Assessing sediment hazard through a Weight Of Evidence approach: a practical model to elaborate data from sediment chemistry, bioavailability, biomarkers and bioassays

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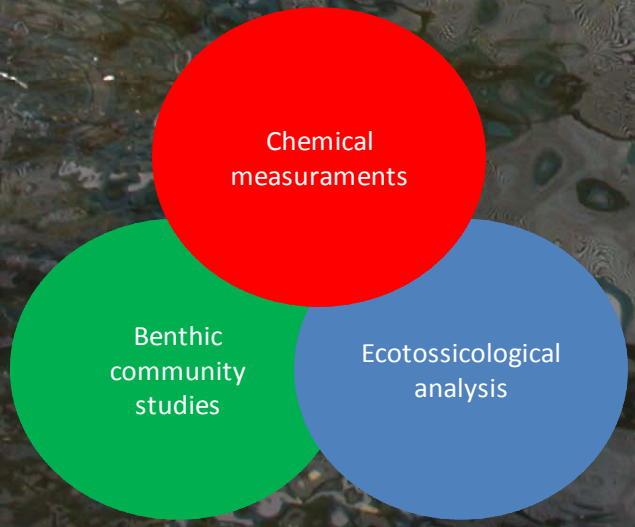
Chemical analyses
Bioavailability of chemicals
Biological Early warnings (biomarkers)
Toxicological Bioassays
Ecological analyses (population, community biodiversity...)
Human Health
Sediment Quality Assessment
Integrated environmental management

Questions to solve related to:

1. Interpretation and significance of results
2. Indices and scales development
3. Synthetic integration of different kinds of results

Chemical analysis	Ecotoxicological studies	Ecological studies	Conclusions
+	+	+	Evident loss of environmental quality caused by contamination.
-	-	-	Evident lack of environmental contamination.
+	-	-	Presence of non-bioavailable contaminants.
-	+	-	Presence of conditions or contaminants that have not been analysed that could cause potential loss of environmental quality.
-	-	+	Ecological alteration not caused by the toxicity of pollutants.
+	+	-	The toxicity of the pollutants is the cause of environmental stress.
-	+	+	Loss of environmental quality caused by contaminants that have not been analysed.
+	-	+	Contaminants are not bioavailable or the ecological alterations are not due to the toxicity of pollutants.



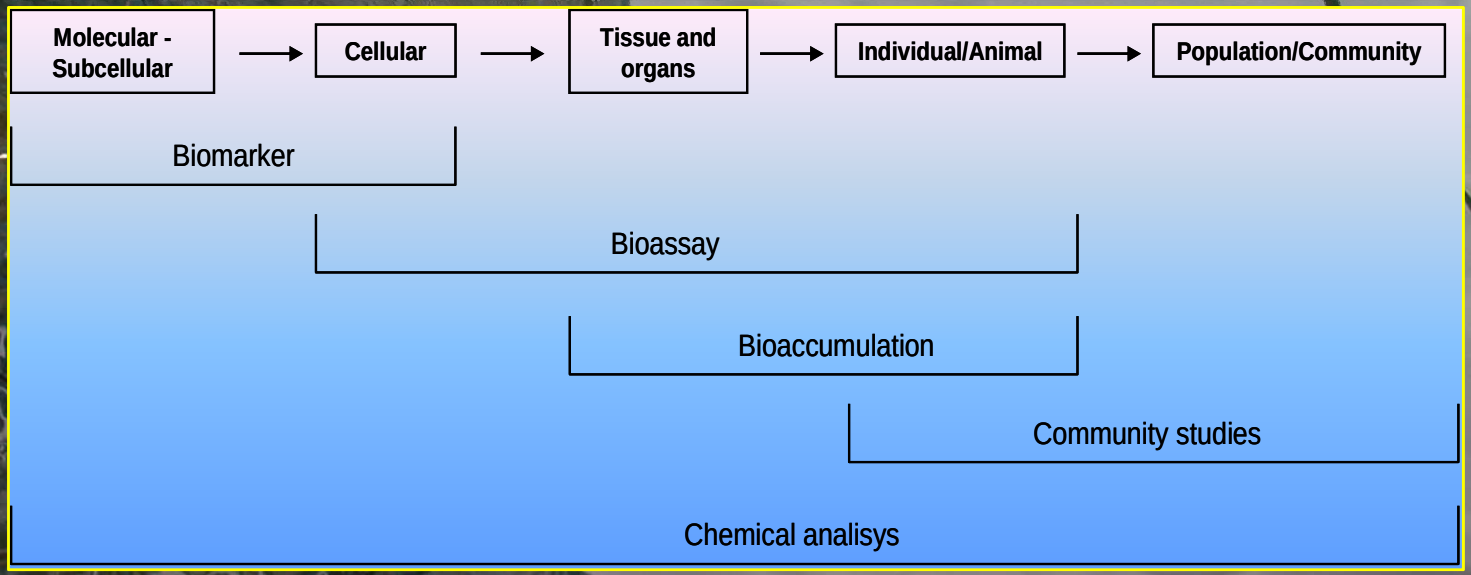
General structure of the Triad approach

This approach combines three types of analysis, referred to as *lines of evidence* (LOE):

