Update of AQUATRIT, USER approach, what to do with irrigation

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EMRAS II
Approaches for Assessing Emergency Situations
Working Group 7
“Tritium” Accidents
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USER QUESTIONS

Did I need?

Yes, if your tritium sources are near
RIVERS, LAKES, close to ESTUARY or in COASTAL WATER

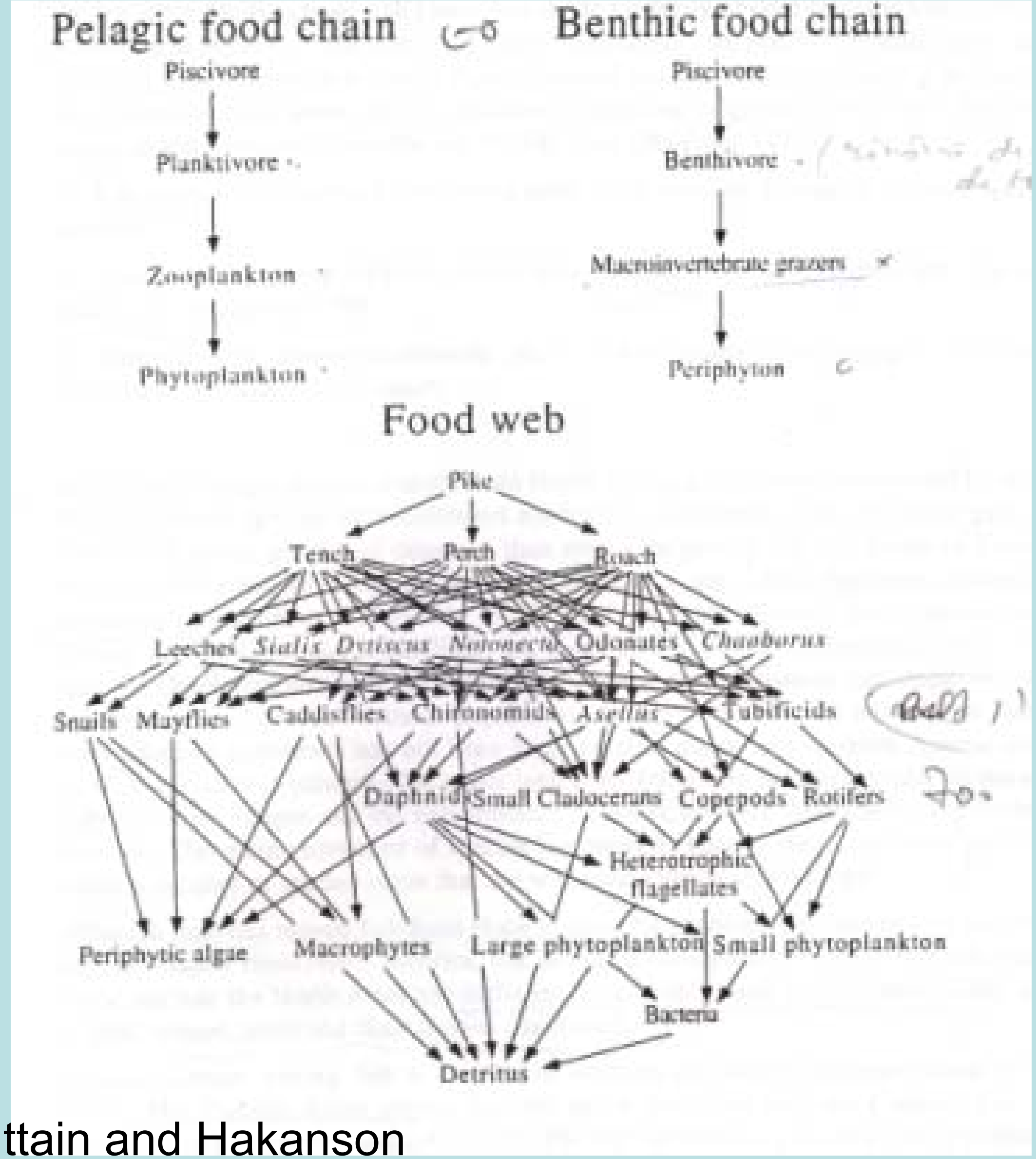
Can I trust the model?

