Integrated methodology for the management of uncertainty in climate change adaptation policies

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Outline

1. Research topics
2. Research objectives
3. Methodology and tools
4. Application of the integrated methodological framework to the case study
5. Assessment of the outputs and uncertainty analyses
6. Discussion of the results and further research needs

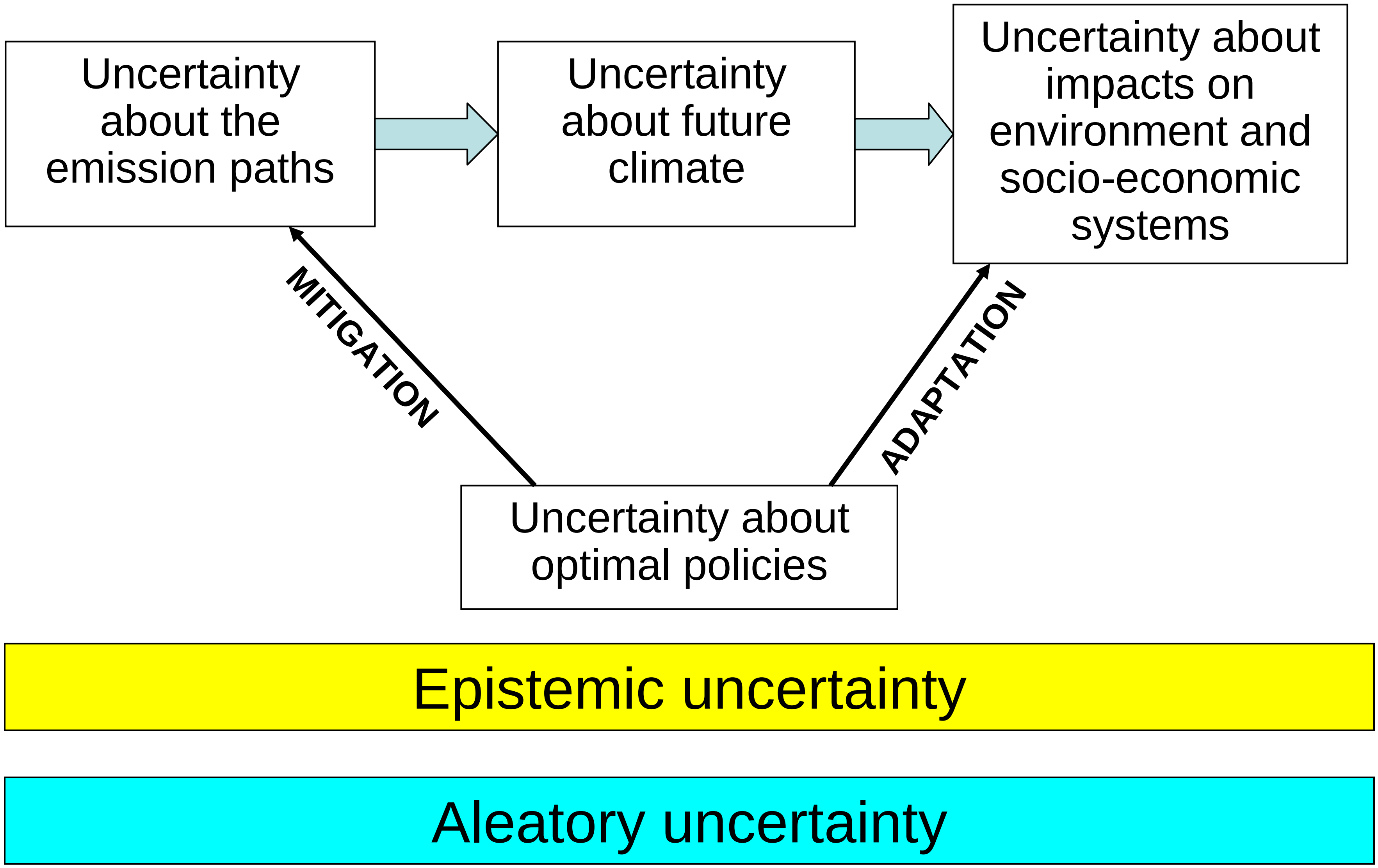
Adaptation to SLR

"*<u>Adjustment in ecological, social, or economic systems</u> in response to actual or expected climatic stimuli, and their effects or impacts. This term refers to changes in processes, practices or structures to <u>moderate or offset potential damages</u> or to <u>take advantage of opportunities</u> associated with changes in climate*" (IPCC, 2001).

"Hard" decision (Clemen and Reilly, 2001):

- Complexity of the issue;
- Multiple objectives and different perspecitives;
- Inherent uncertainty in the situation.

Uncertainty in climate change policy



Management of uncertainty

Three-step approach (Morgan, 2008)

Characterise → **Incorporate** → **Communicate**

Use of probabilities to quantitatively characterise uncertainty:

- **Frequentist approach**
- **Bayesian (Subjectivist) interpretation**

Incorporate uncertainty into the analysis of complex issues:

- **Transparent and comprehensive policy analyses**
- **Interdisciplinary approaches**

Incorporate uncertainty into the models:

- **Sensitivity analysis**
- **Uncertainty propagation**
- **Learning**

Informed and transparent decision making process:

- **Quali-quantitative intstruments from decision analysis (Cognitive maps; Decision trees; Influence diagrams; Bayesian networks..)**
- **Interfaces and graphical structures**

Objectives of the research

The main objective of the research is to explore and define a **replicable methodological framework**, to guide the assessment process of **alternative adaptation policies** to the impacts of SLR.

The study investigates the potential **synergies of combining tools and approaches**, in order to **characterise, incorporate and communicate the uncertainty**.

- ❑ Innovative **methodological framework**
- ❑ Application of the **Bayesian network** tool to CC policy issues
- ❑ Original approches to carry out **uncertainty analyses**

Integrated methodology

Decision analysis

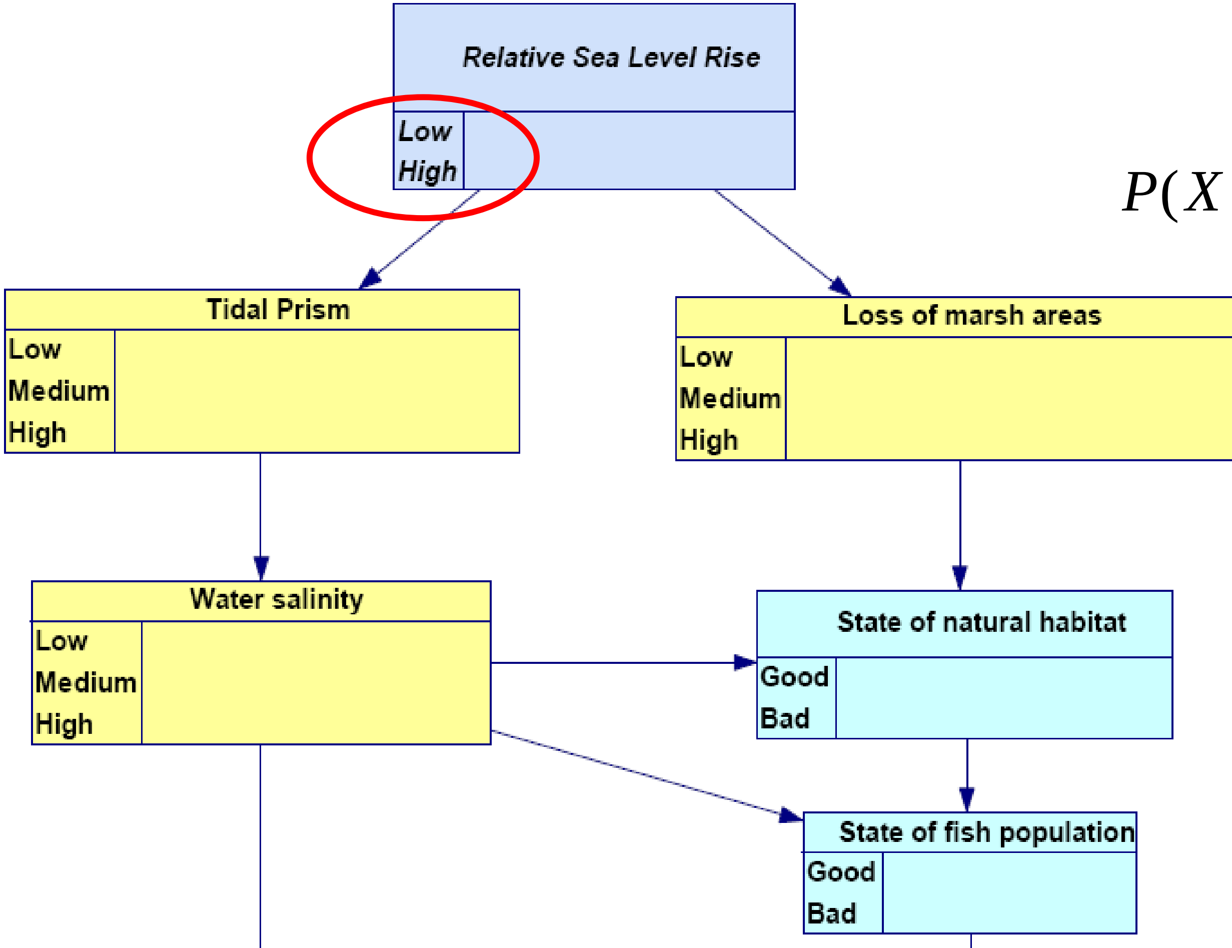
+

Participatory modelling

+

Probabilistic modelling

Key tool: Bayesian network (BN)