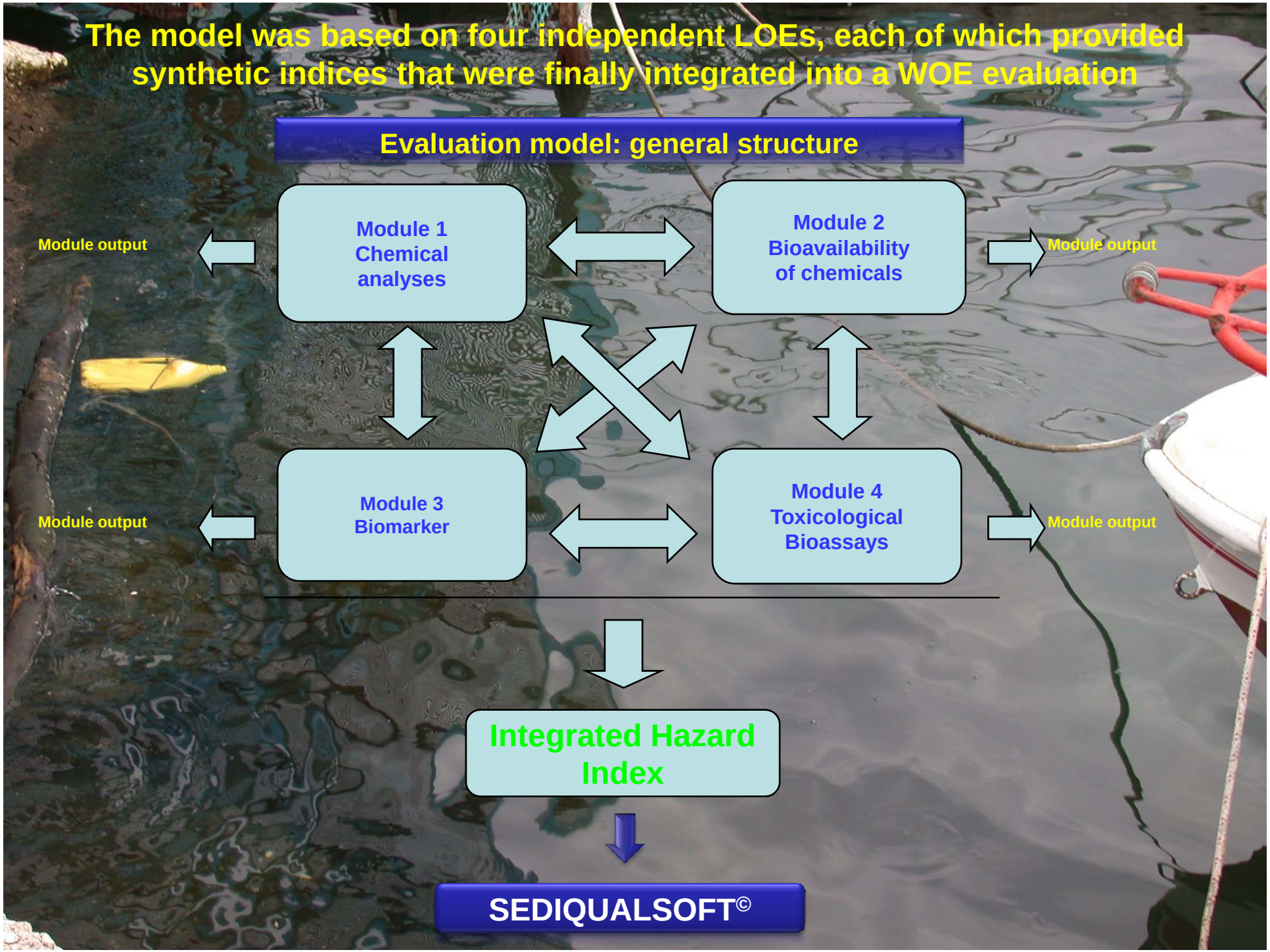
- **LOE 1**: *Chemical analysis*, to determine the level of contamination;
- **LOE 2**: *Ecotoxicological analysis*, to measure the toxicity of the sediment as a whole;
- **LOE 3**: *Ecological analysis* (benthic ecology), i.e. the analysis of the structure of benthic communities to identify changes at the biological level.

A multidisciplinary and integrated Multiple Lines of Evidence Approach (MLEA) is widely used in recent years to assess sediment quality around the world

Through the use of MLEA it is possible to quantify pollutant effects at different levels of biological organisation



The model was based on four independent LOEs, each of which provided synthetic indices that were finally integrated into a WOE evaluation



Module 1- Chemical analyses of sediments

Chemical

START

For each submitted value

(1) Data accuracy control → no → MSG

yes

(2) if reference value(i) exists

(3) $$RTR(i) = \frac{measured\ value(i)}{reference\ value(i)}$$

(4) $$RTR_W(i) = RTR(i) \cdot weight(i)$$

(5) $$HQ_C = \frac{\sum_{j=1}^{N} RTR_W(j)_{RTR(j)\leq 1}}{N} + \sum_{k=1}^{M} RTR_W(k)_{RTR(k)>1}$$

(6)

HQ_C value		Class of chemical hazard
0 to < 0.7	→	Absent
0.7 to <1.3	→	Negligible
1.3 to <2.6	→	Slight
2.6 to <6.5	→	Moderate
6.5 to <13	→	Major
≥ 13	→	Severe

MAIN TOPICS

- Selection of chemical reference values (SQG, national and international legislations)
- Selection of 115 analytes (with reference values)
- Calculation of *Ratio To Reference* (RTR)
- Weighting to each RTR in function of the environmental and toxicological significance of the contaminant, according to 105/2008/EC for the 105 *Hazardous substances*
- Calculation of cumulative chemical Hazard Quotient (HQc)
- Assignment to one of 6 classes of chemical hazard

Module 1- Model out put for sediment chemistry data processing

Tab_misure

Chemical characterization

Area name: Fosso Conocchio
Note:
Latitude:
Longitude:
Site code: Ramo A
Core code: H2
Core level: 1
Sample code:
Sampling code:
Sampling date: 03/03/2008

Process and save
Clean record
Import from Excel

Unit measures to be used:
- Grain size: %
- Heavy metals and trace elements: mg/Kg (d.wt.)
- Organic compounds: mg/Kg (d.wt.)
- Radionuclides: Bq/g (d.wt.)

