the shrimp fishery sector (small fleet)

EQUATION: constant

ARRAY: none

UNITS: trips

VALUE: range between 0 and unlimited; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Monthly_trips_over_the_year

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

2.5 monthly trips over the year

DEFINITION: the number of sea journeys (trips) per month for the shrimp fishery sector (small fleet), depending on the season of the year

EQUATION: IF((INT(MOD(TIME,12))+1) = 1) OR ((INT(MOD(TIME,12))+1) = 2) OR ((INT(MOD(TIME,12))+1) = 12) THEN Trips_to_offshore_fish_grounds ELSE Trips_to_inshore_fish_grounds

ARRAY: none

UNITS: trips

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Trips_to_inshore_fish_grounds; Trips_to_offshore_fish_grounds
- Output: Total_monthly_fuel_cost

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

2.6 fuel cost per trip

DEFINITION: the total fuel cost per trip including sailing and fishing per trip for the shrimp fishery sector (small fleet)
EQUATION: Fuel_cost_fishing_per_trip+Fuel_cost_sailing_per_trip
ARRAY: none
UNITS: EUR/trips
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Fuel_cost_fishing_per_trip; Fuel_cost_sailing_per_trip
- Output: Total_monthly_fuel_cost_small_fleet

DATA: Calculated result not verifiable

2.7 fuel cost fishing per trip

DEFINITION: the total fuel cost of fishing per trip, defined per fishing zone (shrimp sector)
EQUATION: Fuel_consumption_fishing*(Fuel_price*(1-Public_help_on_fuel_price)) *Time_fishing_per_trip_over_the_year
ARRAY: none
UNITS: EUR/trips
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Fuel_consumption_fishing; Fuel_price; Time_fishing_per_trip_over_the_year
- Output: Fuel_cost_per_trip; Public_help_on_fuel_price

DATA: calculated but not verifiable

2.8 fuel consumption fishing

DEFINITION: the amount of fuel consumed per hour fishing (shrimp sector)
EQUATION: constant
ARRAY: none
UNITS: l/hr

VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_fishing_per_trip

DATA:

- Source: Personnal communication fisher
- Dataset: see Annex

2.9 time fishing per trip over the year

DEFINITION: the average time of fishing during one trip, depending on the season of the year
EQUATION:IF((INT(MOD(TIME,12))+1) = 1) OR ((INT(MOD(TIME,12))+1) = 2) OR ((INT(MOD(TIME,12))+1) = 12) THEN Time_fishing_per_trip_in_offshore_ fishgrounds ELSE Time_fishing_per_trip_in_inshore_fish_grounds
ARRAY: none
UNITS: hr/trips
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Time_fishing_per_trip_in_inshore_fish_grounds; Time_fishing_per_trip_in_offshore_fish_grounds
- Output: Fuel_cost_fishing_per_trip; Time_fishing_per_trip_over_the_year: Input to Environmental Fisheries sub-model

DATA: calculated but not verifiable

2.10 time fishing per trip in inshore fish grounds

DEFINITION: the average time of fishing during one trip on inshore fishing grounds,
EQUATION: constant
ARRAY: none
UNITS: hr/trips
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Time_fishing_per_trip_over_the_year

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

2.11 time fishing per trip in offshore fish grounds

DEFINITION: the average time of fishing during one trip on offshore fishing grounds
EQUATION: constant
ARRAY: none
UNITS: hr/trips
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Time_fishing_per_trip_over_the_year

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Dataset: see Annex

2.12 fuel price

DEFINITION: the average price for gas oil fuel used for vessels in the shrimp fishery sector (small fleet)
EQUATION: constant
ARRAY: none
UNITS: EUR/l
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Fuel_cost_fishing_per_trip; Fuel_cost_sailing_per_trip

DATA:

- Source: FPS Economy, SMEs, Self-employed and Energy: Ecodata. Official maximum prices of petroleum products (excl. BTW) (1999-2005).
- Dataset: see Annex

2.13 fuel cost sailing per trip

DEFINITION: the total fuel cost of sailing per trip
EQUATION: Fuel_consumption_sailing*(Fuel_price*(1-Public_help_on_fuel_price))

*Average_steamed_distance_over_the_year*2

ARRAY: none

UNITS: EUR/trip

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Average_steamed_distance_over_the_year; Fuel_consumption_sailing; Fuel_price; Public_help_on_fuel_price
- Output: Fuel_cost_per_trip

DATA: calculated but not verifiable

2.14 fuel consumption sailing

DEFINITION: the amount of fuel consumed per distance sailing (shrimp sector)

EQUATION: constant

ARRAY: none

UNITS: l/km

VALUE: range between 0 and unlimited; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Fuel_cost_sailing_per_trip

DATA:

- Source: Personnal Communication Fisher
- Dataset: see Annex

2.15 distance to inshore fish grounds

DEFINITION: the average distance taken between inshore fish grounds and the harbour of Oostende

EQUATION: constant

ARRAY: none

UNITS: km

VALUE: range between 0 and 60; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Average_steamed_distance_over_the_year

DATA:

- Source: Hans Polet - DVZ
- Dataset: see Annex

2.16 distance to offshore fish grounds

DEFINITION: the average distance taken between offshore fish grounds and the harbour of Oostende

EQUATION: constant

ARRAY: none

UNITS: km

VALUE: range between 0 and 60; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Average_steamed_distance_over_the_year

DATA:

- Source: Hans Polet - DVZ
- Dataset: see Annex

2.17 average steamed distance over the year

DEFINITION: the average steamed distance according to the season of the year

EQUATION: IF((INT(MOD(TIME,12))+1) = 1) OR ((INT(MOD(TIME,12))+1) = 2) OR ((INT(MOD(TIME,12))+1) = 12) THEN Distance_to_offshore_fish_grounds ELSE Distance_to_inshore_fish_grounds

ARRAY: none

UNITS: km

VALUE: range between 0 and 60; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Output: Fuel_cost_sailing_per_trip

DATA: calculated but not verifiable

2.18 total monthly personnel cost small fleet

DEFINITION: the monthly personnel cost for the shrimp fishery sector (small fleet), expressed as a percentage of the total turnover

EQUATION: ratio_turnover*Calculation_turnover

ARRAY: none

UNITS: EUR

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: objective

LINKS:

- Input: Ratio_turnover; Calculation_turnover
- Output: Total_monthly_variable_cost_small_fleet; Cost_per_employee

DATA: calculated but not verifiable

2.19 ratio turnover

DEFINITION: percentage expressing the ratio between the total turnover and the total personnel cost
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Total_monthly_personnel_cost_small_fleet

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division (Period 2002-2003)
- Dataset: see Annex

2.20 cost per employee

DEFINITION: the monthly gross cost per employee (gross pay) on board a shrimp vessel (small fleet)
EQUATION: Total_monthly_personnel_cost_small_fleet/ (Number_of_vessels__in_small_fleet*Number_of_employees__per_vessel)
ARRAY: none
UNITS: EUR/employee
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation

LINKS:

- Input: Total_monthly_personnel_cost_small_fleet; Number_of_vessels_small_fleet; Number_of_employees_per_vessel

DATA: Calculated and verifiable

2.21 number of employees per vessel

DEFINITION: the number of (fixed) employees per vessel (shrimp sector)
EQUATION: constant

ARRAY: none
UNITS: Employee/vessels
VALUE: range between 0 and 10; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Cost_per_employee

DATA:

- Source: Maes, F., Schrijvers, J., Van Lancker, V., Verfaillie, E., Degraer, S., Derous, S., De Wachter, B., Volckaert, A., Vanhulle, A., Vandenabeele, P., Cliquet, A., Douvere, F., Lambrecht, J. and Makgill, R. (2005). Towards a spatial structure plan for sustainable management of the sea. Research in the framework of the BSP programme "Sustainable Management of the Sea" – PODO II, June 2005, pp. 539.
- Dataset: see Annex

2.22 number of vessels in small fleet

DEFINITION: the number of vessels belonging to the small fleet segment of the shrimp fishery sector
EQUATION: constant
ARRAY: none
UNITS: vessels
VALUE: range between 0 and 20; +
TYPE: parameter
FUNCTION: policy choice
LINKS:

- Output: Cost_per_employee; Total_monthly_fixed_cost_small_fleet

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division
- Data: see Annex

2.23 total monthly other cost small fleet

DEFINITION: the monthly cost of other variable costs for the shrimp fishery sector (small fleet); including fish gear, loading/unloading, ice, administrative costs, compass setting, transport costs, literature, working clothes, rent buildings, etc.
EQUATION: Calculation_turnover*Ratio_other_costs
ARRAY: none
UNITS: EUR

VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Calculation_turnover; Ratio_other_costs
- Output: Total_monthly_variable_cost_small_fleet

DATA: calculated and verifiable

2.24 ratio other costs

DEFINITION: percentage expressing the ratio between the turnover and the other costs
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Total_monthly_other_cost_small_fleet

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division (based on year 2002)
- Dataset: see Annex

3. FIXED COST

The fixed costs of shrimp fishery sector (small fleet segment) consist of insurance, maintenance and investment costs.

3.1 total monthly fixed cost small fleet

DEFINITION: the total monthly fixed cost for the shrimp fishery sector (small fleet), including insurance, maintenance and investment costs
EQUATION: Monthly_fixed__cost_per_vessel*Number_of_vessels__in_small_fleet
ARRAY: none
UNITS: EUR
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: objective
LINKS:

- Input: Monthly_fixed_cost_per_vessel; Number_of_vessels_in_small_fleet

DATA: calculated but not verifiable

3.2 monthly fixed cost per vessel

DEFINITION: the monthly fixed cost per ship (shrimp sector) due to investments, maintenance and insurances
EQUATION: Monthly_insurance_cost_per_vessel+ Monthly_investment_cost_per_vessel+Monthly_maintenance_cost_per_vessel
ARRAY: none
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Monthly_insurance_cost_per_vessel; Monthly_investment_cost_per_vessel; Monthly_maintenance_cost_per_vessel
- Output: Total_monthly_fixed_cost_small_fleet

DATA: calculated but not verifiable

3.3 monthly maintenance cost per vessel

DEFINITION: the total maintenance cost per vessel per month (shrimp sector)
EQUATION: constant
ARRAY: none
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario

LINKS:

- Output: Monthly_fixed_cost_per_vessel

DATA:

- Source: Ministry of the Flemish Community, Administration of the Agriculture and Horticulture, Department of Agriculture and Fishery Management – Sea Services Division (based on year 2002)
- Dataset: see Annex

3.4 monthly insurance cost per vessel

DEFINITION: the total insurance cost per vessel per month (shrimp sector)
EQUATION: (Investment_cost_per_vessel*Insurance_rate)/12

ARRAY: none
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: variable
FUNCTION: calculation
LINKS:

- Input: Investment_cost_per_vessel; Insurance_rate
- Output: Monthly_fixed_cost_per_vessel

DATA: calculated but not verifiable

3.5 insurance rate

DEFINITION: the unit insurance rate expressed in terms of a percentage of the investment cost per vessel (shrimp sector)
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_insurance_cost_per_vessel

DATA:

- Source: Personnal communication Fortis Corporate Insurance nv
- Dataset: see Annex

3.6 investment cost per vessel

DEFINITION: the total investment cost per vessel (shrimp sector); excluding the needed (un)loading facilities, the quay's, etc.
EQUATION: constant
ARRAY: none
UNITS: EUR/vessels
VALUE: range between 0 and unlimited; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_insurance_ cost_per_vessel; Monthly_investment_cost_per_vessel

DATA:

- Source: Personnal communication fisher
- Dataset: see Annex

3.7 monthly investment cost per vessel

DEFINITION: the monthly investment cost (part depreciation, part interest) for a new vessel (shrimp sector)

EQUATION: (Investment_cost_per_vessel-Public_help_on_investment)*(Monthly_interest_rate*((1+Monthly_interest_rate)^(Economic_lifetime_of_a_ship*12)))/(((1+Monthly_interest_rate)^(Economic_lifetime_of_a_ship*12))-1)

ARRAY: none

UNITS: EUR/vessels

VALUE: range between 0 and unlimited; +

TYPE: variable

FUNCTION: calculation

LINKS:

- Input: Investment_cost_per_vessel; Monthly_interest_rate; Economic_lifetime_of_a_ship; Public_help_on_investment
- Output: Monthly_fixed_cost_per_vessel

DATA: calculated but not verifiable

3.8 economic lifetime of a ship

DEFINITION: the total time the vessel will be used for fishing activities (operational and distinct from depreciation period (account) estimated on 15 years).

EQUATION: constant

ARRAY: none

UNITS: years

VALUE: range between 0 and 50; +

TYPE: parameter

FUNCTION: scenario

LINKS:

- Output: Monthly_investment_cost_per_vessel

DATA:

- Source: Expert judgement DVZ
- Data: see Annex

3.9 monthly interest rate

DEFINITION: the interest rate that can be used on a monthly basis

EQUATION: (((1+(Yearly_real_interest_rate/12))^12)-1)/12

ARRAY: none

UNITS: unspecified

VALUE: range between 0 and 1; +

TYPE: variable

FUNCTION: calculation
LINKS:

- Input: Yearly_interest_rate
- Output: Monthly_investment_cost_per_vessel

DATA: calculated but not verifiable (See Annex)

3.10 yearly real interest rate

DEFINITION: the annual interest rate
EQUATION: constant
ARRAY: none
UNITS: unspecified
VALUE: range between 0 and 1; +
TYPE: parameter
FUNCTION: scenario
LINKS:

- Output: Monthly_interest_rate

DATA:

- Source: Vito (2003) Background document environmental cost model: private real interest rate, p. 47 http://www.emis.vito.be/EMIS/Media/BBT_rapport_milieukostenmodel.pdf
- Data: See Annex

NOTE: Public help on fuel price, fish price and investment will be addressed in Section III: Chapter 1 on Modelling and Integration.

Fig. II.3.1 and Fig. II.3.2 are the Stella model components for the Socio-economy Shrimp Fisheries. They represent 'variable costs', 'economic results' and 'fixed costs' respectively. Elements in the figure that are not described in this text are characteristic of the modelling process and are used to allow the model run.

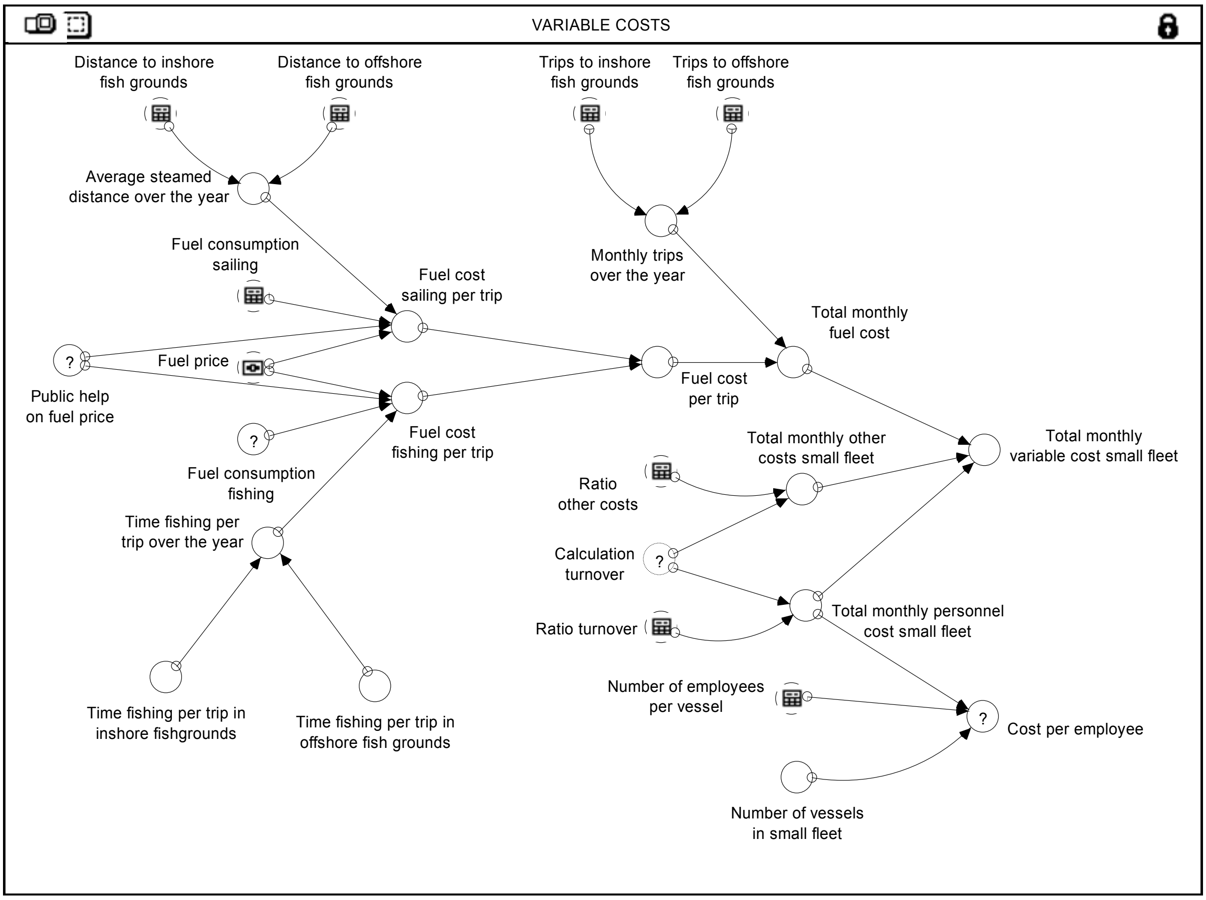


Fig. II.3.1 STELLA sub-model for the Shrimp Fisheries Socio-economy

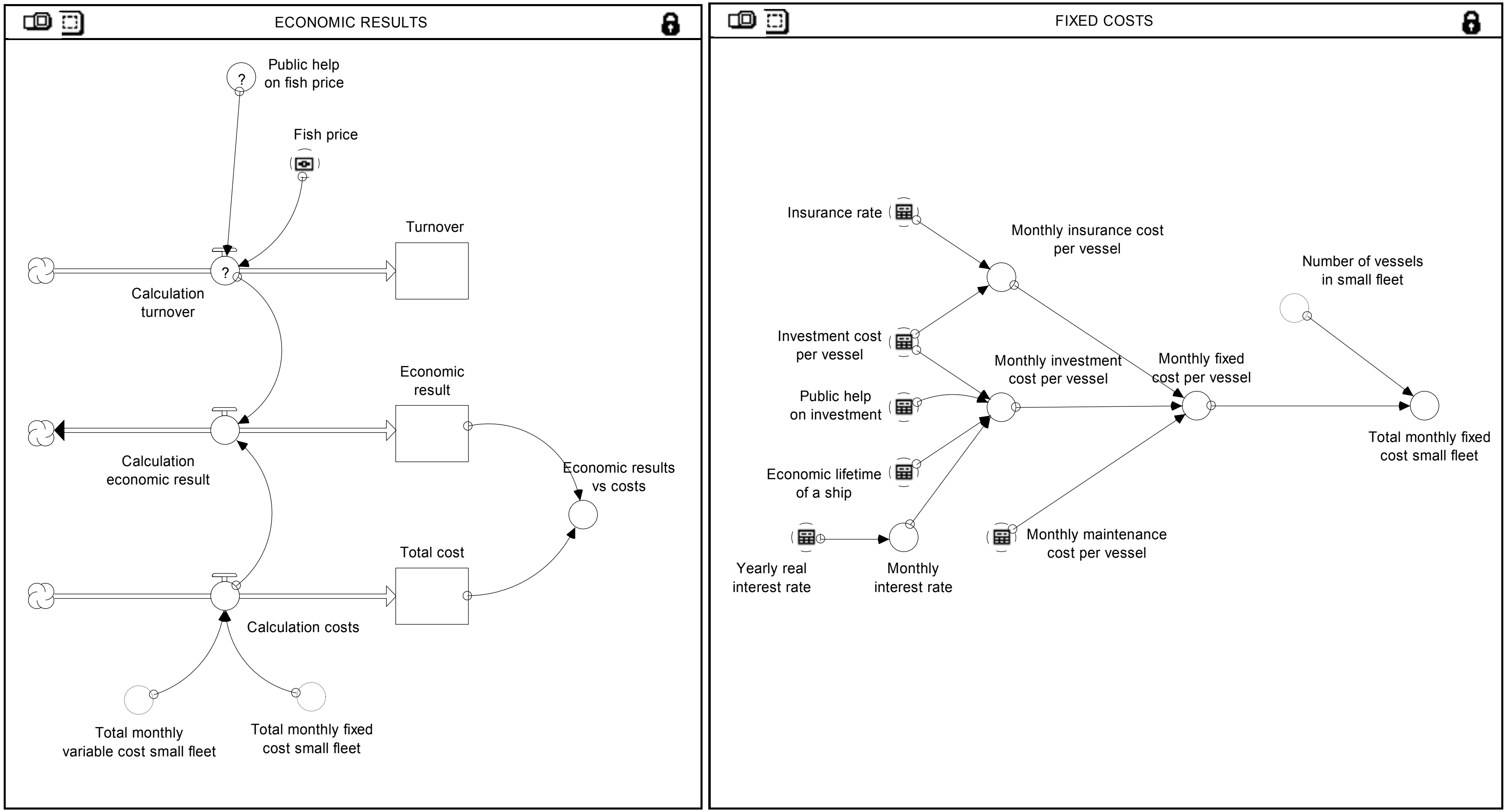


Fig. II.3.2 STELLA sub-model for the Shrimp Fisheries Socio-economy

SECTION THREE

MODELLING

MUMM
Management Unit of the North Sea Mathematical Models
Serge Scory

CHAPTER ONE

1. MODELLING AND INTEGRATION

1.1 what is a model?

The main purpose of BALANS is to "Model the shrimp fisheries and the sand & gravel extraction activity in a perspective of sustainable development". In this sentence, the word "model" looks the most innocuous. It covers, however, such a broad range of concepts and meanings that it deserves some clarification. Depending on who is using it or where or when it is used, the word "model" always contains an implicit semantic restriction.

In our study, we had to handle four basic types of models: conceptual models, mathematical models, numerical models and computer models. A conceptual model describes the behaviour of a system in general terms. It usually answers the following questions:

- What are the variables that describe the state of the system ("state variables"): V_1, V_2, ...V_n?
- What are the key relationships between theses state variables?
- What are the key parameters of these relationships: p_1, ..., p_n?
- What is the domain $\Omega(t, \varphi, \lambda, V_1, V_2, ...V_n, p_1, ..., p_n)$ of investigation?
- What is the initial state of the system and the constraints at its boundaries?