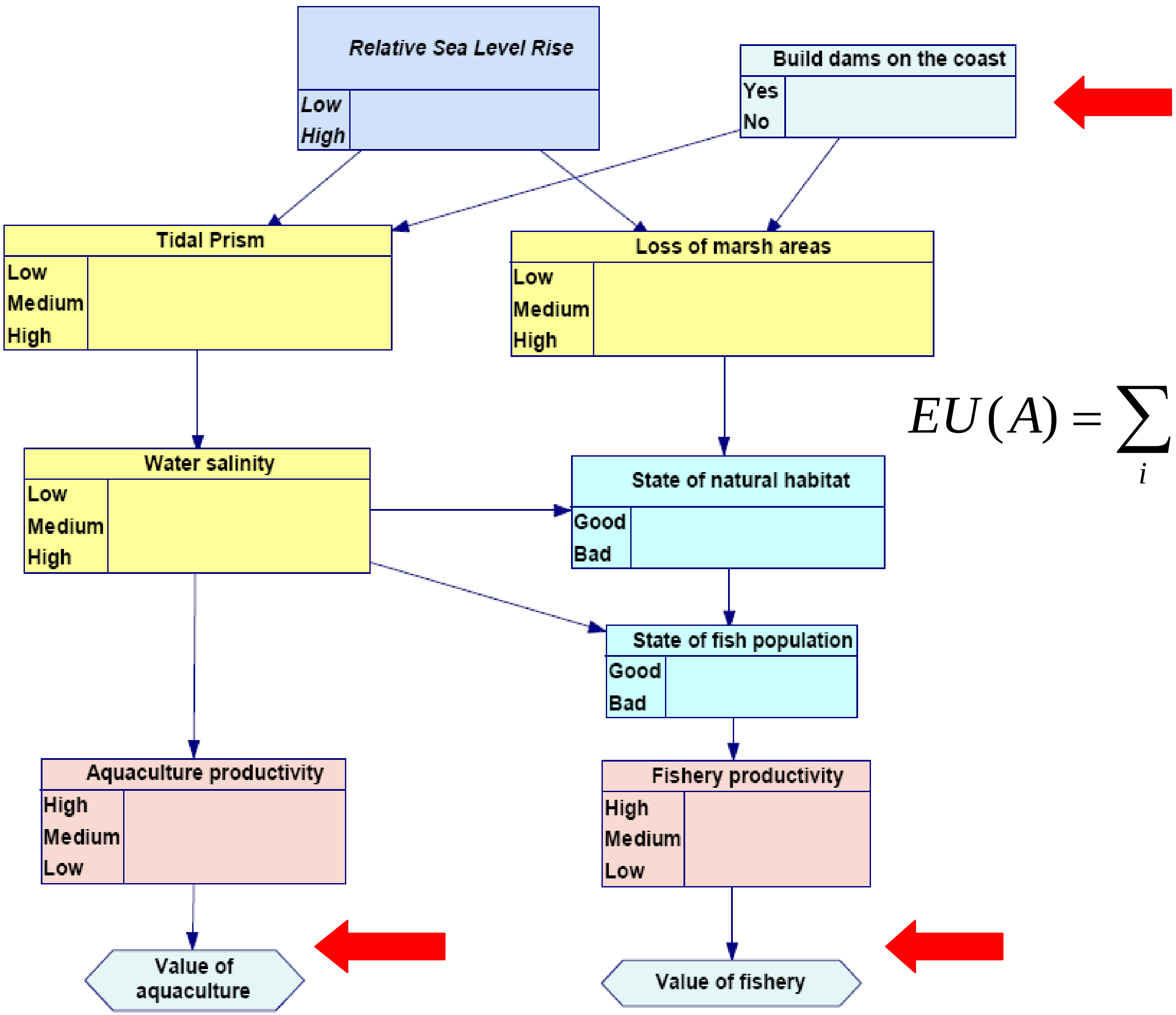


$$P(X) = \prod_{i=1}^{n} p(Xi \mid parents(Xi))$$

$$P(h \mid e) = \frac{P(e \mid h)P(h)}{P(e)}$$

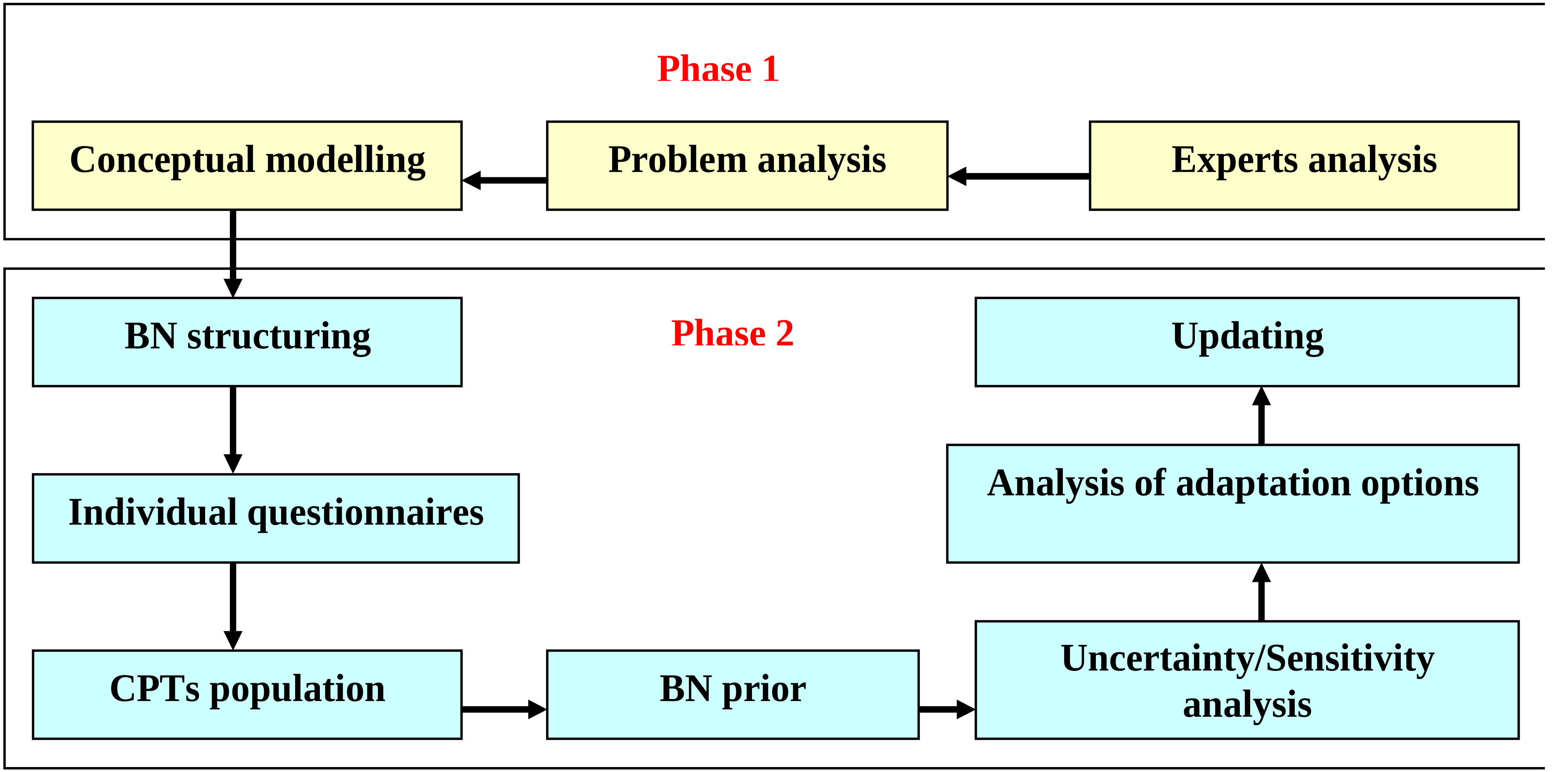
	State of natural habitat	Good			Bad		
	Water salinity	Low	Medium	High	Low	Medium	High
State of fish population	Good	0.8	0.5	0.4	0.5	0.3	0.3
	Bad	0.2	0.5	0.6	0.5	0.7	0.8

Bayesian *Decision* network (BDN)



$$EU(A) = \sum_i U(Oi \mid A) x P(Oi \mid A)$$

Methodological flow



Expert judgment elicitation (EJE)

- Deal with **complex phenomena** characterised by **lack or scarcity of data**

- **Overcome uncertainty limits** of analytic modelling and draw future projections

- Enhance the interaction and the synergies of **inter-experts discussions**

- Provide **subjective probabilities** for feeding the BN model, verify an fine-tune information obtained from other sources

- Support **decision-making** processes

Ad hoc protocols for EJE

Introductory assessment

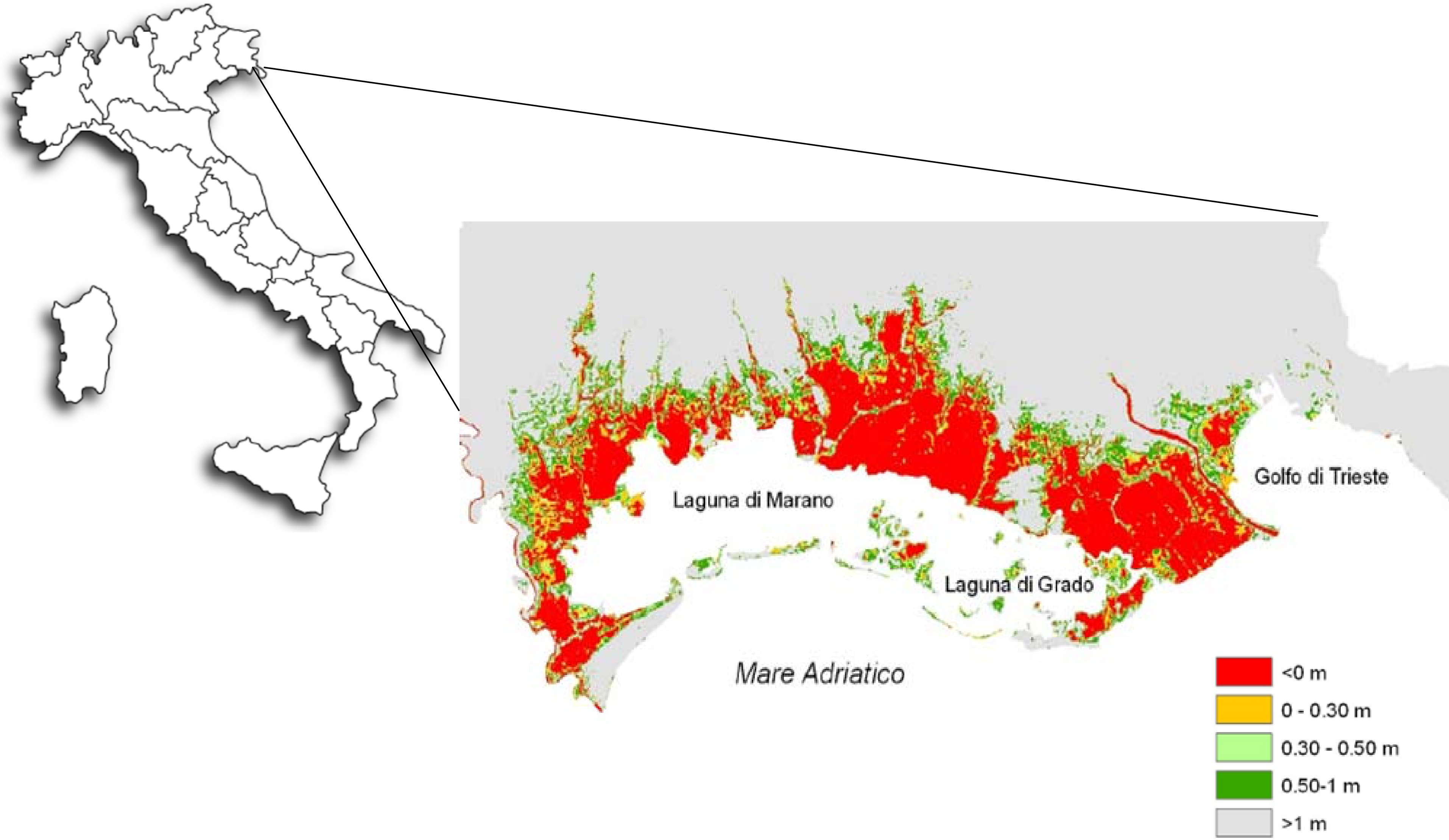
Selection of the elicitation components

Elicitation process

Analysis procedures

*(Morgan and Henrion (1990), Keeney and Von Winterfeldt (1991), Meyer and Booker (1991), Phillips (1999) etc.

Case study: the lagoon of Grado and Marano

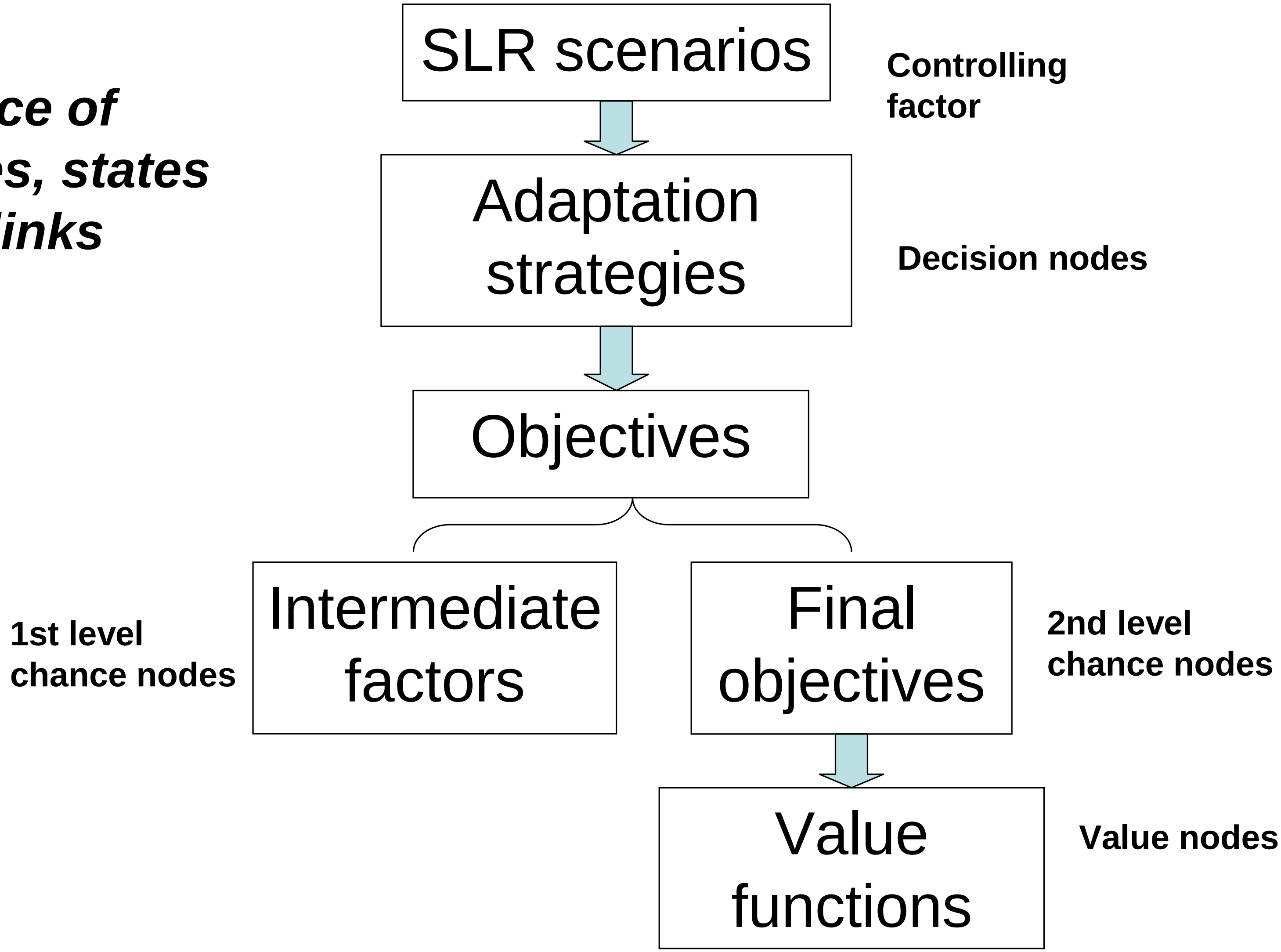


Phase 1: Conceptual modelling

1. **Group elicitation**: workshop with the experts
2. **Cognitive map** of the system (DPSIR framework)
3. **Ranking** of the impacts
4. Identification of **adaptation measures**