Concerning ERM, ERL, SL ANZECC 09 and SQHV ANZECC 09 organic compounds have to normalized to 1% of TOC.

	LCB (Pelite>10%)	LCB (Pelite<10%)	LCL	ERL	ERM	TEL	
Chemical HQ	21,98298	39,27748	9,863871	13,28911	0,3931875	19,97384	Chemical HQ
Max % contr to HQ	85,10638	83,33334	83,33334	66,66666	0	51,12782	Max % contr to HQ
N° exceeding param.	2	2	2	2	0	2	N° exceeding param.
N° param with refer.	6	6	6	6	6	6	N° param with refer.
N° analysed param.	14	14	14	14	14	14	N° analysed param.
Class of 'chemical' hazard	SEVERE	SEVERE	MAJOR	SEVERE	ABSENT	SEVERE	Class of 'chemical' hazard

	PEL	DM56/09 (SQA)	SL ANZECC 09	SQHV ANZECC 09	Col A (Dlg.vo_152/06)	Col B (Dlg.vo_152/06)	
Chemical HQ	3,5511	26,3968	13,27825	0,3397013	3,555909	0,1093271	Chemical HQ
Max % contr to HQ	54,74643	83,33333	66,66666	0	100	0	Max % contr to HQ
N° exceeding param.	2	2	2	0	1	0	N° exceeding param.
N° param with refer.	6	6	7	7	7	7	N° param with refer.
N° analysed param.	14	14	14	14	14	14	N° analysed param.
Class of 'chemical' hazard	MODERATE	SEVERE	SEVERE	ABSENT	MODERATE	ABSENT	Class of 'chemical' hazard

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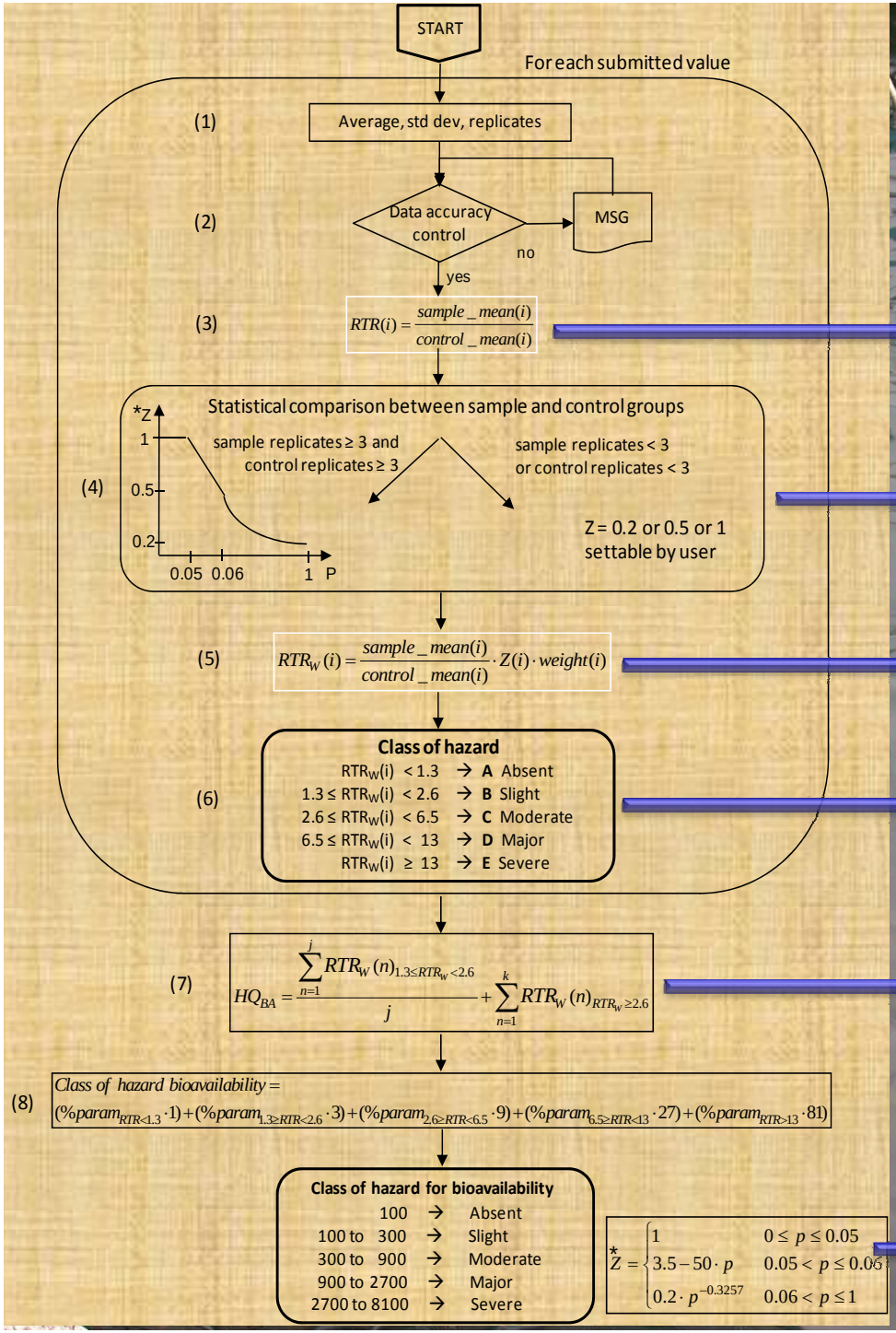
- HQ value;
- Maximum % contribution given to HQ by a single analyte;
- n. parameters exceeding the reference;
- n. parameters with a reference;
- n. analyzed parameters;
- class of chemical hazard



