RABAT CONFERENCE ON COASTAL RISKS

(APRIL 23-24, 2019)

ESTIMATION OF HEALTH RISKS DUE TO THE PRESENCE OF POLYCYCLIC AROMATIC HYDROCARBONS IN A COASTAL LAGOON

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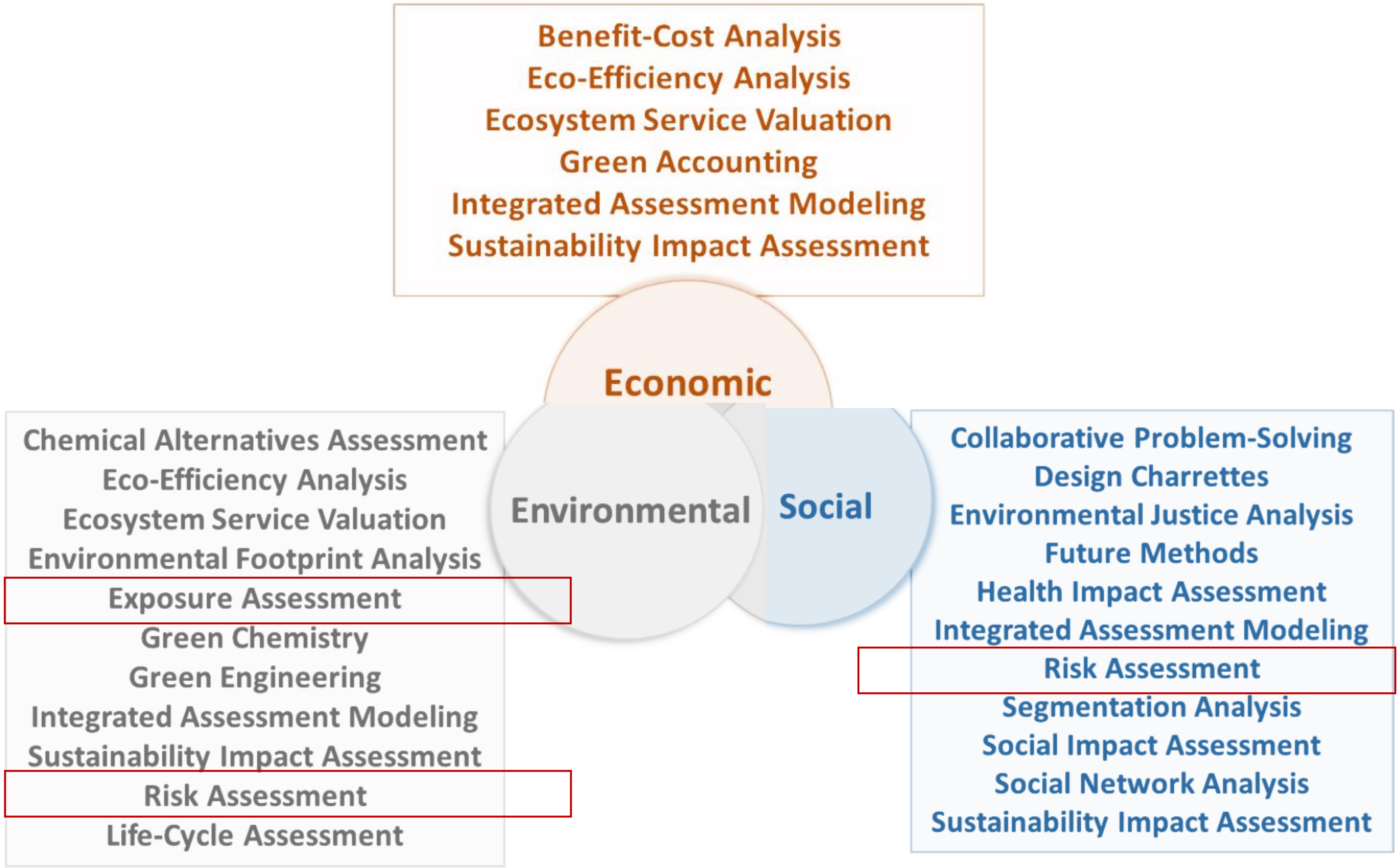
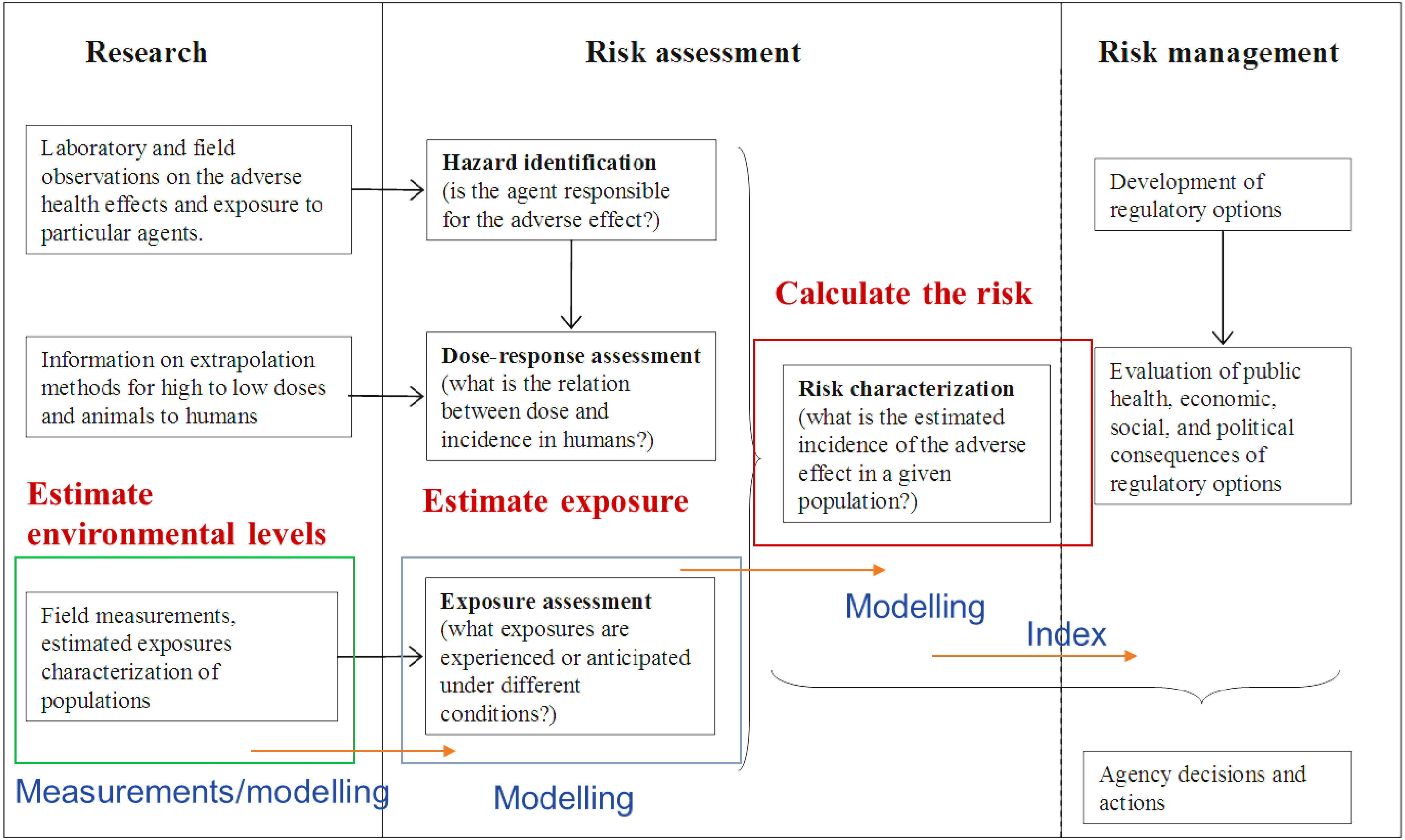
OBJECTIVE:

Estimate health risk due to the presence of PAH in a coastal lagoon:
shellfish farmers