NO, if the model can’t demonstrate a scientific basis and some tests with EXPERIMENTAL DATA

HOW TO USE?
Need a minimal scientific and practical knowledge AND a
model documentation explaining model basis, test and how to adapt
in various environment and management practice

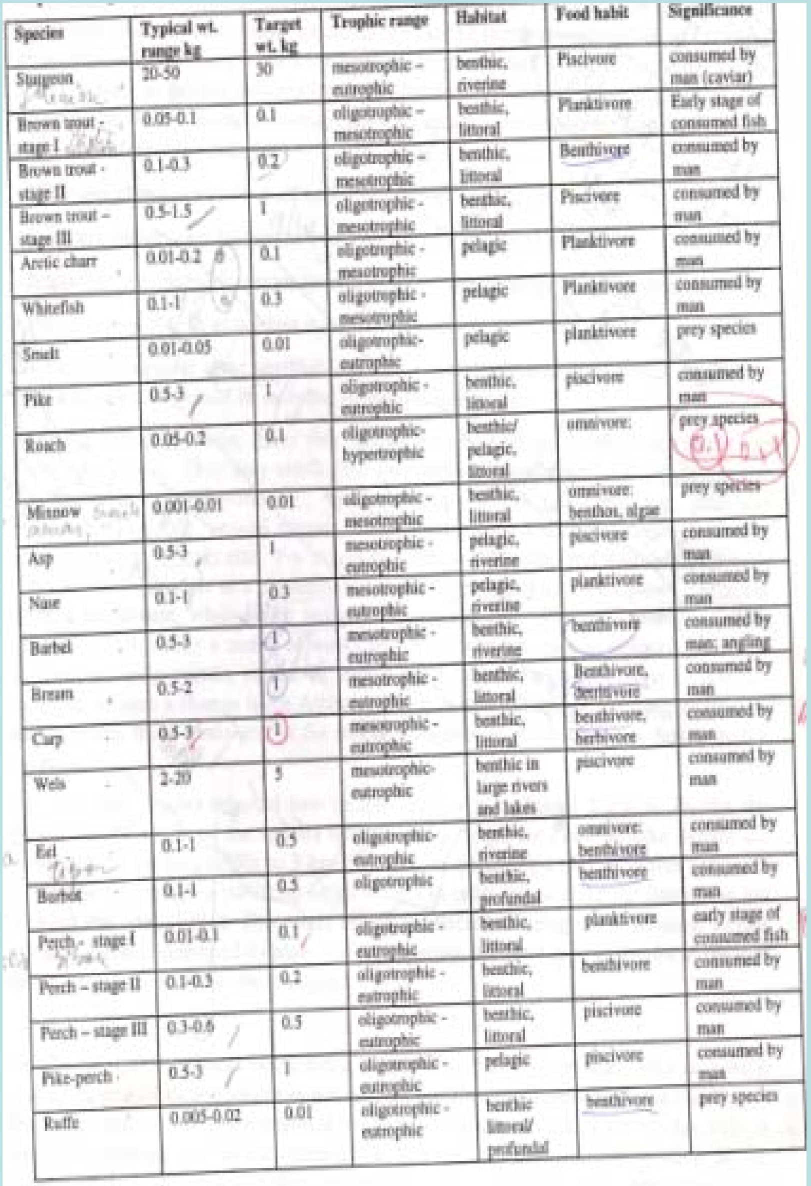
SCOPE of this presentation
A step to answer users question
NEED YOU IMPLICATION