Module 2- Bioavailability

MAIN TOPICS

- Selection of species, tissue/organ, experimental conditions, time exposure
- Calculation of *Ratio To Reference* (RTR)
- Correction with regards to statistical significance
- Weighting to each RTR in function of the environmental and toxicological significance of the contaminant (like Module 1)
- Assignment of each parameter to one of 5 classes of chemical hazard (expert judgement)
- Calculation of cumulative Hazard Quotient (HQ_{BA})
- Assignment of Hazard of bioavalability to one of 5 classes

Module 2- Model out put for bioavailability data processing

Mas_biodisp_riassuntiva

Tab_biodisp_riassuntiva

Bioavailability

ID:	4509
Area name:	Sedimento industriale
Site code:	exp1
Sampling code:	K37
Sample code:	d
Species:	Anguilla_anguilla
Tissue / organ:	Gills
Experimental condition:	laboratory_sediment
Control / exposed:	Exposed

N° param in class 1 (hazard ABSENT)	11
N° param in class 2 (hazard SLIGHT)	4
N° param in class 3 (hazard MODERATE)	3
N° param in class 4 (hazard MAJOR)	4
N° param in class 5 (hazard SEVERE)	4
Bioavailability HQ	145,5523
Level of hazard for bioavailability	MAJOR

Process 1 Process 2

-n. of parameters in each of the 5 classes of hazard
- cumulative HQ value
- class of hazard for bioavailability

ID	Area name	Site code	Sampling	Sample	Species	Tissue / orga	Experimenta	Control / expose
4499	Marina dorica	pontile interno	K37		Mytilus_galloprovincialis	Gills	Transplanted	Reference area
4501	Marina dorica	pontile interno	K37	b	Mytilus_galloprovincialis	Gills	Transplanted	Investigated area
4503	sito_controllo_A	b	K37		Mytilus_galloprovincialis	Gills	Transplanted	Reference area
4505	Marina dorica	pontile interno	K37	g	Mytilus_galloprovincialis	Liver_dig gland	Transplanted	Investigated area
4507	sito_controllo_A	d	K37		Mytilus_galloprovincialis	Liver_dig gland	Transplanted	Reference area
4509	Sedimento industriale	exp1	K37	d	Anguilla_anguilla			
4511	sed_controllo_B	a	K37		Anguilla_anguilla			
4513	Sedimento industriale	exp1	K37	d	Mullus_spp			
4515	sed_controllo_B	a	K37		Mullus_spp			
4517	Sedimento industriale	exp1	K37		Mullus_spp			
4519					Mullus_spp			
4521					Mytilus_galloprovincialis			
4523					Mytilus_galloprovincialis			
4525					Mytilus_galloprovincialis			

Record:

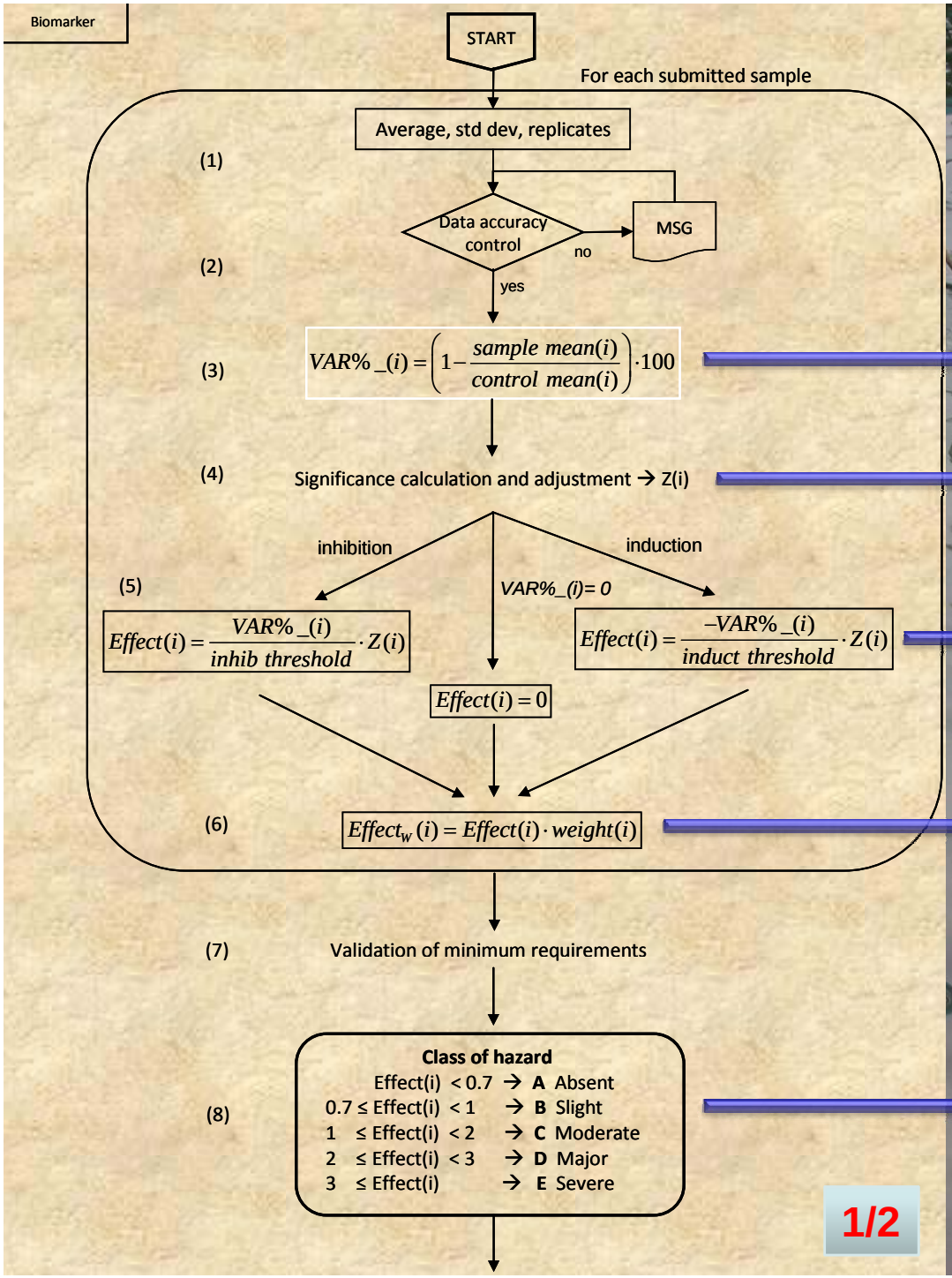
- wild specimens
- caged organism
- laboratory exposure

Mytilus galloprovincialis

Tapes philippinarum

Hediste diversicolor

Anguilla anguilla



Module 3- Biomarker (1/2)

MAIN TOPICS

- Selection of species, biomarker, tissue/organ, experimental condition
- Calculation of variation (%) vs. control
- Correction with regards to statistical significance
- Calculation of effect variation (%) vs. specific threshold
- Correction of effect with the specific weight
- Assignment of Hazard of Biomarker to one of 5 classes

Module 3- Biomarker (2/2)

MAIN TOPICS

(9)

$$HQ_{BM} = \left(\frac{\sum_{j=1}^{N} Effect_W(j)_{1<Effect(j)\leq 2}}{num\ biomark_{1<Effect(j)\leq 2}} + \sum_{k=1}^{M} Effect_W(k)_{Effect(j)>2} \right)$$

Calculation of HQ_{BM} of Battery of Biomarker

(10)

$$\text{Class of hazard for biomarkers} = (\%biomark_{Effect<0.7} \cdot 0.7) + (\%biomark_{0.7>Effect<1} \cdot 1) + (\%biomark_{1>Effect<2} \cdot 2) + | (\%biomark_{2\geq Effect<3} \cdot 4) | (\%biomark_{Effect\geq 3} \cdot 8)$$

(11)

Class of hazard bioamarker

< 70	→	Absent
≥ 70 to < 100	→	Slight
≥ 100 to < 200	→	Moderate
≥ 200 to < 400	→	Major
≥ 400 to ≤ 800	→	Severe

Assignment of Hazard of battery of biomarker to one of 5 classes

2/2

Module 3- Model out put for biomarker data processing

Mas_biomarker

Tab_biomarker

ID:	65
Area name:	Marina dorica
Site code:	K37
Sample code:	A1
Sampling date:	25/02/2008
Exposure time:	4 weeks
Note:	
Latitude:	
Longitude:	

Species:	Anguilla_anguilla
Tissue:	bile
Experimental_condition:	Transplanted

Mean sample	7,15
St. Dev. sample	
n value sample	
Mean contro	7,72
St. Dev.	6,24
n value control	5

RESULTS

	Weighted mean	n° biomarker
Class A	0,2350914	10
Class B	0	0
Class C	1,512854	3
Class D	2,842105	1
Class E	3,34	1
HQ	7,702708	MODERATE