HEALTH RISK ASSESSMENT FRAMEWORK



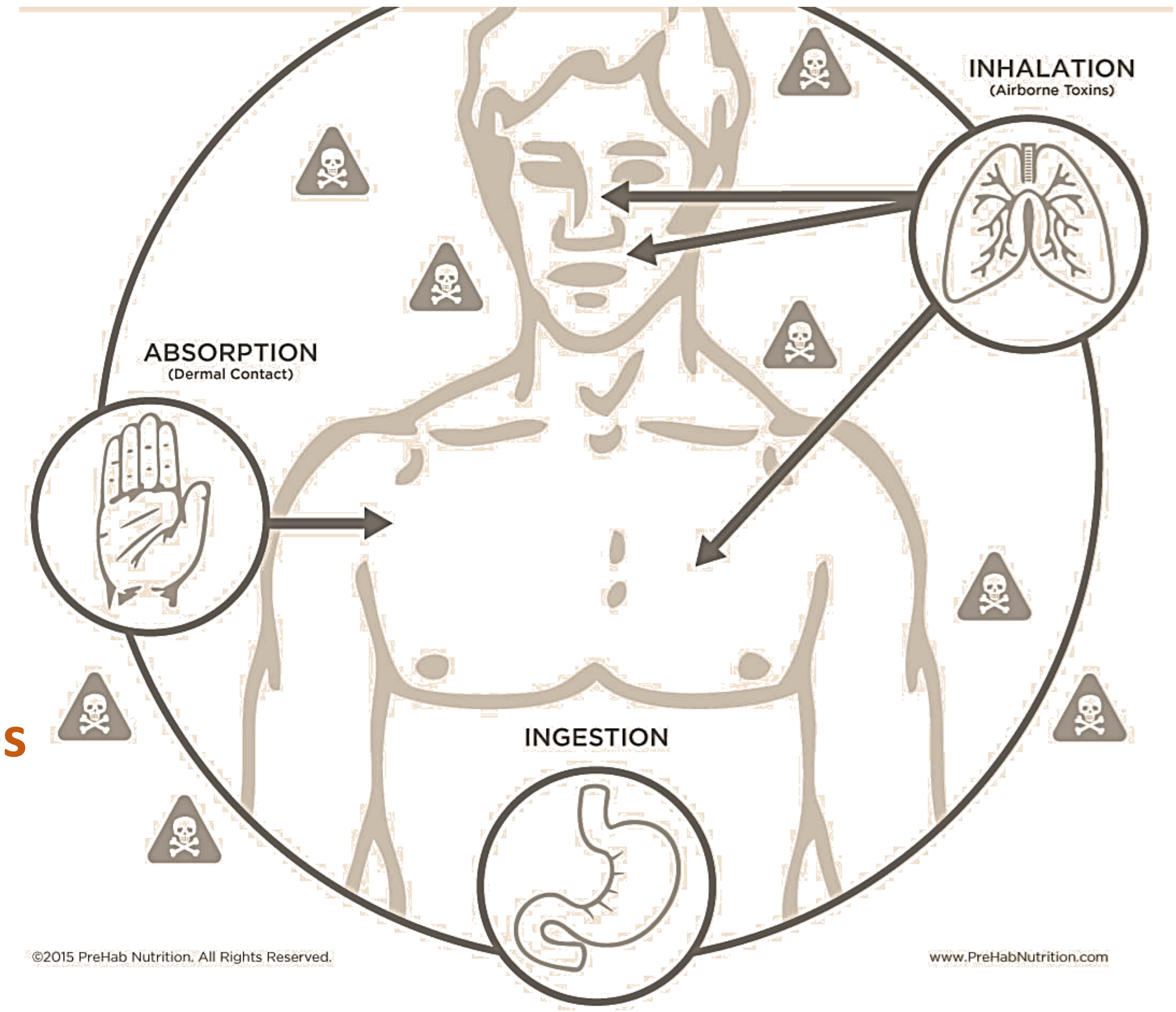
HEALTH RISK ASSESSMENT FRAMEWORK



Health risk assessment:

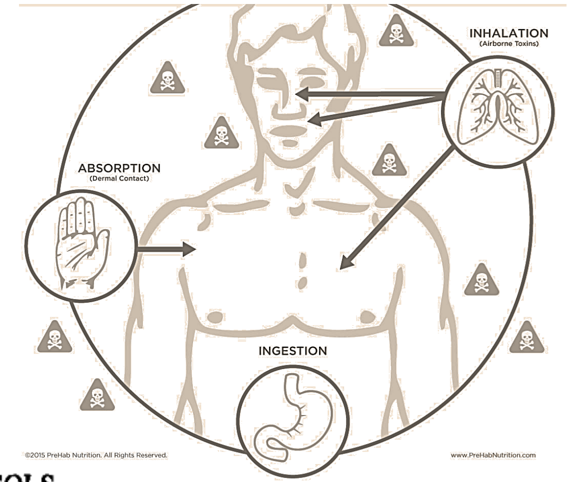
Environmental levels

Exposure is made through different routes



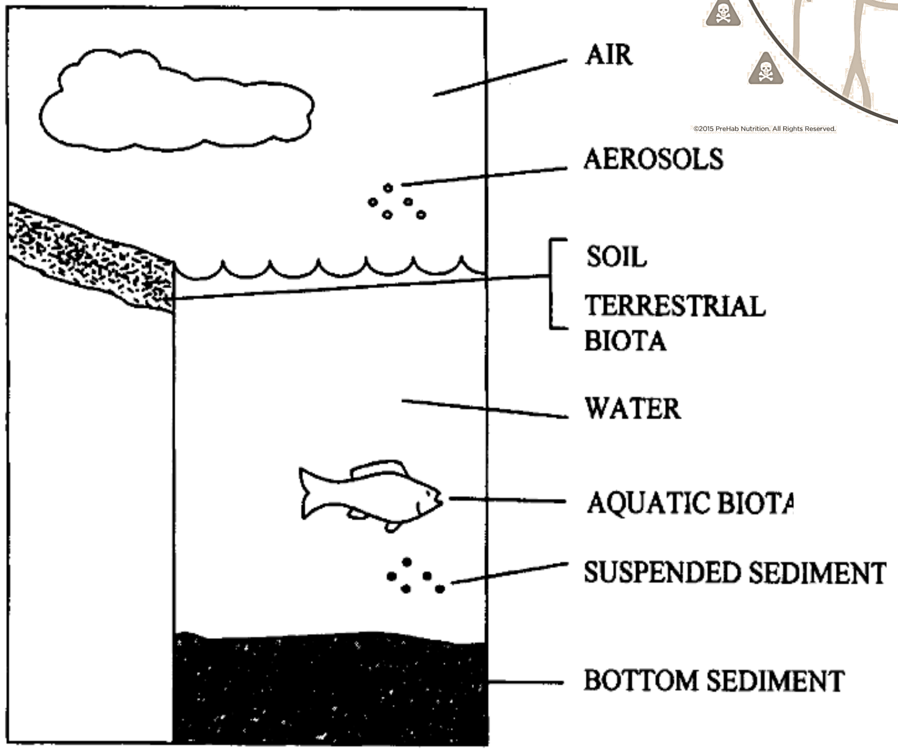
ESTIMATE ENVIRONMENTAL CONCENTRATIONS

Use models to complement environmental data



Fugacity approach (Lewis (1901):

Given a concentration in one phase, what will be the concentration in another phase that has been in contact with it long enough to achieve equilibrium?



-Compartment Environment

Mackay, D., 1991. Multimedia environmental models: the fugacity approach. CRC Press, Boca Raton, FL, USA.