Basically, a conceptual model is an "abstract object" but is commonly represented by a scheme. Such a scheme can be drawn at different degrees of detail. Fig. III.1.1 and Fig. III.1.2 show two such schemes.

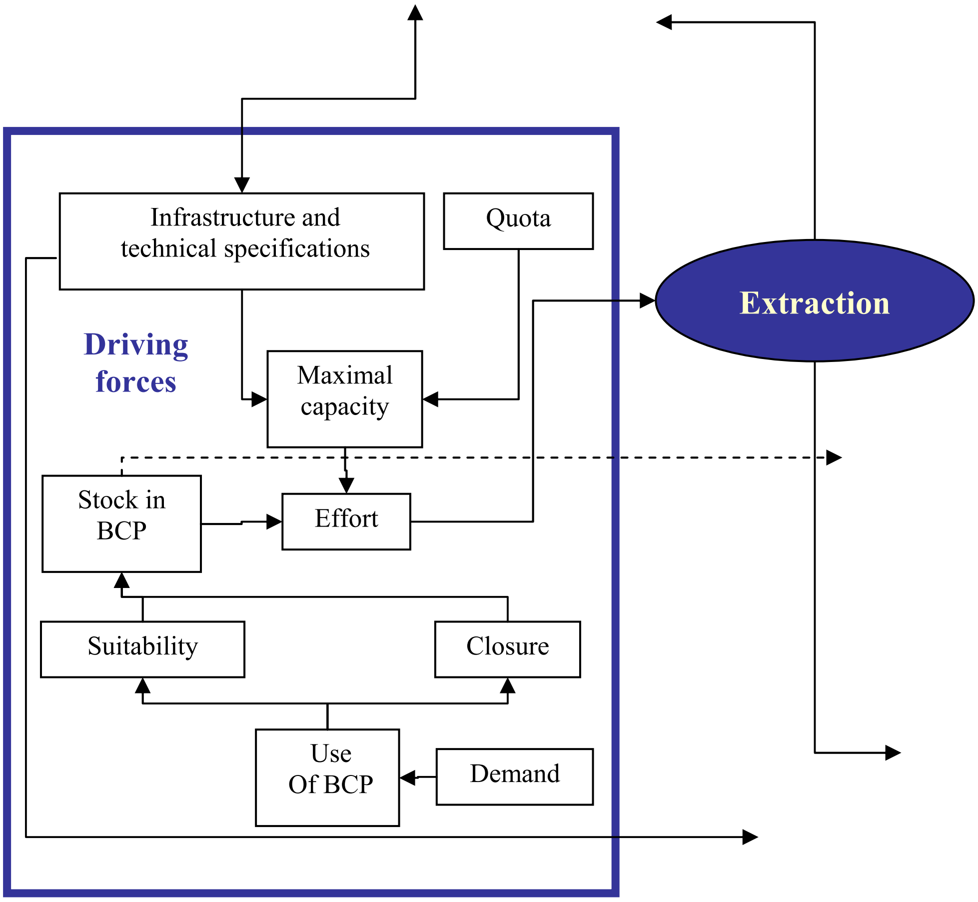


Fig. III.1.1. A conceptual model of the driving forces for the sand and gravel extraction activity at a high level of abstraction.

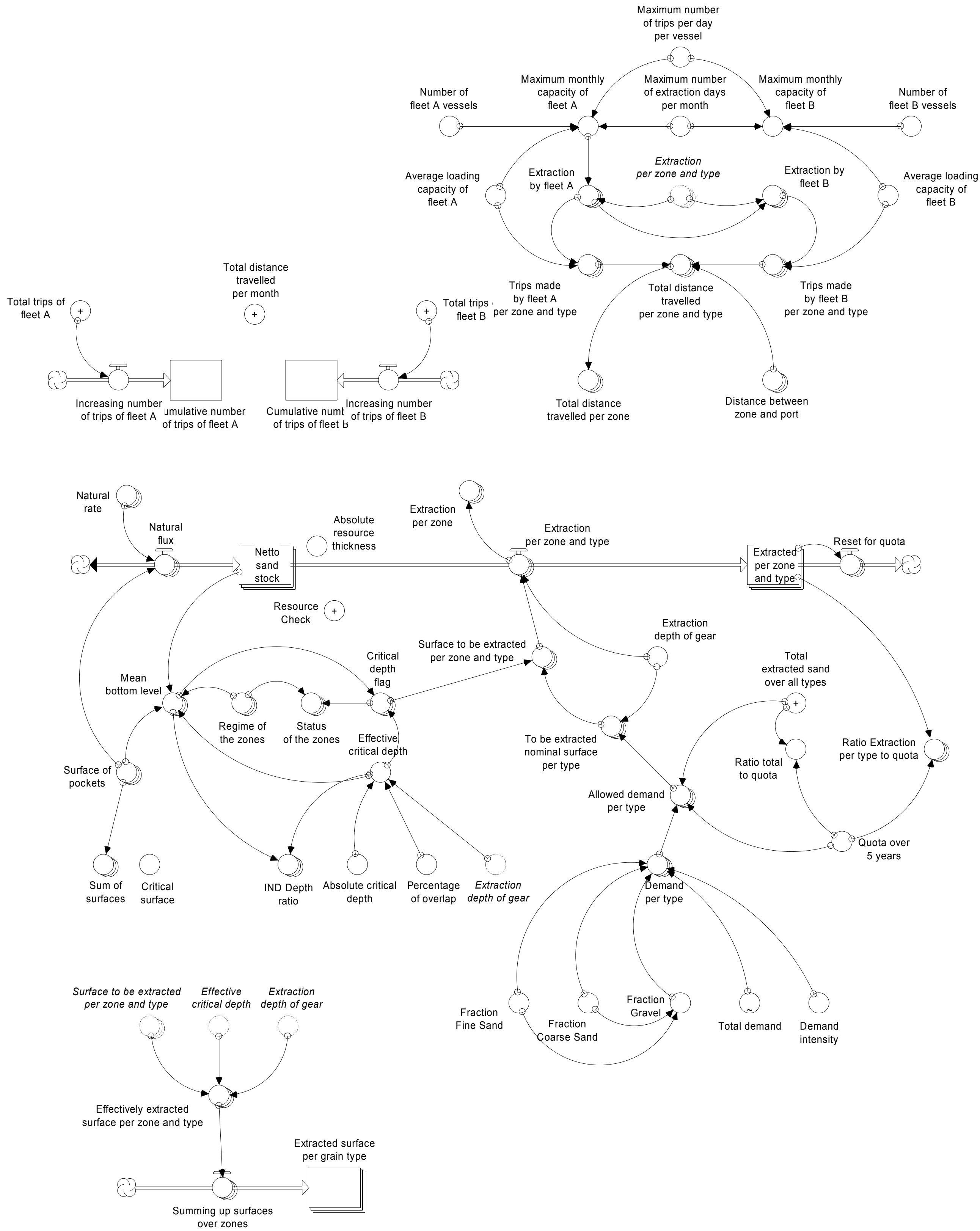


Fig. III.1.2. Another view of the conceptual model of the driving forces for the sand and gravel extraction activity, where state variables, processes and parameters are clearly identified.

In a second step, a mathematical model can be built, where the relationships mentioned above are translated into mathematical and logical functions:

Key relationships = key processes = $\frac{dV_i}{dt} = F_{ij}(V_1, V_2, \ldots V_n, p_1, \ldots p_n)$

In this case, the "model" is thus basically made of equations.

In most cases, the equations of the mathematical model do not have an analytical solution (*i.e.* a solution than can be expressed using the same mathematical language than the problem). They are thus transformed ("discretized") in order to be solved. The resulting model is a "numerical model" (*i.e.* numbers can replace abstract mathematical objects):

$$\frac{dV_i}{dt} \xrightarrow{becomes} \text{(V(t)-V(t-dt))/dt}$$

Finally the model is implemented on a computer. This computer model is a piece of computer code incorporating the discretized equations, the initial and the boundary conditions and all the other elements (like data) needed to evaluate them, the solving algorithm and some sort of input/output mechanisms in order to allow the user to set some parameters and to access the results of the computation.

1.2 stella

At a very early stage of the project, a choice had to be made regarding the software to be used. Required functionalities were listed as follows:

- the software should allow to design a conceptual model;
- the software should allow to translate the conceptual model into an actual simulation model;
- the software should allow to develop a simple but attractive interface to end users;
- the software should be easy to use by all the partners, independently of their various levels of computer skills; and
- the software should be available for the Windows® environment (common to all the partners).

An overview of the available software lead the partners to elect "STELLA" as, if not the best (we had not the opportunity to perform in-depth comparisons), a good candidate. STELLA (by Isee Systems Inc., http://www.iseesystems.com/) indeed covers all the requirements listed above, furthermore in one software environment. It is used within a large community of users and according to the freely available examples, it is used to address a broad range of problems: economics, social science, mathematics, physical science, life science and even literature.

Particularly useful was the direct connection between the conceptual level and the actual simulation tool. The user friendliness of the graphical interface makes it very attractive and handy. As for every design and modelling tool, the underlying concepts and the way to implement them must of course be mastered to get a fruitful use of the software. Aside from the technical documentation, a well-written book gradually leads the reader through the complexity of system modelling in order to be able to use STELLA as a "systems thinking tool".

The STELLA modelling environment consists of an "execution kernel" and four layers: (1) the map layer (2); the model layer; (3) the equation layer; and (4) the interface layer.

The "Map" and "Model" layers are graphical user interfaces (GUI) that the modeller uses to describe his/her model by means of graphical elements and related "dialog boxes". "Stocks" (variables) interact through "Flows" (fluxes), both depending on "converters" (parameters, input data, …), to name the basic building bricks of the software. The map layer is devoted to the design of the conceptual model and the dialog boxes allow documentation notes on each element to be entered. The model layer is the one –as the name says– where the effective model is actually defined. The dialog boxes at this level allow to set the initial values (for stocks), the units, the mathematical and logical equations (for flows, converters, …). Support for one- and two-dimensional arrays is provided. It is also possible to run the model from this layer and it is the best level to fine-tune it: several tools are available at this level that help in following the evolution of the system during a simulation (*i.e.* graphs, tables, numeric displays).

Within the "Equation" layer, the model defined using the graphical interface appears here in textual form. More familiar to Fortran or Basic aficionados, it does not allow however editing, or visualization of the full computer code, as a programmer would have written it.

Finally, the "Interface" layer is also designed as graphical user interface (GUI) with specific input/output (I/O) devices that allow the user to concentrate on the runs of the model and their results. These devices may be used to set values to key-parameters and rapid access to results can be provided in numerical or graphical formats. When provided to third parties as a "runtime" version, the STELLA model will only be accessible ("visible") through that interface.

The "Execution kernel" is not visible to the user. It is the place where everything occurs: the evaluation of the parameters and the numerical integration of the differential equations represented by the "Flows". Three integration algorithms are available: Euler, 2nd–order Runge-Kutta and 4th–order Runge-Kutta, in order of increasing theoretical precision. There are, however, advantages and disadvantages bound to each method and it is worth looking to their underlying theory before selecting one. Besides the choice of the numerical integration scheme, the user should also carefully select the value of the integration time step. See Section 1.6 for more information regarding numerical techniques (integration schemes and integration time step).

STELLA is a very useful environment for building models of dynamic systems and processes, and to simulate their behaviour. It is easy to use by beginners in modelling because they can focus on concepts and relationships rather than details of mathematics and computer codes. At the beginning at least! For, to let a model run, mathematics are needed: equations that describe the evolution of the system need to be carefully and consistently written, together with the functions defining the parameters "controlling" the system. The iconic approach offered by the software to build models can lead to a misperception in that the resulting schematic looks like a flow-chart however it is not. In a flow-chart, one starts at a given point and ends at another specified point following a succession (in time) of actions and states. Instead, the model describes how these actions occur; thus, how the various states are reached. It is to some extent a snapshot of the flow-chart.

Another difficulty is the fact that STELLA relies on its own vocabulary that differs from the ones commonly used in modelling. To mention a few terms, "state variable" reads "stock" in Stella, while the differential equations describing the evolution of state variables over time are denoted "flows". These and other differences make it sometimes difficult to find and understand how something specific has to be implemented.

It is also sometimes useful or even necessary, when running a model, to fix the order of evaluation of a given set of parameters ("converters" in Stella). When you are directly programming the code, it is straightforward. However, although the "equations" layer of the software can also show and print the equations and functions in their execution order, these cannot be modified.

Despite these small annoyances, STELLA appeared to be rather powerful and very well suited for the development of the project.

1.3 modelling methodology

The methodological backbone for the modelling process was defined a priori at the beginning of the project as follows.

Table III.1.1. Reference modelling methodology

Step 1	Setting–up of the conceptual model Validation of the conceptual model
Step 2	Identification of the state variables (*i.e.* the time-varying fundamental elements describing the system) and of the relationships between them (conceptual model matrix)
Step 3	Inventory of the available information on the variables (units, initial values, ranges, level of uncertainty, uncertainty range) Description of the form (logical, analytical, qualitative) of the relationships Description of the internal dynamics of the state variables Inventory of the available information on the parameters of the relationships, where applicable, and of the internal dynamics of the state variables (units, values, ranges, level of uncertainty, uncertainty range)
Step 4	Consolidation (simplification) of the conceptual model on the basis of the identified available information
Step 5	Translation of the conceptual model into a computer model
Step 6	Tests of the computer model Sensitivity analysis (influence of both the variability and the uncertainty) Possible iteration (from step 2)
Step 7	Documented scenario's

In practice, this theoretical scheme was adapted to cope with the characteristics of the BALANS project (several teams initially working more or less independently on subsets of the full model) and of the software chosen to implement the conceptual model. The effective procedure that was applied is reflected in the following sequence of steps: (1) conceptual model development; (2) translation into a system-thinking environment; (3) data entry; (4) integrated conceptual policy and interface development; and (5) scenario development.

1.4 integration

One of the final outputs of the BALANS project are exploratory policy models integrating three points of view for each activity: driving forces, socio–economics and environmental aspects. The corresponding Stella sub–models were first developed 'independently' but at a given moment integrated into one sole structure. The main issue of such an integration were to ensure the coherency of the whole system, in terms of terminology, functionalities, units, … and the actual coupling of the sub–models.

Common time base, units and parameter names were discussed in due time within the consortium. However, despite the careful preparation, slight discrepancies and mismatches were still at the time of bringing the various models together. To mention an example: in one of the sub-models surface areas where expressed in square meters while in the other it was expressed in square kilometres. As can be seen from the description of the models in the previous chapters, there were numerous possible cause of mismatches and many things had thus to be carefully checked when bringing the sub–models together.

Technically speaking, a lot of effort was required during the integration stage. When two partly similar models are brought together STELLA has no mechanism to map variables or constants having the same name onto each other. Unfortunately, during their (independent) development phase the socio–economics and environment sub–models needed specific forcing and they were therefore built with connections to a prototype of the "Driving forces" sub–model. Once copied in one unique workspace, conflicts arose and it has been a tedious and sometimes tricky exercise to disconnect the prototype and then reconnect flows and converters as they ought to be.

"Tedious" doesn't mean "impossible", fortunately. And, if for the moment, the models for the shrimp fisheries on one hand and for the sand & gravel extraction on the other hand are distinct ones, it is practically feasible to merge them into one workspace and to consequently couple the processes that interact in reality (*e.g. the combined* influence of both activities on the density of the macro–benthos).

1.5 adaptation

Once the sub–models were merged into one structure, it was possible to test them using the full set of input data and tuning parameters. Doing so revealed some necessary changes at the conceptual level, at the implementation level but also to the underlying mathematical formulation of some processes. Rather than being exhaustive, we shall give here some examples.

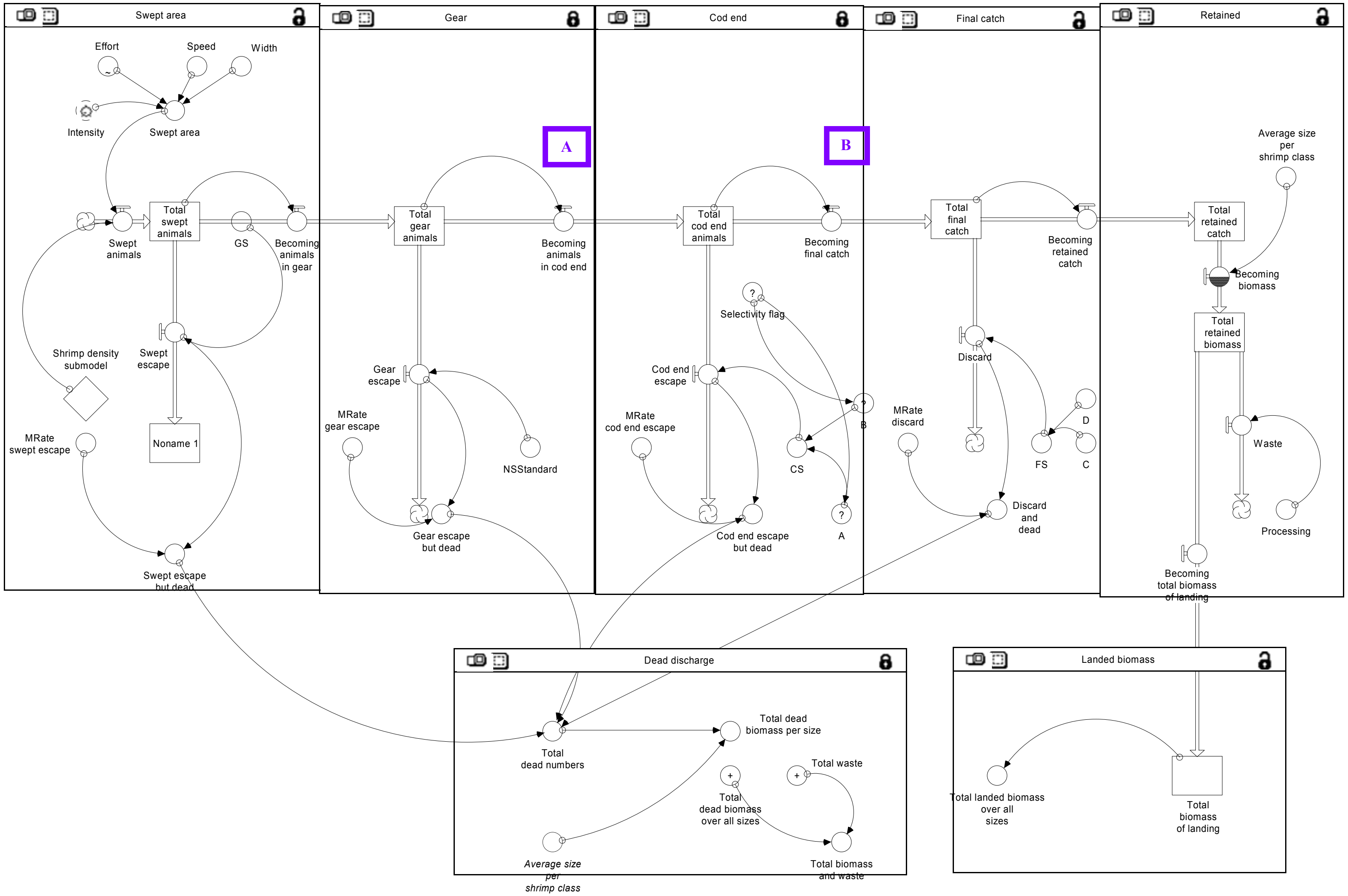


Fig. III.1.3. Early version of the conceptual scheme of the driving forces in the shrimp fisheries model. "A" : "Total gear animals"; "B" : "Total cod end animals" (see text).

A very early version of the shrimp fisheries model is depicted on Fig. III.1.3. It resembles a flow-chart where "actions" are described as they succeed chronologically. The shrimp population "enters" the process on the left, goes through a series of filters and, finally, a fraction of the population results in "landings". This view is correct to some extent. But it is in fact a static view of a dynamic process. Stocks like "Total gear animals" or "Total cod end animals" are pseudo–stocks as they are in fact emptied as soon as they are fed. This conceptual scheme required thus an in-depth revision resulting in the one shown in Fig. III.1.4. In this dynamic representation of the system, there is basically one stock ("Netto catch animals") that is fed by the action of sweeping and that has some outgoing flows representing the losses due to the filtering action of the trawl. This structure represents, at any time, the dynamic balance of these ingoing and outgoing fluxes.

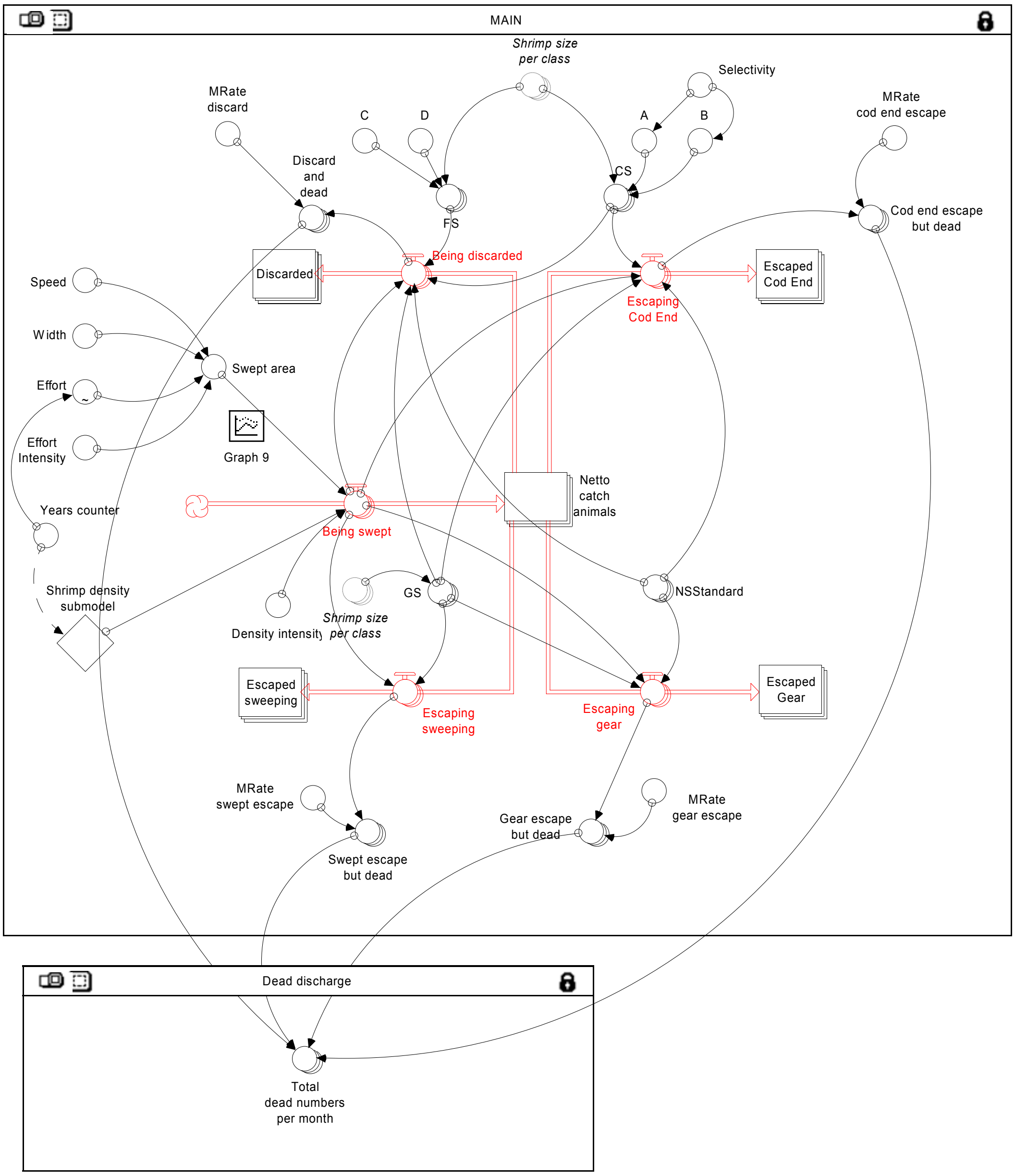


Fig. III.1.4. Final version of the conceptual scheme of the driving forces in the shrimp fisheries model.