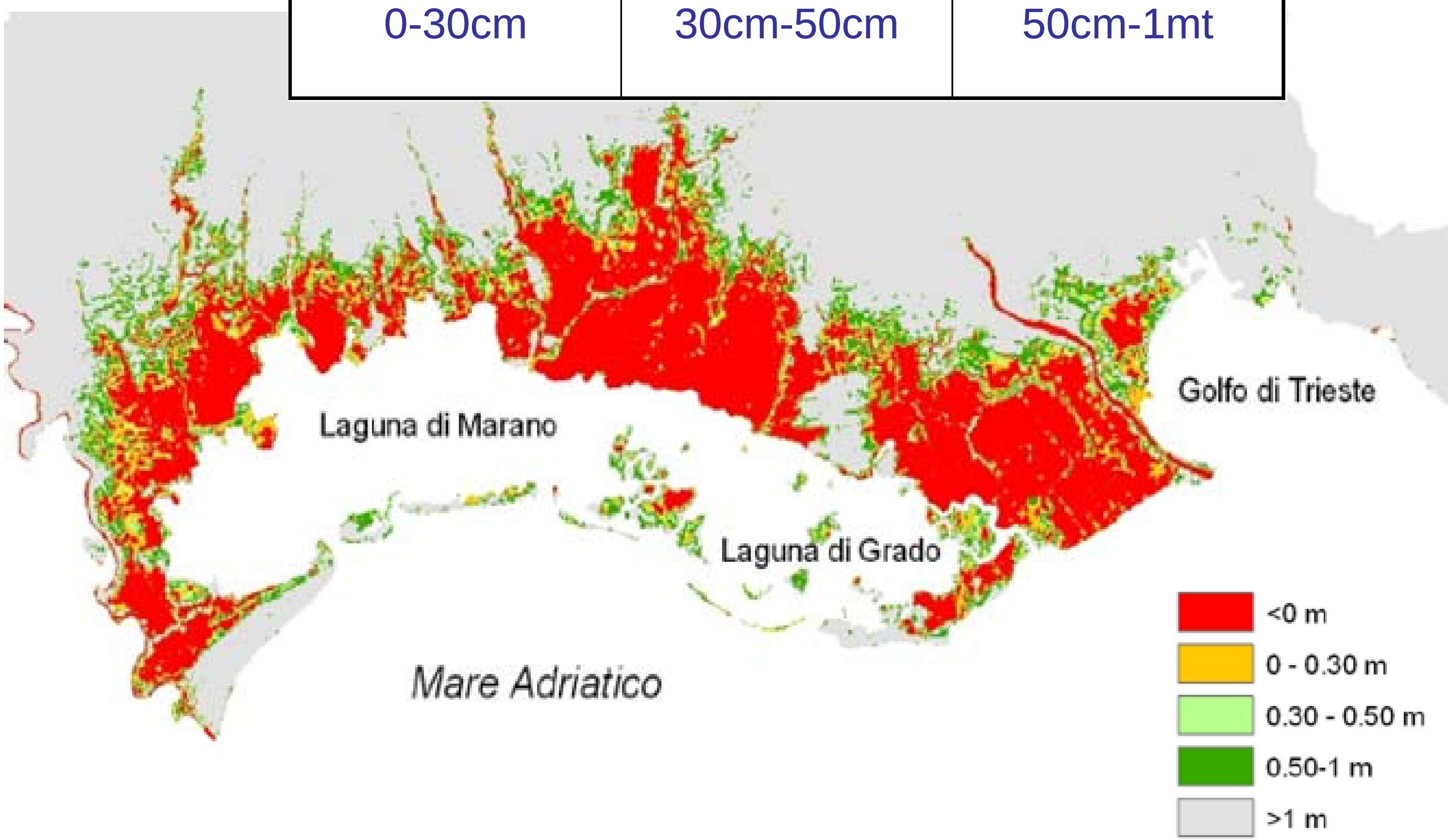
Phase 2: Structuring the BDN

Choice of nodes, states and links



Controlling factor: SLR

Projections to 2100		
Low	Medium	High
0-30cm	30cm-50cm	50cm-1mt



Decision nodes

Restoration of salt marshes:

- Enhance the capacity of the lagoon to comprensate the erosive and levelling effects of SLR
- Highly auto-adaptive capacity

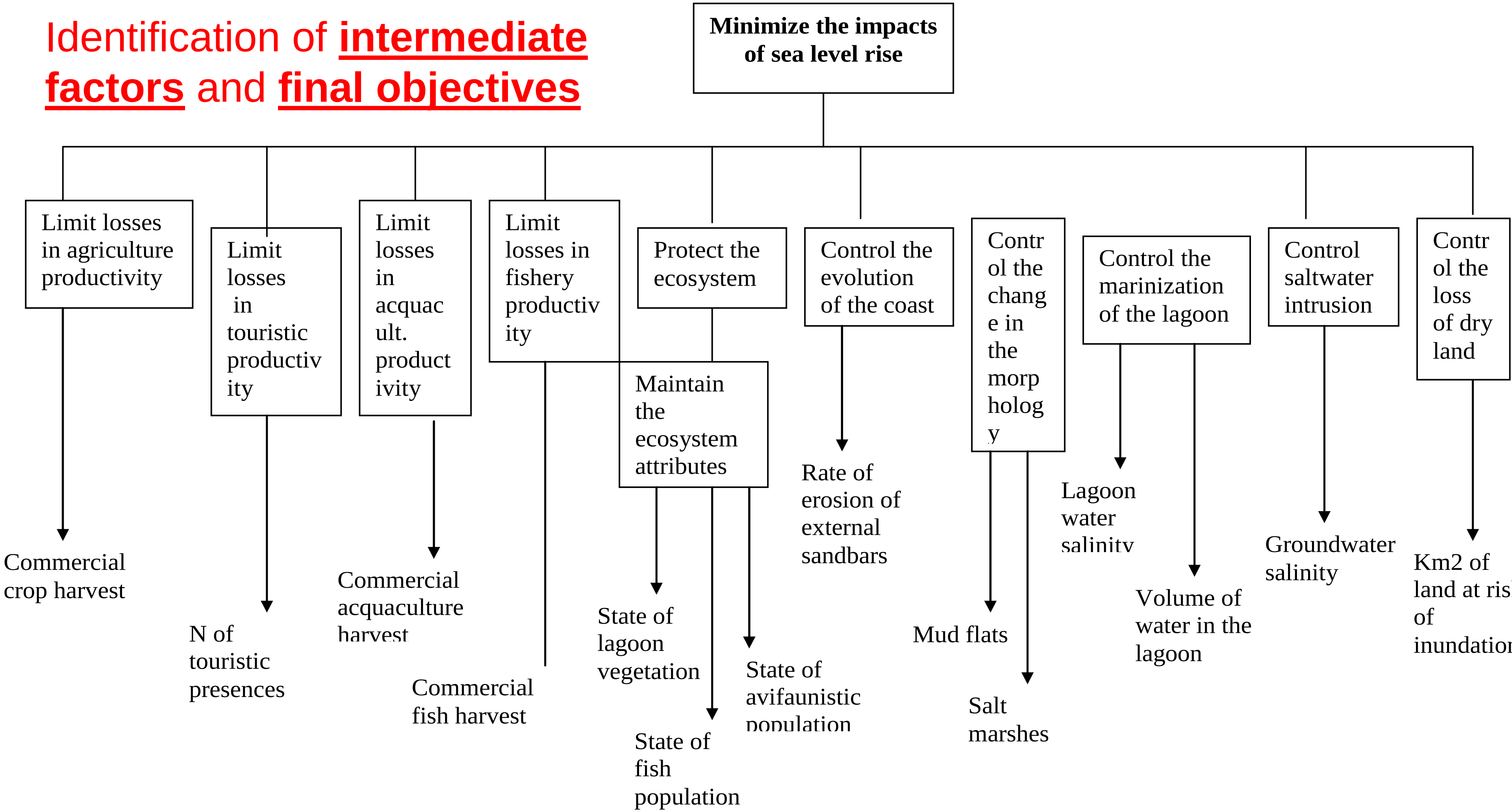
Beach nourishment:

•Protection from marine ingression; control of erosion; dissipation of wave strength

•Increase the economic value of beaches

Chance nodes

Identification of **intermediate factors** and **final objectives**

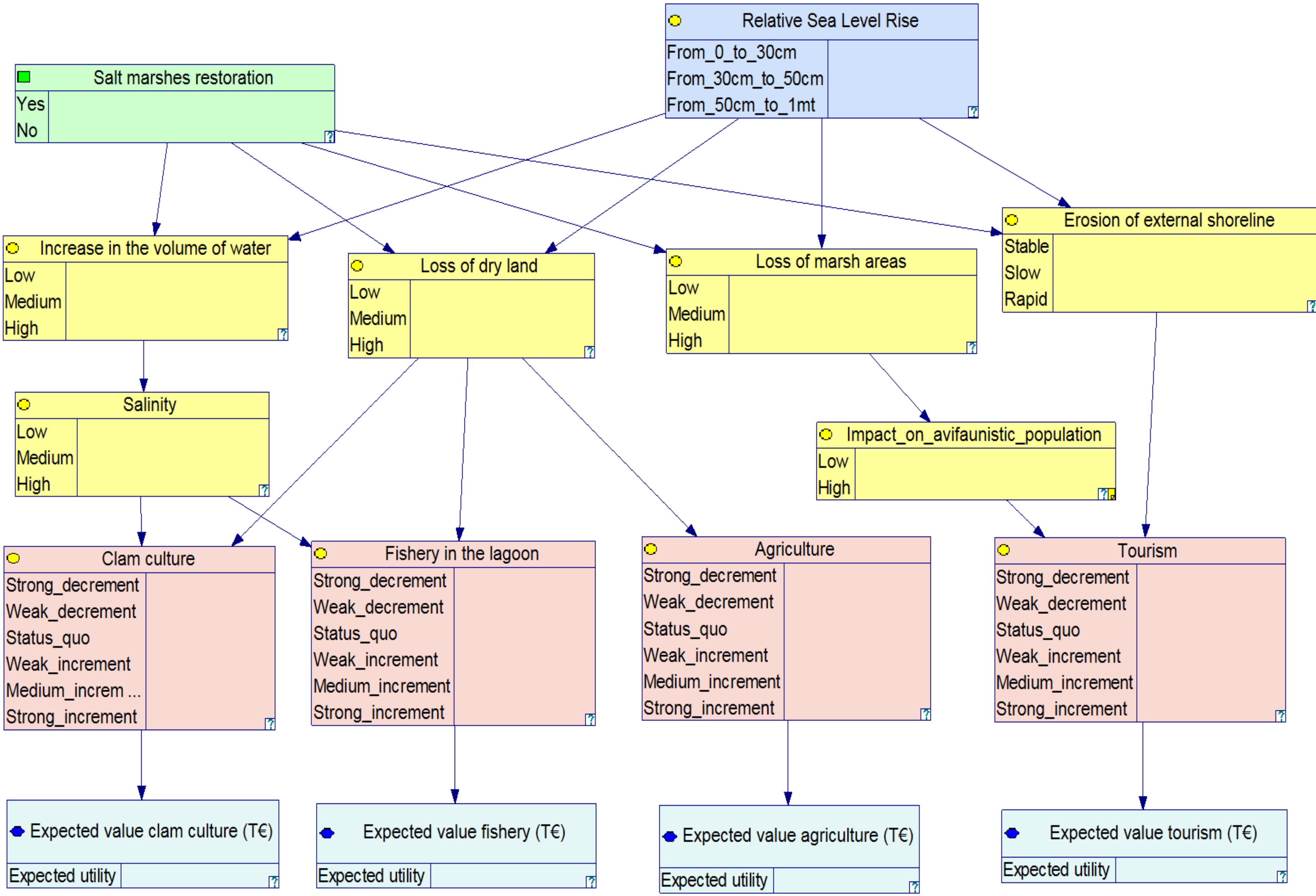


Discretization into a set of mutually exclusive and exhaustives <u>STATES</u> of each node