ESTIMATE ENVIRONMENTAL CONCENTRATIONS

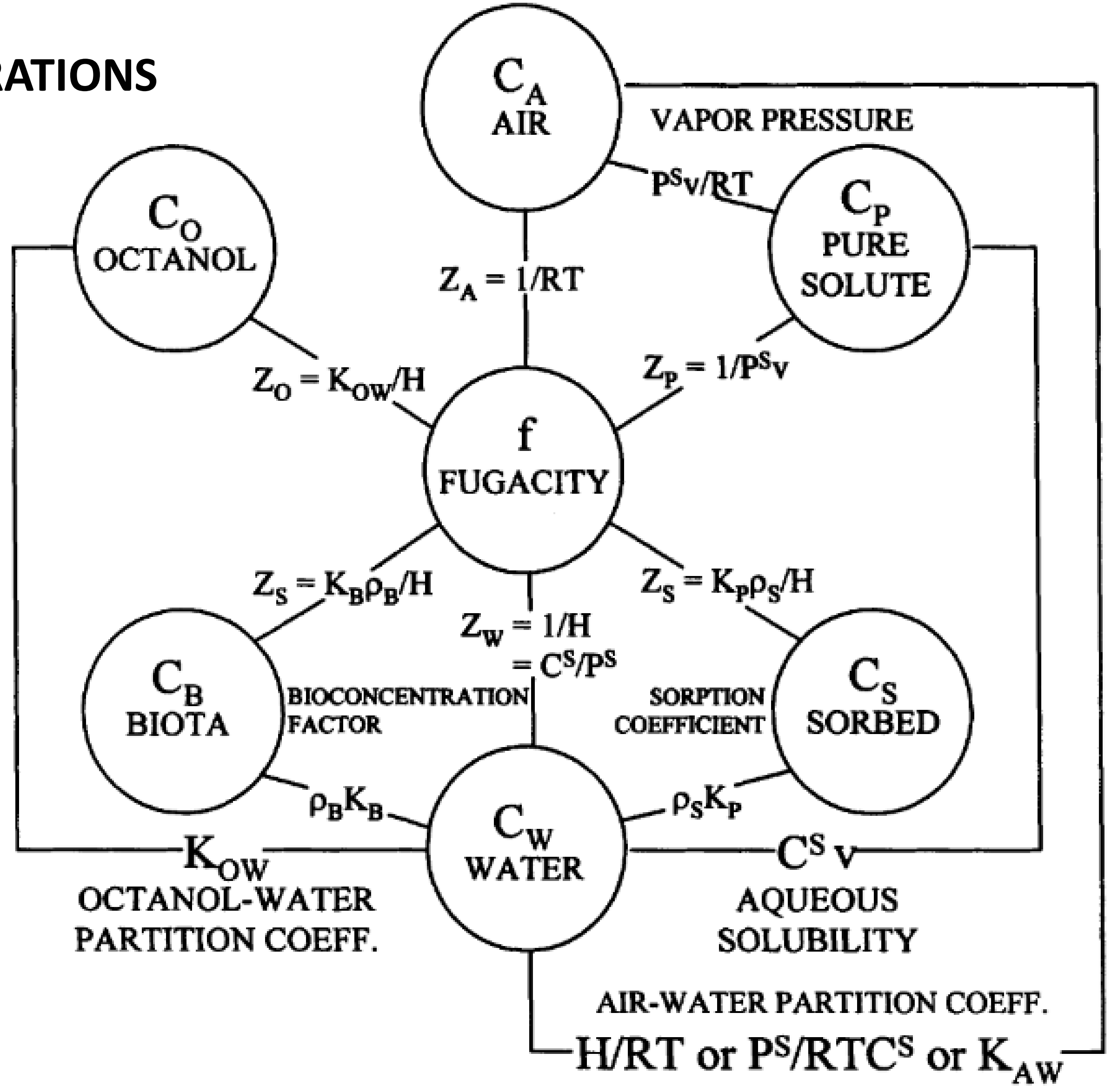
The multimedia equilibrium model:

Definition of Fugacity Capacities

Definition of Z (mol/m³ Pa)	
$1/RT$	R = 8.314 Pa m³/mol K T = temp. (K)
$1/H$ or C^S/P^S	C^S = aqueous solubility (mol/m³) P^S = vapor pressure (Pa) H = Henry's law constant (Pa m³/mol)
$K_P \rho_S/H$	K_P = partition coeff. (L/kg) ρ_S = density (kg/L)
$K_B \rho_S/H$	K_B = bioconcentration factor (L/kg) ρ_B = density (kg/L)
$1/P^S v$	v = solute molar volume (m³/mol)

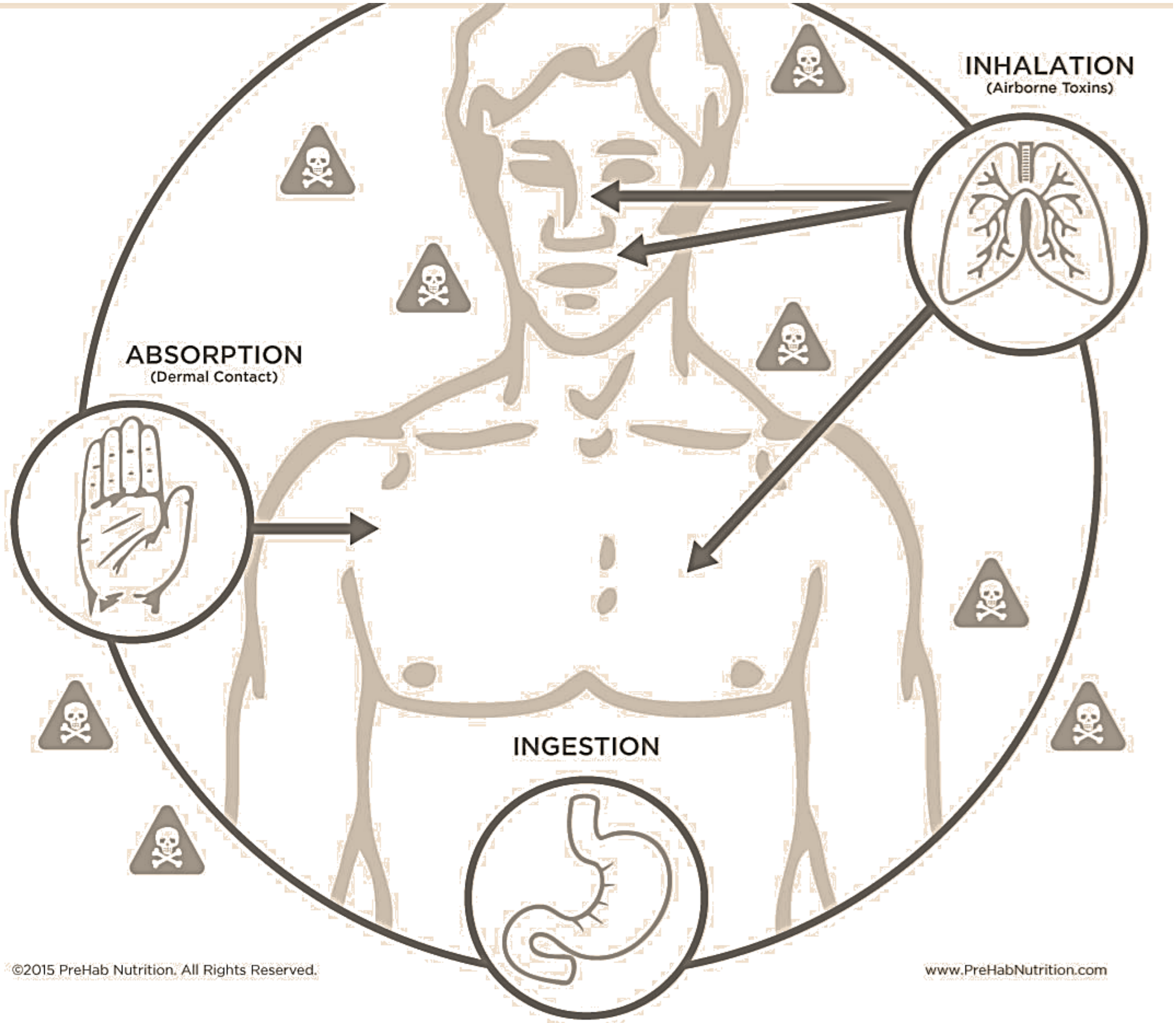
$$C = Z \cdot f$$

C = concentration (mol/m)
f   = fugacity (Pa)
Z = proportionality constant (*fugacity capacity*) (mol/mPa)



Health risk assessment:

Exposure



Risk is a function of exposure and hazard

EXPOSURE ASSESSMENT

Accidental sediment ingestion

$$ADD_{si} = \frac{C_s \cdot IRS \cdot CF_{km} \cdot EF_{dy} \cdot ED}{BW \cdot AT_c}$$