A second example of the changes we made at the conceptual level comes from the socio-economic sub–model of the shrimp fisheries. After a few runs of the fully integrated model, it appeared that given the described processes and the available input data, the economic result of the activity was in all circumstances, negative from the very first month of the simulation. Although coherent with the model, this result wasn't, as such, matching reality and common sense. We thus decided to add, as tuning parameters, three elements that were not documented nor evaluated during our quest for data but that, undoubtedly, exist or can exist, *i.e.* public help (subsidies) on the investment (€), on fuel price (discount : %) and fish price (€). These changes are shown on Fig. III.1.5 and lead to the following corrected equations:

<u>Monthly_investment_cost_per_vessel=</u>
(Investment_cost_per_vessel-*Subsidy_on_investment*)*
(Monthly_interest_rate*
((1+Monthly_interest_rate)^(Economic_lifetime_of_a_ship*12)))/
(((1+Monthly_interest_rate)^(Economic_lifetime_of_a_ship*12))-1)

<u>Fuel_cost_sailing_per_trip=</u>
Fuel_consumption_sailing*(Fuel_price*(1-*Subsidy_on_fuel_price/100*))
*Average_steamed_distance_over_the_year*2

<u>Fuel_cost_fishing_per_trip=</u>
Fuel_consumption_fishing*(Fuel_price*(1-*Public_aid_on_fuel_price/100*))
*Time_fishing_per_trip_over_the_year

<u>Calculation_turnover=</u>
Total_commercial_biomass_per_month*1000*(Fish_price+*Subsidy_on_fish_price*)

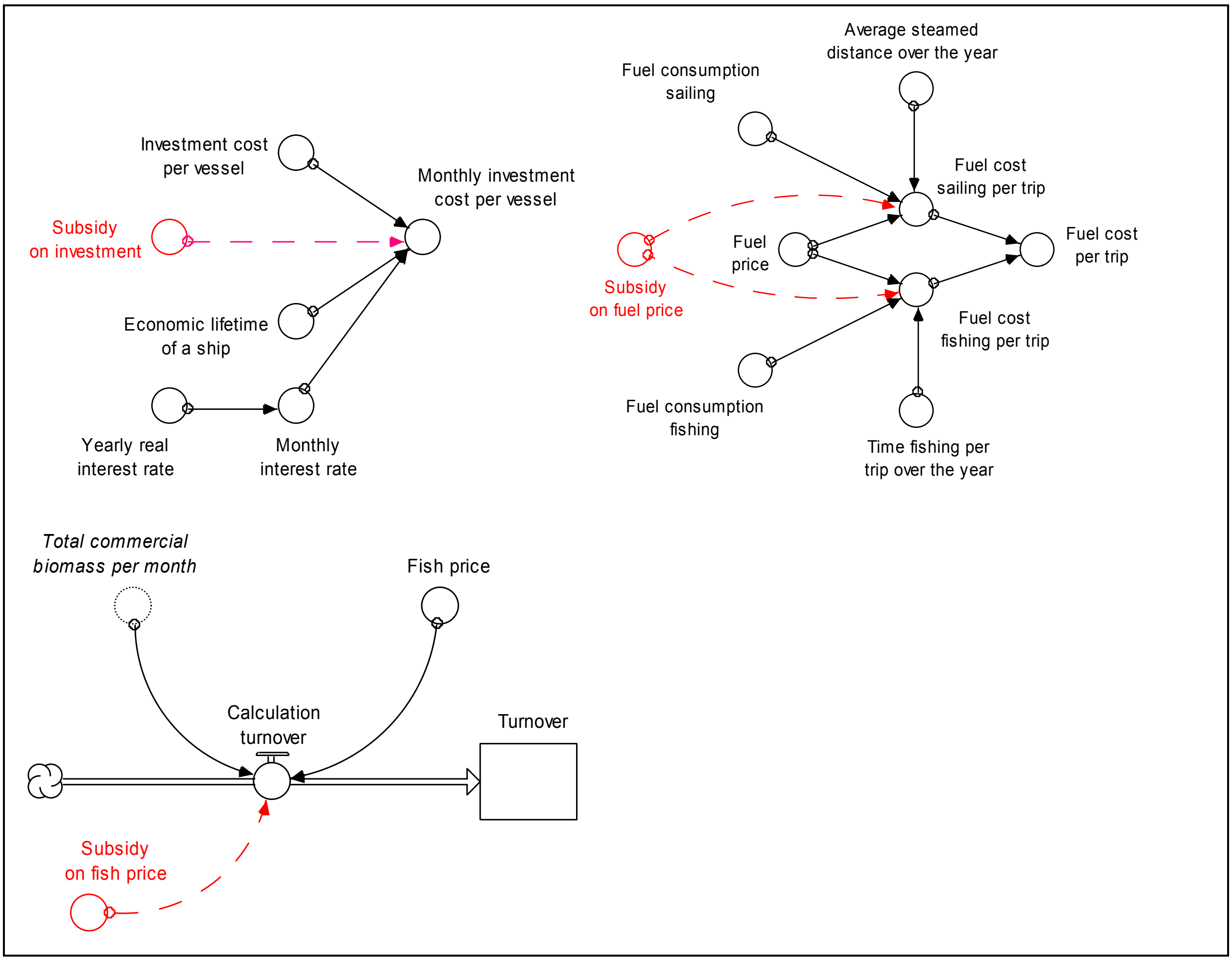


Fig. III.1.5. Modified economical schemes in order to take possible public helps into account.

A further example of a change we had to test and eventually make at the implementation level is fully developed under section 1.6 Numerical models ("Simple population/competition model").

Another example of an adaptation, depicted by Fig. III.1.6, corresponds to a structural issue encountered rather frequently in the various models we had to handle: a stock is fed by two mutually exclusive fluxes. The example given below deals with the export and import of a sediment from/to a given zone due to natural processes. Erosion and deposition do not occur at the same time, as the conceptual scheme shown in Fig. III.1.6 (a) yet allows. Depending on the time scale of the processes compared to the one of the model, two approaches must be applied. At small time scales, *i.e.* during a tidal cycle, there usually is an alternation between erosion and deposition, due to the variation of the current velocities. Such a variation cannot be represented in our models because the basic time scale of the model is one month. It is therefore necessary to estimate a monthly balance of the sediment transport that can be either positive or negative and to allow the flux to be bi–directional, see Fig. III.1.6 (b). (Another, less readable and less flexible solution would have been to simultaneously control the two rates in Fig. III.1.6 (a) by an external, time–dependent function and some logical tests.) Variation at seasonal scales however –there might be more energy during the winter months due to the storms than during the summer– can be represented by the model. With the chosen adaptation, the "Natural_sediment_flux_rate" of our example can then easily be implemented as a time–varying function ("graphical" or analytical) expressing the variations on a monthly basis.

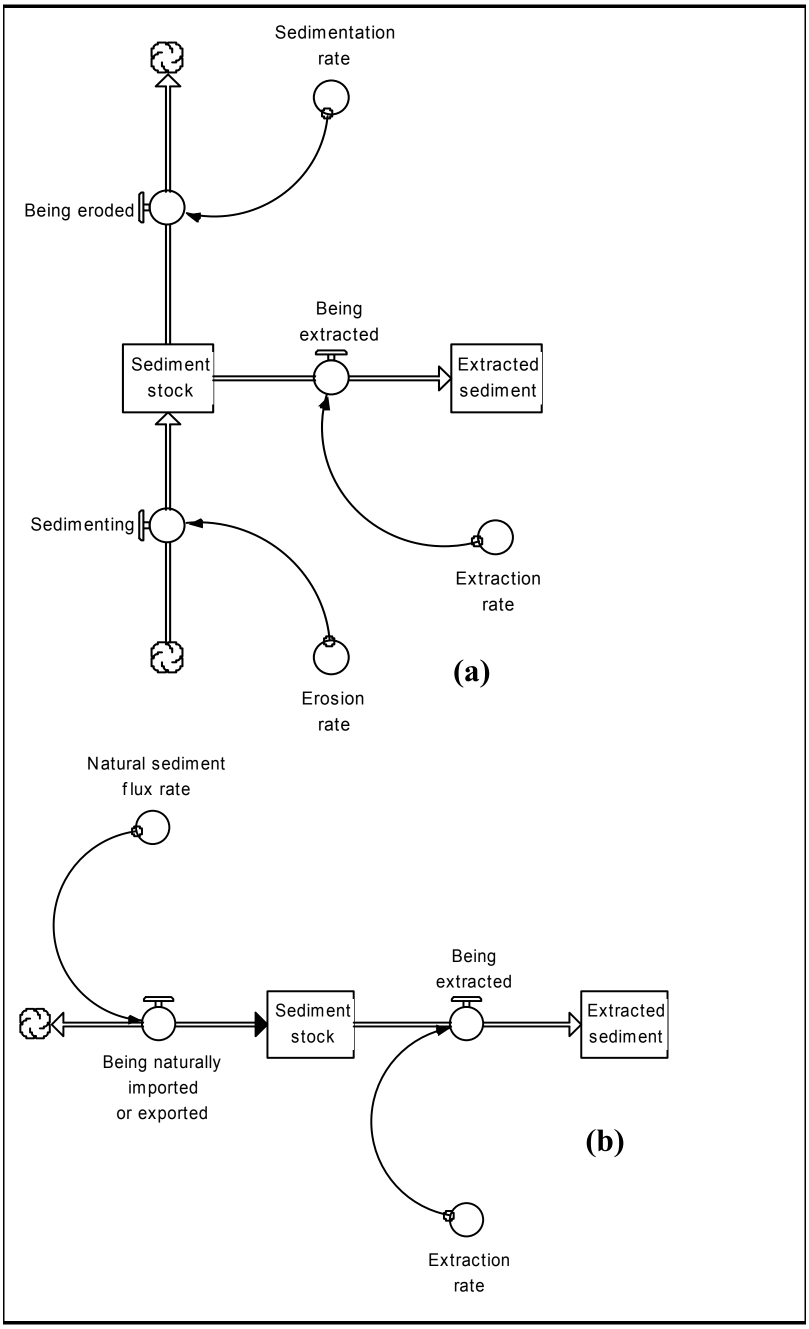


Fig. III.1.6. Implementation changes to cope with mutually exclusive fluxes. (a) before; (b) after.

Finally, the last major family of changes that we applied is related to the transformation into a computer model of mathematical functions that look nice in their analytical form but lead to problems when used in the model. This was particularly – but not only– the case with functions derived from the "meta–analysis" methodology used in the environmental sub–models. With three data points, for instance, the best fit regression will always be given by a parabolic function. Unfortunately, the inputs to such a function generated by the model can sometimes lay outside the domain of the original data. Fig. III.1.7 mimics the relationship between a bottom area impacted by an activity and the corresponding "mean log effect" (arbitrary data and units). This effect is supposed to be always negative. However, when the formula is implemented as such, and the impacted area is greater than approximately 30 km² or lower than 1 km², the effect becomes positive.

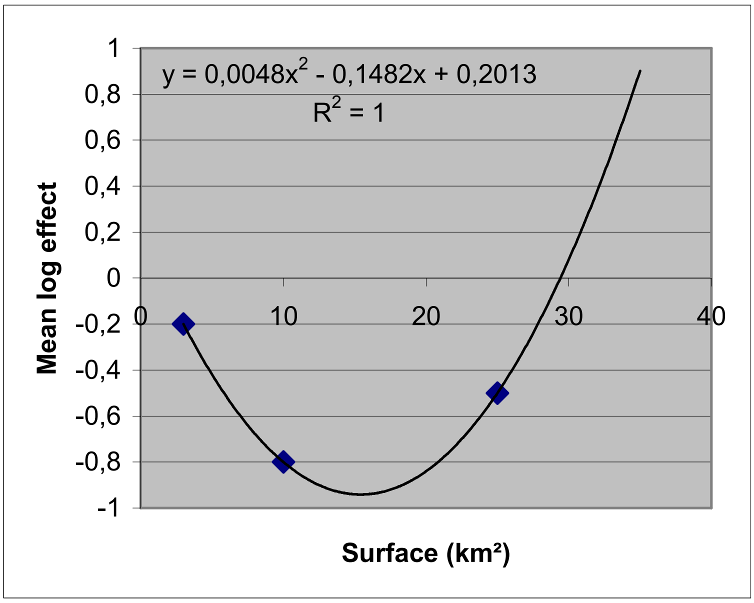


Fig. III.1.7. Example of parabolic relationship between the surface of an impacted area and the effect on the benthos (arbitrary data).

With more than a few data points, the "best fit" can even be achieved by a logarithmic function that leads to other problems ($\lim_{x \to 0}(\pm \ln(x) + b) = \mp\infty$). In our opinion, this practical application of the "meta–analysis" methodology together with the best fit approach shows the limits of the method. In practice, it has been solved by forcing the resulting values to stay within realistic limits (*e.g.* negative). This is however a "blind" solution that should be reviewed on an *ad hoc* basis.

1.6 numerical models

The way computers work have an influence on how a conceptual model is to be implemented. Some background in mathematics, logic, numerical analysis and computer science is needed to avoid common errors and to understand some –apparently– strange behaviour of computer models. This is not however a common background in most scientific education programs[1]. STELLA allows the user to some extent ignore these things. We give hereafter detailed examples of what we had to examine in order to validate the various sub–models in this field.

[1] Suggested further reading on ins and outs of numerical analysis and computers : "Numerical recipes in Fortran 77 : the art of scientific computing", Press, W.H., S.A. Teukolsky, W.T. Vetterling & B.P. Flannery, 2nd ed., 2001, Cambridge University Press. Current (Oct. 2006) URL: http://www.nrbook.com/

Most computer codes are not based on analytical algebra. Equations need to be discretized in order to be solved. This transformation means that an equation is no more evaluated at every point but at points separated by discrete intervals (in time and/or space, for instance).

The most basic approach to represent the evolution of a variable with time is to write a differential equation describing how it evolves. Let us take the example of a simple population model:

$$\frac{dP}{dt} = f(t,P) = rP - mP = kP \tag{0.1}$$

where t denotes the time, r the recruitment rate and m the mortality. It means that the bigger the population, the bigger the births and the bigger the deaths. The balance depends on the relative values of the birth rate and of the mortality. The analytical solution of this equation is straightforward and reads

$$P(t) = P(0).e^{kt} \tag{0.2}$$

The fundamental principle for integrating such an equation on a computer, knowing its value a given time t, is to approximate its value at the next time step ($t+\Delta t$) by extrapolating its first order derivative, *i.e.* the "slope" of the function at a given abscissa. The simplest method is known as Euler's method where the derivative at point n is extended up to the next abscissa ($x_n + h$):

$$y_{n+1} = y_n + h \times f(x_n, y_n) \tag{0.3}$$

In our example, the resulting discrete equation reads:

$$P(t+\Delta t) = P(t) + \Delta t \cdot k \cdot P(t) = (1 + k \cdot \Delta t) \cdot P(t) \tag{0.4}$$

In most cases, however, Euler's method give accurate enough results only when using very small time steps, hence at the cost of computer time. Furthermore, this method can sometimes be unstable (*i.e.* any round–off error is progressively magnified and masks the true answer).

To exemplify this, let's take the case of a simple population model where $\frac{dP}{dt} = -cP$ where $c > 0$ is a constant. The solutions resulting from the application of Euler's method with several time steps are shown and commented on Fig. III.1.. The choice of the right method and then of the right time step influences not only the accuracy of the solution but allows the time needed to compute it and the stability of the approximation of the modelled system.

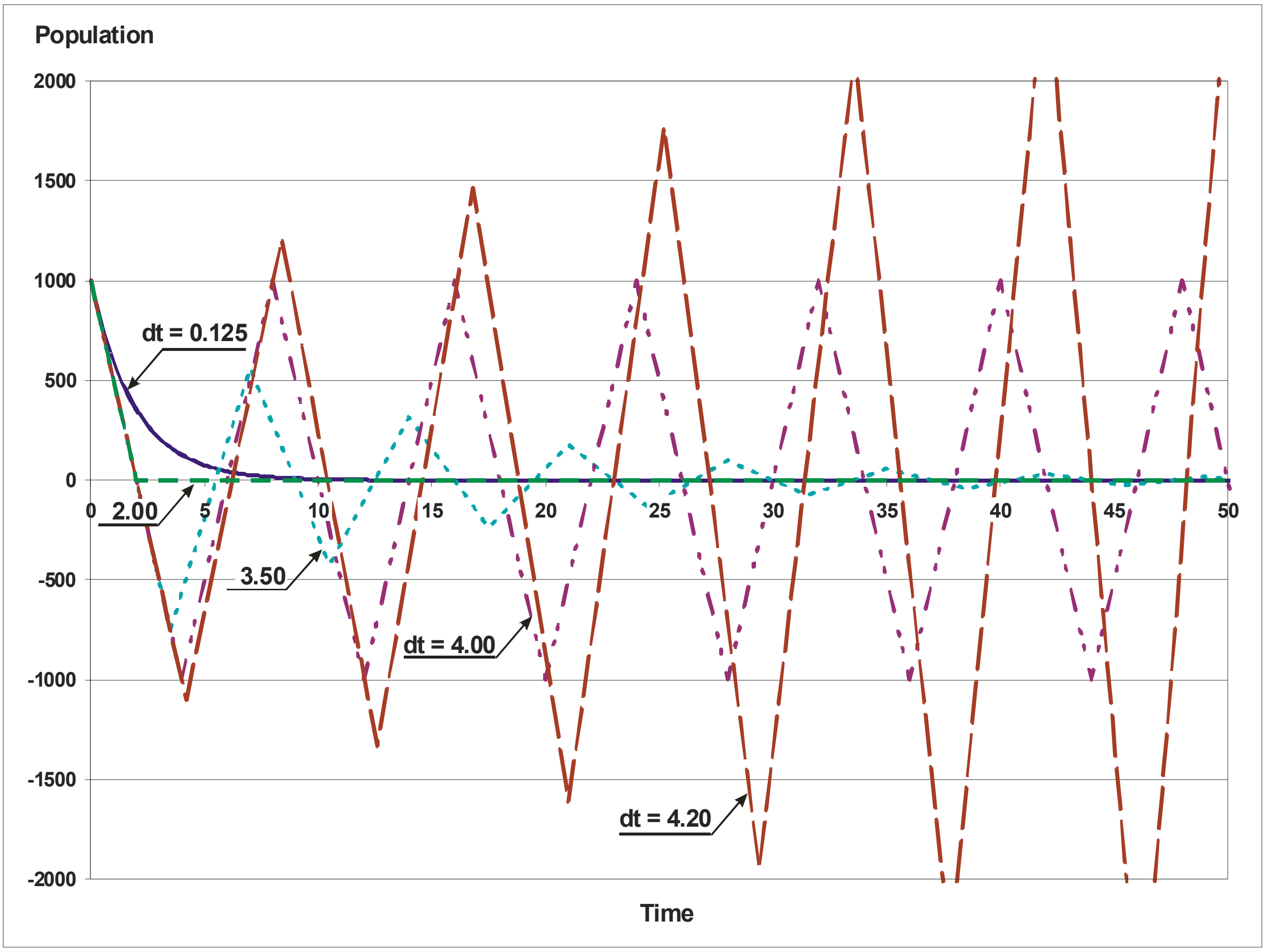


Fig. III.1.8. Model of decaying population $\frac{dP}{dt} = -cP$. $P(0) = 1000$, $c = 0.5$.

The numerical solutions computed by means of the Euler scheme are shown for different time steps. With small time steps ($0 < \Delta t \cdot c \leq 1$, *i.e.* $0 < \Delta t \leq 2$), the exact final solution is found, with more or less accurate intermediate results. With time steps in the middle range $1 < \Delta t \cdot c \leq 2$ (*i.e.* $2 < \Delta t \leq 4$) the solutions are unstable but converge to the exact solution after a while. Intermediate results oscillate around the true solution. And finally, with larger time steps ($2 < \Delta t \cdot c \leq +\infty$ or $4 < \Delta t \leq +\infty$) the solutions are clearly instable, exhibiting larger and larger oscillations around the theoretical solution.

The underlying principle of the *Runge-Kutta* family of methods is to compute Euler's approximation at intermediate points and then to combine this information according to a Taylor series expansion up to some order, narrowing the uncertainties on the computed value of the function at the next step.