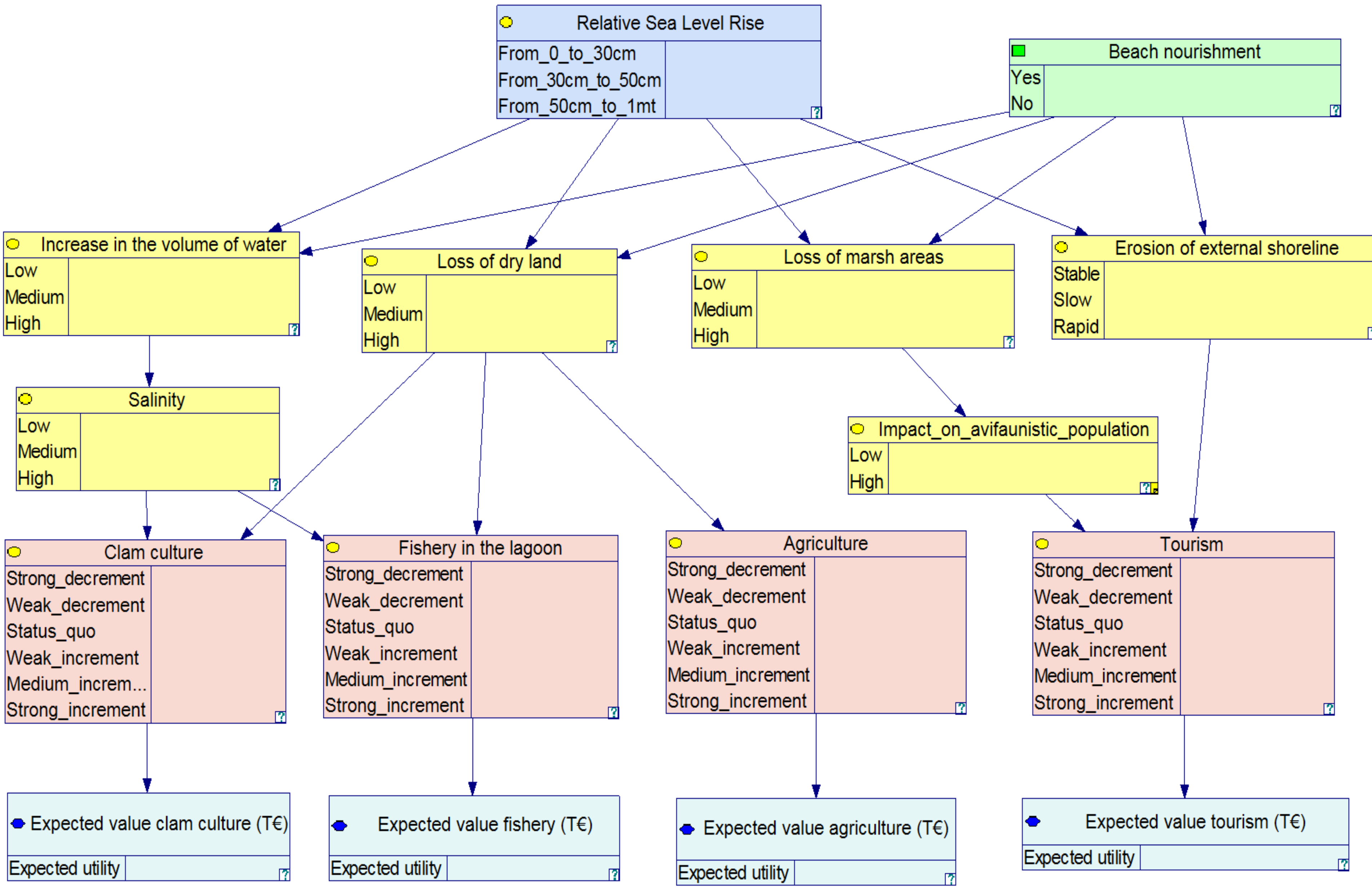
Value nodes

	Expected values (€)					
Value nodes	**Strong decrement (-40%)**	**Weak decrement (- 20%)**	**Status quo**	**Weak increment (+ 20%)**	**Medium increment (+ 40%)**	**Strong increment (+ 60%)**
Clam culture	876,576.00	1,168,768.00	1,460,960.00	1,753,152.00	2,045,344.00	2,337,536.00
Fishery in lagoon	279,174.20	372,232.27	465,290.34	558,348.41	651,406.47	744,464.54
Agriculture	113,767,323.12	151,689,764.16	189,612,205.20	227,534,646.24	265,457,087.28	303,379,528.32
Tourism	140,244,432.00	186,992,576.00	233,740,720.00	280,488,864.00	327,237,008.00	373,985,152.00