ADD_{si}	=	Average daily dose from incidental soil ingestion (mg/[kg·d])
C_s	=	Chemical concentration in soil (mg/kg)
IRS	=	Incidental soil ingestion rate (mg/d) [child or adult]
CF_{km}	=	Conversion factor (10^{-6} kg/mg)
BW	=	Body weight (kg) [child or adult]
EF_{dy}	=	Exposure frequency (d/yr) [child or adult]
ED	=	Exposure duration (yr) [child or adult]
AT_c	=	Averaging time, carcinogens (d)

Occupational contact with sediment

$$ADD_{sd} = \frac{DA_{soil} \cdot SA \cdot EF_{evd} \cdot EF_{dy} \cdot ED}{BW \cdot AT_c}$$

ADD_{sd}	=	Absorbed daily dose from contact with soil (mg/[kg·d])
SA	=	Exposed skin surface area (cm^2)

EXPOSURE ASSESSMENT

Occupational contact with water

$$ADD_{wd} = \frac{DA_{water} \cdot SA \cdot EF_{evd} \cdot EF_{dy} \cdot ED}{BW \cdot AT_c}$$

$$DA_{water} = 2 \cdot K_p \cdot (C_w \cdot CF_{cl}) \cdot \sqrt{\frac{6 \cdot \tau \cdot t_{event}}{\pi}}, \text{ for } t_{event} < t^*$$

$$DA_{water} = K_p \cdot (C_w \cdot CF_{cl}) \cdot \left[\frac{t_{event}}{1+B} + 2\tau \cdot \left(\frac{1+3B+3B^2}{(1+B)^2}\right)\right], \text{ for } t_{event} > t^*$$

$$\log K_p(\text{organics}) = -2.72 + 0.71 \cdot \log K_{ow} - 0.0061 \cdot MW$$

ADD_{wd}	=	Absorbed daily dose from contact with water (mg/[kg·d])
EF_{evd}	=	Event frequency (events/d)
DA_{water}	=	Dose absorbed per unit area per water contact event (mg/cm^2·event)
C_w	=	Contaminant concentration in water (mg/L)
CF_{cl}	=	Conversion factor (10^{-3} L/cm^3)
t_{event}	=	Duration of exposure event (hr/event)
K_p	=	Dermal permeability coefficient (cm/hr) [10^{-3} for inorganics]
τ	=	Lag time (hr/event)
t*	=	Time to reach steady-state (hr)
B	=	Relative contribution of permeability coefficients (unitless)
K_{ow}	=	*n*-Octanol-water partition coefficient
MW	=	Contaminant-specific molecular weight (g/mol)

EXPOSURE ASSESSMENT

Inhalation of vaporized contaminant

$$ADC_{av} = \frac{C_a \cdot (ET / 24hr / day) \cdot EF \cdot ED}{AT_c}$$

ADC_{av}	=	Average daily concentration from inhalation of vaporized contaminant (mg/m^3)
C_a	=	Contaminant concentration in air (mg/m^3)
C_s	=	Contaminant concentration in soil (mg/kg)

Ingestion of Fish/Shellfish

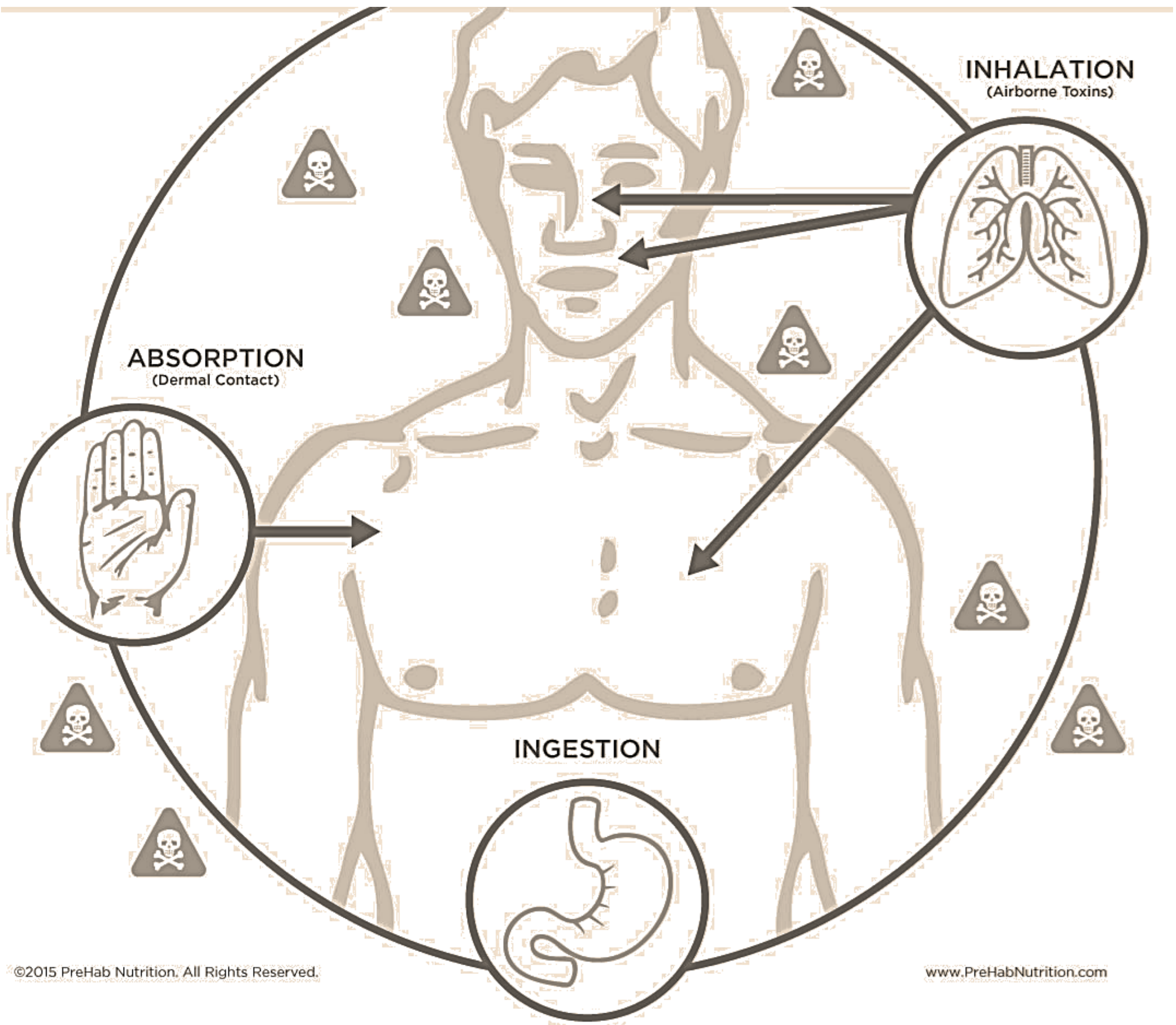
$$ADD_f = \frac{C_f \cdot IRF_{adj} \cdot F_f \cdot CF_{gg} \cdot EF_{dy}}{AT_c}$$

ADD_f	=	Average daily dose from ingestion of local fish (mg/[kg·d])
C_f	=	Concentration of contaminant in finfish (mg/kg)
F_f	=	Fraction of finfish obtained from site (unitless)
CF_{gg}	=	Conversion factor ($kg/10^3$ g)

Health risk assessment:

Characterization

Risk is a function of exposure and hazard



RISK CHARACTERIZATION

Excess Lifetime Cancer Risk (ELCR) due to inhalation of vaporized contaminant

$$ELCR = ADC_{av}\ (\mu g/m^3) \times IUR\ (\mu g/m^3)^{-1}$$

IUR = Inhalation unit risk (risk per $\mu g/m^3$)

Excess Lifetime Cancer Risk (ELCR) due to the remaining routes of exposure

$$ELCR = CDI\ (mg/kg/day) \times SF\ (mg/kg/day)^{-1}$$

$$CDI = \sum ADD_i$$

SF = Carcinogenic Slope Factor $(mg/kg/day)^{-1}$ = 1.5 $(mg/kg/d)^{-1}$

COASTAL LAGOON (RIA FORMOSA)

SOUTH PORTUGAL

System of barrier islands that communicates with the sea through six inlets.