Runge–Kutta method of order two will use a first extrapolation up to the mid-point of the interval and then a second extrapolation using the slope at that point over the whole the interval:

$$
\begin{aligned}
s_1 &= h \times f(x_n, y_n) \\
s_2 &= h \times f(x_n + \tfrac{1}{2}h, y_n + \tfrac{1}{2}s_1) \\
y_{n+1} &= y_n + s_2 + O(h^3)
\end{aligned} \qquad (0.5)
$$

or, for our example:

$$
P(t+\Delta t) = P(t) + \Delta t \cdot k \cdot P(t) + \frac{k^2 \Delta t^2}{2} P(t) \qquad (0.6)
$$

Similarly, the Runge-Kutta method of order four writes

$$
\begin{aligned}
s_1 &= h \times f(x_n, y_n) \\
s_2 &= h \times f(x_n + \tfrac{1}{2}h, y_n + \tfrac{1}{2}s_1) \\
s_3 &= h \times f(x_n + \tfrac{1}{2}h, y_n + \tfrac{1}{2}s_2) \\
s_4 &= h \times f(x_n + h, y_n + s_3) \\
y_{n+1} &= y_n + \frac{s_1}{6} + \frac{s_2}{3} + \frac{s_3}{3} + \frac{s_4}{6} + O(h^5)
\end{aligned} \qquad (0.7)
$$

what, in our case, reduces to:

$$
P(t+\Delta t) = P(t) + \Delta t \cdot k \cdot P(t) + \frac{k^2 \Delta t^2}{2} P(t) + \frac{k^3 \Delta t^3}{6} P(t) + \frac{k^4 \Delta t^4}{24} P(t) \qquad (0.8)
$$

The fourth-order Runge-Kutta method requires four evaluations of the derivatives per time step. But, as it is more accurate, it usually allows larger time steps than the two other methods described above and the superior ratio accuracy/computing time makes it one of the favourite methods to solve ordinary differential equations. There are some cases, however where “higher order” doesn’t necessarily mean “higher accuracy”.

STELLA offers the possibility of using any of the three methods described above and the choice of the time step. Many of the sub-models could run smoothly and accurately enough even using Euler’s method and a relatively large time step *(e.g.* one fourth of a month). However, due to the exponential nature of their equations, the biological effects sub-models made us look more carefully to the accuracy of the results.

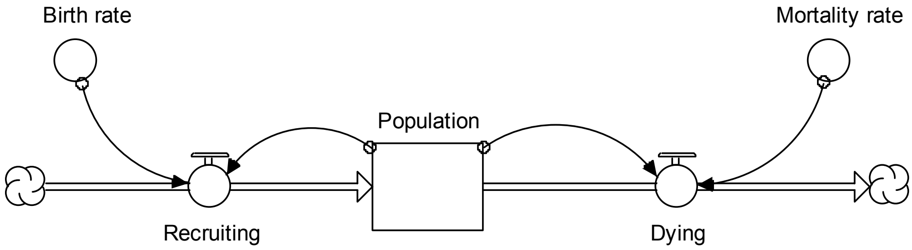


Fig. III.1.9. Conceptual scheme of a simple population model in STELLA.

Table III.1.2. Test of the influence of the numerical integration method on the accuracy of the results of a simple population model using STELLA.

Runs:

Mortality rate :1.0
Birth rate : 2.0

Initial population : 1000 Ind./m²

Results:

t	Analytical	Euler dt=1.00	Euler dt=0.25	Euler dt=0.0625	RGK2 dt=1.00	RGK2 dt=0.25	RGK2 dt=0.0625	RGK4 dt=1.00	RGK4 dt=0.25	RGK4 dt=0.0625
0	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1	2718	2000	2441	2638	2500	2695	2717	2708	2718	2718
…	…	…	…	…	…	…	…	…	…	…
5	148413	32000	86736	127737	97656	142127	147953	145717	148394	148413
…	…	…	…	…	…	…	…	…	…	…
10	22026466	1024000	7523164	16316620	9536743	20200175	21890043	21233479	22020641	22026439
11	59874142	2048000	18367099	43042077	23841858	54436557	59466348	57507338	59856726	59874062
12	162754791	4096000	44841551	113541920	59604645	146698666	161545896	155749040	162703147	162754556

Relative error:

t	Analytical	Euler dt=1.00	Euler dt=0.25	Euler dt=0.0625	RGK2 dt=1.00	RGK2 dt=0.25	RGK2 dt=0.0625	RGK4 dt=1.00	RGK4 dt=0.25	RGK4 dt=0.0625
0	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,000%	0,000%	0,000%
1	0,00%	-26,42%	-10,19%	-2,96%	-8,03%	-0,86%	-0,06%	-0,366%	-0,003%	0,000%
…	…	…	…	…	…	…	…	…	…	…
5	0,00%	-78,44%	-41,56%	-13,93%	-34,20%	-4,24%	-0,31%	-1,817%	-0,013%	0,000%
…	…	…	…	…	…	…	…	…	…	…
10	0,00%	-95,35%	-65,84%	-25,92%	-56,70%	-8,29%	-0,62%	-3,600%	-0,026%	0,000%
11	0,00%	-96,58%	-69,32%	-28,11%	-60,18%	-9,08%	-0,68%	-3,953%	-0,029%	0,000%
12	0,00%	-97,48%	-72,45%	-30,24%	-63,38%	-9,87%	-0,74%	-4,304%	-0,032%	0,000%

As mentioned above, no absolute conclusion can be drawn from such a simple test. A complex algorithm can make things more difficult. In particular, when the model includes binary logic or sudden changes in behaviour the Runge–Kutta algorithm may lead to inappropriate results. Fig. III.1.10 shows such a case: in our implementation of the legal quota mechanism for sand and gravel exploitation, when the quota is reached within a five year period, the exploitation is stopped everywhere. When the five year period ends, the policy managers have the opportunity to set other conditions or to re–open the exploitation with the same quota. In our model, the ratio "extracted quantity vs. quota" is therefore then reset to zero. Fig. III.1.10 exemplifies that process for a level of exploitation that never reaches the quota over 5 years. Curve 1, obtained with the Euler's method, is correct while curve 2, computed with a 4^{th}–order Runge–Kutta is not correct.

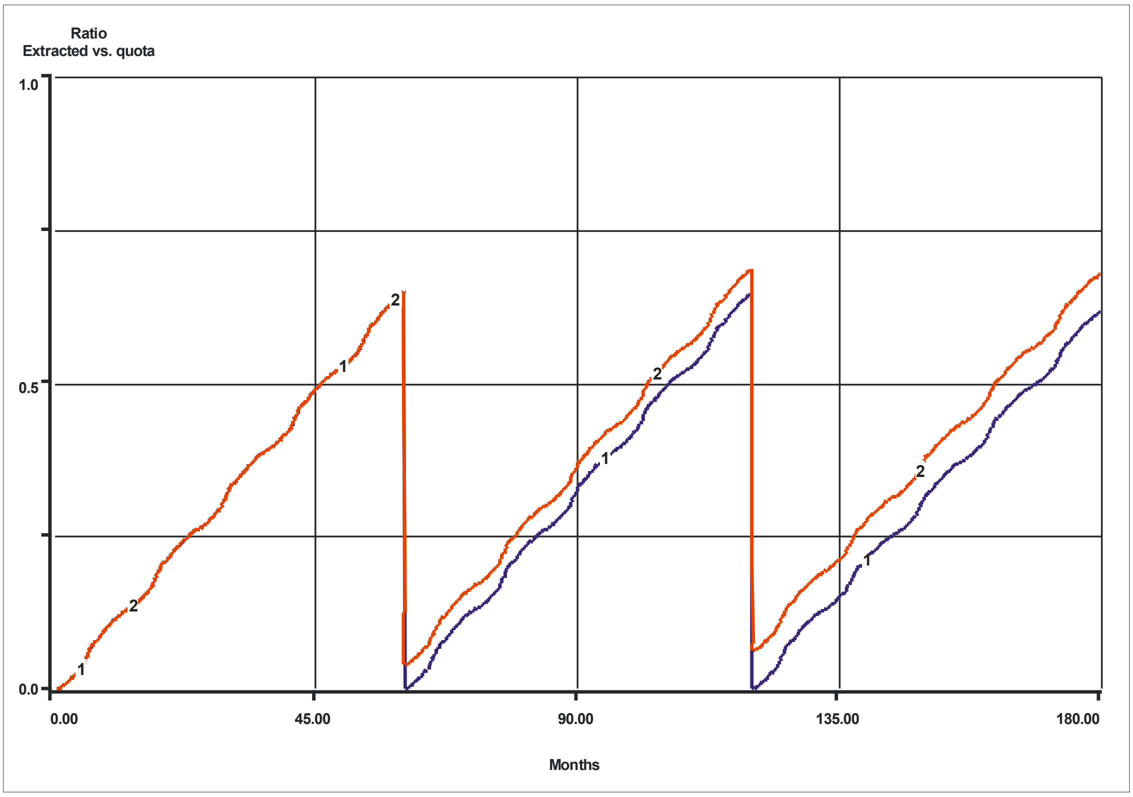


Fig. III.1.10. Computing artifact that appears when applying the 4-th order Runge-Kutta integration scheme (2) to the mechanism of resetting the quota in the sand & gravel extraction model. In this case the true behaviour is given by the Euler scheme (1).

Finally, as an example of how implementation issues might influence the results, we take the population model with a supplementary condition (as is the case in both biological sub-models): an absolute limit is set to the growth of the population.

This example can be expressed in different ways, including, when a given value of P is reached:

a) a "sink" term drains the population of the surplus,
b) the "recruiting" and the "dying" flows are set to zero,
c) the "mortality rate" is the same as the "recruitment rate",

These variants have been implemented in Stella, as shown on Fig. III.1.11.

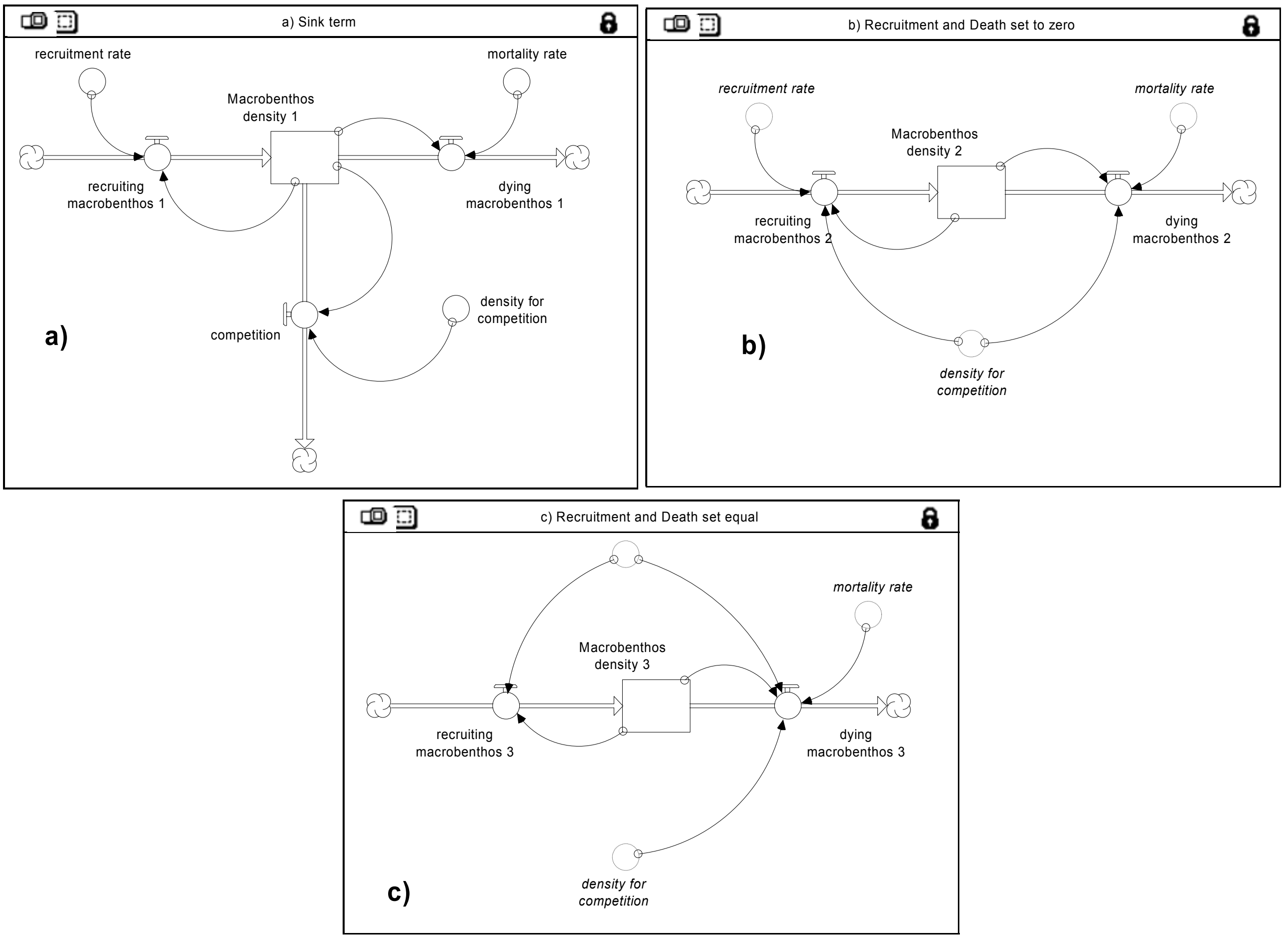


Fig. III.1.11. Various implementations of the simple population/competition model.

Table III.1.3 and Fig. III.1.12 to Fig. III.1.14 summarize the results of the runs performed with the three integration schemes and time steps ranging from 1 to 1/16th of a month. The other parameters taken for these simulations are:

Mortality rate	0.05 month^{-1}
Recruitment rate	0.40 month^{-1}
Initial population	1000 individuals/m²
Limit population	2000 individuals/m²

Table III.1.3. Test of the influence of the integration method, of the time step and of the practical implementation of a competition mechanism in a simple population model. The error relative to the exact solution (i.e. 2000 ind./m²) is expressed as a percentage. Models as designated in Fig. III.1.11.

Euler																
dt=1/...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Model (a)	3077	2424	2264	2192	2151	2124	2105	2092	2081	2073	2066	2060	2055	2051	2048	2045
	35,0%	*17,5%*	*11,7%*	*8,8%*	*7,0%*	*5,8%*	*5,0%*	*4,4%*	*3,9%*	*3,5%*	*3,2%*	*2,9%*	*2,7%*	*2,5%*	*2,3%*	*2,2%*
Model (b)	2460	2240	2165	2127	2105	2090	2079	2071	2064	2059	2055	2052	2049	2046	2044	2042
	18,7%	*10,7%*	*7,6%*	*6,0%*	*5,0%*	*4,3%*	*3,8%*	*3,4%*	*3,1%*	*2,9%*	*2,7%*	*2,5%*	*2,4%*	*2,2%*	*2,2%*	*2,1%*
Model (c)	2460	2240	2165	2127	2105	2090	2079	2071	2064	2059	2055	2052	2049	2046	2044	2042
	18,7%	*10,7%*	*7,6%*	*6,0%*	*5,0%*	*4,3%*	*3,8%*	*3,4%*	*3,1%*	*2,9%*	*2,7%*	*2,5%*	*2,4%*	*2,2%*	*2,2%*	*2,1%*

2nd–order Runge–Kutta																
dt=1/...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Model (a)	3074	2424	2264	2192	2151	2124	2105	2092	2081	2073	2066	2060	2055	2051	2048	2046
	34,9%	*17,5%*	*11,7%*	*8,8%*	*7,0%*	*5,8%*	*5,0%*	*4,4%*	*3,9%*	*3,5%*	*3,2%*	*2,9%*	*2,7%*	*2,5%*	*2,3%*	*2,2%*
Model (b)	2340	2007	2011	2009	2010	2011	2012	2012	2013	2013	2013	2013	2013	2013	2013	2013
	14,5%	*0,3%*	*0,5%*	*0,4%*	*0,5%*	*0,5%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*
Model (c)	2340	2007	2011	2009	2010	2011	2012	2012	2013	2013	2013	2013	2013	2013	2013	2013
	14,5%	*0,3%*	*0,5%*	*0,4%*	*0,5%*	*0,5%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*	*0,6%*

4th–order Runge–Kutta																
dt=1/...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Model (a)	3075	2424	2264	2192	2151	2124	2105	2092	2081	2073	2066	2060	2055	2051	2048	2045
	35,0%	*17,5%*	*11,7%*	*8,8%*	*7,0%*	*5,8%*	*5,0%*	*4,4%*	*3,9%*	*3,5%*	*3,2%*	*2,9%*	*2,7%*	*2,5%*	*2,3%*	*2,2%*
Model (b)	2228	2126	2090	2071	2060	2052	2047	2043	2001	2002	2003	2004	2005	2005	2006	2006
	10,2%	*5,9%*	*4,3%*	*3,4%*	*2,9%*	*2,5%*	*2,3%*	*2,1%*	*0,0%*	*0,1%*	*0,1%*	*0,2%*	*0,2%*	*0,2%*	*0,3%*	*0,3%*
Model (c)	2228	2126	2090	2071	2060	2052	2047	2043	2001	2002	2003	2004	2005	2005	2006	2006
	10,2%	*5,9%*	*4,3%*	*3,4%*	*2,9%*	*2,5%*	*2,3%*	*2,1%*	*0,0%*	*0,1%*	*0,1%*	*0,2%*	*0,2%*	*0,2%*	*0,3%*	*0,3%*

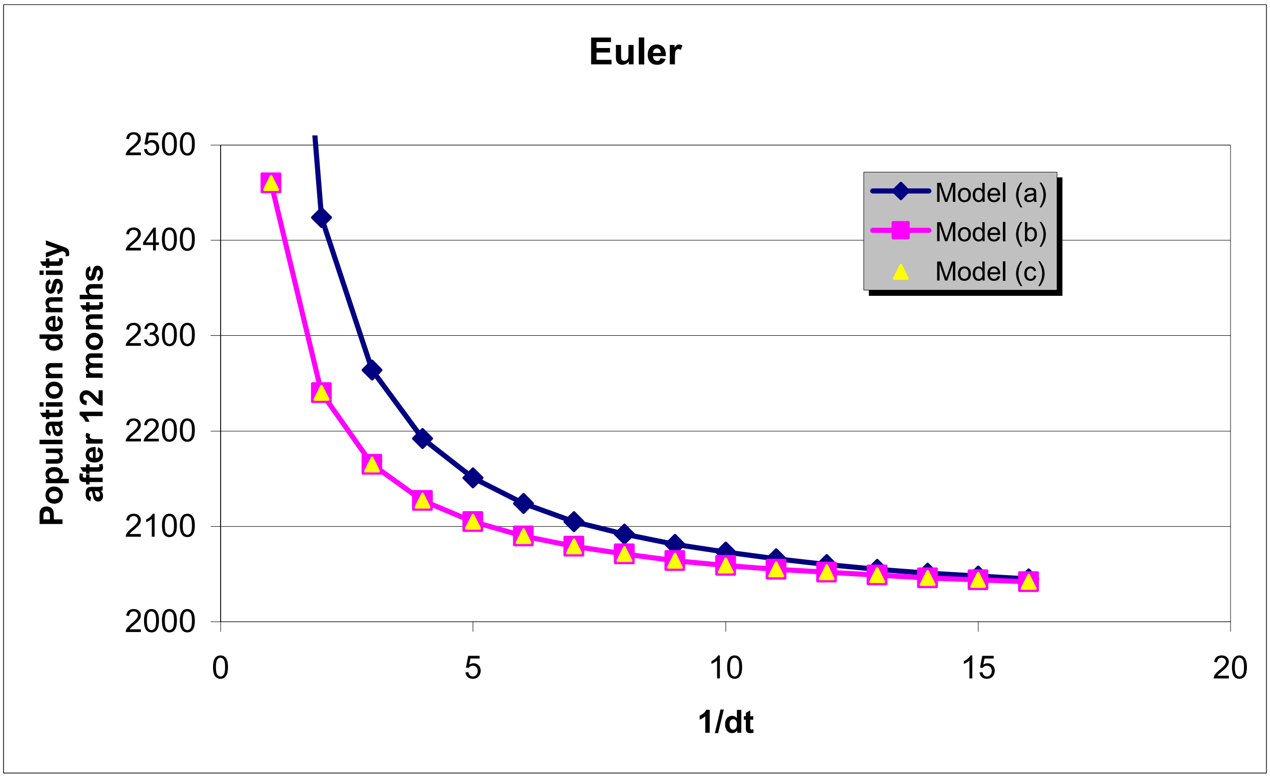


Fig. III.1.12. Solution of the simple population model with competition after 12 simulated months, using the Euler integration scheme, as a function of the time step. The exact solution is 2000 ind./m².

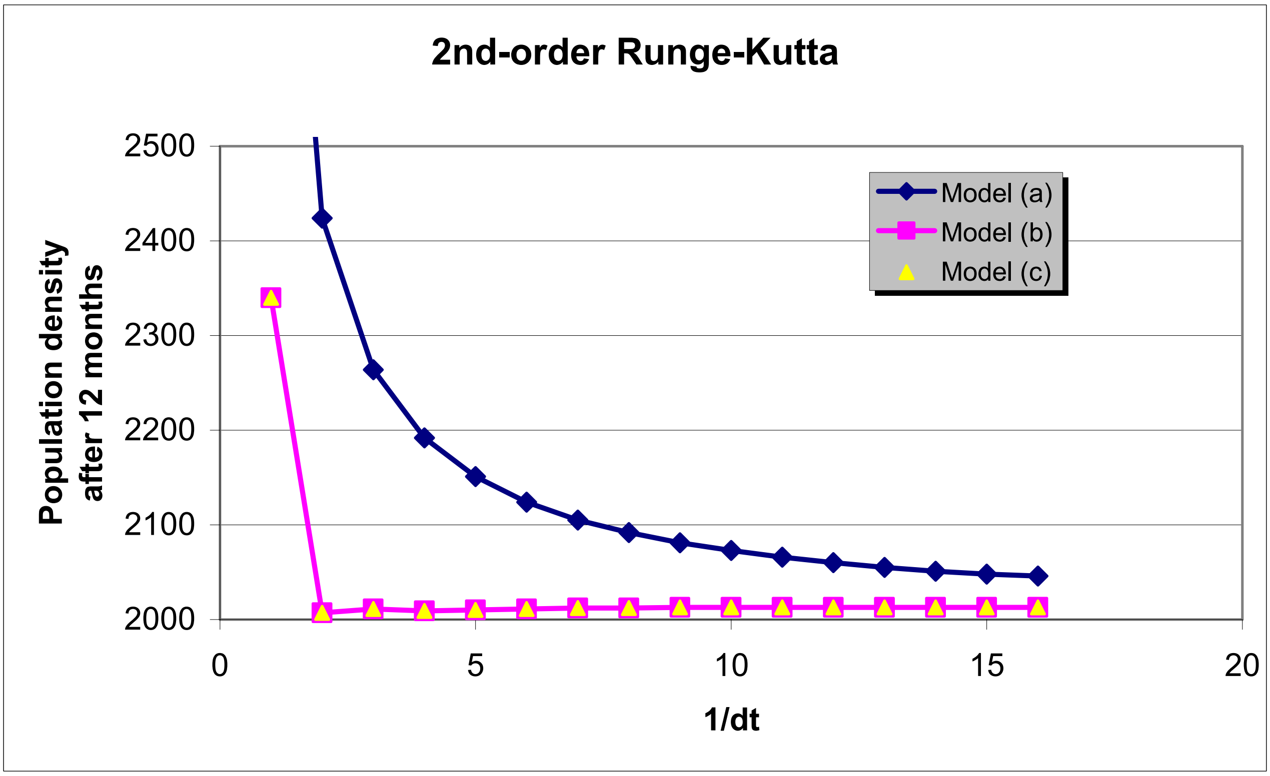


Fig. III.1.13. Solution of the simple population model with competition after 12 simulated months, using the 2nd–order Runge–Kutta integration scheme, as a function of the time step. The exact solution is 2000 ind./m².