BDN: Salt marshes



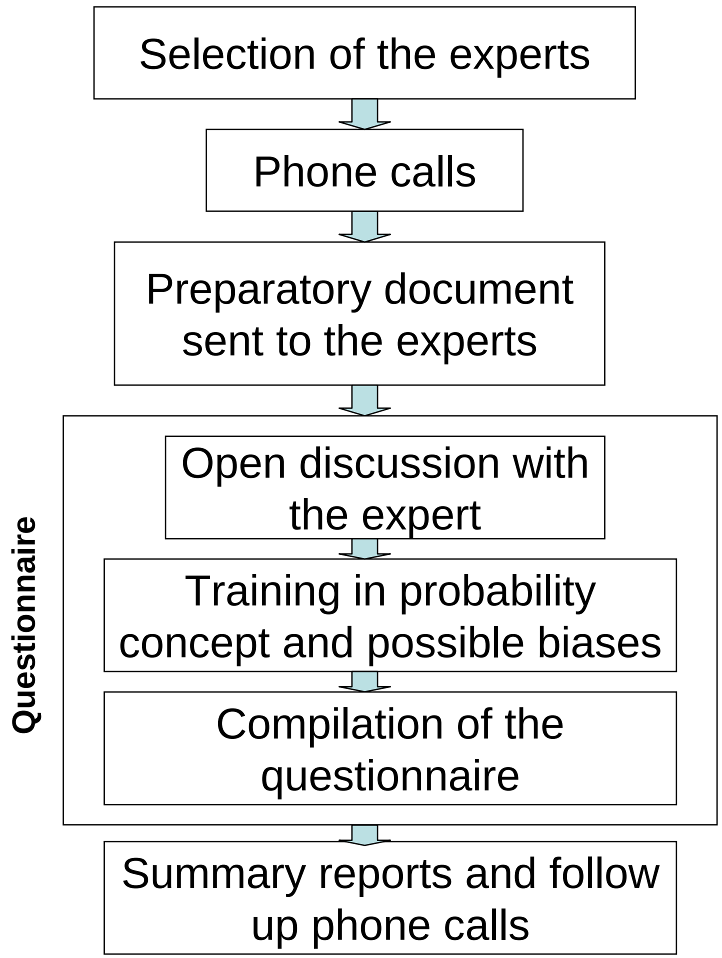
BDN: Beach nourishment



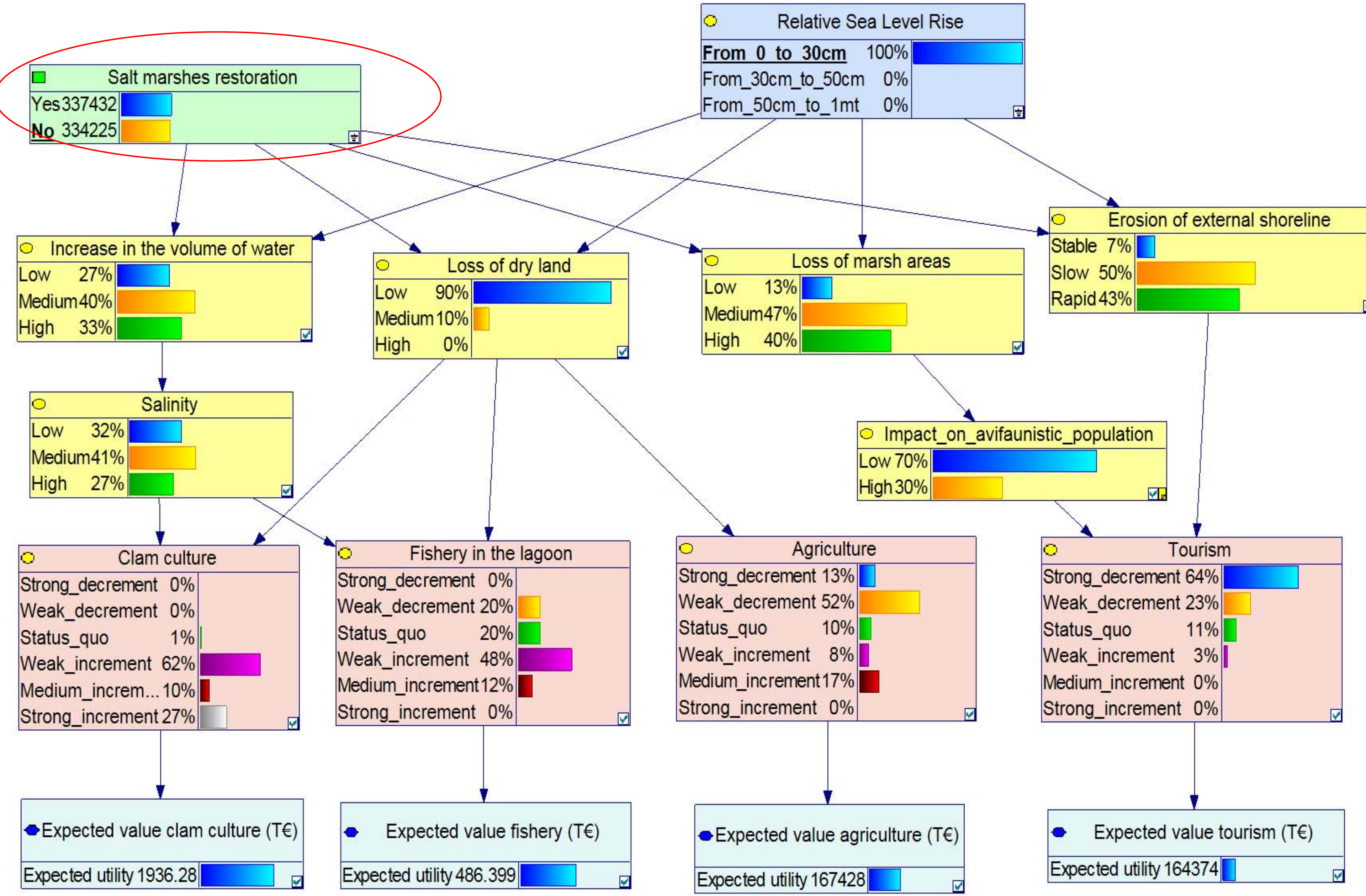
Phase 2: Populating the BN

CPT of the node: *Loss of dry land*

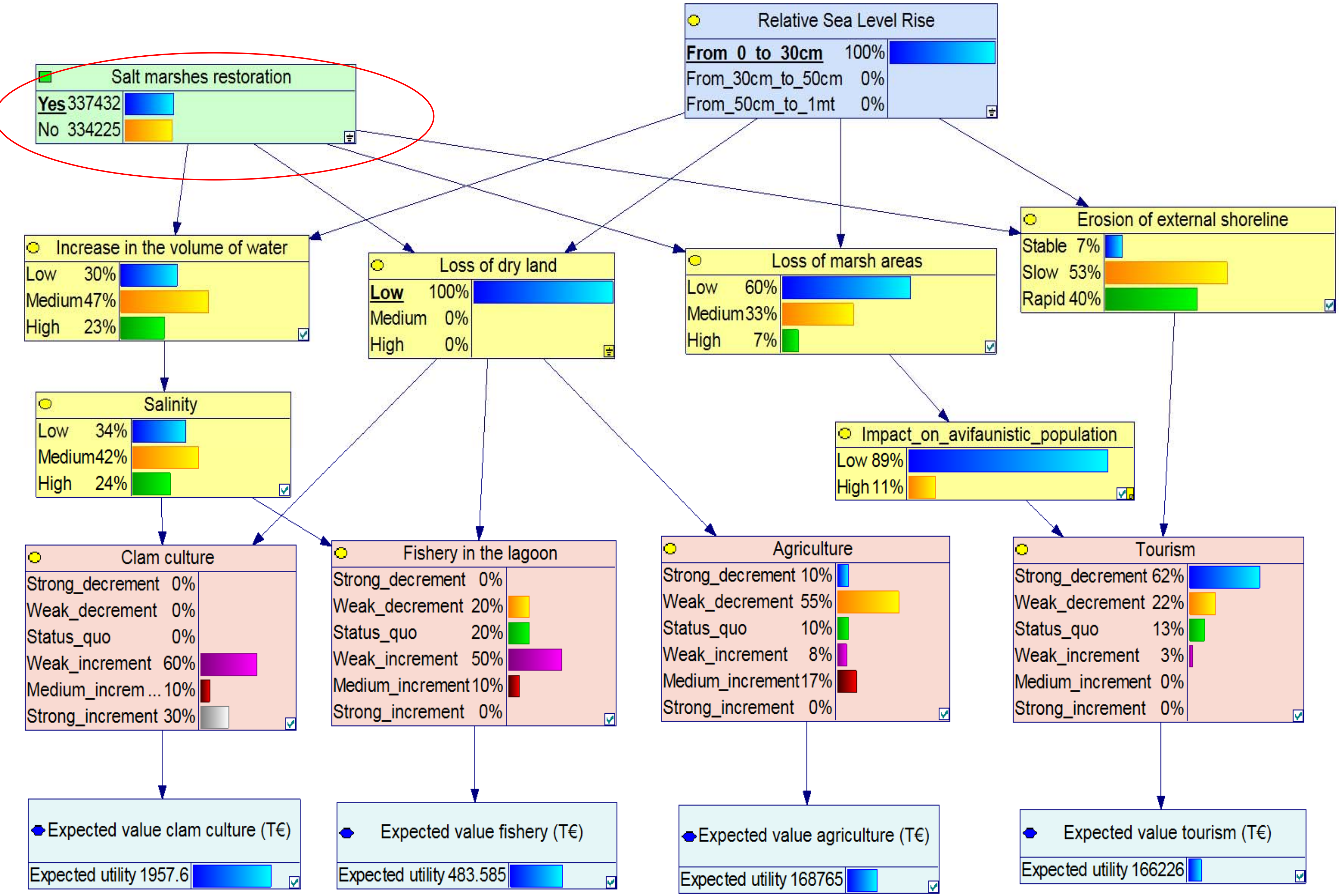
Relative Sea Level Rise	From_0_to_30cm		From_30cm_to_50cm		From_50cm_to_1mt	
Beach nourishment	Yes	No	Yes	No	Yes	No
Low	0.9	0.9	0.83	0.7	0.4	0.3
Medium	0.1	0.1	0.17	0.3	0.5	0.6
High	0	0	0	0	0.1	0.1



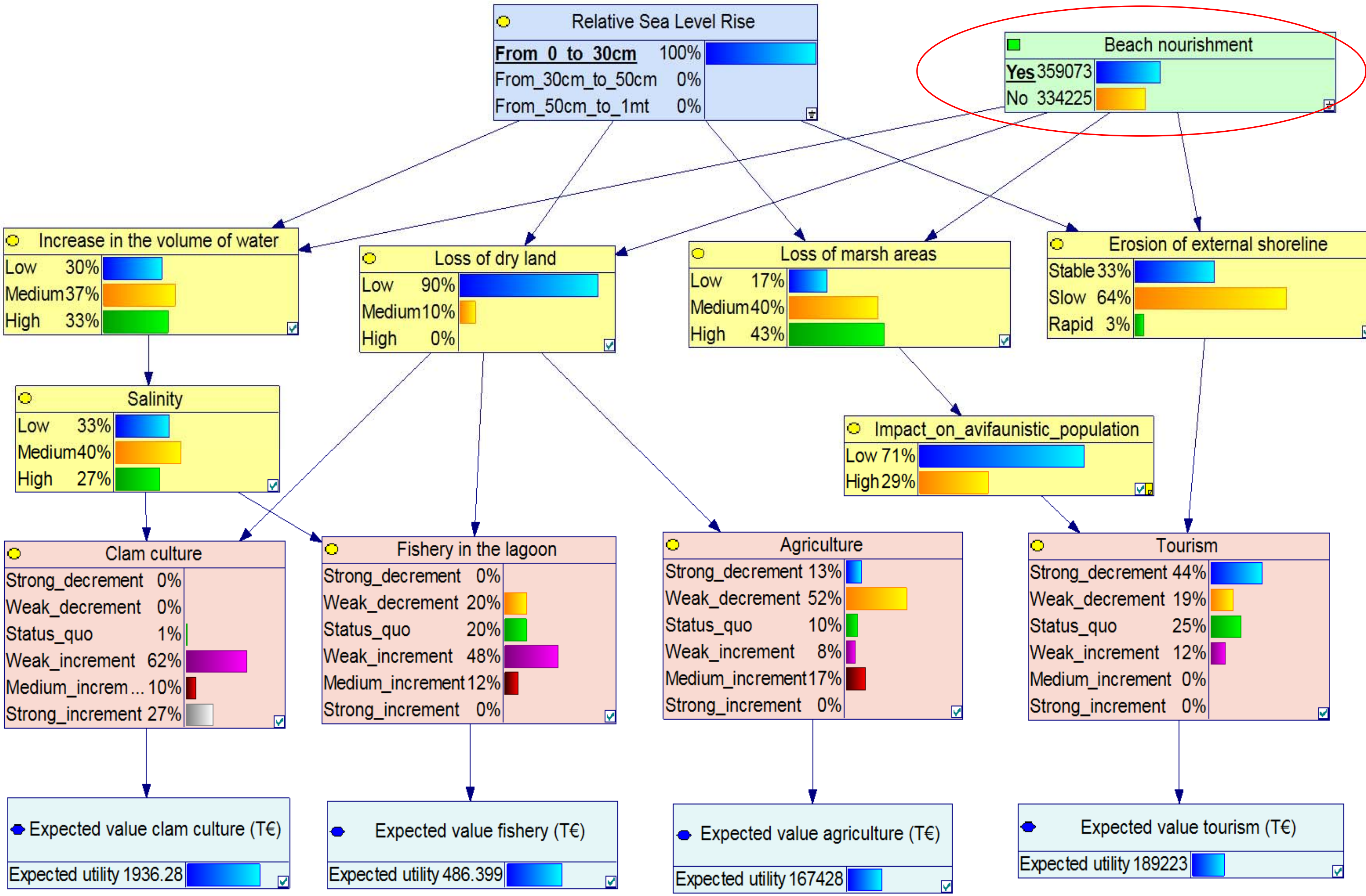
+30cm No Adaptation



+30cm Salt Marshes



+30cm Beach Nourishment



Analyses

Correlation analysis among the experts' answers: Pearson's correlation.

Policy analyis: assessment of adaptation alternatives in terms of aggregate and sectoral expected losses.

Local uncertainty analysis: effects of variations in one node at a time on the outputs; identification of the most influencing nodes;

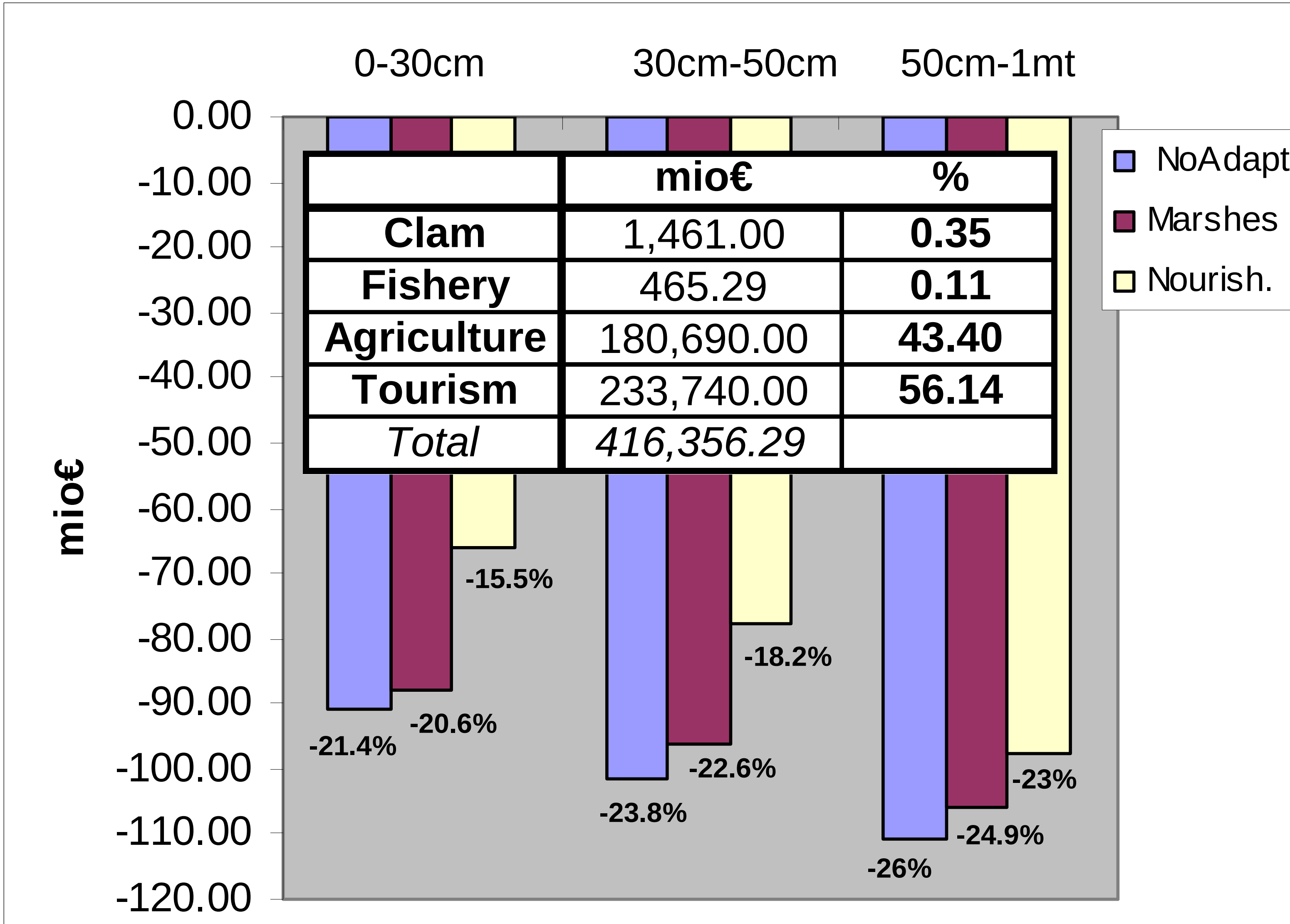
Global uncertainty analysis: assessment of the variability of the outputs arising from the simultaneous variation of the nodes' CPTs;

Uncertainty in SLR scenarios: sensitivity of the outputs to variations in the probability of SLR