Case-study

Ria Formosa lagoon

Area: 14 500 ha

Extension: 55 km

Average depth: 3 m

Salinity: 35.5 – 36.9%o

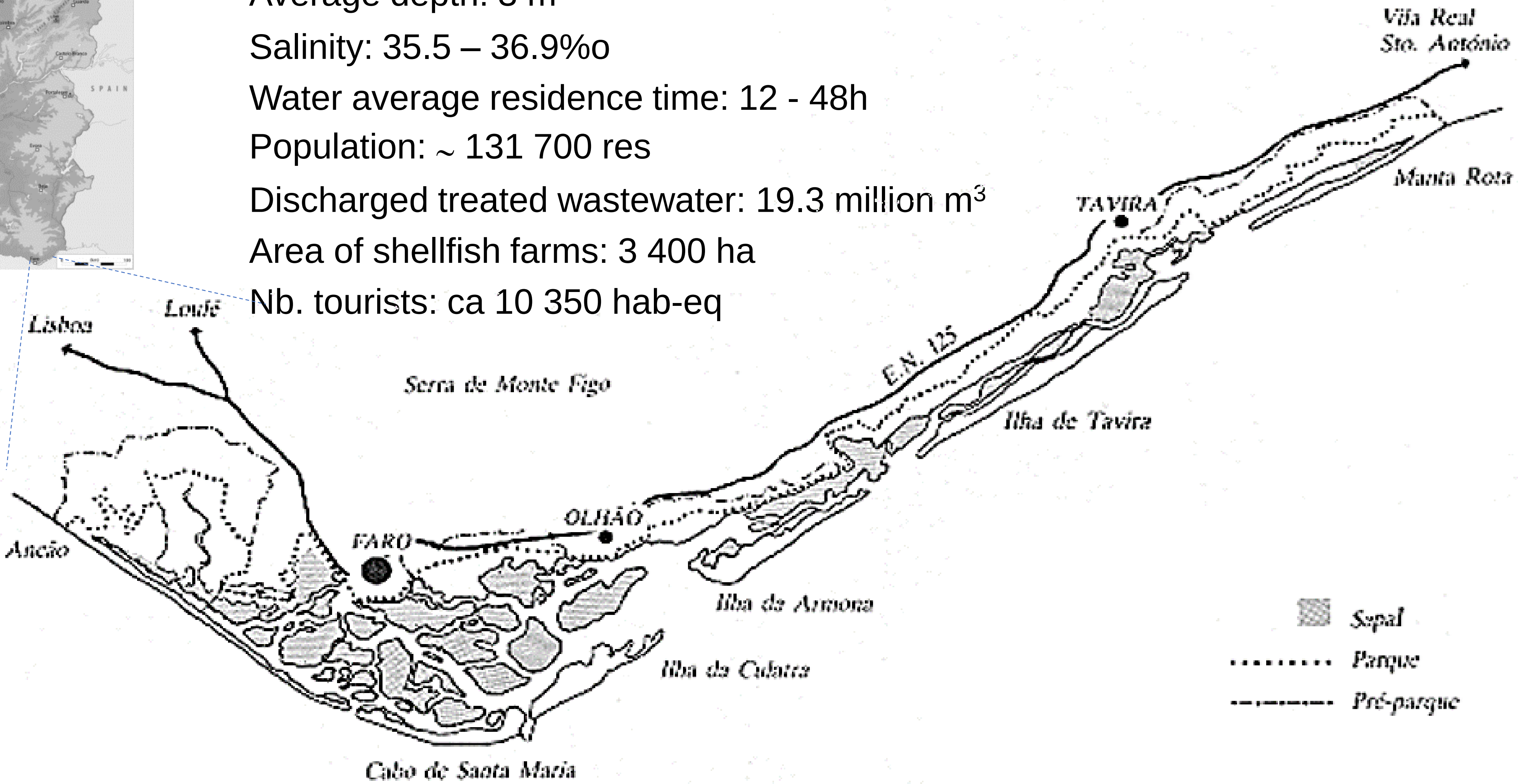
Water average residence time: 12 - 48h

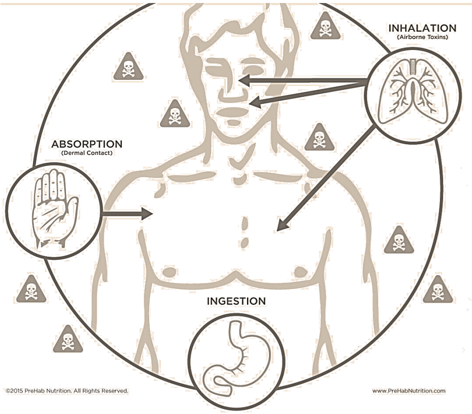
Population: ~ 131 700 res

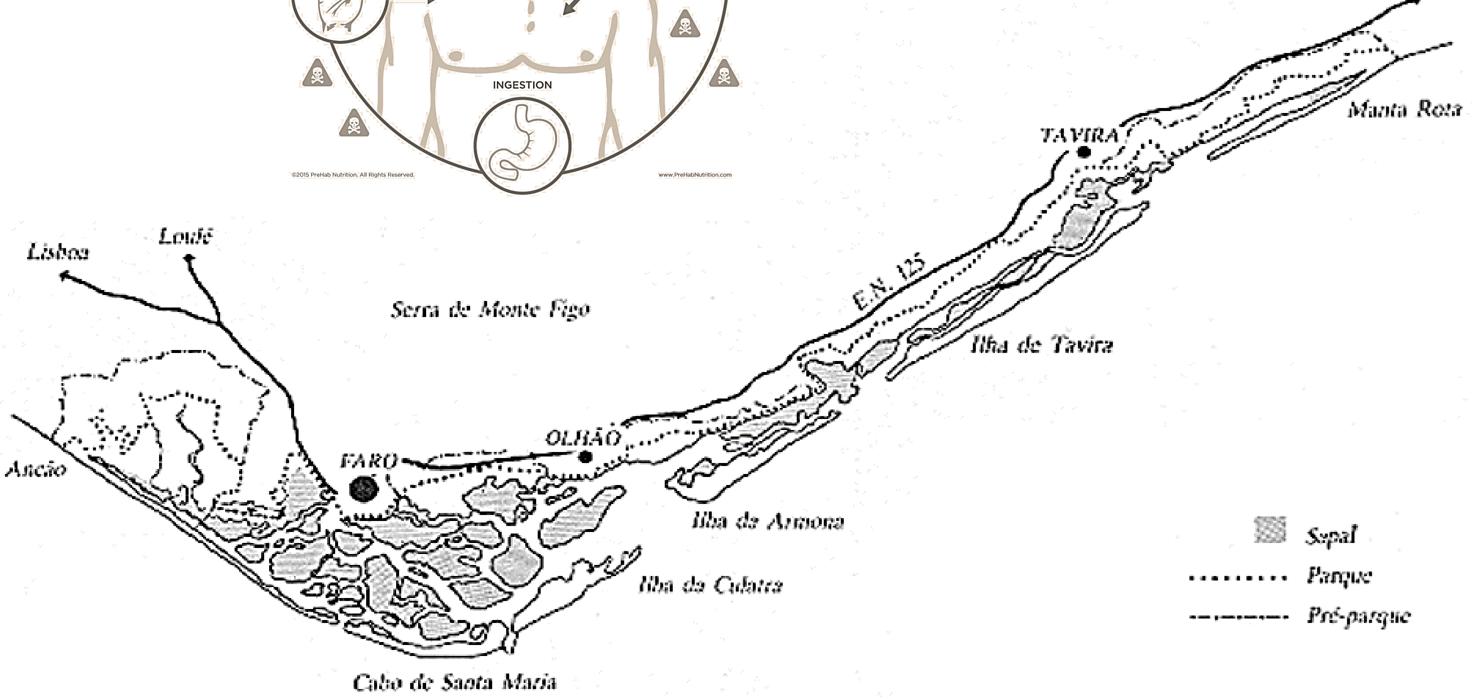
Discharged treated wastewater: 19.3 million m^3