FOOD CHAIN AND FOOD WEB



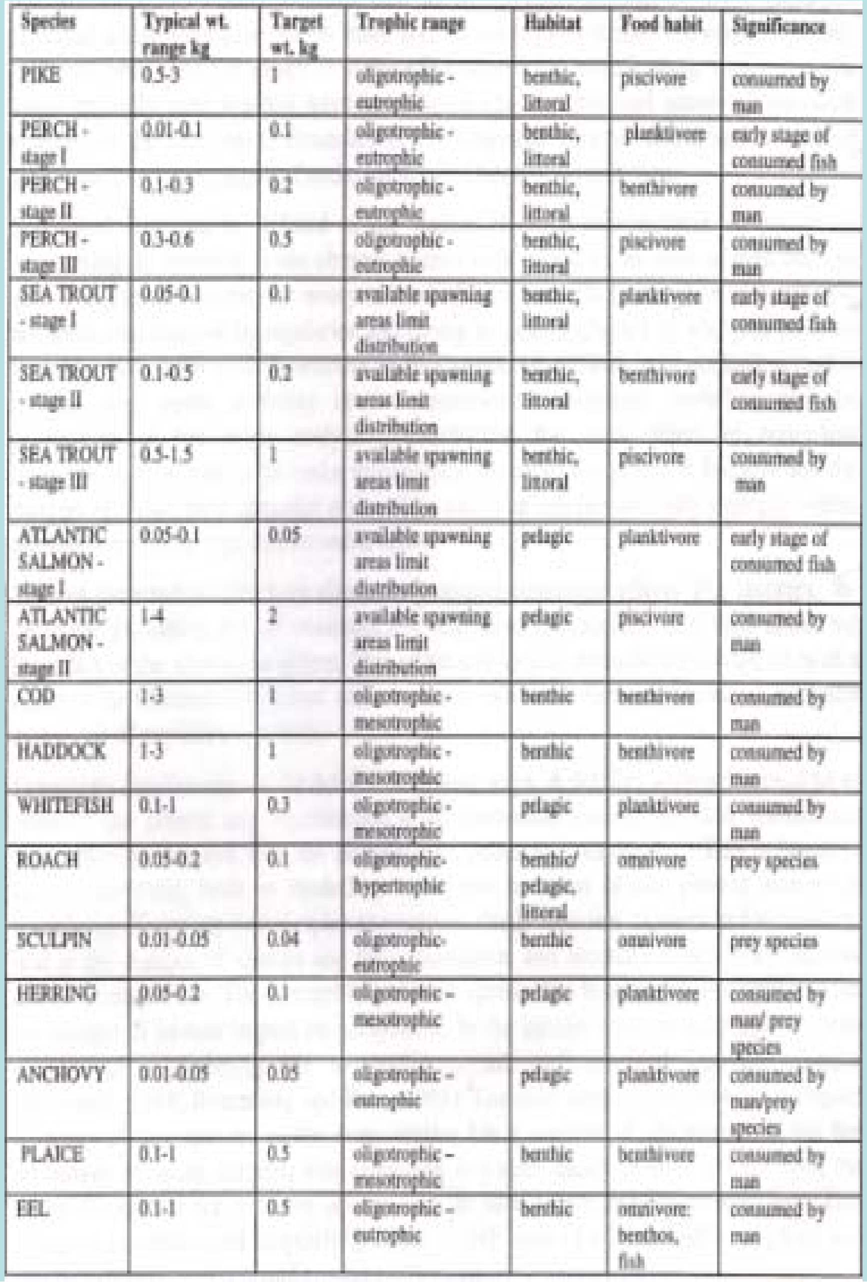
From Brittain and Hakanson

FISH FRESHWATER AND SALTWATER fish species of interest



Species	Typical wt. range kg	Target wt. kg	Trophic range	Habitat	Food habit	Significance
Sturgeon	20-50	30	mesotrophic – eutrophic	benthic, riverine	Piscivore	consumed by man (caviar)
Brown trout - stage I	0.05-0.1	0.1	oligotrophic – mesotrophic	benthic, littoral	Planktivore	Early stage of consumed fish
Brown trout - stage II	0.1-0.3	0.2	oligotrophic – mesotrophic	benthic, littoral	Benthivore	consumed by man
Brown trout – stage III	0.5-1.5	1	oligotrophic - mesotrophic	benthic, littoral	Piscivore	consumed by man
Arctic charr	0.01-0.2	0.1	oligotrophic - mesotrophic	pelagic	Planktivore	consumed by man
Whitefish	0.1-1	0.3	oligotrophic - mesotrophic	pelagic	Planktivore	consumed by man
Smelt	0.01-0.05	0.01	oligotrophic-eutrophic	pelagic	planktivore	prey species
Pike	0.5-3	1	oligotrophic - eutrophic	benthic, littoral	piscivore	consumed by man
Roach	0.05-0.2	0.1	oligotrophic-hypertrophic	benthic/ pelagic, littoral	omnivore:	prey species
Minnow	0.001-0.01	0.01	oligotrophic - mesotrophic	benthic, littoral	omnivore: benthos, algae	prey species
Asp	0.5-3	1	mesotrophic - eutrophic	pelagic, riverine	piscivore	consumed by man
Nase	0.1-1	0.3	mesotrophic - eutrophic	pelagic, riverine	planktivore	consumed by man
Barbel	0.5-3	1	mesotrophic - eutrophic	benthic, riverine	benthivore	consumed by man; angling
Bream	0.5-2	1	mesotrophic - eutrophic	benthic, littoral	Benthivore, herbivore	consumed by man
Carp	0.5-3	1	mesotrophic - eutrophic	benthic, littoral	benthivore, herbivore	consumed by man
Wels	2-20	5	mesotrophic-eutrophic	benthic in large rivers and lakes	piscivore	consumed by man
Eel	0.1-1	0.5	oligotrophic-eutrophic	benthic, riverine	omnivore: benthivore	consumed by man
Burbot	0.1-1	0.5	oligotrophic	benthic, profundal	benthivore	consumed by man
Perch - stage I	0.01-0.1	0.1	oligotrophic - eutrophic	benthic, littoral	planktivore	early stage of consumed fish
Perch – stage II	0.1-0.3	0.2	oligotrophic - eutrophic	benthic, littoral	benthivore	consumed by man