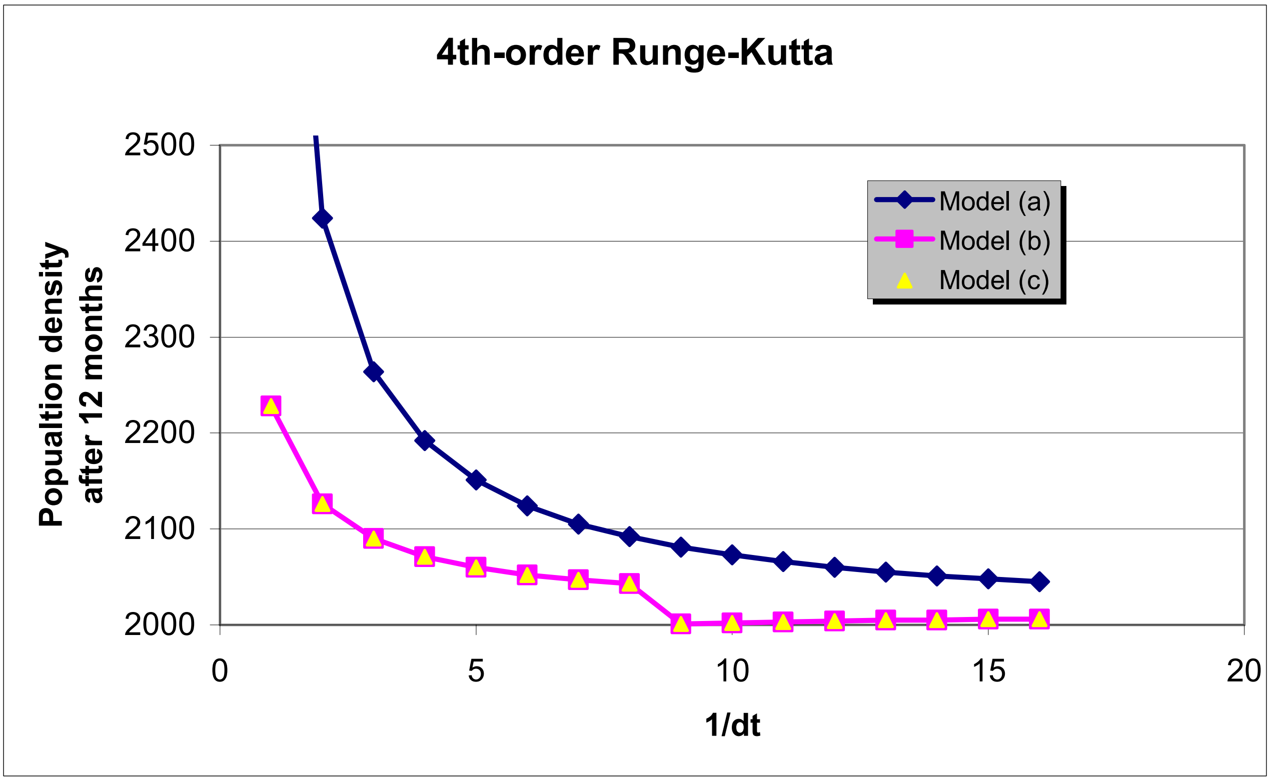


Fig. III.1.14. Solution of the simple population model with competition after 12 simulated months, using the 4th–order Runge–Kutta integration scheme, as a function of the time step. The exact solution is 2000 ind./m².

From these results it is obvious that implementation (b) and implementation (c) are equivalent and that both always perform better than formulation (a). The latter gives the same results whatever the integration method is. For a given method, the accuracy of the results depends clearly on the time step, although a smaller time step do not always give better results. With the 2nd–order Runge–Kutta, for example, the results are (slightly) worse when dt is smaller than ½. The relationship between accuracy and time step is also not linear, as can be seen by comparing the results of the 4th–order Runge–Kutta for dt ≤ 1/8 and dt ≥ 1/9.

This example also illustrates our previous statement ("higher order" doesn't necessarily mean "higher accuracy"). In this case, the 2nd–order Runge–Kutta method would give better results than the 4th–order Runge–Kutta.

Like real systems, limited systems represented by numerical models can show very complex behaviour. There is no unique or straightforward choice regarding the techniques and the parameters used to solve ('integrate') them. It is always worth testing and tuning the models on this aspect.

1.7 interface

The end–user interface (Fig. III.1.15) consists of a static part which gives access to the information on the consortium and the project, the report and user's guide and the models themselves. The software comes bundled on a CD, together with the environment necessary to run STELLA models and a self install procedure.

Although two different software environments are used (a regular "Internet" browser for the static information and the STELLA environment) we managed to keep the same "look & feel" where possible.

Once a model has been selected, the inputs and the outputs are structured in a hierarchical way (Fig. III.1.15). The key simulation parameters and the major outputs appear on the two main screens (Fig. III.1.16 and Fig. III.1.17 for Fisheries, and Fig. III.1.18and Fig. III.1.19 for Sand and Gravel) and the detailed and thematic information on further screens. The models, being rather complex in terms of number of parameters and of possible ways of showing results, made it indeed necessary to prioritize the possible inputs and outputs at the user interface level. Furthermore, only the parameters identified as "scenario" or "policy choice" were made available as inputs. An advantage of limiting the number of parameters at the main user interface is to reduce the complexity that the user is required to consider during a simulation session.

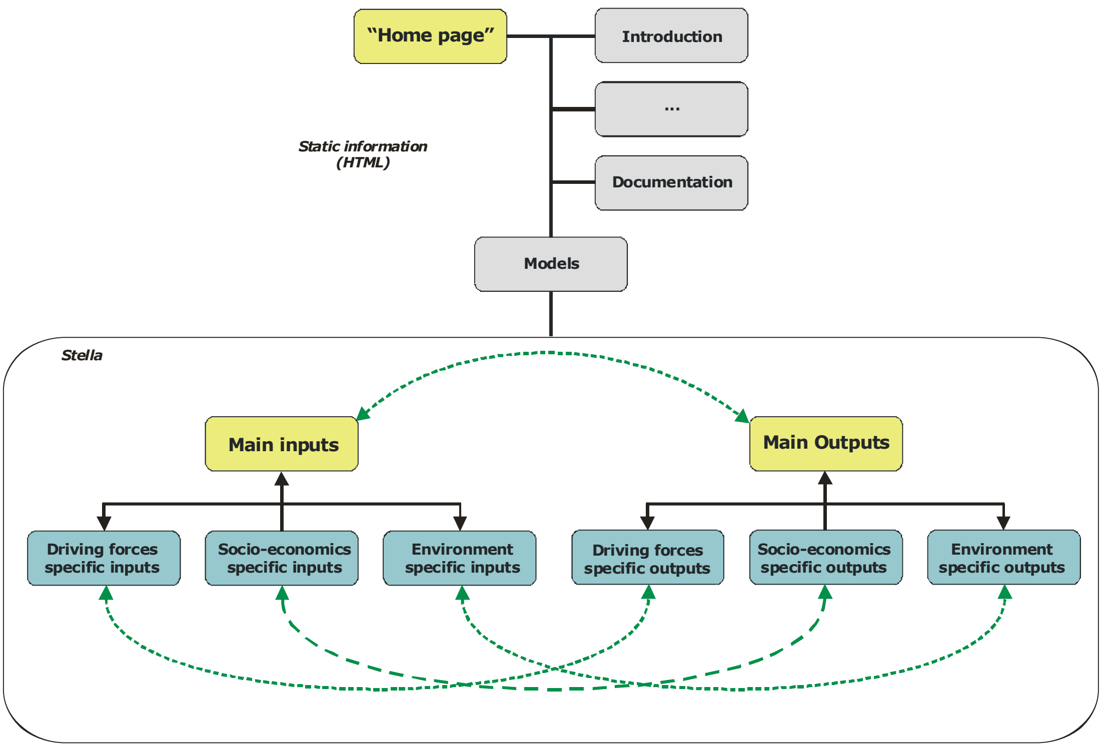


Fig. III.1.15. Sketch of the user interface. The static information is given in a web–like environment. The actual user interfaces for the models are imbedded in Stella programs. The arrows show the allowed navigation within the models.

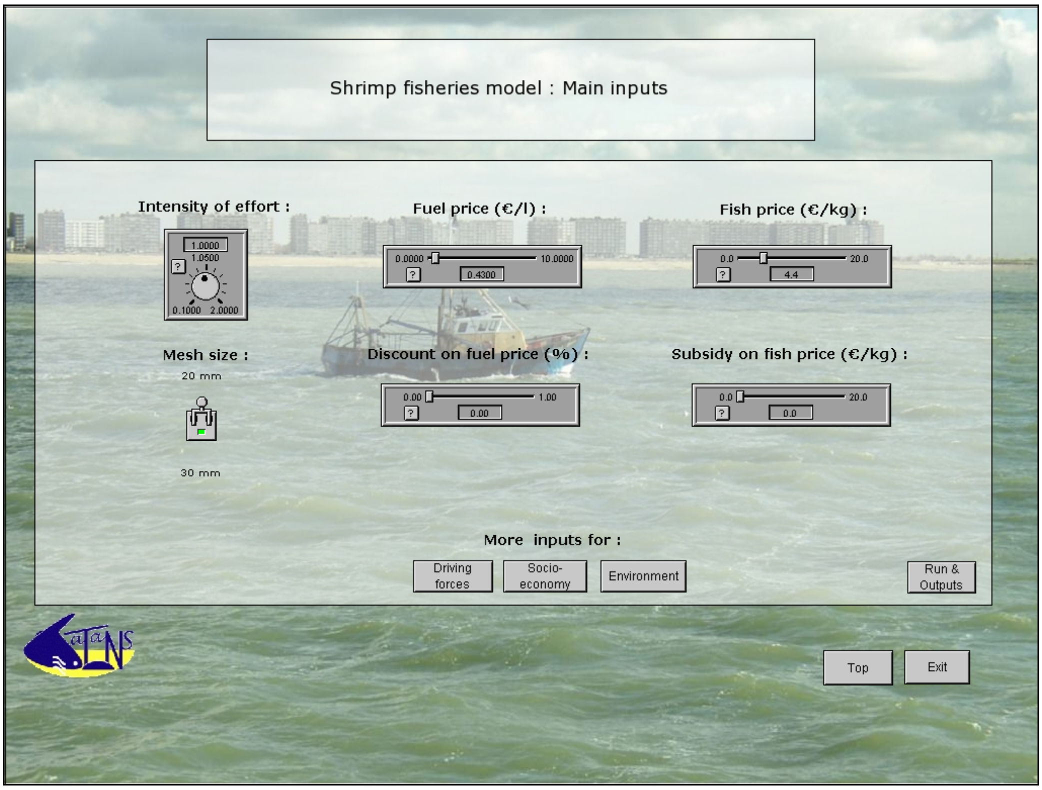


Fig. III.1.16. Main input screen for the "Shrimp fishery" model.

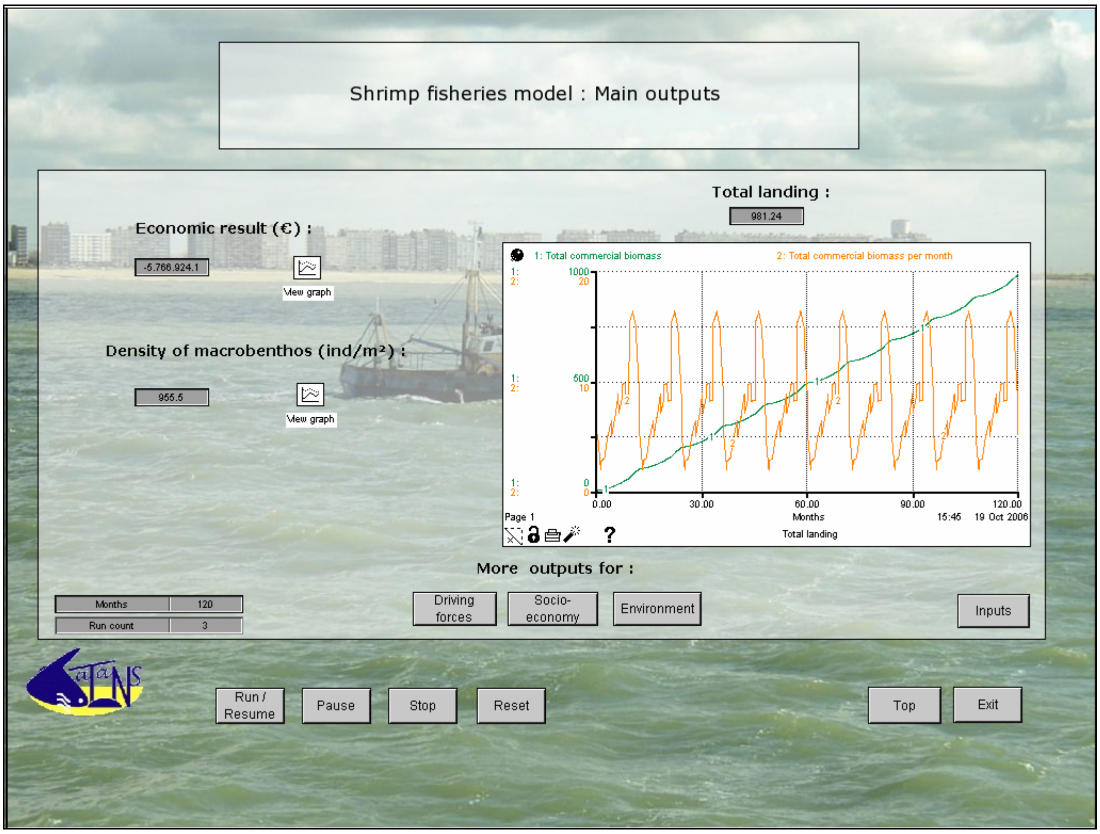


Fig. III.1.17. Main output screen for the "Shrimp fishery" model.

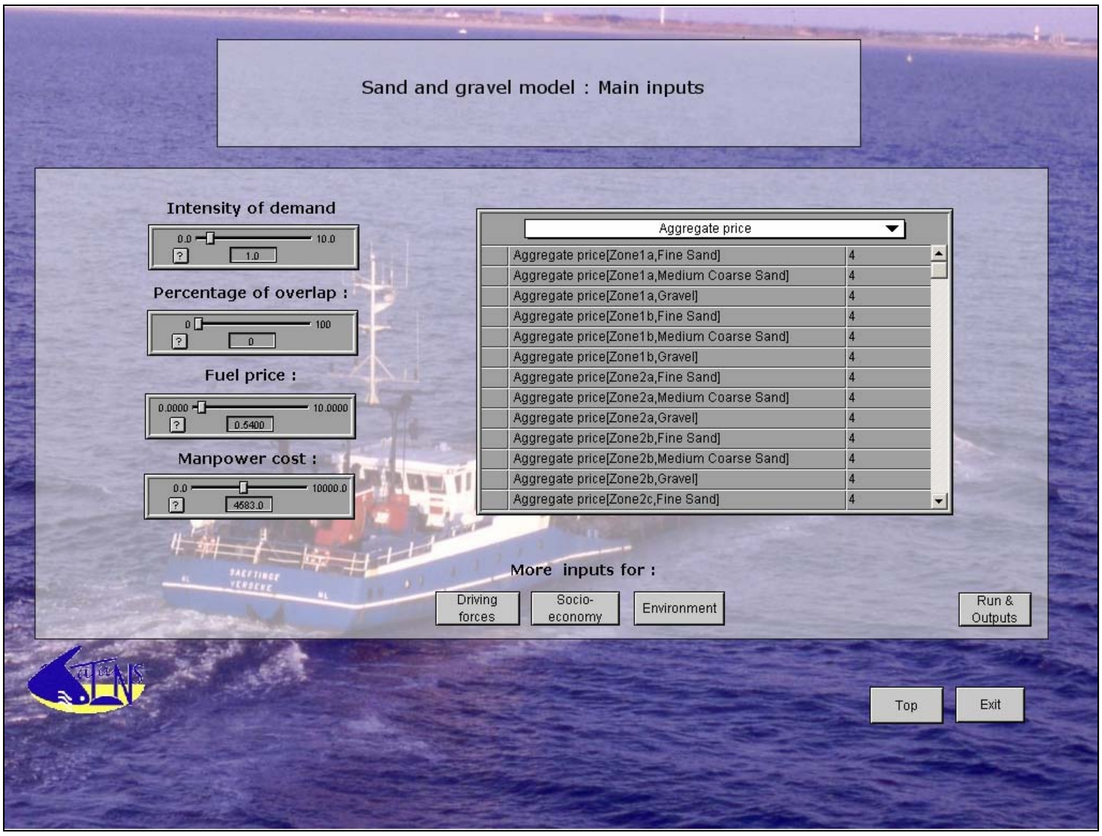


Fig. III.1.18. Main input screen for the "Sand & Gravel extraction" model.

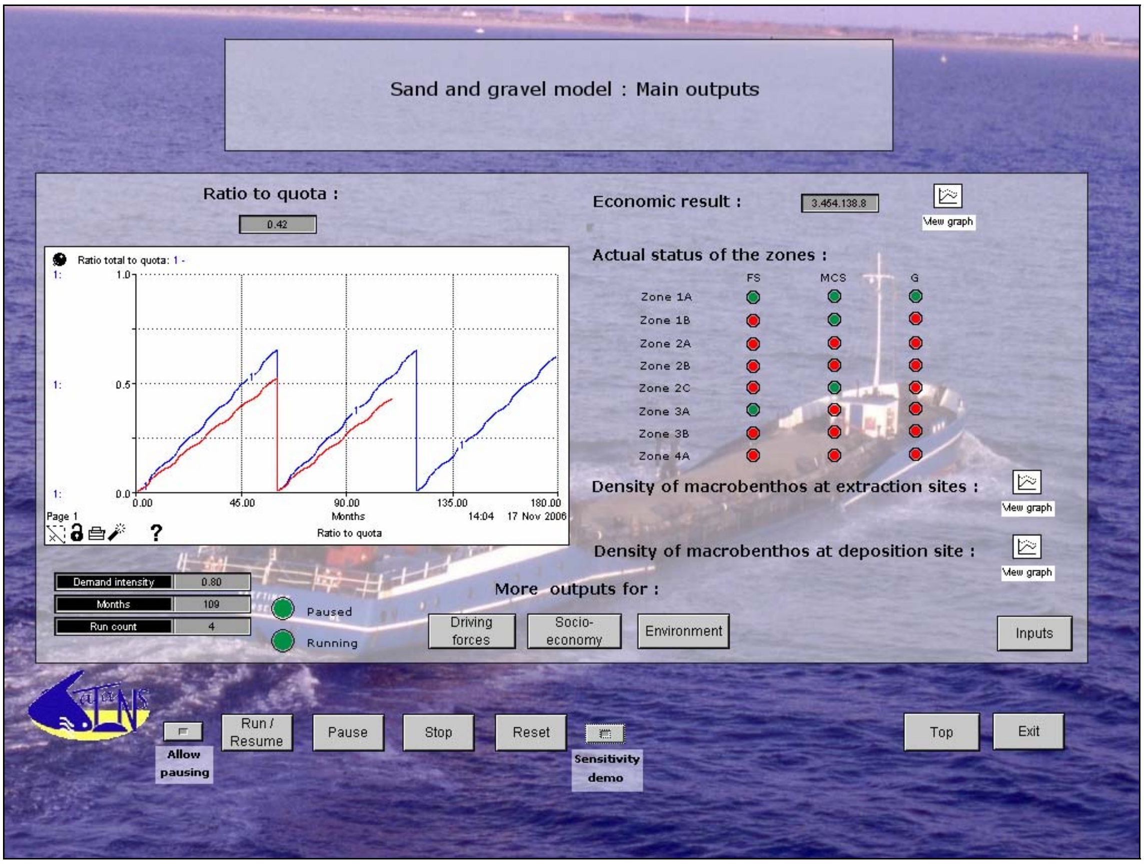


Fig. III.1.19. Main output screen for the "Sand & Gravel extraction" model.

In most of the cases, the input parameters are represented at the interface level as "slider input devices" that allow the user to select a value between two extremes (with or without a pre-defined step). The various parameters made available at the general user interface level are listed in the Table III.1.4 and Table III.1.5 below.

Table III.1.4. Input parameters (user defined) on the general interface level for Sand and Gravel model

Name	*Comment*
Intensity of demand	a multiplicative factor of the monthly demand (given per grain type)
Percentage of overlap	a measure of the spatial intensity of the activity
Fuel price	expressed in EUR/l
Price of aggregates per zone and grain type	expressed in EUR/ton
Manpower cost	expressed in EUR/person

Table III.1.5. Input parameters (user defined) on the general interface level for Shrimp Fisheries model

Name	*Comment*
Intensity of effort	a multiplicative factor of the monthly fishing effort
Mesh size	20 or 30 mm
Fuel price	expressed in EUR/l
Discount on fuel price	expressed in %
Fish price	expressed in EUR/kg
Subsidy on fish price	expressed in EUR/kg

A full list of input parameters is given in Annex 8 (User Inputs).

The use of the model is rather intuitive. There are buttons to start, stop, pause or resume the simulation, buttons to move from one page to the other and a button to reset all the modified values and to erase results of previous simulations performed during the same session.

Any input parameter can be individually reset after a change using a specific button on its input device as shown on Fig. III.1.20 together with some other useful features of the input devices. These features are described in a short "User's manual" that is included in the distribution of the software.