PROCESS

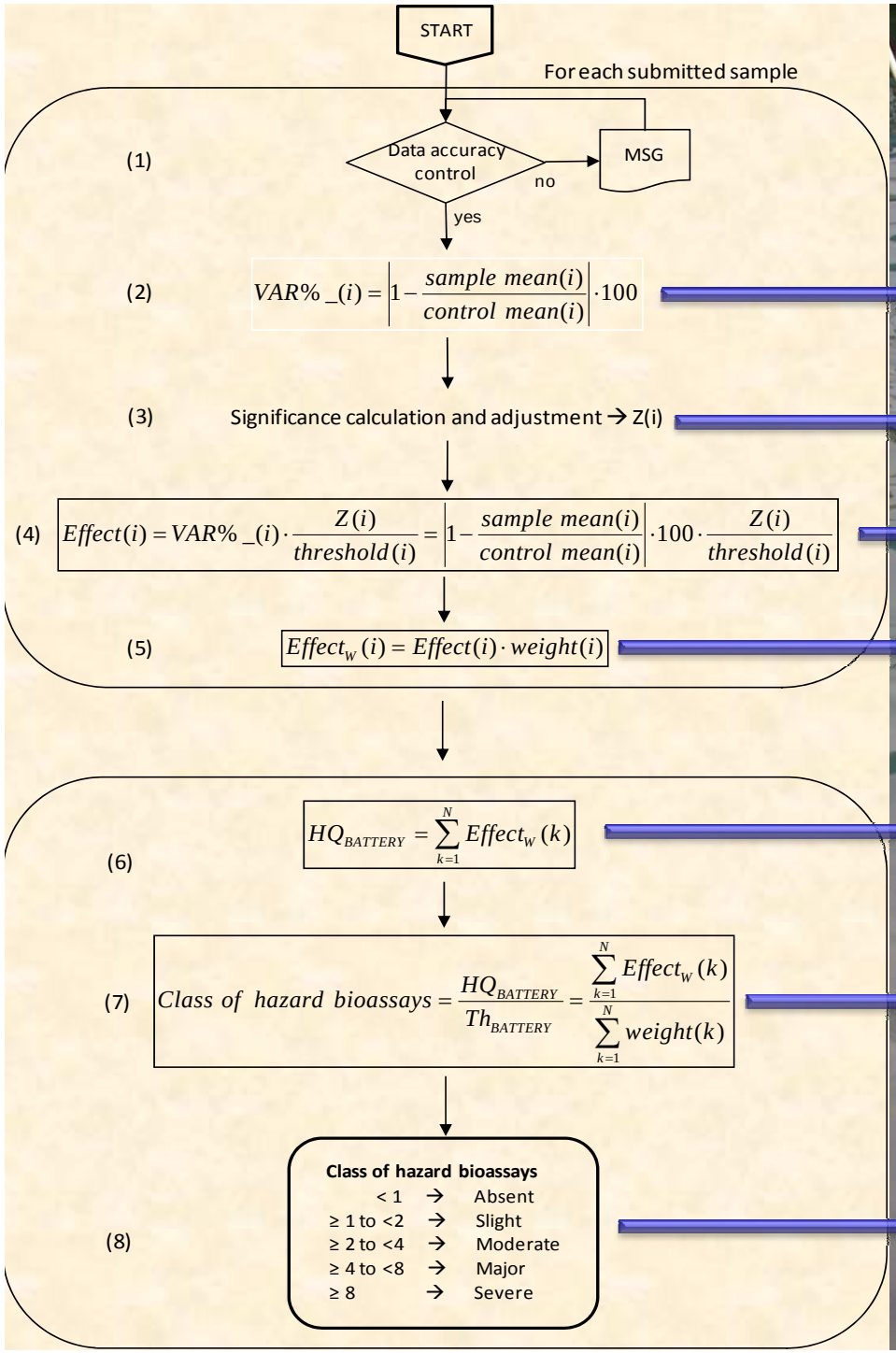
Species	Tissue	Experimental_cond	Biomarker	Mean san	St. Dev. s	n vali	Mean cor	St. Dev. c
Anguilla_anguilla	liver_dig gland	Transplanted	TOSCA_peroxyl_radicals	261,08	91,6	5	277,7	55,43
Anguilla_anguilla	liver_dig gland	Transplanted	TOSCA_hydroxyl_radicals	393,55	135,17	5	284,09	52,25
Anguilla_anguilla	liver_dig gland	Transplanted	Acetylcholinesterase	55,05	3,15	5	40,76	16,9
Anguilla_anguilla	liver_dig gland	Transplanted	Metallothioneins	16,77	9,55	5	18,76	8,9
Anguilla_anguilla	liver_dig gland	Transplanted	EROD	28,3	9,36	5	9,43	3,33
Anguilla_anguilla	liver_dig gland	Transplanted	Lysosomal_stability_LEI	15	3,54	5	28,5	3
Anguilla_anguilla	bile	Transplanted	Metabolites_nap	7,15	2,46	5	7,72	6,24
	bile		Metabolites_pyr	8,9	2,06	5	7,27	2,31
	bile		Metabolites_BaP	22,14	6	5	24,17	10
Anguilla_anguilla	liver_dig		Antioxidants_Glutathione_reductase	14,9	2,7	5	18,38	3,24

Record: 45 di 48 | Nessun filtro | Cerca

- test-specie selection;
-Tissue selection;
-- experimental condition selection

-n. of biomarker in each of 5 classes of hazard;
- cumulative Hazard for biomarkers

Module 4 - Bioassays



MAIN TOPICS

- Selection of species, end-point, matrices
- Calculation of variation (%) vs. control (Abbott)
- Correction with regards to statistical significance
- Calculation of effect variation (%) vs. specific threshold
- Effect weighting in function of endpoint, threshold and matrix
- Calculation of Hazard Quotient of the battery
- Calculation of class of Hazard of battery vs. cumulative threshold of battery
- Assignment of Hazard of battery of bioassays to one of 5 classes