Perch – stage III	0.3-0.6	0.5	oligotrophic - eutrophic	benthic, littoral	piscivore	consumed by man
Pike-perch	0.5-3	1	oligotrophic - eutrophic	pelagic	piscivore	consumed by man
Ruffe	0.005-0.02	0.01	oligotrophic - eutrophic	benthic littoral/ profundal	benthivore	prey species

From Brittain and Hakanson



Species	Typical wt. range kg	Target wt. kg	Trophic range	Habitat	Food habit	Significance
PIKE	0.5-3	1	oligotrophic - eutrophic	benthic, littoral	piscivore	consumed by man
PERCH - stage I	0.01-0.1	0.1	oligotrophic - eutrophic	benthic, littoral	planktivore	early stage of consumed fish
PERCH - stage II	0.1-0.3	0.2	oligotrophic - eutrophic	benthic, littoral	benthivore	consumed by man
PERCH - stage III	0.3-0.6	0.5	oligotrophic - eutrophic	benthic, littoral	piscivore	consumed by man
SEA TROUT - stage I	0.05-0.1	0.1	available spawning areas limit distribution	benthic, littoral	planktivore	early stage of consumed fish
SEA TROUT - stage II	0.1-0.5	0.2	available spawning areas limit distribution	benthic, littoral	benthivore	early stage of consumed fish
SEA TROUT - stage III	0.5-1.5	1	available spawning areas limit distribution	benthic, littoral	piscivore	consumed by man
ATLANTIC SALMON - stage I	0.05-0.1	0.05	available spawning areas limit distribution	pelagic	planktivore	early stage of consumed fish
ATLANTIC SALMON - stage II	1-4	2	available spawning areas limit distribution	pelagic	piscivore	consumed by man
COD	1-3	1	oligotrophic - mesotrophic	benthic	benthivore	consumed by man
HADDOCK	1-3	1	oligotrophic - mesotrophic	benthic	benthivore	consumed by man
WHITEFISH	0.1-1	0.3	oligotrophic - mesotrophic	pelagic	planktivore	consumed by man
ROACH	0.05-0.2	0.1	oligotrophic-hypertrophic	benthic/ pelagic, littoral	omnivore	prey species
SCULPIN	0.01-0.05	0.04	oligotrophic-eutrophic	benthic	omnivore	prey species
HERRING	0.05-0.2	0.1	oligotrophic – mesotrophic	pelagic	planktivore	consumed by man/ prey species
ANCHOVY	0.01-0.05	0.05	oligotrophic – eutrophic	pelagic	planktivore	consumed by man/prey species
PLAICE	0.1-1	0.5	oligotrophic – mesotrophic	benthic	benthivore	consumed by man
EEL	0.1-1	0.5	oligotrophic – eutrophic	benthic	omnivore: benthos, fish	consumed by man