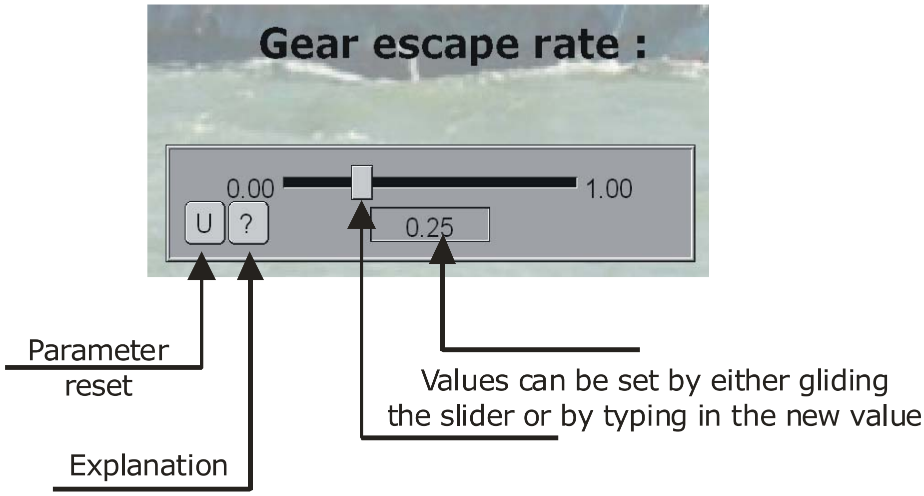


Fig. III.1.20. Example of some useful functionalities of the input devices.

1.8 sensitivity analysis

Another aspect we have to deal with when developing and running models is their sensitivity to the input parameters. This sensitivity, *i.e.* how the results are modified when some input parameters are changed might result from the system itself or from the numerical implementation. Non–linear systems can suddenly exhibit large variation when a forcing parameter only slightly changes. This is typically the case when the relationships in the model are expressed in terms of logical functions that make the system change its behaviour when a parameter reaches a given threshold.

The STELLA software has a specific execution mode that allows the developer to explore how changes in the inputs affect the results. Fig. III.1.21 shows the corresponding interface for the advanced user, working in the STELLA development environment. In order to give the regular user an idea of this feature, a "sensitivity demo" mode can be enabled in the bundled "Sand & Gravel" model (see Fig. III.1.18) that makes the "demand intensity" parameter uniformly and automatically vary between 0.5 and 5.0 by steps of 0.25. Results being superimposed on graphs as long as no general reset has been done, it is then possible to compare the effects of these variations on the outputs values of the model, as in Fig. III.1.22 and Fig. III.1.23.

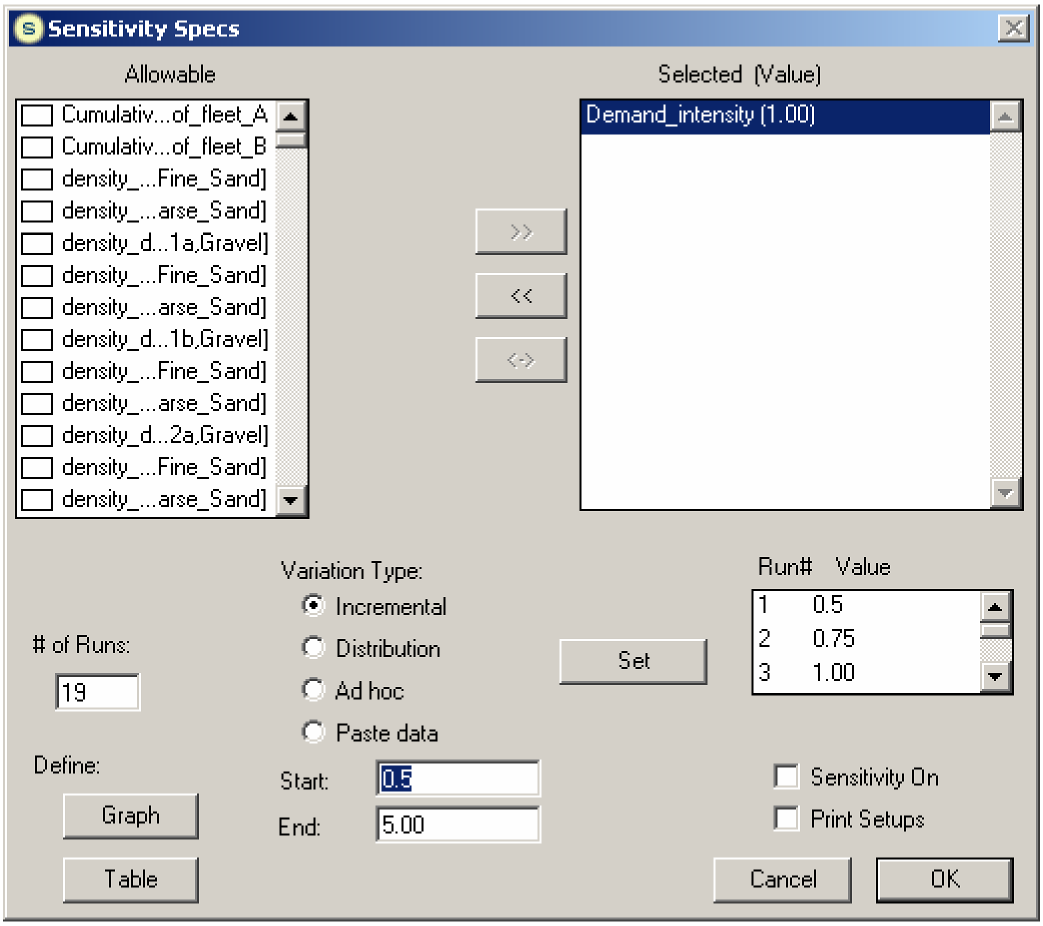


Fig. III.1.21. Advanced–user's interface in STELLA for performing sensitivity analyses.

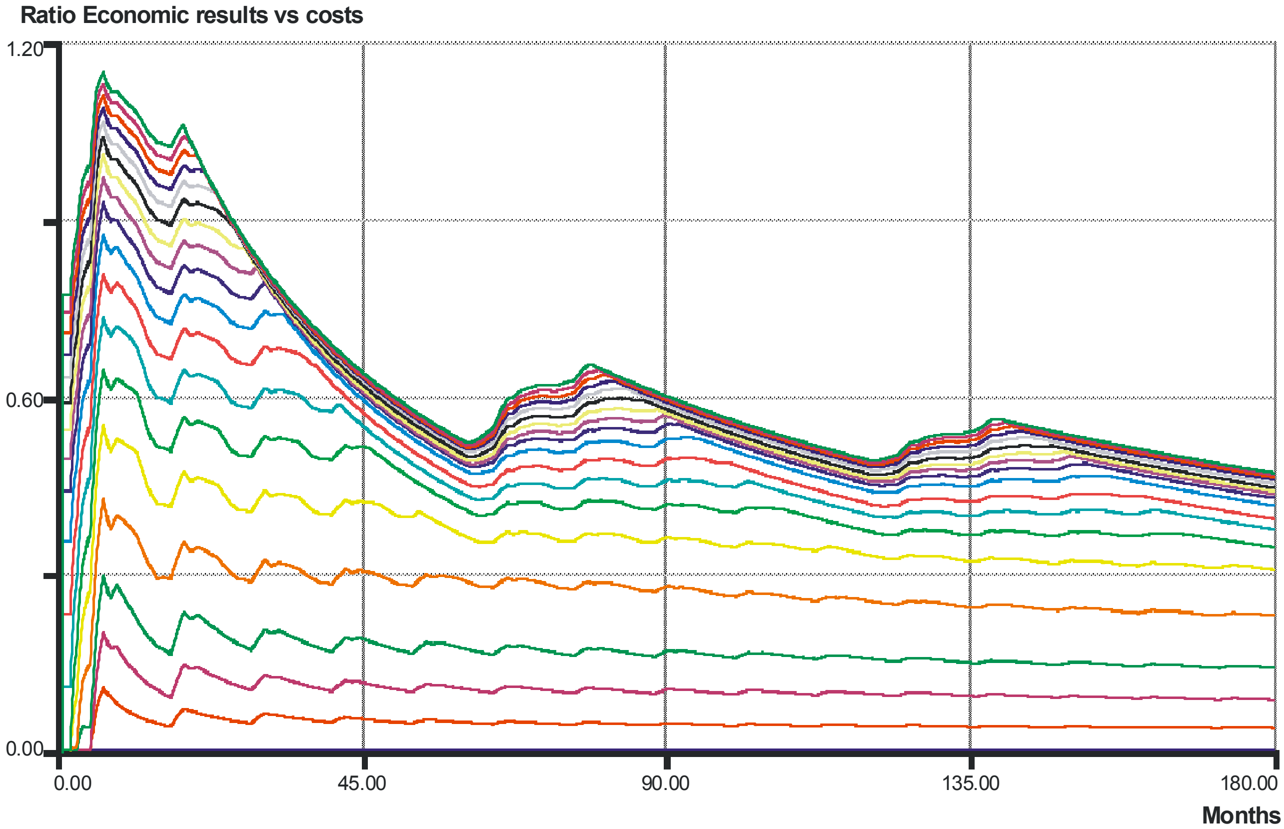


Fig. III.1.22. Effect of the variation of the demand on the economic results vs. costs ratio. A low ratio corresponds to a low demand.

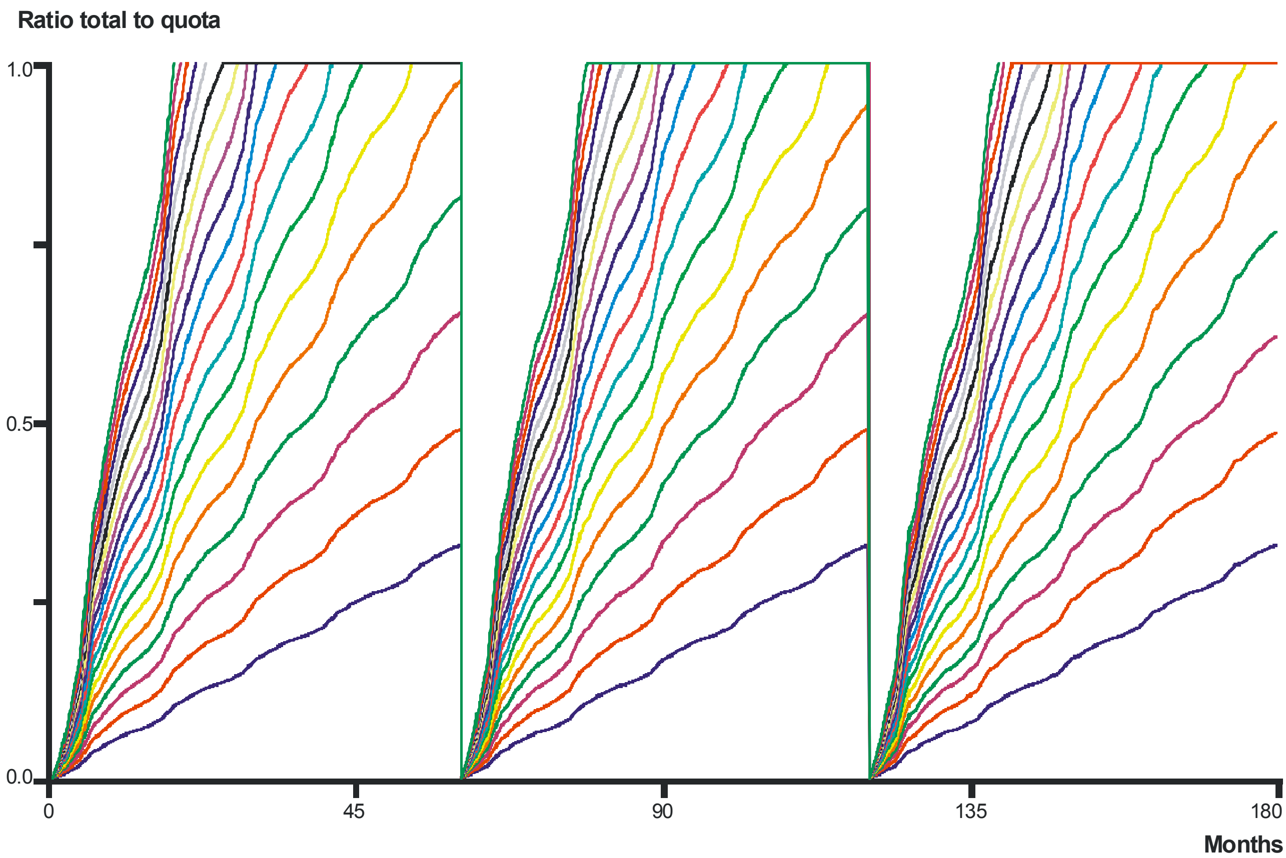


Fig. III.1.33. Effect of the variation of the demand on the ratio between extracted quantities and quota. A low ratio corresponds to a low demand.

Such a sensitivity analysis should be systematically performed, input parameter by input parameter and, also, with combinations of them. It is only justified, however, when a model has reached a sufficient stage of maturity. The software that has been developed in the frame of BALANS is more a "proof of concept" than a definitive and stable prognostic tool. Therefore, no systematic sensitivity has been performed in the frame of the project.

1.9 models performance

As mentioned under Section 1.6 the choice of the integration method and of the integration time step is in our case a multi–criteria problem. We decided to use the Euler scheme with a time step of 0.0625 month. This choice has of course an influence on the time that is needed to perform a simulation (representing 10 years for the "Shrimp fisheries" model and 15 years for the "Sand & Gravel model"). The software could only be tested so far on a limited set of computers. Indicatively, the wall clock time necessary for running the standard simulations on these computers is given in Table III.1.6. This seems acceptable.

Table III.1.6. Indicative wall-clock time needed for running standard simulations.

Model	***Pentium IV 3.0 GHz Windows XP***	***Intel Core Duo 2.0 GHz Windows XP under MacOS***
Fisheries	~3.5s/10yr	1.5s/10yr
Sand and gravel	~17s/15yr	~17s/15yr

1.10 possible improvements

First of all, the software produced during the BALANS project needs to be considered as a prototype or, better, as the "Release 1.0" of an evolving software. We are awaiting the comments of the users and are willing to improve the product. Support and improvement will be provided by the Management Unit of the North Sea Mathematical Models

Focusing on the aspects bound to the models and not the methodology, the following possible improvements have however already been identified.

For both activities:

- To incorporate more "feedback effects", like the closing of zones devoted to a given activity when the macro–benthos density falls under a given threshold and their re–opening when this variable has reached a sufficient level again;
- To eliminate, if possible, formulations that prevent the use of the faster and most accurate integration scheme;

For the shrimp fishery:

- To distinguish clearly everywhere possible the two fishing grounds (*e.g.* in the environmental sub–model);
- To let the shrimp population vary as a function of the season and of the fishing ground;
- To develop and couple a shrimp population model.

For the sand and gravel extraction:

- To allow for a greater flexibility in the input of the demand, in order to allow for these quantities to vary over the years;
- To provide for a more realistic extraction pattern, in case of partially or full "intensive" activity;

- To allow to change the reference harbour and, hence, the distance exploitation vessels have to travel to and from the extraction zones.

MUMM
Management Unit of the North Sea Mathematical Models
Serge Scory

CHAPTER TWO

CASES STUDIES

1. TEST CASES AND SCENARIO'S

1.1 methodology of scenario development

Through the development of economic, social and environmental scenarios, "what if" questions can be examined, *e.g.*: "What if policy measures restrict the exploitation for the purpose of environmental protection?", "What if the market demand induces 10 times the current level of exploitation?". Consequences on indicators pertaining to each of the three domains in response to a system change can be explored. The purpose of running decision making models while making the input parameters vary is to assess how the system will evolve and how its behaviour will change when some external conditions or internal characteristics are modified. With our models for sand and gravel extraction and for shrimp fishery, referring to the DPSIR scheme given in Fig. III.2.1, this mainly means letting vary the parameters defining:

- the natural resources uses;
- the policies and strategies;
- some of the ecosystem and natural resources properties

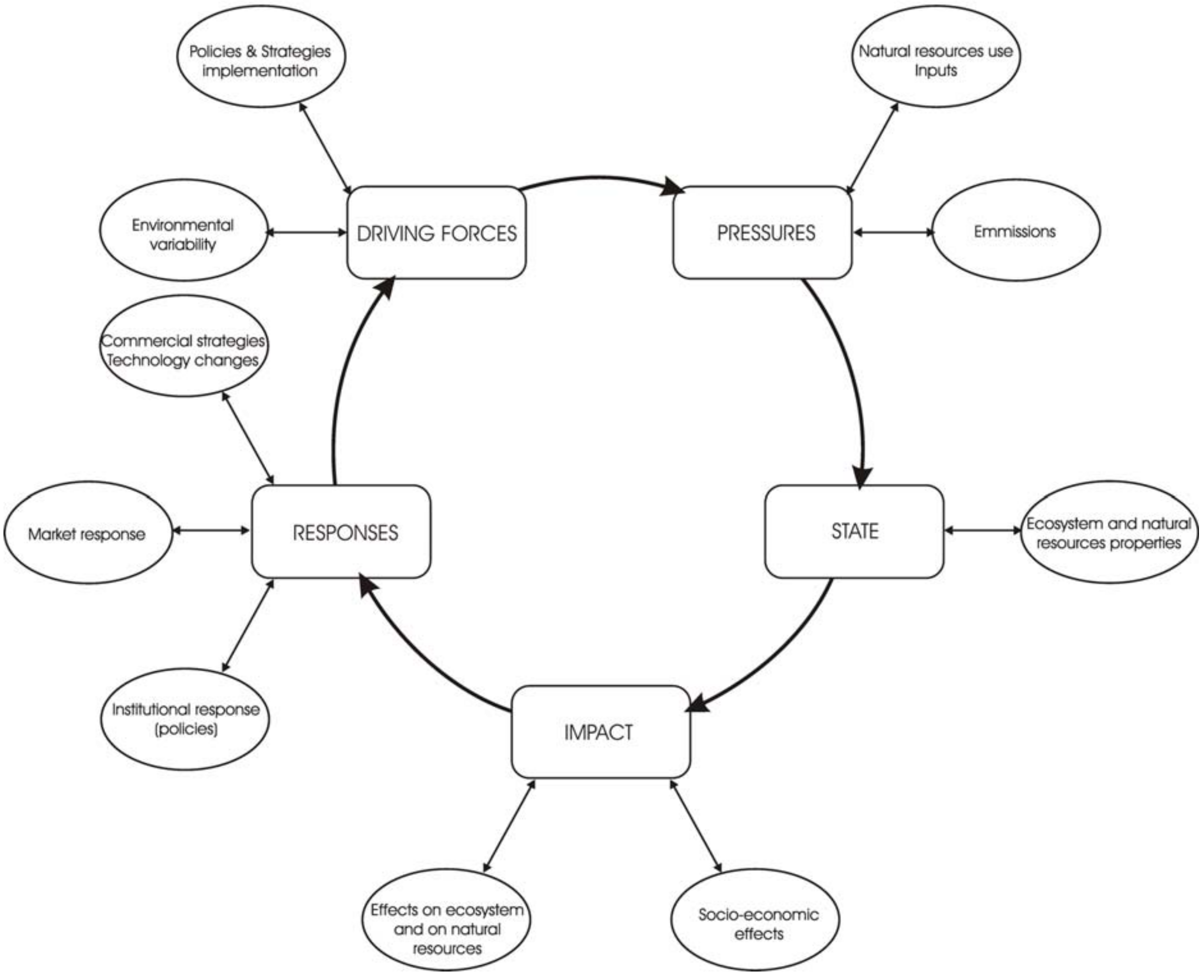


Fig. III.2.1. The DPSIR scheme showing how a system adapts dynamically and continuously to internal and external changes.

These broad categories are reflected in the input parameters that the user is allowed to change at the interface level.

The basic principles to define a scenario are the following:

1. <u>Define simulation objectives</u>

In our case, we want to answer "What if?" questions. We are interested in knowing how the system will react and evolve when some endogenous or exogenous changes occur.

2. <u>Identify evaluation criteria</u>

Key output indicators were identified (see Table III.2.1).

Table III.2.7. Key output indicators identified as evaluation criteria for each component (driving forces, socio-economy and environment) of the fisheries and sand and gravel extraction activities.

Model	*Driving forces*	*Socio-economics*	*Environment*
Fisheries	Ratio (Dead+Waste) vs. Commercial catch Total landing Landings Per Unit of Effort	Turnover Economic result Total costs Ratio economic results/costs	Density of macrobenthos
Sand and Gravel	Ratio actual depth/critical depth Ratio extracted sand/quota Total extracted surface	Turnover Economic result Total costs Ratio economic results/costs	Density of macrobenthos at extraction sites Density of macrobenthos at deposition site

3. Determine relevant scenario characteristics

This step requires identification of the actual values the input (*i.e.* "forcing") parameters are likely to take in the future. It implies making credible assumptions on the evolution of the external market (*e.g.* price of fuel), of the internal market (*e.g.* changes in the demand of gravel, change in the price of fish), of the policy (*e.g*. potential policy restriction on the deepening of sand extraction zones), of the field strategy (*e.g*. changes in fish grounds, changes in the spatial intensity of sand extraction), and the possible combination of these specific changes. The models allows to explore the effects of the increase of fuel price, of a more strict "policy" about deepening (sand and gravel), or variations of the fishing effort, *etc*.

4. Analysis of the effects

A standard simulation is to be run, where the scenario parameters are set to their default value, which correspond to their present value. This scenario is usually named "BAU – Business as usual". It serves as a reference basis for the analysis of the "What if?" scenarios. Values and trends can then be compared.

There are many possible scenario's and study cases. The following sections exemplify a few of them.

Note of Caution: In no case should the results shown in this chapter be taken as representing the truth. The models developed in BALANS are to be considered so far as "proofs of concept". The many uncertainties on the input data do not allow direct use of the results.

1.2 the quest of sustainability

The models allow us to answer questions on the sustainability of the system. In order to assess the sustainability of the ecosystem being influenced by an activity, for instance, it is possible to let vary some of the pressures the activity exert on it.

Fig. III.2.2 shows how the benthic communities react to different levels of fishing effort. Curve labelled '1' corresponds to the present fishing effort. The density of the reference macrobenthos community increases slowly and exhibit some variation corresponding to the seasonal variation of the fishing effort. Curve labelled '2' reflects an intensity of effort of one half of the current effort. The population reaches its saturation level after three years and is then no more affected by the fishing activity. Curve labelled '3' corresponds to an effort one and a half bigger than the current one. The population declines steadily. At last, curve '4' has been obtained after a few iterations and shows that with an effort intensity set to 111.45% of the current one, the benthic community reaches a steady state, *i.e.* the extra-mortality caused by the fishing activity is compensated by the regeneration capacity of the population. Considering the overall intensity of the effort, with respect to the macrobenthic fauna, the shrimp fishery activity is thus 'sustainable' in this case.