Pearson's correlation

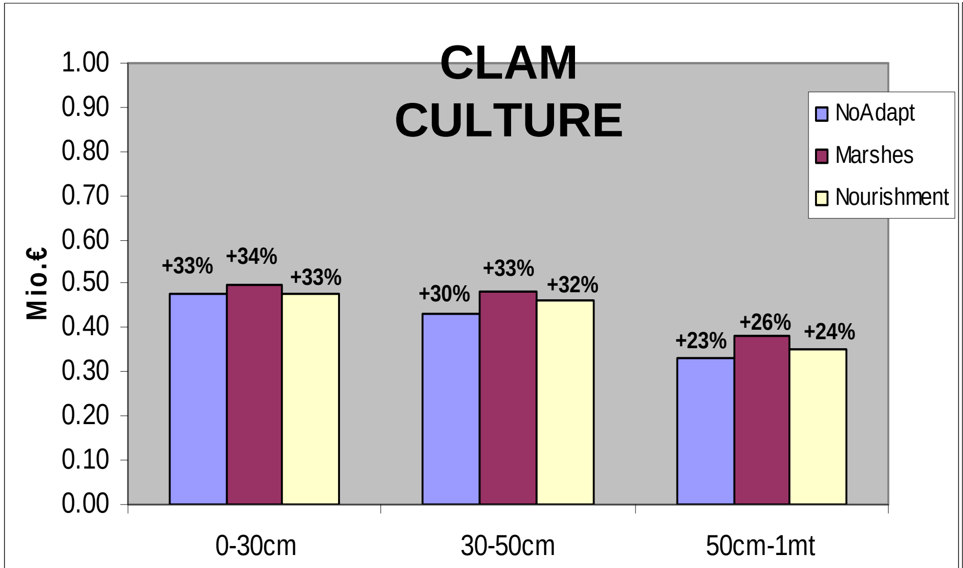
Nodes	Experts			
Volume of water in the lagoon		*A1*	*A2*	*A3*
	A1	1		
	A2	0.897674	1	
	A3	-0.59052	-0.4998	1
Loss of dry land		*B1*	*B2*	*B3*
	B1	1		
	B2	0.949305	1	
	B3	0.978307	0.954085	1

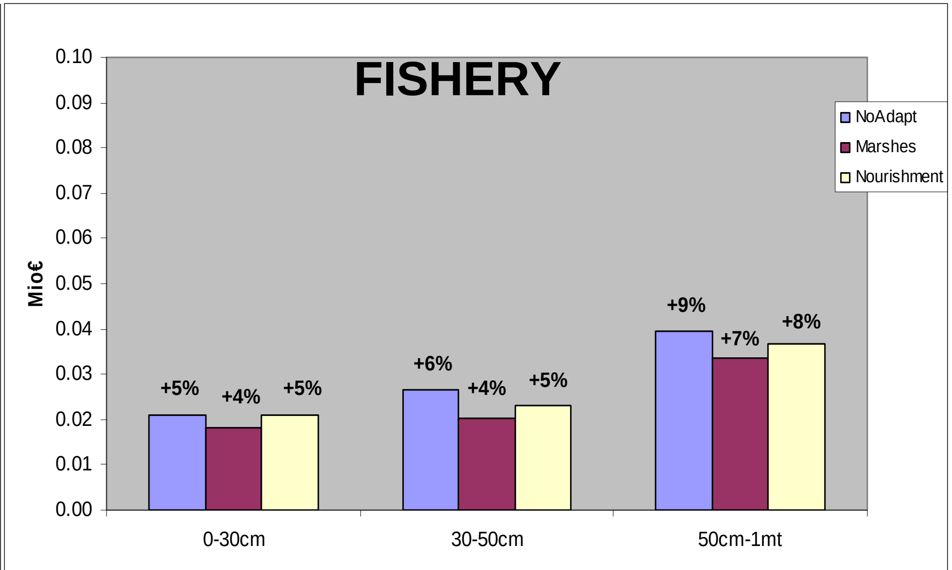
Aggregate outputs

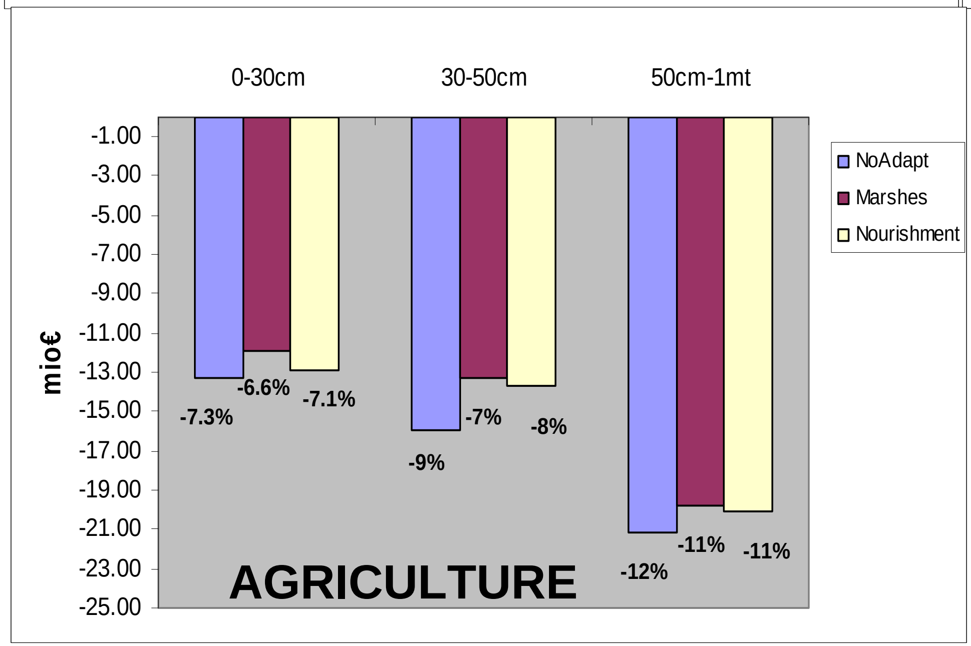


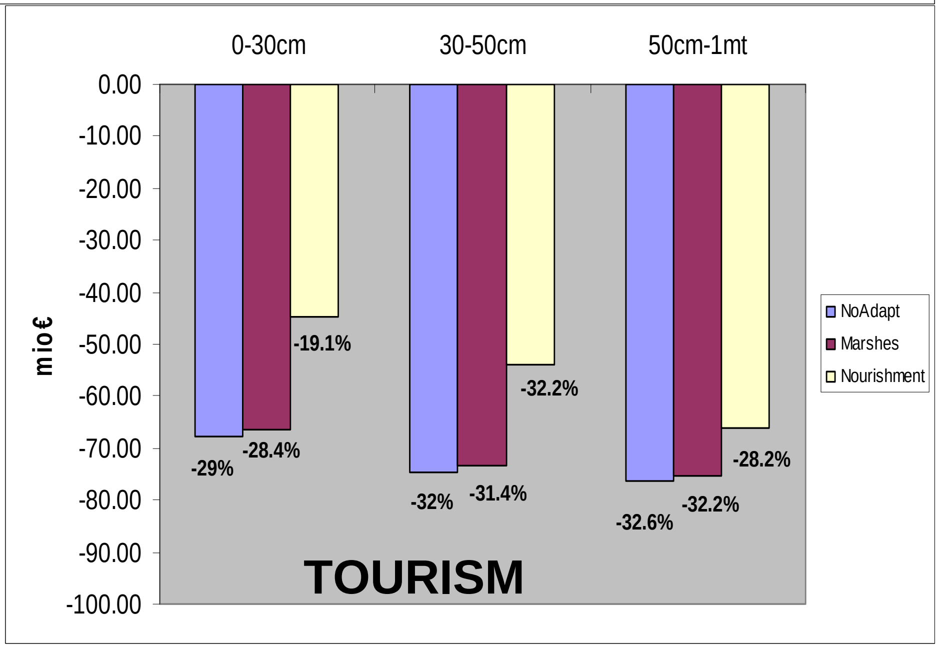
	mio€	%
Clam	1,461.00	**0.35**
Fishery	465.29	**0.11**
Agriculture	180,690.00	**43.40**
Tourism	233,740.00	**56.14**
Total	*416,356.29*	