Module 4- Model out put for bioassays data processing

Mas_saggi_biologici

Bioassays

ID:	26	Species:	Balanus_amphitrite
Area name:	Fosso Conocchio	Exposure time:	Acute
Site code:	Sponda Nord	Matrix:	Interstitial water
Sample code:	A1	Endpoint:	mortality
Latitude:		Control mean:	0,3164557
Longitude:		Control Std Dev:	1,5822
Core code:		n value control:	3
Core level:		Exposed mean:	0,0427899
Sampling code:		Exposed Std Dev:	0,0770416
Sampling date:		n value exposed:	2
Note:			

PROCESS

SINGLE BIOASSAY RESULTS

Effect percentage	86,47839
Specific HQ	0,7509657
Specific threshold	2,4

BATTERY BIOASSAYS RESULTS

n° bioassays	4
Cumulative HQ	33,35121
Battery threshold	7,3
Class of hazard for bioassays	MAJOR

Area name	Site code	Sample cod	Species	Exposure t	Matrix	Endpoint	Control me	Control St	n value cc
Fosso Conocchio	Sponda Nord	A1	Balanus_amphit	Acute	Interstitial water	mortality	0,3164557	1,5822	3
Fosso Conocchio	Sponda Nord	H43	Balanus_amphit	Acute	Centrifuged sediment	mortality	100	6	3
Fosso Conocchio	Sponda Nord	K37	Vibrio_fischeri	Acute	Elutriate	bioluminesc	100	0	3
Fosso Conocchio	Sponda Nord	A2	Vibrio_fischeri	Acute	Whole sediment	bioluminesc	100	0	3
M	1a	AS2	Vibrio_fischeri	Acute	Water column	bioluminesc	0,3355705	1,67785	3
M	1a		Artemia_salina	Acute	Interstitial water	mortality	100	6	3
M	1a		Brachionus_plic	Acute	Interstitial water	mortality	100	8	3
Marina dorica	1a		Tigriopus_fulv	Chronic	Water column	growth	100	0	3
			Phaeodactylu	Chronic	Elutriate	growth	100	5	3
			Dunaliella_tertic	Chronic	Elutriate	growth	100	5	3
			Vibrio_fischeri	Acute	Elutriate	bioluminesc	111,8	2,49	5

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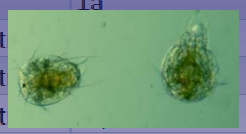
- test-specie selection;
-Tissue selection;
-- experimental condition selection



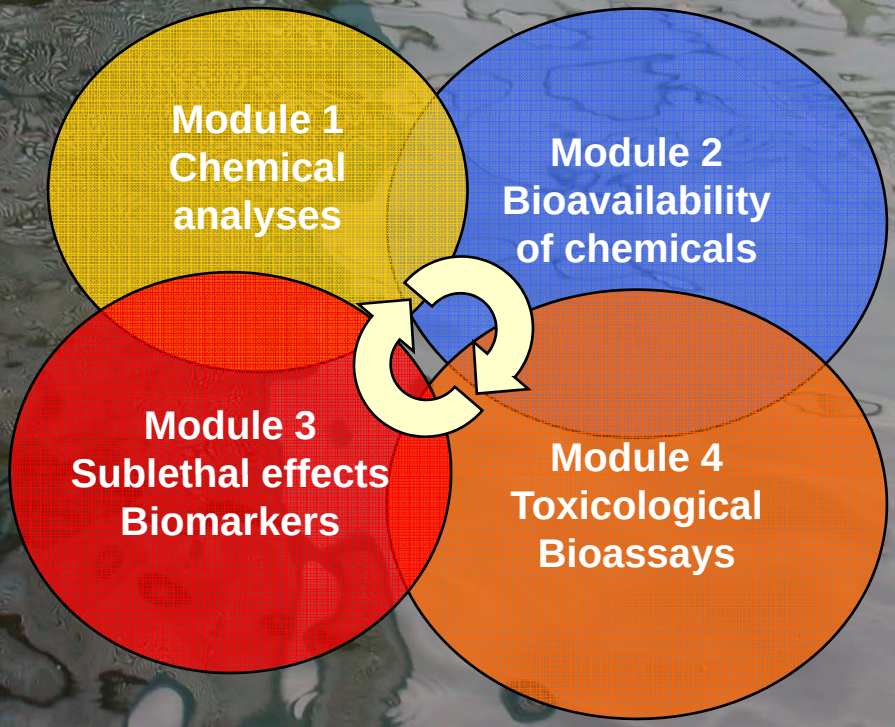




FOR EACH BIOASSAY
-% of effect;
- specific HQ;
- specific threshold;