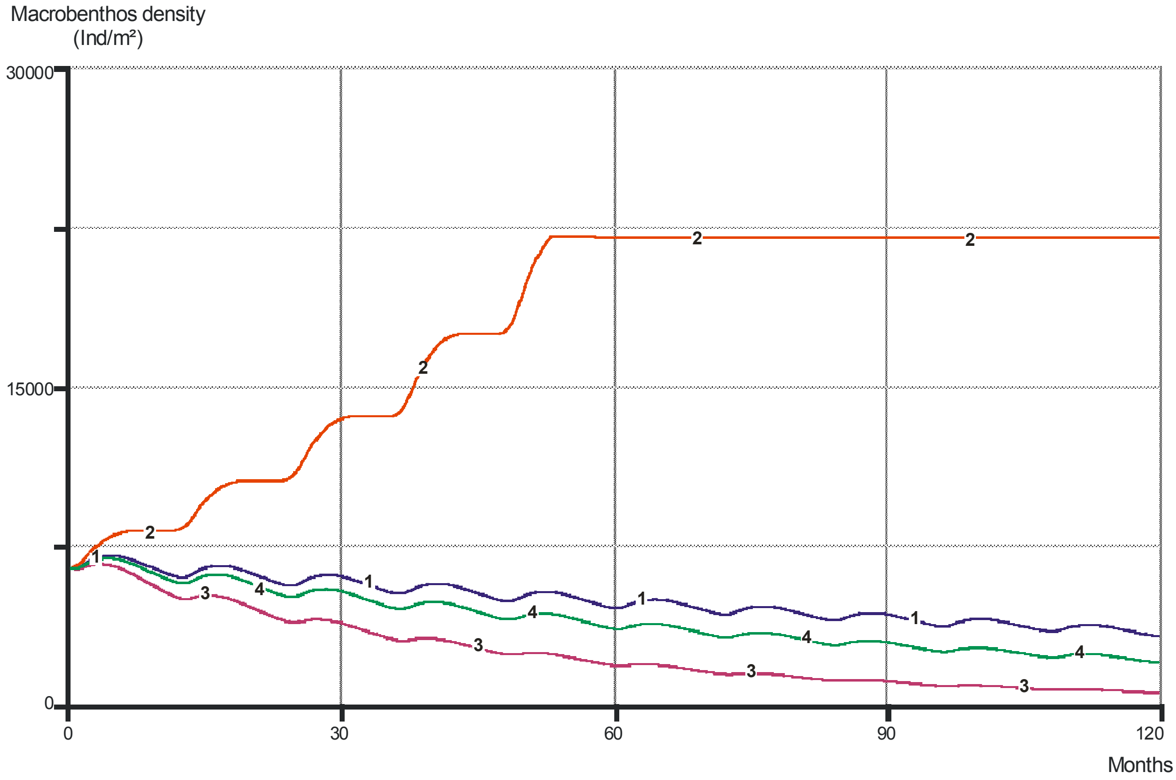


Fig. III.2.2. Evolution of the macrobenthos density as a function of the fishing intensity, all other things staying the same. Curve labels correspond respectively to: '1', Effort intensity (EI) = 1; '2', EI = 0.5; '3', EI =1.5 and '4', EI = 1.1145.

The next question should then be: "Is the sector profitable and, if not, what can be done to make it profitable?". Given a basic investment cost of 800 000 euros per vessel, one can similarly try to valuate the public subsidies needed to make the sector "sustainable" from an economic point of view. Various trials and a possible solution are given in Fig. III.2.3. The curve labelled '1' corresponds to effort intensity (EI) = 1 and no subsidy: the sector looses about 600,000 euros per year. The curves labelled '2', '3', '4' and '5' correspond to the "optimal" fishing effort of 111.45%. With no subsidy (Curve '2') the sector only looses about 31,000 euros less each year. With a subsidy of 400,000 euros on the investment (*i.e.* 50% Curve '3'), the loss is still important (about 270,000 euros a year in total). Allowing a further subsidy of 3.50 euros on each landed kilogram of shrimps reduces the losses, on average, to 35,000 euros per year (Curve '4'). Finally, a complementary discount of 25% on the fuel price allows the sector to maintain a sustainable ("non-loss") level (Curve '5').

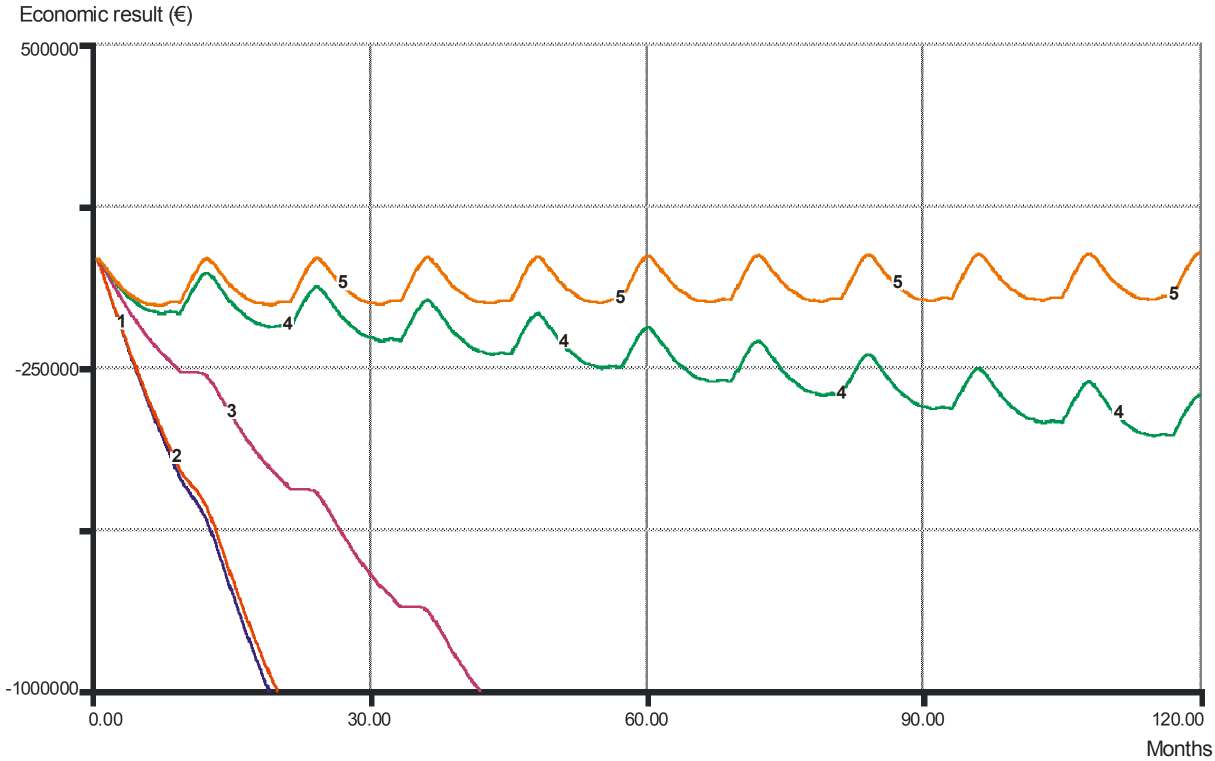


Fig. III.2.3. Evolution of the economic result as a function of the fishing effort and of the subsidies on investment, all other things staying the same. Curve labels correspond respectively to: '1', Effort intensity (EI) = 1 and no subsidy; '2', EI = 1.1145 and no subsidy; '3', EI = 1.1145 and a subsidy of 50% of the investment value; '4', idem '3' + a subsidy of 3.50€/kg on the fish price and, finally, '5', idem '4' + a discount of 25% on the cost of the fuel.

1.3 scenario's

There are many possible combinations of the input parameters of the model. We have chosen to compare, for each of the two considered sectors, (1) the present situation (aka "Business as usual" – BAU) with a (2) situation where the activity level increases significantly and with another one, (3) driven by nature conservation constraints. These various scenario's are summarized on Table III.2.2.

Table III.2.8. Synthetic sketch of the various scenarios

	Shrimp fisheries	Sand & Gravel extraction
Business as usual		80% overlap
Green line	Twice as much shrimps	No overlap allowed
Heavy business	Twice as much fishing effort	Full overlap, twice as much extracted quantities

1.3.1. sand and gravel extraction

The three scenarios for sand and gravel extraction are based on the variation of the "overlap" factor. This parameter has been defined as a possible policy constraint that limits (or not) the number of passes on the same place. When no overlap is allowed (scenario 2) the exploitation is extensive and the affected depth is limited to the extraction depth of the gear. When a full overlap is allowed (scenario 3, together with doubling of the extracted quantities), the extraction depth can go up to a critical depth (default = 4m). We have estimated the current practice of being equivalent to 80% overlap (scenario 1).

Fig. III.2.4 shows the ratio of the total extracted sand and gravel volume to the legal quota. Fig. III.2.5 gives the evolution of the economic result. Fig. III.2.6 and Fig. III.2.7 allow to compare the number of trips made by the fleet A and the fleet B, respectively. Finally, Fig. III.2.8 gives an example of the evolution of the macrobenthos density. The labels of the curves in the next figures correspond to the numbers of the scenario's.

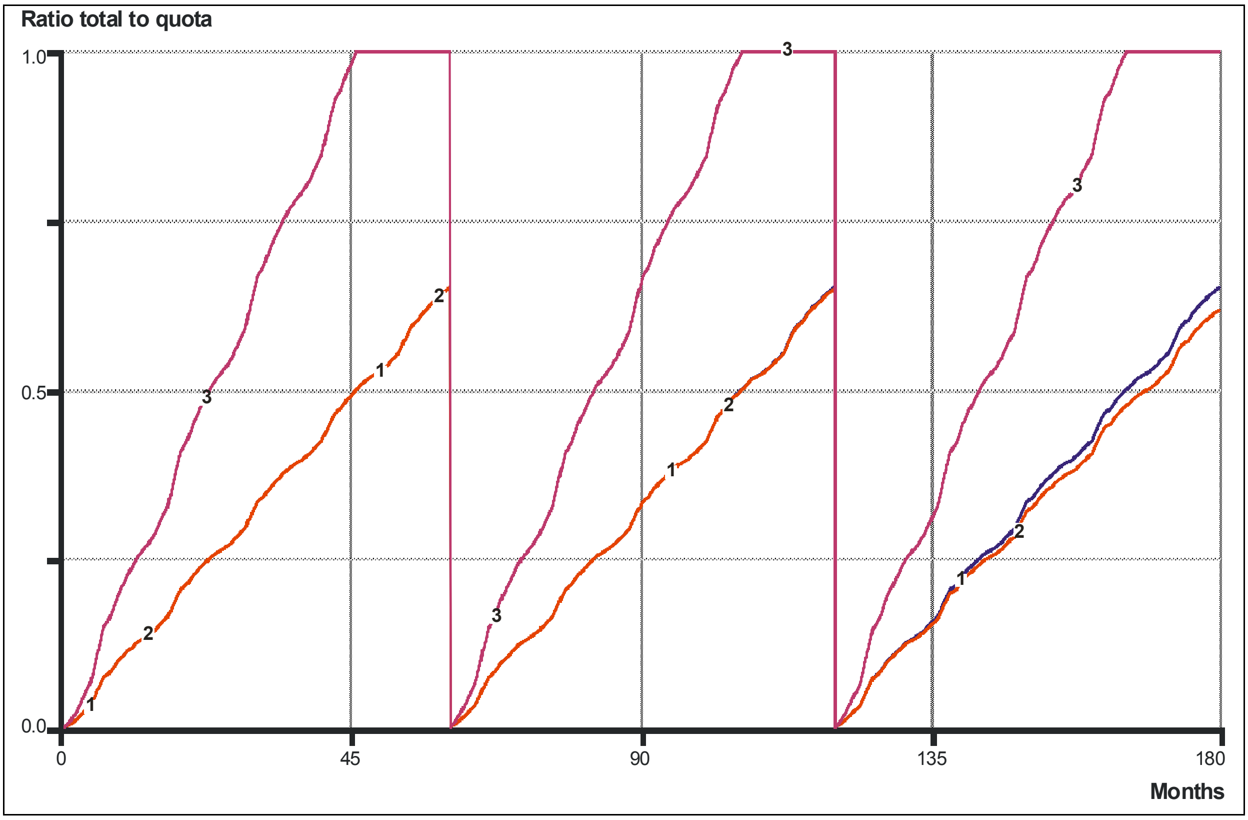


Fig. III.2.4. Ratio of the total extracted quantity per period of 5 years to the quota. The final value for the second scenario is slightly smaller than the one for the first scenario because the extensive exploitation prevents the demand to be fully fulfilled.

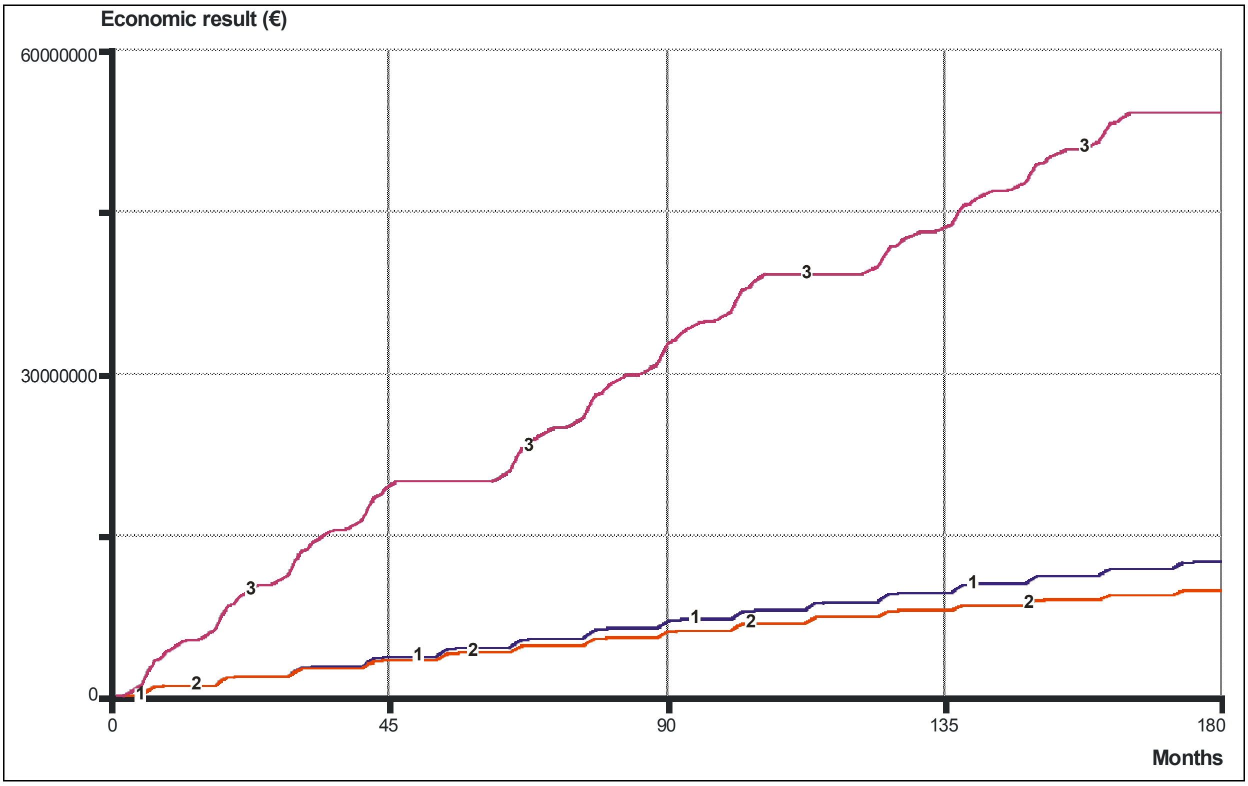


Fig. III.2.5. Economic result (EUR). An intensive exploitation satisfying a higher demand (scenario 3) yields a higher result. In this case, the quota being reached before the end of the 5–yrs periods, there is however a stagnation period of about 15 months at the end of each period.

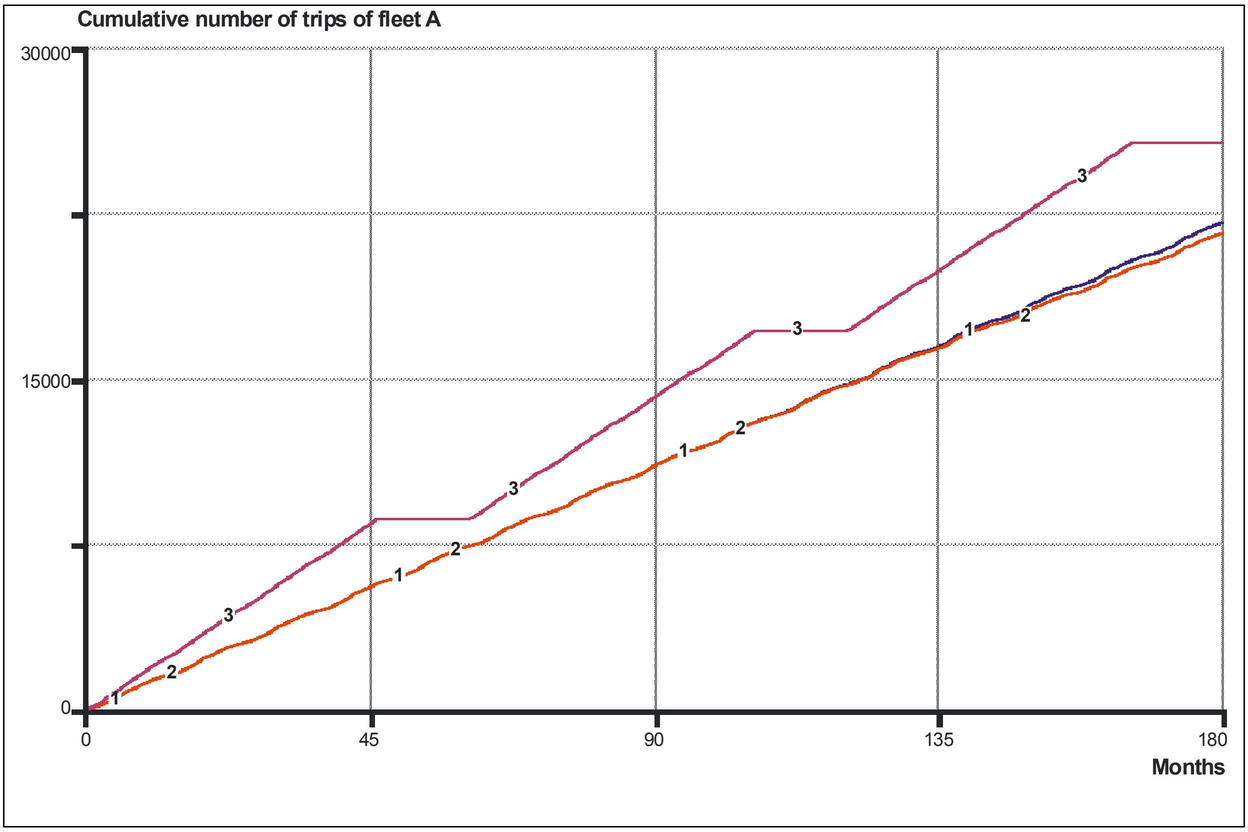


Fig. III.2.6. Cumulative number of trips of fleet "A".

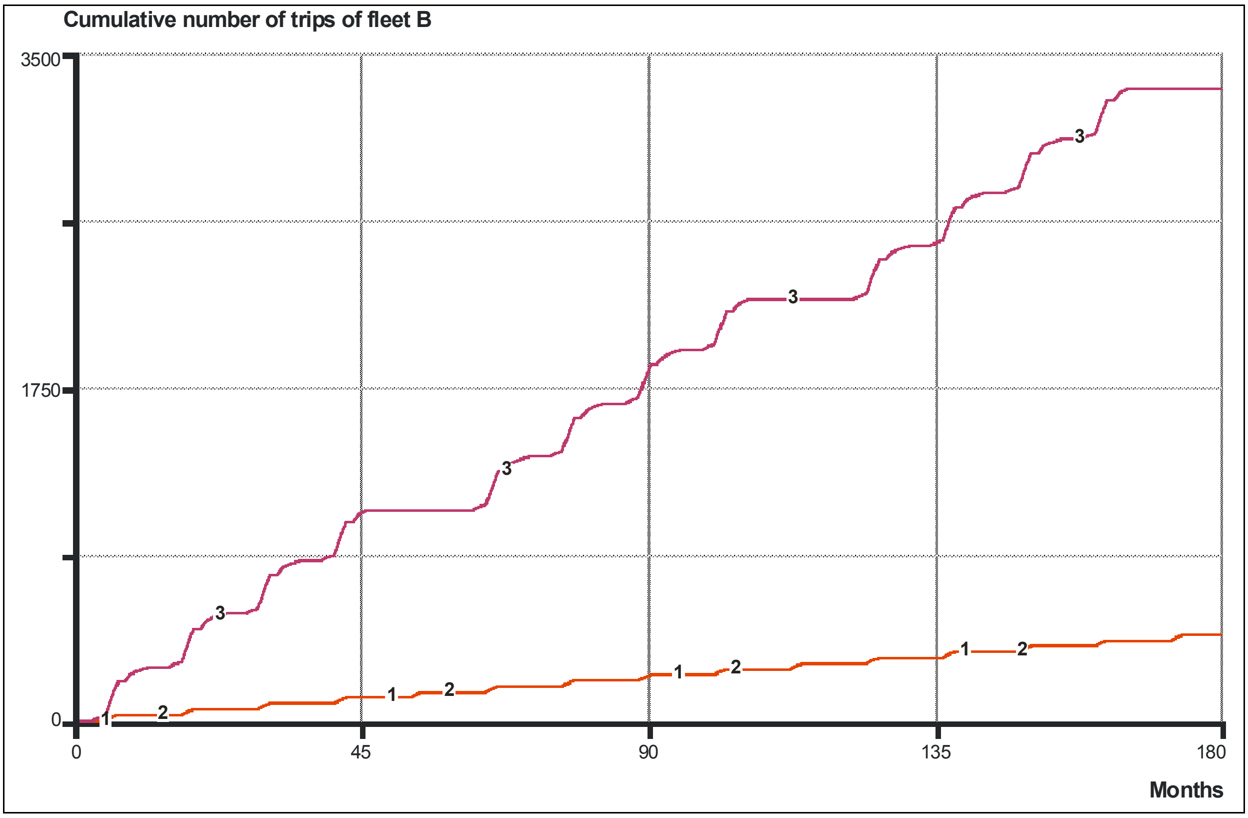


Fig. III.2.7. Cumulative number of trips of fleet "B". To be compared to the previous figure (note the different scales). In case of scenario's 1 and 2, fleet "A" is most of the time able to satisfy the demand. In the third scenario, the demand is such that vessels of fleet "B" are activated much more often.