Sectoral outputs

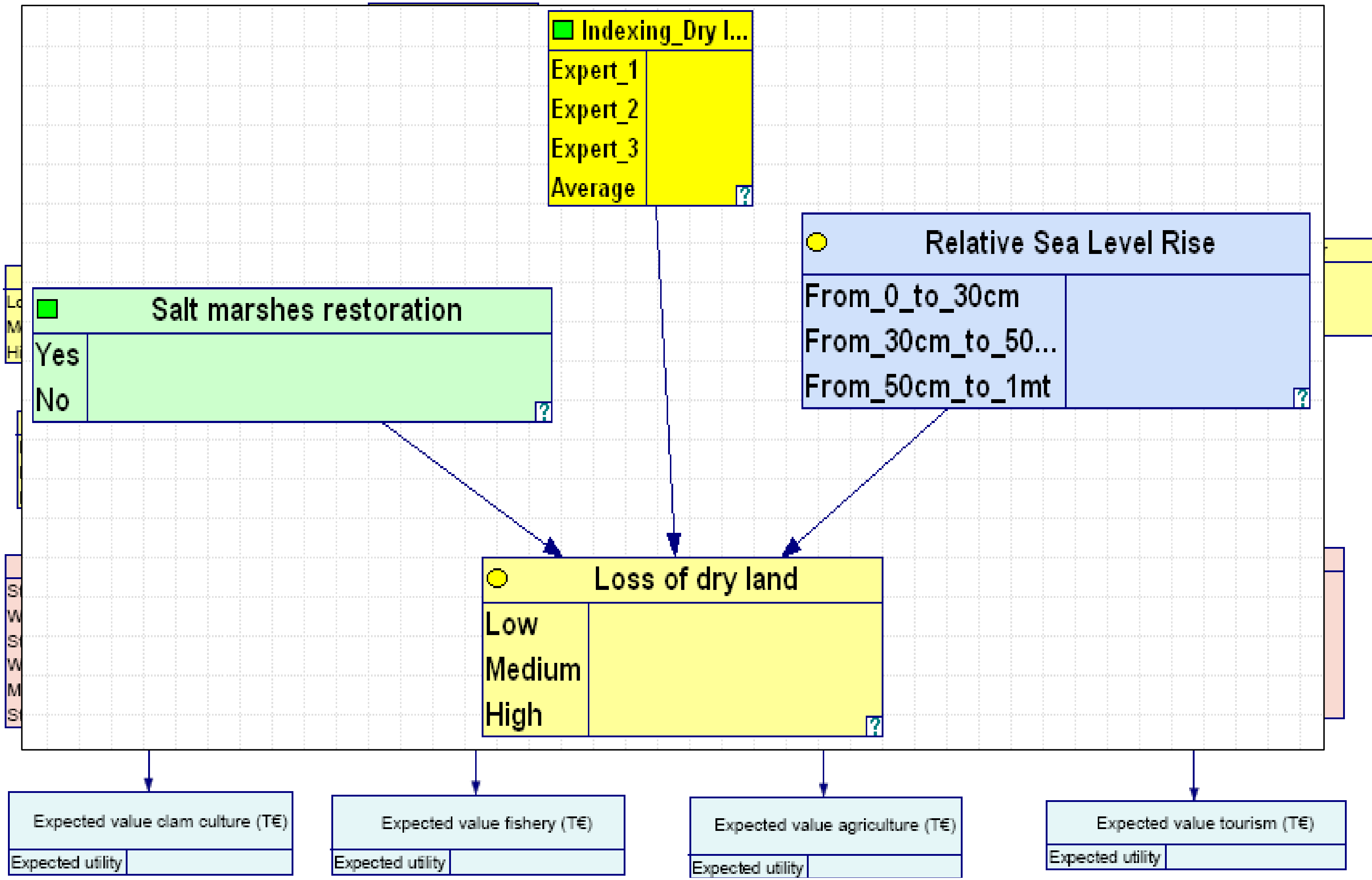




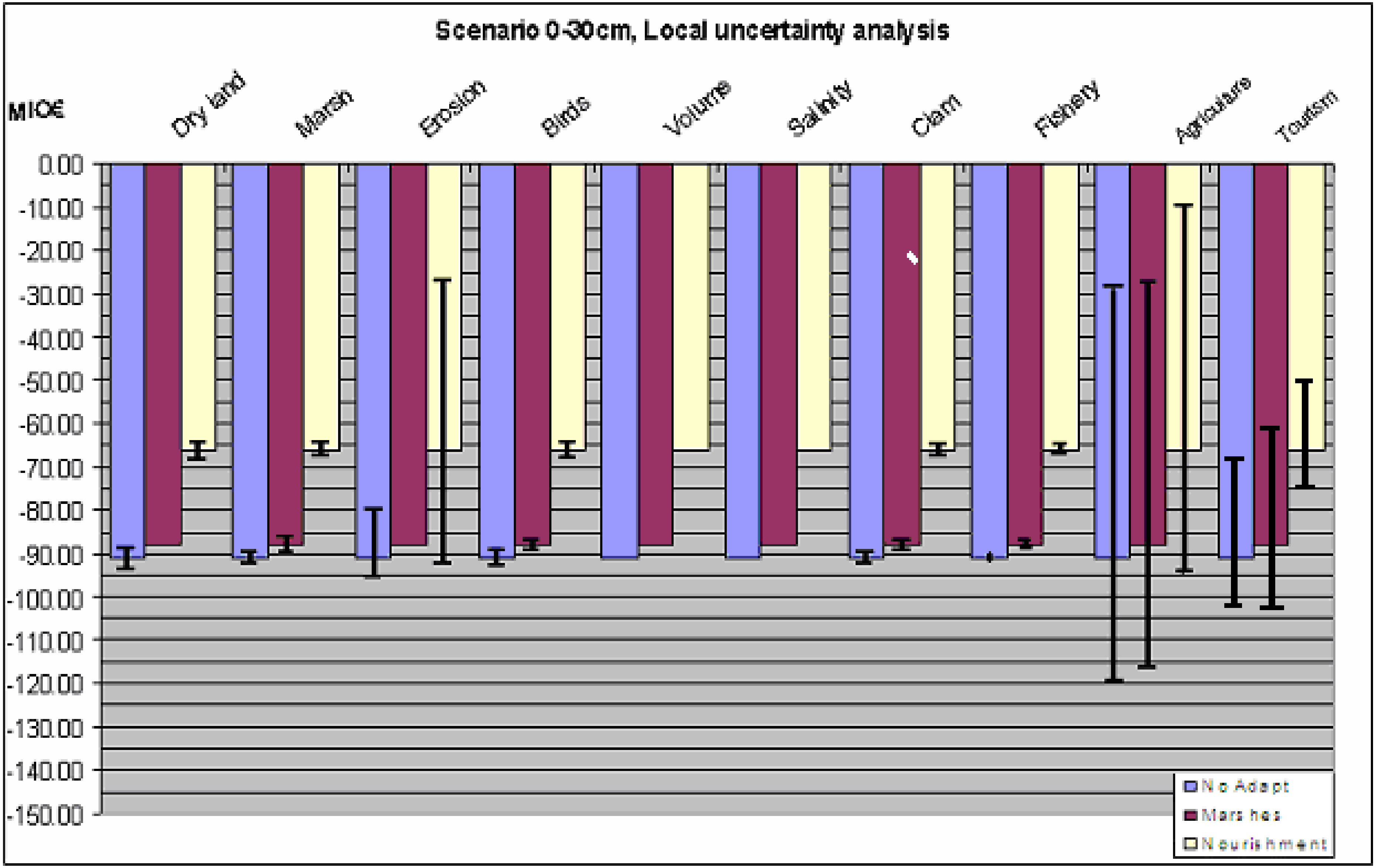




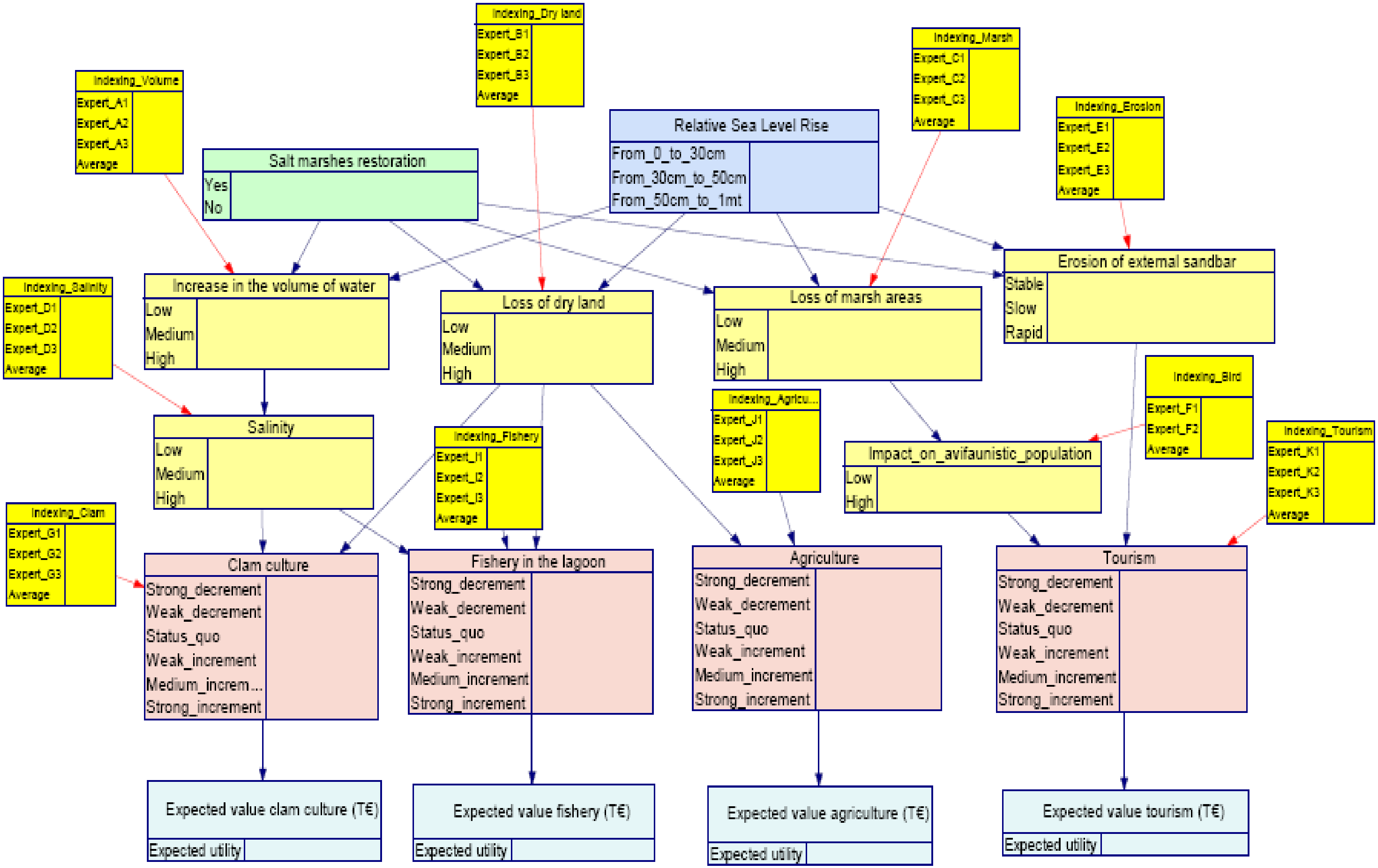
Local uncertainty analysis (1)



Local uncertainty analysis (2)



Global uncertainty analysis (GUA)



GUA: Frequency distributions

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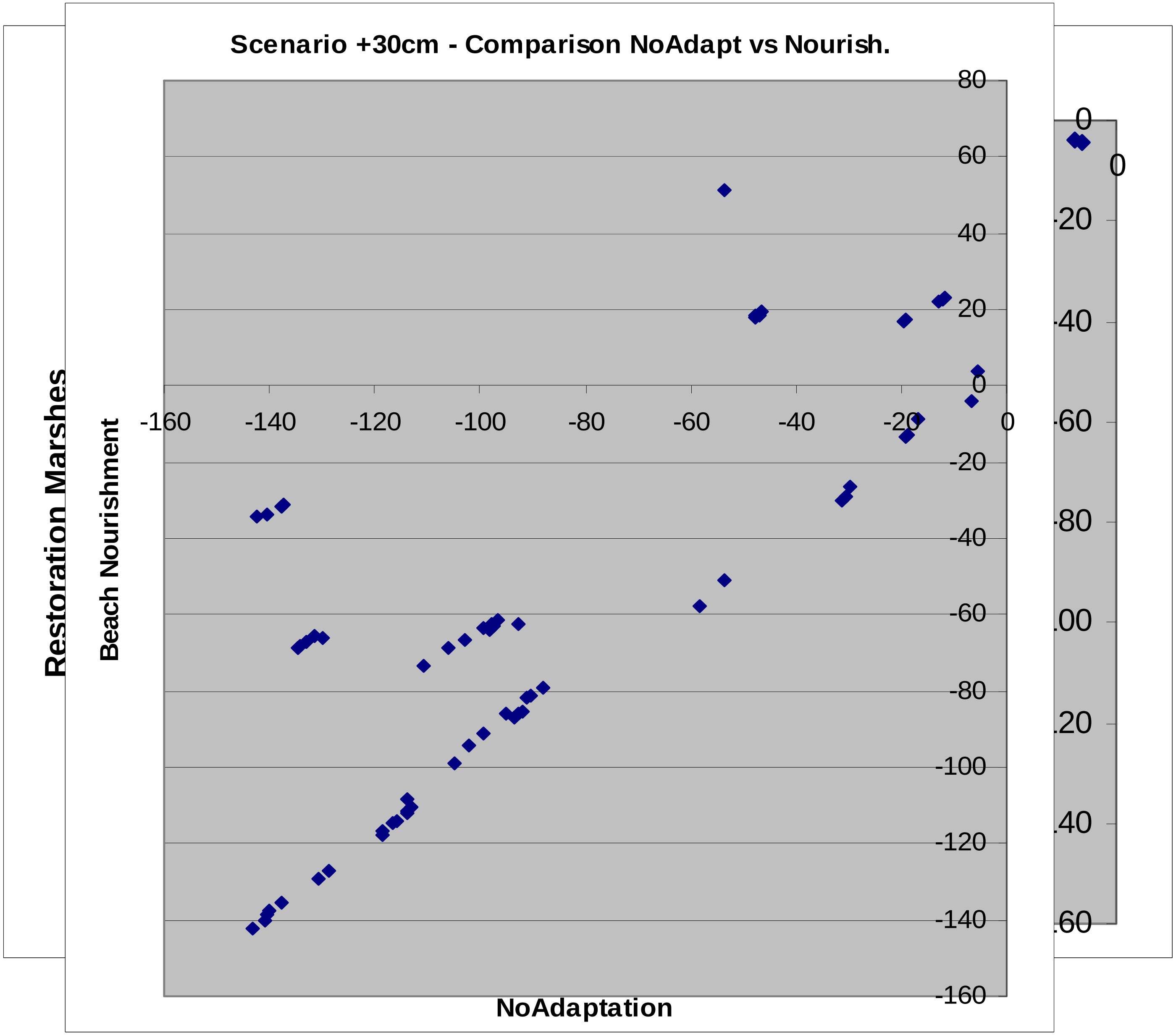
Scenario	*Option*	Mean	Median	Max	Min	Std.Dev.
0-30cm	**No Adapt**	-88.89	-98.82	-5.51	-143.04	44.07
	Marshes	-86.68	-94.75	-3.92	-141.73	44.70
	Nourishment	-56.53	-65.57	51.43	-142.37	51.04
30cm-50cm	**No Adapt**	-96.56	-108.76	-14.50	-147.89	44.91
	Marshes	-92.08	-99.59	-11.58	-143.67	45.18
	Nourishment	-66.69	-73.52	39.41	-145.05	51.87
50cm-1mt	**No Adapt**	-107.19	-121.35	-23.69	-157.59	45.44
	Marshes	-102.15	-114.52	-20.38	-153.29	45.66
	Nourishment	-90.13	-106.00	-3.50	-151.49	46.74