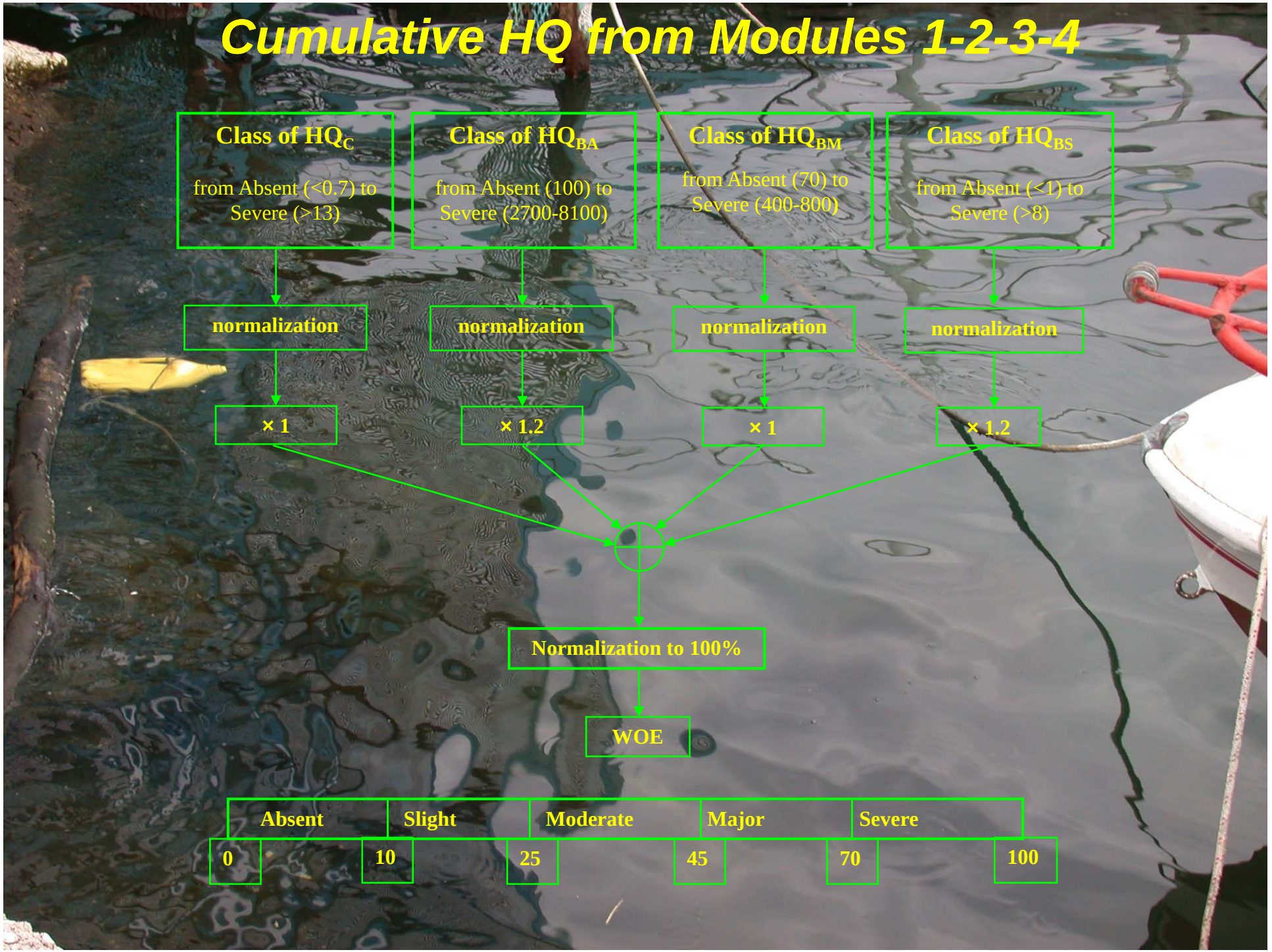
FOR THE BATTERY
- n. endpoint;
- cumulative HQ;
-- Threshold of battery;
- Class of hazard

Cumulative HQ from Modules 1-2-3-4

TRIAD-like approach



Cumulative HQ from Modules 1-2-3-4



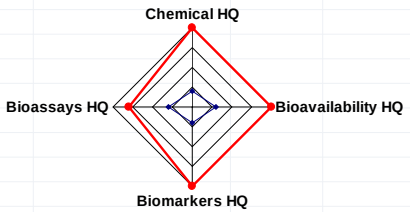
Model output for the WOE integration of data from the multiple LOEs

Mas_riassuntiva

Tab_riassuntiva

Area name:	Sedimento industriale
Site code:	exp1
Chemical HQ:	SEVERE
Bioavailability HQ:	SEVERE
Biomarker HQ:	SEVERE
Bioassay HQ:	MAJOR
Total HQ:	SEVERE

ID	Area name	Site code	Chemical	Bioavailat	Biomarke	Bioassay	Total HQ
86	Sedimento industriale	exp1	SEVERE	MAJOR	SEVERE	MAJOR	SEVERE
87	Sedimento industriale	exp1	SEVERE	SEVERE	SEVERE	MAJOR	SEVERE
* (Nuovo)							



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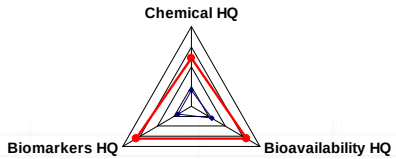
Mas_riassuntiva

Tab_riassuntiva

Area name:	Fosso Conocchio
Site code:	Fosso Conocchio
Chemical HQ:	MODERATE
Bioavailability HQ:	MAJOR
Biomarker HQ:	MAJOR
Bioassay HQ:	
Total HQ:	MAJOR

ID	Area name	Site code	Chemical HQ	Bioavailability HQ	Biomarker HC	Bioassay I	Total HQ
131	Fosso Conocchio	Fosso Conocchio	MODERATE	MAJOR	MAJOR		MAJOR
132	Fosso Conocchio	Fosso Conocchio	MODERATE	MODERATE	MAJOR		MAJOR
(Nuovo)							



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Conclusions and perspectives

- *The model is versatile, easy to update or adapt to local or national specificities*
- *Modules can be used singularly or in an integrative approach*
- *Elevated sensibility and capability to discriminate different condition*

- *New modules including, i.e., benthic communities and human health*
- *Useful additional tool in a more comprehensive process of risk assessment and management decisions*