Area of shellfish farms: 3 400 ha

Nb. tourists: ca 10 350 hab-eq



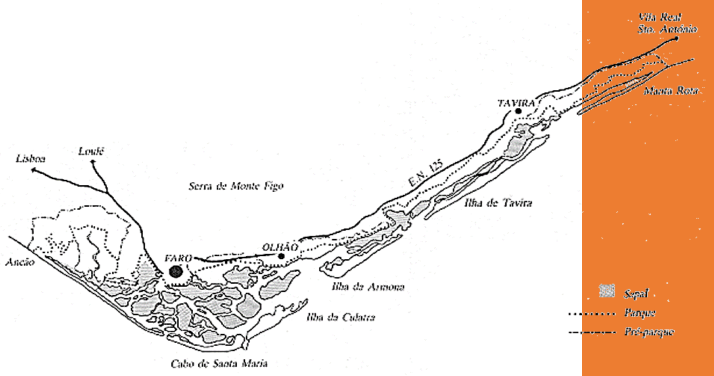




Health risk assessment:

Environmental levels

CASE STUDY



PAH concentration in sediment

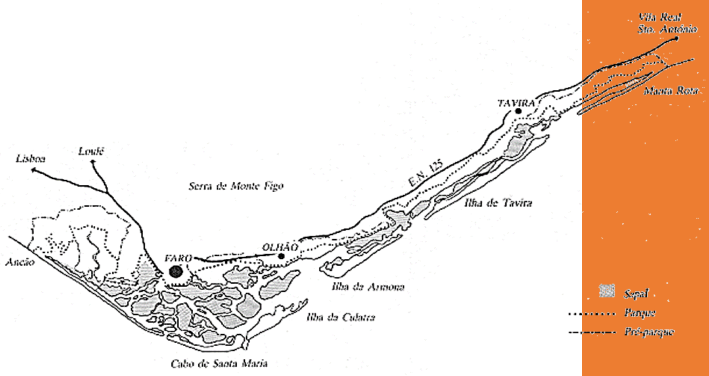
PAHs (ng/g^{-1} p.h)	Range	m±sd
Naftaleno	0,02 – 0,53	0,35 ± 0,20
Acenafteno	0,44 – 13,3	4,34 ± 3,48
Fluoreno	0,18 – 2,44	0,63 ± 0,52
Fenantreno	0,14 – 3,17	0,70 ± 0,63
Antraceno	0,04 – 0,83	0,14 ± 0,18
Fluoranteno	0,07 – 9,90	0,22 ± 2,06
Pireno	0,08 – 5,87	1,00 ± 1,45
Benzo[a]antraceno	0,05 – 4,79	0,89 ± 1,25
Criseno	0,04 – 4,19	0,50 ± 0,87
Benzo[b]fluoranteno	0,06 – 5,41	0,84 ± 1,41
Benzo[k]fluoranteno	0,01 – 3,2	0,55 ± 0,93
Benzo[a]pireno	0,02 – 6,22	1,44 ± 2,12
Dibenzo[a,h]antraceno	0,01 – 26,5	5,44 ±0,50
Benzo[g,h,i]perileno	0,01 – 4,14	2,08±2,98
Indeno[1,2,3cd]pireno	0,01 – 0,99	0,43± 0,50
tPAHs (ng/g^{-1} p.s)	1,01- 66,3	9,51±14,27

in water

PAHs (µg/L)	m
Naftaleno	<0,008
Acenafteno	<0,010
Acenaftileno	<0,010
Fluoreno	<0,010
Fenantreno	<0,010
Antraceno	<0,001
Fluoranteno	<0,023
Pireno	<0,010
Benzo[a]antraceno	<0,01
Criseno	<0,010
Benzo[b]fluoranteno	<0,011
Benzo[k]fluoranteno	<0,012
Benzo[a]pireno	<0,03
Dibenzo[a,h]antraceno	<0,005
Benzo[g,h,i]perileno	<0,037
Indeno[1,2,3cd]pireno	<0,01

CASE STUDY

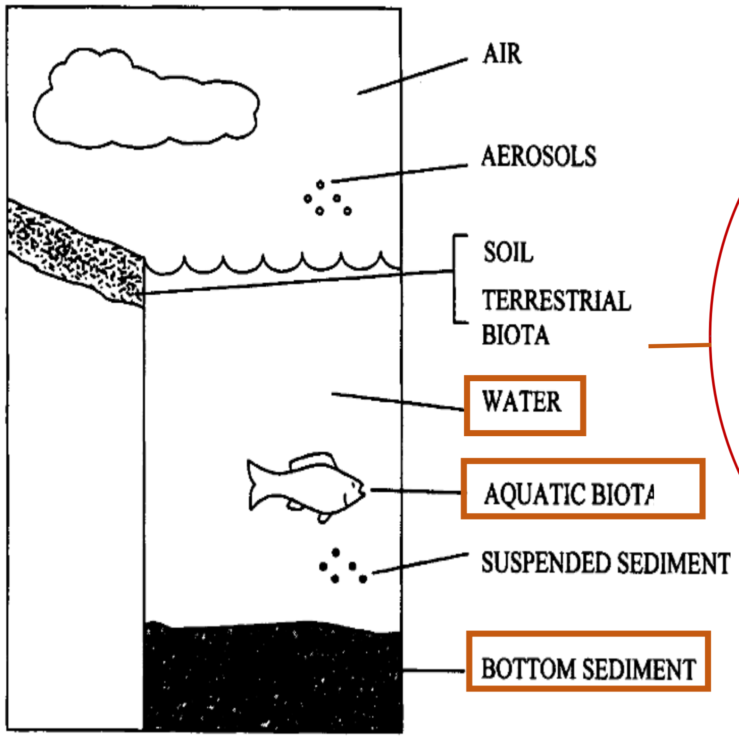
PAH concentration in shellfish



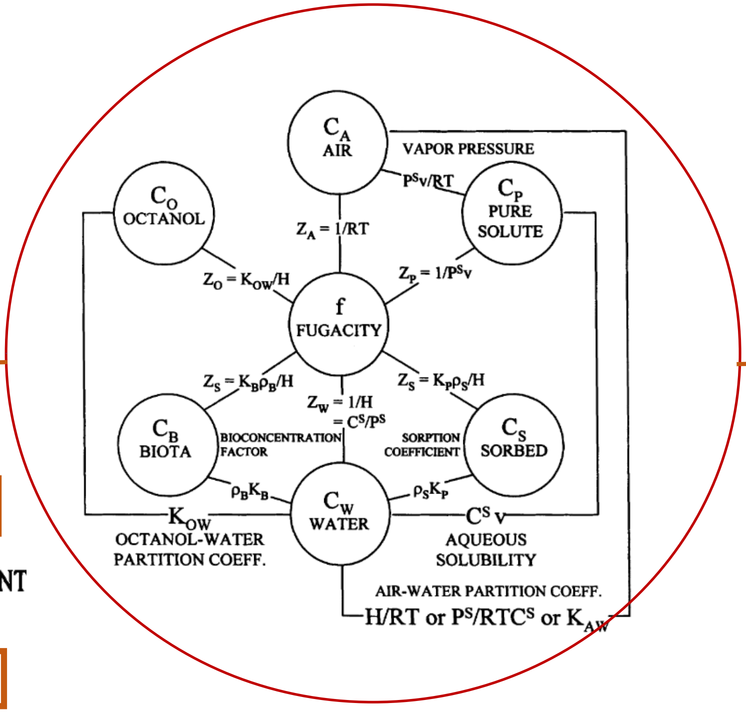
PAHs (ng/g^{-1} p.h)		Range	m±sd
Naftaleno	*Ruditapes decussatus*	0,12- 6,97	2,01± 2,4
Acenafteno		0,39 – 74,1	19,99± 23,69
Acenaftileno		1,47 – 58,5	19,2 ±22,77
Fluoreno		0,33 – 9,96	3,47 ± 4,44
Fenantreno		0,24 – 64,6	10,16 ± 10,83
Fluoranteno		3,42 – 110	17,31 ± 16,23
Pireno		3,07 – 138	17,49 ± 22,62
Benzo[a]antraceno		4,21 – 212	51,38 ± 51,31
Criseno		2,01 – 159	35,19 ± 37,97
Benzo[b]fluoranteno		2,53 – 104	16,69 ± 20
Benzo[k]fluoranteno		0,23 – 47,5	11,37 ± 18,38
Benzo[a]pireno		0,4 – 122	25,90 ± 39,94
Dibenzo[a,h]antraceno		0,01 – 312	29,62 ± 73.32
Benzo[g,h,i]perileno		0,02 – 161	10,17 ± 36,68
Indeno[1,2,3cd]pireno		0,01 - 49	2,18 ± 8,47
tPAHs	*Ruditapes decussatus*	30,4 - 1191	204,92 ± 216,68
tPAHs	*Mytilus galloprovincialis* (ng/g^{-1} p.s)	49,3 - 911	260,9 ± 304,34
		145 - 2291	648,13 ± 531