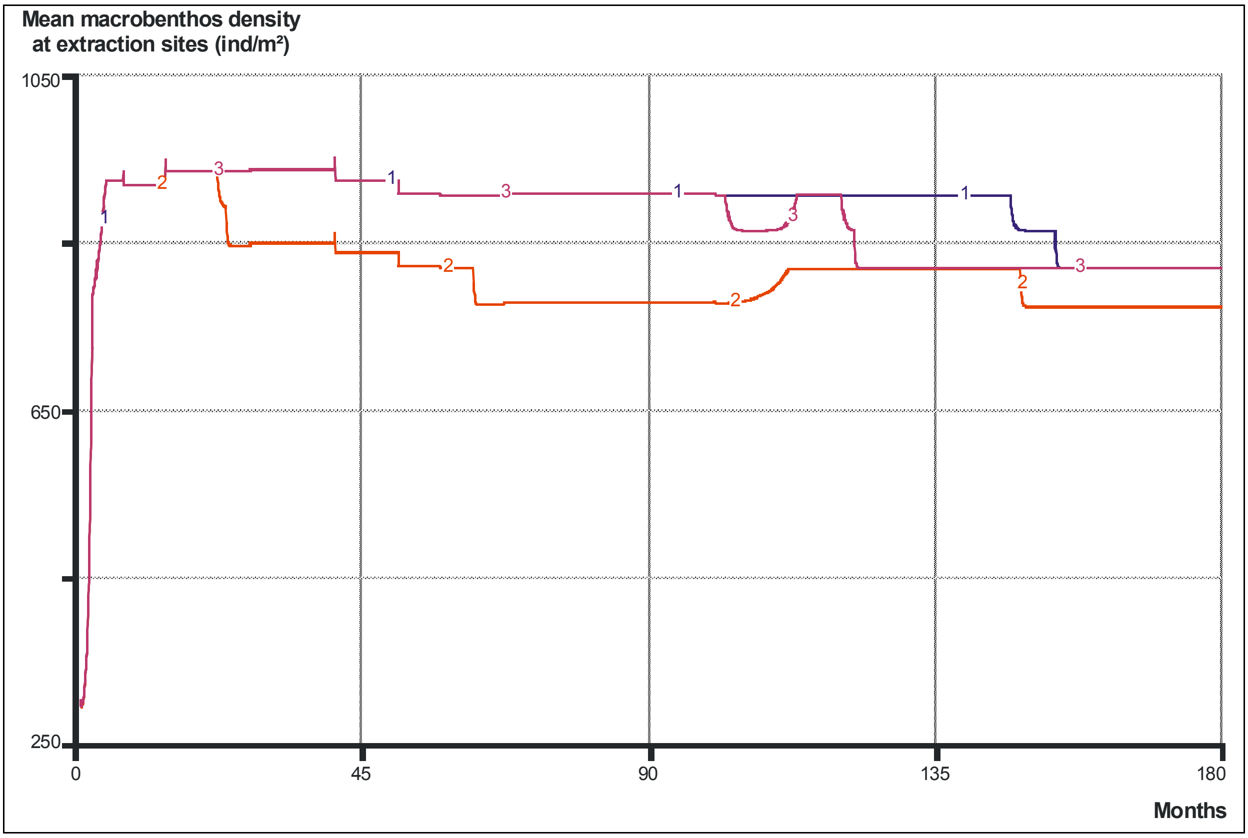


Fig. III.2.8. Mean macrobenthos density at extraction site.

The model for Sand & Gravel extraction seems to qualitatively behave as intuitively expected for the "driving forces" and the "socio-economics" sub-models. For the environmental component, where the intuition is of little help, it is difficult to assess how much realistic are the results.

1.3.2 shrimp fisheries

In the case of the shrimp fishery model, the second and third scenario's were indistinguishable from each other in terms of results. We therefore also simulated the case were the population of shrimps doubles and so does the fishing effort (see Table III.2.3). Fig. III.2.9 shows the variation in the total landings (in tons), Fig. II.2.10 the evolution of the economic result (€), Fig. III.2.11the evolution of the ratio "economic results vs. costs" and, finally, Fig. III.2.12 shows the effect of the various scenarios on the macrobenthic population.

Table III.2.9. The four different scenario's for the shrimp fisheries model. The labels of the curves in the next figures correspond to the numbers of the scenario's.

	Present density of shrimps	**Twice as much shrimps**
Present intensity of fishing effort	Scenario 1 B.A.U.	Scenario 2
Twice as much fishing effort	Scenario 3	Scenario 4

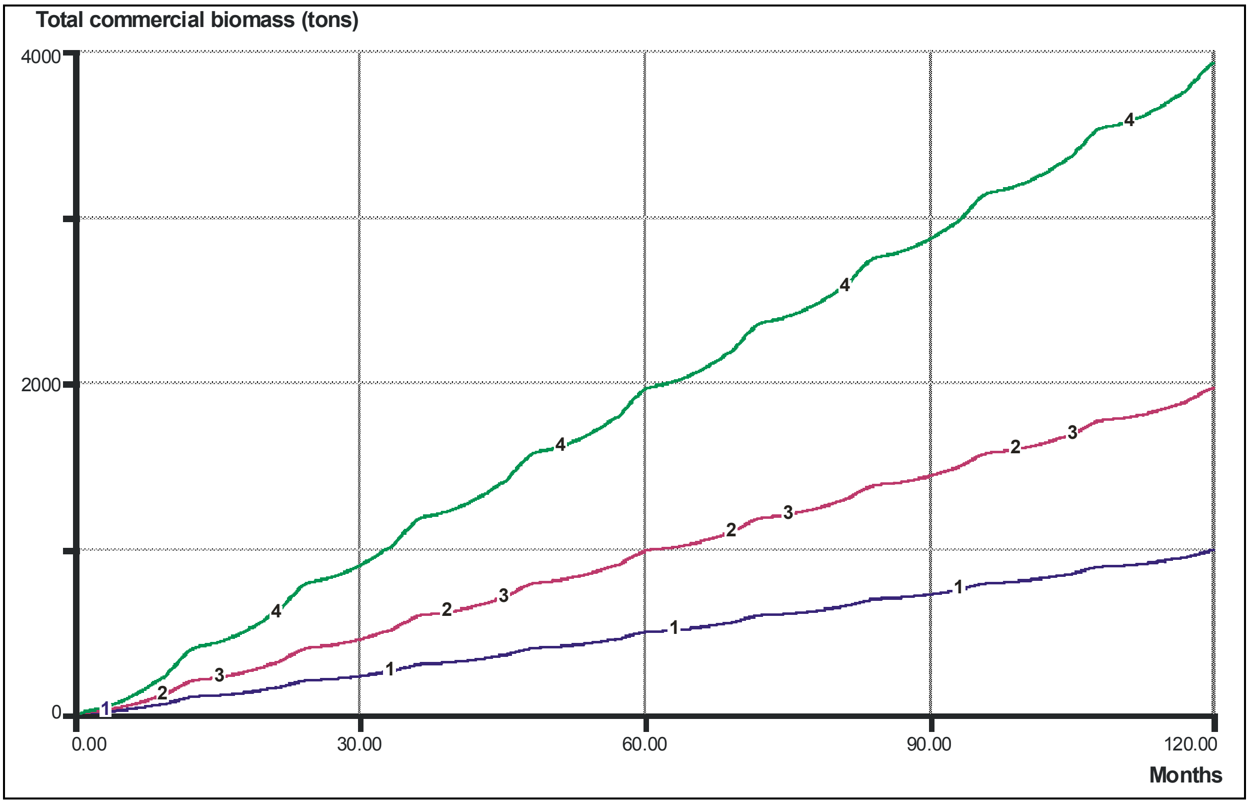


Fig. III.2.9. Evolution of the total landings (tons).

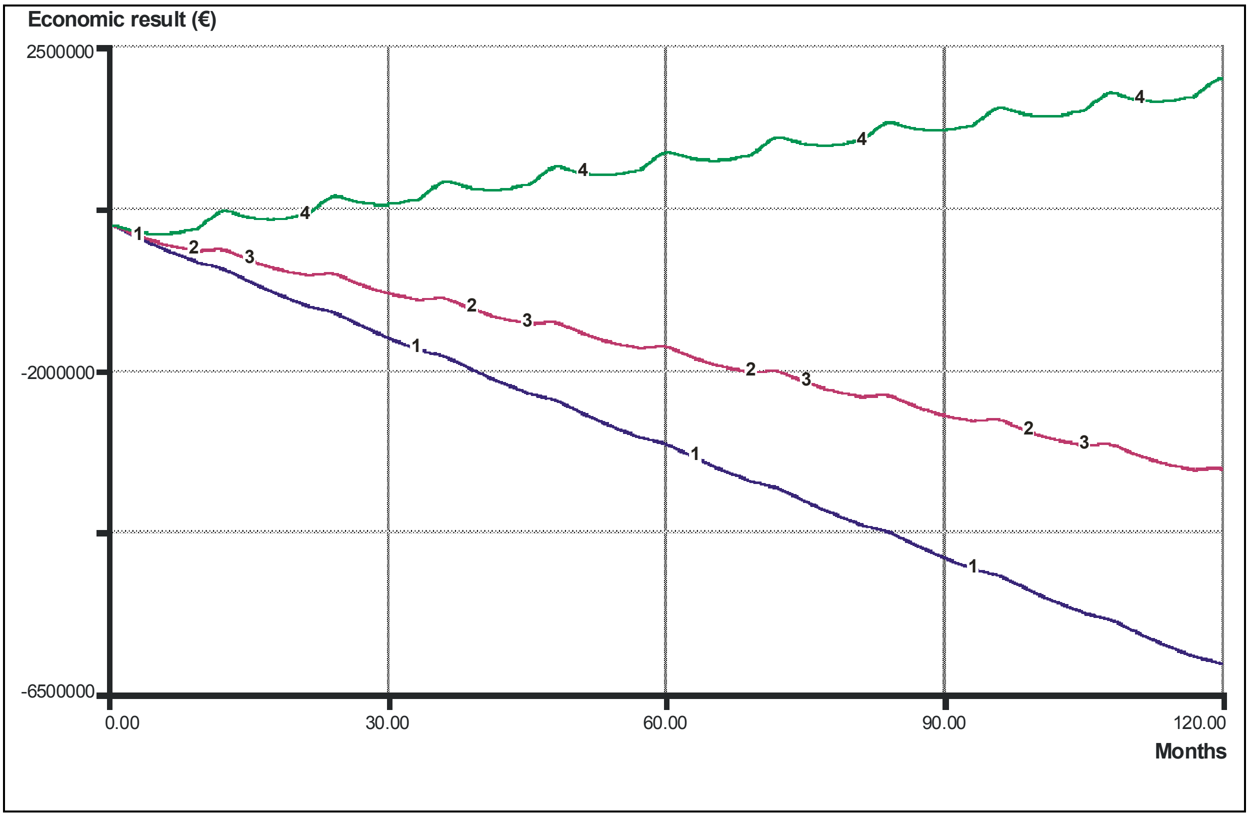


Fig. III.2.10. Evolution of the economic result (EUR).

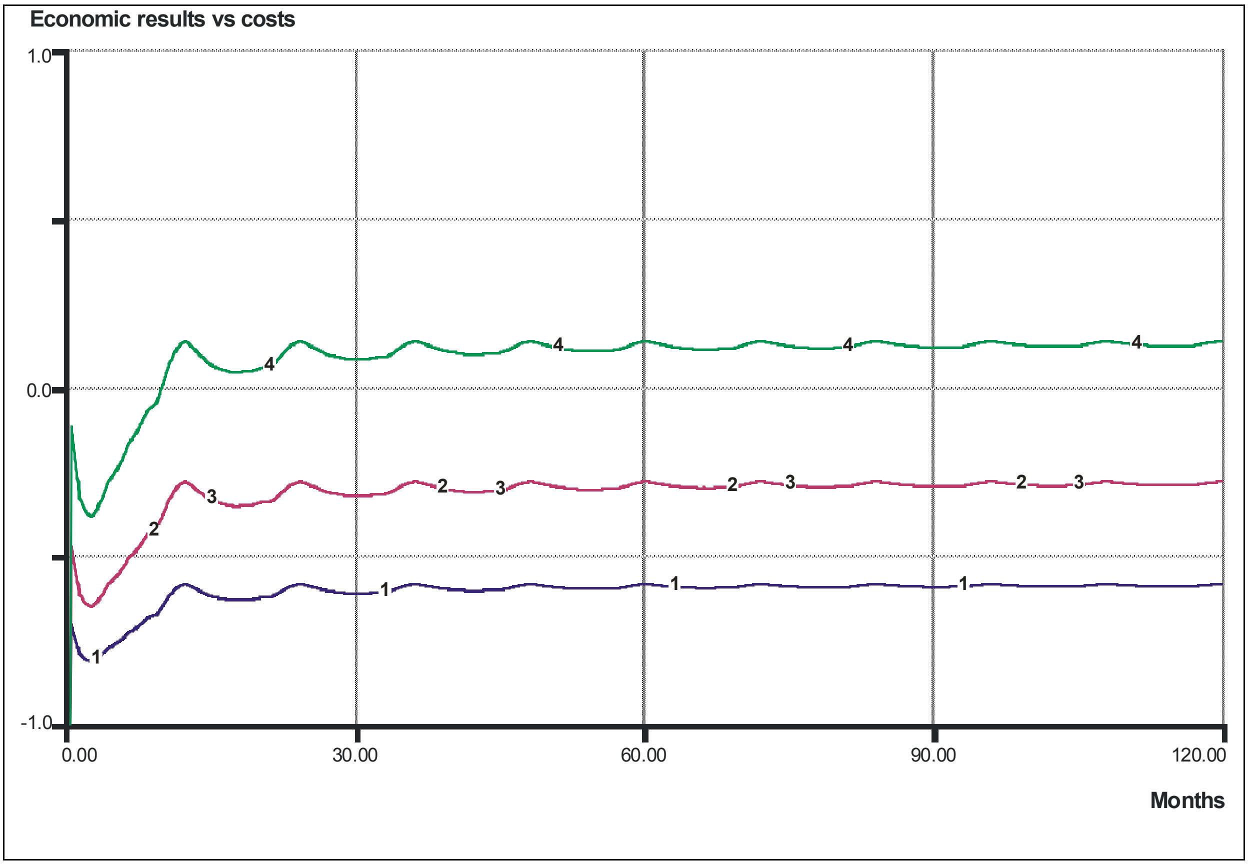


Fig. III.2.11. Evolution of the ratio "Economic results vs. costs".

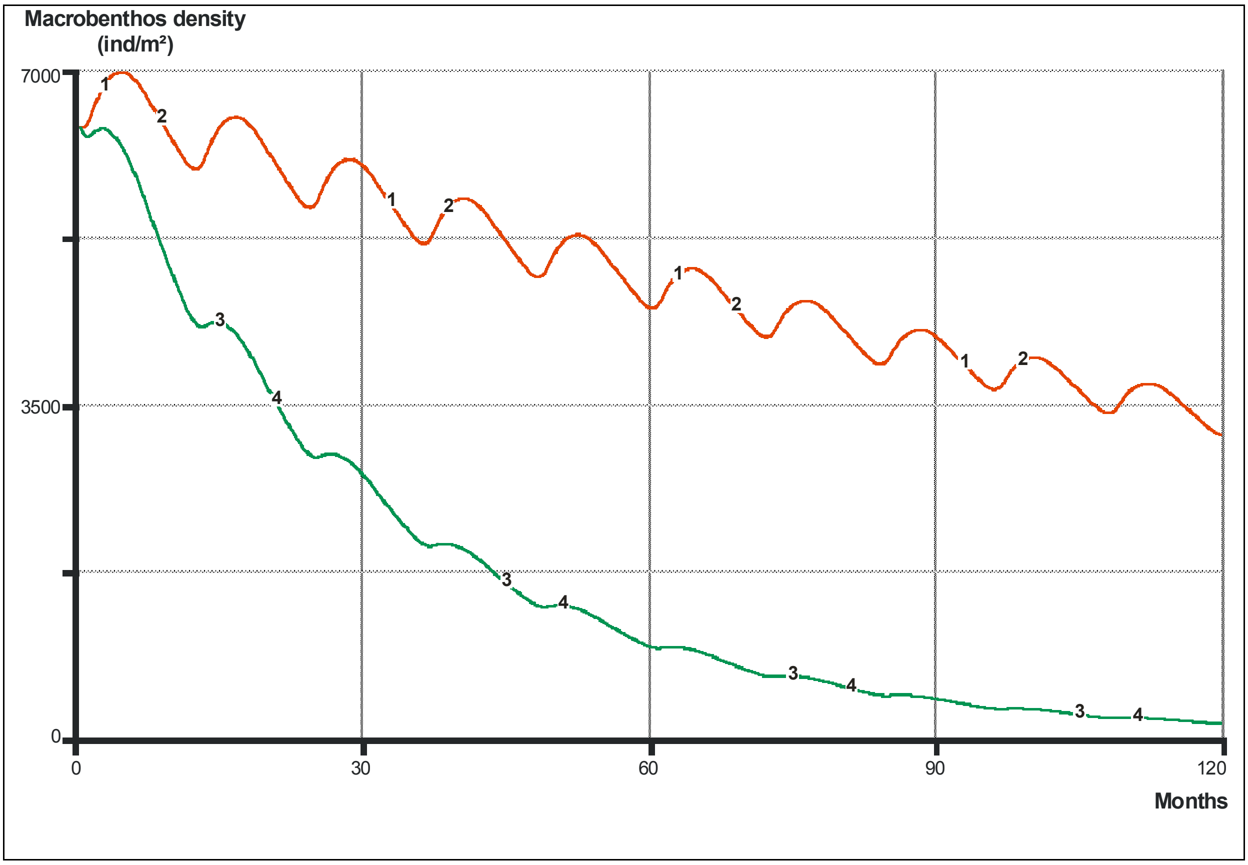


Fig. III.2.12. Evolution of the macrobenthos density.

As shown by the few outputs above, the model behaves as expected. Due to its very linear nature, doubling the fishing effort (scenario 3) or doubling the available shrimps (scenario 2) yield the same total catch. On the contrary the benthos population is only –but identically- affected in the two cases (scenario's 3 & 4) where the fishing intensity is doubled.

More unexpectedly, there is no difference in the economic result between scenario's 2 and 3. This is due to the present implementation of the variable costs of the fishing navigation. It is currently based on a static table of numbers of fishing trips per month. If possible, an objective relationship between the fishing effort and the variable costs should be implemented in a next version of the model.

SECTION FOUR

CONCLUDING REMARKS

CONCLUDING REMARKS

Globally, the importance of a more integrated approach to environmental management, involving economics, social issues (labour, …) and the ecosystem is apparent and occurs with varying degrees of legislation and commitment of government and society (Argent 2004). In Belgium, this issue has become prominent with the fifth North Sea Declaration (2002). Ministers stressed the need to establish an ecosystem based management of the North Sea in order to conserve biological diversity and ensure sustainable development. It was recognized that to achieve the latter, integration of science, environmental and socio-economic factors influencing the functioning of the North Sea ecosystems are essential. Various research activities in the Belgium part of the North Sea identified ecological indicators without any link to the socio-economical indicators or vice versa. The absence of accepted systems and techniques for integrating, weighing and balancing social, economic and ecological indicators related to the North Sea ecosystem was seen as an important lacuna, and the trigger to set-up the BALANS research.

BALANS is a project that attempts to bridge the gap between scientific data, information and application of knowledge in support of a sustainable management of the marine environment. Decision support systems (DSS) are well-known applications that provide support of a formal type by allowing decision makers to "access" and use data and appropriate analytic models (Van Buuren *et al*. 2002). It is the task of scientists from both the natural and social sciences to come together and integrate their knowledge towards this goal. In BALANS, the partners teaming together belong to different disciplines covering socio-economics, ecology, modelling and fisheries. The expectations for developing a decision support tool within the BALANS project was to provide end-users and decision makers involved in shrimp fisheries and sand and gravel exploitation with a guided approach to decision making and ultimately sustainable use of the marine resources. While the "tool" developed from BALANS may not be a definitive decision support system, it should be seen as a tool that generates a thinking process for users.

The BALANS research experiences of the interdisciplinary team resulted in several positive experiences:

- BALANS provides a basic methodology that can be further developed and extended to the other activities of the BPNS.
- BALANS delivers an operational tool that is useful for educational and communication purposes and for gaining insight into the factors influencing the impacts of the selected activities.
- In regards to recommendations on model improvements BALANS revealed that with the addition of good and detailed data (input from users) in the future, components of the models can be improved and issues such as flexibility of the user interface can be further explored.
- As a result of the initial survey of data availability, BALANS revealed that the resource of fisheries knowledge for the Belgian fisheries was not adequate. As

a result, the modelling of fisheries component was limited to the Belgian shrimp fishery.

The main output of BALANS is a tool that users can play with to improve the understanding of the activity to manage and the effects of policy choices on sustainable management. Some limitations of the tool are inherently linked to the embryonic stage of the development of instruments for mapping Belgian North Sea activities. However, BALANS proved a valuable exercise from which researchers have identified data and knowledge gaps and new research needs. BALANS has opened the path to further development of complete decision support tools covering more marine activities. At the same time, the tool resulting from BALANS is operational in the sense that decision makers and coastal managers might use it to become better informed and acquainted with the underlying relationship, interests, indicators, etc. of the environment and activities without resulting in immediately applicable and clear-cut instructions for policy and management options.

Most of the time, models as the ones developed in BALANS do more fit to reality qualitatively than quantitatively. They reflect the general behaviour of a system, not its various states in accurate details, largely because lacking data must be substituted by best estimates, poorly known processes by first order relationships, etc. However, a qualitative approach is what a policy maker needs in first instance. When the model represents correctly the qualitative evolution of a system under a given set of constraints, it is valid to compare the various sets of results corresponding to various sets of input data.

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