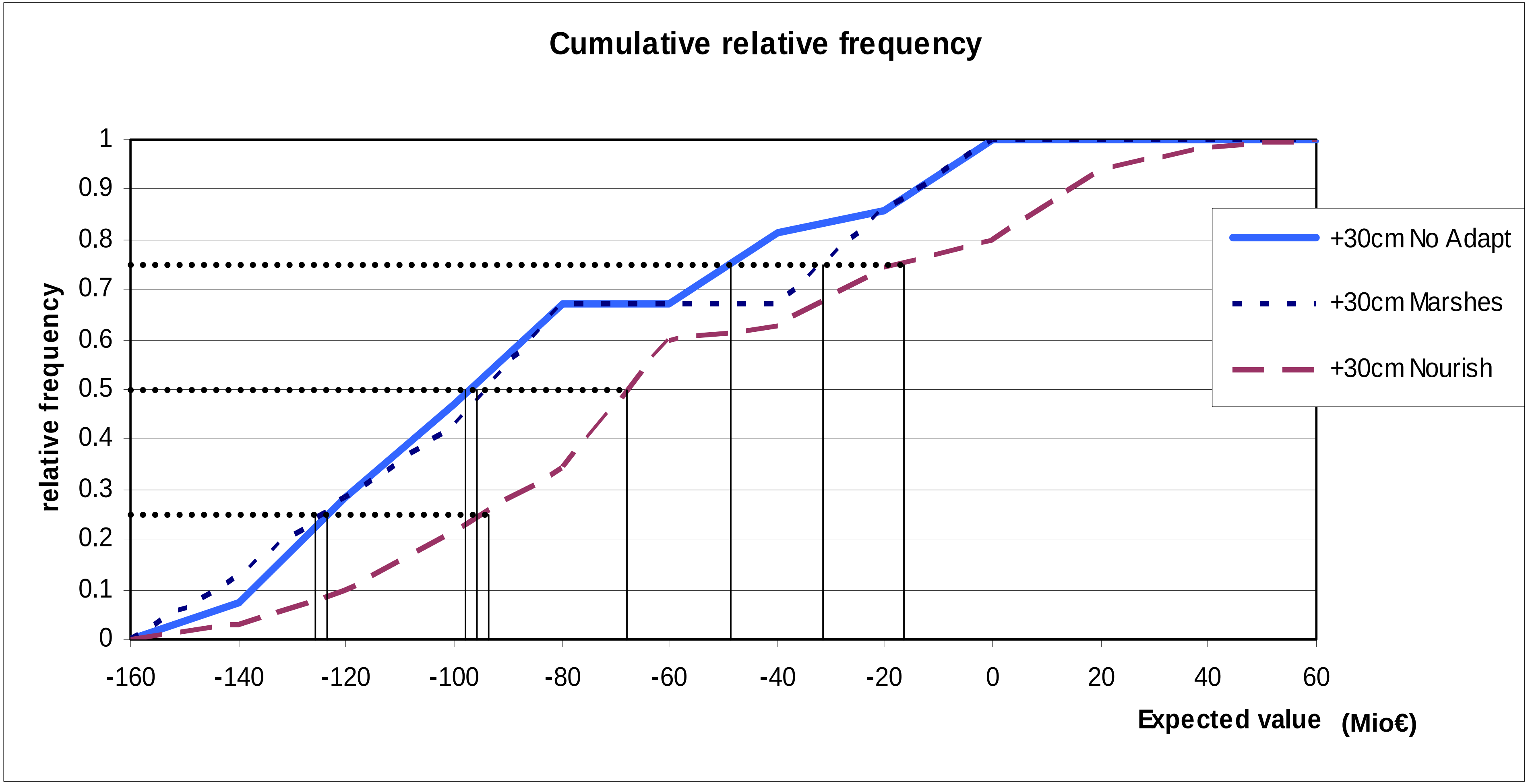
Test for Equality of Medians Between NoAdapt and Marshes			
Method	df	Value	Probability
Wilcoxon/Mann-Whitney		0.537617	0.5908
Kruskal-Wallis	1	0.291277	0.5894
Test for Equality of Medians Between No Adapt and Nourishment			
Wilcoxon/Mann-Whitney		3.686217	0.0002
Kruskal-Wallis	1	13.60356	0.0002

Mio€

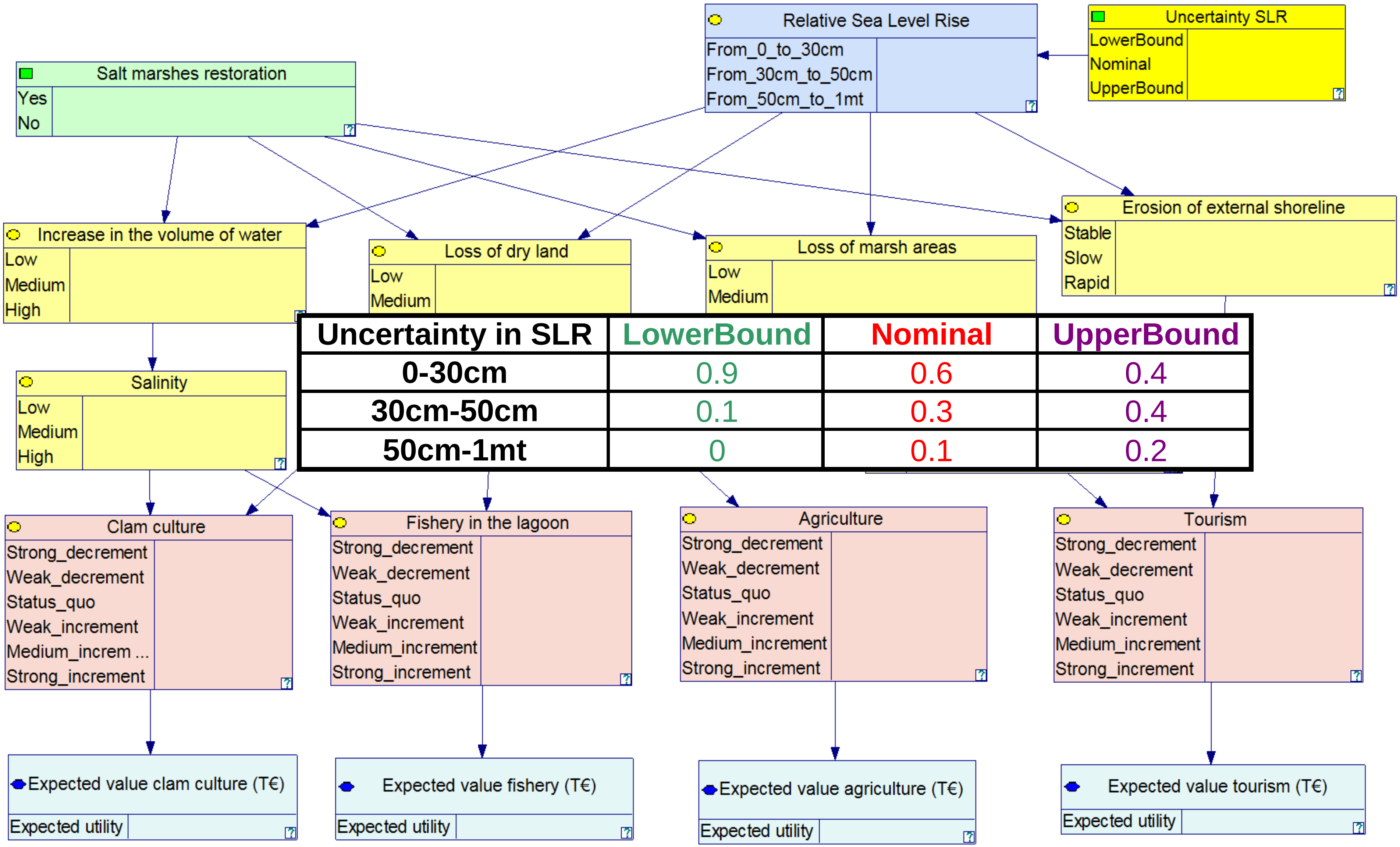
GUA: Comparison btw series



GUA: Cumulative relative frequency

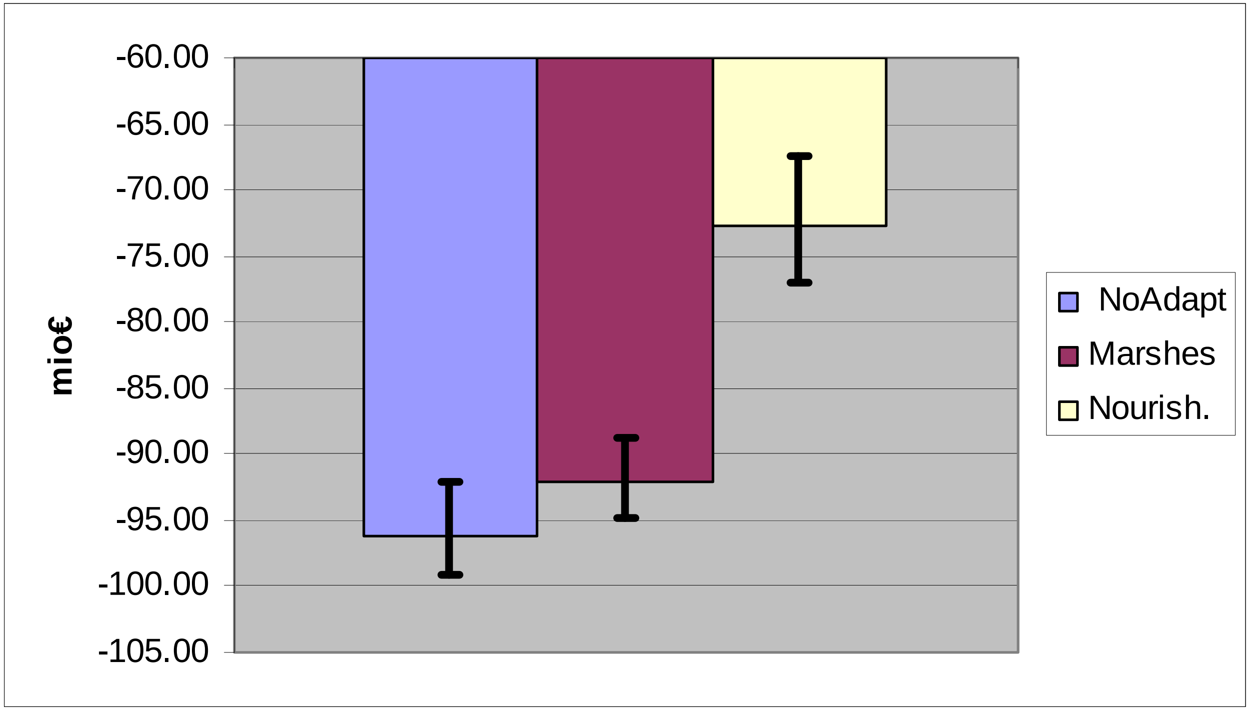


Likelihood evidence of SLR scenarios (1)



Uncertainty in SLR	LowerBound	Nominal	UpperBound
0-30cm	0.9	0.6	0.4
30cm-50cm	0.1	0.3	0.4
50cm-1mt	0	0.1	0.2

Likelihood evidence of SLR scenarios (2)



	Expected Losses (%)					
	+30cm	LowerBound	Nominal	UpperBound	+50	+1mt
NoAdapt	-21.41	-21.66	-22.61	-23.32	-23.88	-26.01
Marshes	-20.66	-20.85	-21.67	-22.29	-22.61	-24.91
Nourish.	-15.57	-15.83	-17.11	-18.12	-18.23	-23.01

Conclusions: methodology (1)

The **BN tool** emerges as a **synthesis model**, which allows the user to:

- **integrate knowledge** and data from different fields in a single framework of analysis
- assess **alternative “what-if” management approaches**
- structure **policy recommendations**, to define policy scenarios and to identify **optimal policy choices**
- **take into account key uncertainties** in models’ hypotheses and outputs

- ❑ **characterise** the uncertainty of the models’ hypotheses and outputs in a stochastic framework;
- ❑ **incorporate** the uncertainty into Bayesian models through updating processes (ADAPTIVE management);
- ❑ **communicate** the uncertainty to the policy makers through the BNs’ user-friendly graphical interface.

Conclusions: methodology (2)

The proposed methodology:

- Provides a fully-functional tool to **support policy makers** in the assessment of future scenarios of global change, and in the design of effective, equitable and efficient policies;
- Enhances the **interaction among the experts**, and the communication between **science and policy**
- Can be tailored for the assessment of **different CC policy issues**

Conclusions: policy

- The aggregate outputs of the BDN model demonstrated that the implementation of the "**beach nourishment**" option would lead to higher expected benefits (lower exp. losses) than the "restoration of salt marshes", but the **marginal benefits would decrease** with higher SLR scenarios
- The "**restoration of salt marshes**" would not bring to important limitations in the expected losses, except for clam culture activity. **Sectoral outputs do not always reflect aggregate results**.

Implications for further research

- Expand the BDN, subdividing it into **sub-models**
- Integration of expert knowledge with **data from models and/or empirical studies**
- Take feedbacks into account into a **Bayesian dynamic network**
- Include a phase of **engagement of local stakeholders and decision-makers**
- Carry out a **CBA**, considering also the monerary value of **non-market goods**
- Carry out a **MCA**, considering different measures of utility

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