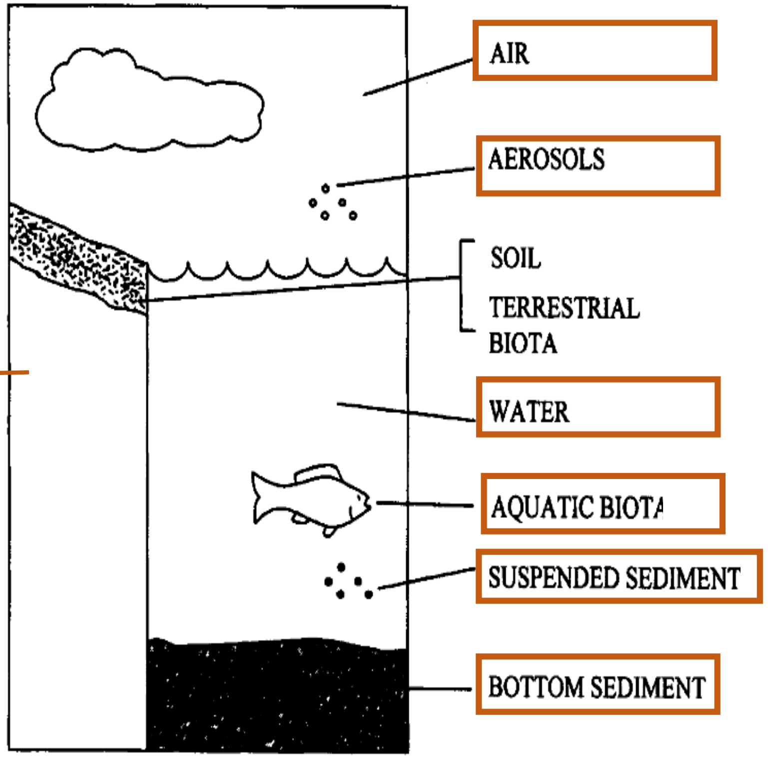
CASE STUDY

The multimedia equilibrium model:



-Compartment Environment





-Compartment Environment

ESTIMATE ENVIRONMENTAL CONCENTRATIONS

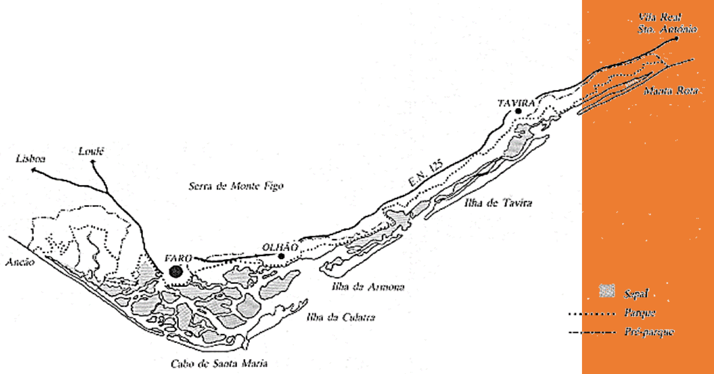
The multimedia equilibrium model:

Information about the media and substance: introduced by the modeller

Compartment	*Air*	*Water*	*Soil*	*Sediment*
Volume m^3 (V)	6×10^9	7×10^6	45000	21000
Z	4×10^{-4}	0.1	12.3	24.6
VZ	2.4×10^6	7×10^5	5.5×10^5	5.17×10^5
Reaction half life (h)t	∞	693	69.3	6930
Rate constant $k = 0.693/t$ (h^{-1})	0	0.001	0.01	0.0001
Advective flow G m^3/h	10^7	1000	0	0
D reaction = VZk = D_R	0	700	5535	51.7
D advection = GZ = D_A	4000	100	0	0
$D_R + D_A = D_T$	4000	800	5535	51.7
Total D value = ΣD_T =	*10387*	Fugacity $f = I/\Sigma D$ =	$120/10387 = 1.15 \times 10^{-2}$	
C = Z f mil/m^3	4.6×10^{-6}	1.15×10^{-3}	*0.14*	*0.28*
m = C V mol				
Percent				
C_G g/m^3, i.e., C_W				
Density ρ kg/m^3				
C_U μg/g, i.e., $C_G \times 1000/\rho$	0.79	0.23	19	38

Calculated

CASE STUDY



Environmental concentrations (mean error= 0.15%)

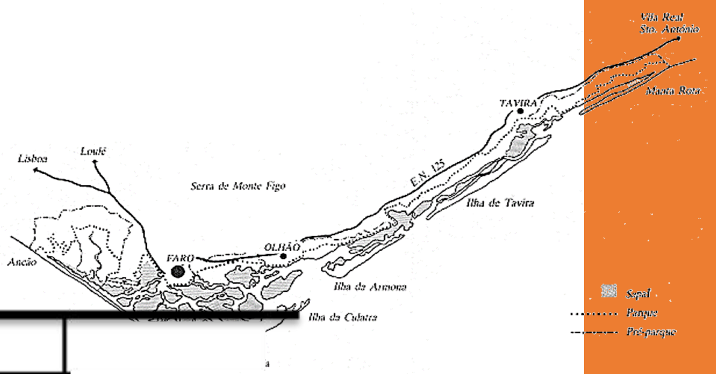
PAH	Shellfish µg/g	Sediment µg/g	Water g/m^3	Air g/m^3	Soil g/m^3
Naphthalene	2,00x10^{-03}	3,56x10^{-05}	1,16x10^{-06}	9,44x10^{-11}	2,42x10^{-07}
Acenaphthylene	1,92x10^{-02}	4,92x10^{-05}	2,51x10^{-06}	2,58x10^{-11}	1,44x10^{-08}
Acenaphtene	2,01x10^{-02}	1,12x10^{-04}	2,72x10^{-06}	1,49x10^{-10}	2,02x10^{-07}
Fluorene	3,51x10^{-03}	5,00x10^{-05}	2,59x10^{-07}	2,47x10^{-11}	2,54x10^{-08}
Phenanthrene	1,04x10^{-02}	8,75x10^{-05}	4,26x10^{-07}	1,23x10^{-09}	1,81x10^{-06}
Anthracene	1,43x10^{-03}	1,09x10^{-06}	6,08x10^{-08}	3,49x10^{-14}	1,04x10^{-08}
Fluoranthene	1,75x10^{-02}	2,16x10^{-05}	1,71x10^{-07}	1,86x10^{-12}	8,94x10^{-08}
Pyrene	1,74x10^{-02}	2,16x10^{-05}	2,91x10^{-07}	6,47x10^{-14}	3,89x10^{-08}
Benzo(a)anthracene	5,10x10^{-02}	6,29x10^{-05}	1,95x10^{-07}	6,55x10^{-14}	2,68x10^{-08}
Chrysene	3,56x10^{-02}	3,99x10^{-04}	1,36x10^{-07}	5,05x10^{-16}	1,12x10^{-08}
Benzo(b)fluoranthene	1,60x10^{-02}	4,50x10^{-05}	1,44x10^{-07}	1,62x10^{-14}	1,91x10^{-08}
Benzo(k)fluoranthene	1,16x10^{-02}	1,43x10^{-04}	3,42x10^{-08}	1,29x10^{-16}	2,48x10^{-10}
Benzo(a)pyrene	2,67x10^{-02}	2,93x10^{-04}	7,68x10^{-08}	3,78x10^{-23}	7,87x10^{-13}
Dibenzo(a,h)anthracene	2,95x10^{-02}	4,58x10^{-03}	6,89x10^{-07}	1,55x10^{-17}	2,72x10^{-10}
Benzo(g,h,i)perylene	1,01x10^{-02}	1,25x10^{-05}	2,39x10^{-08}	1,91x10^{-17}	3,42x10^{-10}
Indene(1,2,3 cd)pyrene	2,23x10^{-02}	2,70x10^{-03}	5,18x10^{-09}	4,14x10^{-18}	7,41x10^{-12}

Health risk estimated for fish farmers

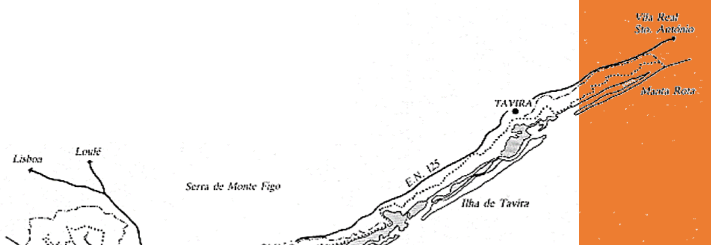
Health risk assessment:

Characterization

CASE STUDY



PAH	Exposure					ELCR
	Air	Water	Shelfish	Sediment	Σ	
Naphthalene	$7{,}39 \times 10^{-11}$	$8{,}24 \times 10^{-08}$	$7{,}58 \times 10^{-08}$	$1{,}02 \times 10^{-13}$	$1{,}58 \times 10^{-07}$	$1{,}58 \times 10^{-10}$
Acenaphthylene	$2{,}02 \times 10^{-11}$	-	$7{,}28 \times 10^{-07}$	$6{,}09 \times 10^{-15}$	$7{,}28 \times 10^{-07}$	$7{,}28 \times 10^{-10}$
Acenaphtene	$1{,}17 \times 10^{-10}$	-	$7{,}62 \times 10^{-07}$	$8{,}54 \times 10^{-14}$	$7{,}62 \times 10^{-07}$	$7{,}62 \times 10^{-10}$
Fluorene	$1{,}93 \times 10^{-11}$	-	$1{,}33 \times 10^{-07}$	$1{,}07 \times 10^{-14}$	$1{,}33 \times 10^{-07}$	$1{,}33 \times 10^{-10}$
Phenanthrene	$9{,}63 \times 10^{-10}$	$9{,}59 \times 10^{-08}$	$3{,}94 \times 10^{-07}$	$7{,}65 \times 10^{-13}$	$4{,}91 \times 10^{-07}$	$4{,}91 \times 10^{-10}$
Anthracene	$2{,}73 \times 10^{-14}$	-	$5{,}42 \times 10^{-08}$	$4{,}40 \times 10^{-15}$	$5{,}42 \times 10^{-08}$	$5{,}42 \times 10^{-09}$
Fluoranthene	$1{,}46 \times 10^{-12}$	$6{,}08 \times 10^{-08}$	$6{,}64 \times 10^{-07}$	$3{,}78 \times 10^{-14}$	$7{,}24 \times 10^{-07}$	$7{,}24 \times 10^{-10}$
Pyrene	$5{,}06 \times 10^{-14}$	-	$6{,}60 \times 10^{-07}$	$1{,}64 \times 10^{-14}$	$6{,}60 \times 10^{-07}$	$6{,}60 \times 10^{-10}$
Benzo(a)anthracene	$5{,}13 \times 10^{-14}$	$1{,}50 \times 10^{-07}$	$1{,}93 \times 10^{-06}$	$1{,}13 \times 10^{-14}$	$2{,}08 \times 10^{-06}$	$2{,}08 \times 10^{-07}$
Chrysene	$3{,}95 \times 10^{-16}$	$1{,}05 \times 10^{-07}$	$1{,}35 \times 10^{-06}$	$4{,}74 \times 10^{-15}$	$1{,}45 \times 10^{-06}$	$1{,}45 \times 10^{-08}$
Benzo(b)fluoranthene	$1{,}27 \times 10^{-14}$	$1{,}11 \times 10^{-07}$	$4{,}47 \times 10^{-07}$	$8{,}08 \times 10^{-15}$	$5{,}58 \times 10^{-07}$	$5{,}58 \times 10^{-08}$
Benzo(k)fluoranthene	$1{,}01 \times 10^{-19}$	$2{,}63 \times 10^{-08}$	$4{,}40 \times 10^{-07}$	$1{,}05 \times 10^{-16}$	$4{,}66 \times 10^{-07}$	$4{,}66 \times 10^{-08}$
Benzo(a)pyrene	$2{,}96 \times 10^{-23}$	$9{,}10 \times 10^{-08}$	$1{,}01 \times 10^{-06}$	$3{,}33 \times 10^{-19}$	$1{,}10 \times 10^{-06}$	$1{,}10 \times 10^{-06}$
Dibenzo(a,h)anthracene	$1{,}21 \times 10^{-17}$	$1{,}92 \times 10^{-06}$	$1{,}12 \times 10^{-06}$	$1{,}15 \times 10^{-16}$	$3{,}04 \times 10^{-06}$	$3{,}04 \times 10^{-06}$
Benzo(g,h,i)perylene	$1{,}50 \times 10^{-17}$	-	$3{,}83 \times 10^{-07}$	$1{,}45 \times 10^{-16}$	$3{,}83 \times 10^{-07}$	$3{,}83 \times 10^{-09}$
Indene(1,2,3 cd)pyrene	$3{,}24 \times 10^{-18}$	$9{,}51 \times 10^{-09}$	$8{,}45 \times 10^{-07}$	$3{,}13 \times 10^{-18}$	$8{,}55 \times 10^{-07}$	$8{,}55 \times 10^{-08}$



CASE STUDY

Table 3: Willingness to pay for a 1 in 1,000,000 risk reduction, by health threat (two scenarios, income = $42,000) [a]

Profile	Sudden Death Now			10 year latency; sick 5 years, then death		
Health Threat						
Age now	**30**	**45**	**60**	**30**	**45**	**60**
Breast Cancer	7.87 (4.65, 11.34)	8.39 (5.89, 11.25)	6.98 (4.56, 9.57)	8.66 (6.6, 11.04)	6.64 (4.08, 8.35)	4.44 (2.93, 6.03)
Prostate Cancer	7.38 (4.22, 10.74)	7.78 (5.29, 10.58)	6.4 (3.82, 9.08)	7.25 (5.26, 9.42)	5.65 (4.1, 7.44)	4.05 (2.62, 5.69)
Colon Cancer	4.46 (1.76, 7.32)	4.88 (3.09, 6.91)	3.47 (1.72, 5.35)	6.32 (4.67, 8.15)	4.76 (3.6, 6.03)	3.09 (2.03, 4.26)
Lung Cancer	.95 (-2.3, 3.14)	0.97 (-1.05, 2.74)	0.22 (-2.49, 1.29)	2.36 (0.8, 3.99)	0.78 (-0.53, 1.92)	0.04 (-2.34, .3)
…* smoker	10.59 (7.18, 14.26)	11.05 (8.32, 14.21)	9.62 (7, 12.79)	12.43 (9.75, 15.7)	10.93 (8.58, 13.59)	9.24 (7.22, 11.86)

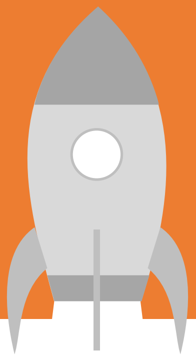
$$\boldsymbol{Amount}\ a\ population\ would\ be\ \boldsymbol{willing\ to\ pay\ to\ save\ one\ statistical\ life}\ in\ a\ year =$$

$$= \boldsymbol{WTP} \cdot \boldsymbol{ELCR} \cdot \boldsymbol{res}$$

e.g., 8.66 ($/pm/res) · 1.1 (pm) · 600 (res) = **5 700 $/year**

Or for the total population, = M€ 1.25/year

Cameron, T. A., DeShazo, J. R., & Johnson, E. H. (2008). Willingness to pay for health risk reductions:Differences by type of illness. Department of Economics, University of Oregon.



Thank you!!