AQUATRIT – the Romanian approach

Initially, it was a contract with NRG, The Netherlands (2002);
latter financed by Romanian ministry of Education and Research
partially update done in Romanian (2007) but full update and publication expenses not covered until now

- body HTO is in fast equilibrium with surrounding water (very few hours) → it could be considered full equilibrium;
- Demonstrated by many experimental facts- halftime between minutes and hour
- OBT:
- **French model** considers the same equation for OBT and 14C, phytoplankton, fish based on Sheppard et all 2006

$$\frac{dA_{fish}^{OBT}(t)}{dt} = -k_{ing} A_{fish}^{OBT}(t) + k_{ing} .DF_{phyto} . \frac{H_{phyto}}{H_{fish}} .A_{eau}^{HTO}(t) \qquad k_{ing} = \frac{I \cdot D}{W}$$

- A_{fish}^{OBT} : OBT specific activity in fish (Bq/L combustion water)
- A_{water}^{HTO} : HTO specific activity in water (Bq/L)
- k_{ing} : relative ingestion rate in day –1
- I : food intake in Kg (dry weight)day –1
- D : digestibility (unitless)
- W : animal dry weight in Kg
- DF_{phyto} : 'discrimination' factor , ratio between OBT in phytoplankton (Bq/L combustion water) and HTO in water (Bq/L)
- H_{phyto} : average phyto OBH in g/kg dry matter
- H_{fish} : average fish OBH in g/kg dry matter

autotrophic level in AQUATRIT

- **Phytoplankton**- original equation derived in 2002

$$\frac{dC_{o,phpl}}{dt} = 0.4 \cdot \mu \cdot Dryf \cdot C_W - \mu \cdot C_{o,phpl}$$

*μ=μo*modlight * modtemp*

Co,phpl – OBT concentration in phytoplankton [Bq kg-1fw];
μ - growth rate of phytoplankton [d-1].
Dryf - dry mass fraction of aquatic organism, tipycal value 0.07
C_W - HTO concentration in water [Bq m-3]
*Modlight=min+(1-min)*sin(π*julianday/365)* min=0.3 (Romania=winter/summer light)
Modtemp=$1.065^{(T-20)}$) T water temperature C
*T=TM+TR*sin(2*π*(julianday+273-lat/2)/365) cf Hakanson*
*TM=33.5-0.45*lat*
TR=TM(0.018*lat)*
TESTED SUCCESFULLY WITH LABORATORY DATA
Average growth rate μ ~0.5 [d-1], as in French model

- **macrophyte** (benthic algae) same equation but

$\mu_{ba}=0.01*1.07^{(T-8)}modlight^{0.31}$
Conservative in respect with available experimental data, need adaptation to specific depth, water tranparency, nutrients

Dynamics of OBT in heterotrophic level (consumers)

- **We considered the transfer from water (direct metabolisation of free H(T)) and transfer from food**:

$$\frac{dC_{org,x}}{dt} = a_x\, C_{f,x}(t) + b_x\, C_w(t) - K_{0.5,x}\, C_{org,x}$$

$C_{org,x}$ - the OBT concentration in animal x (Bq kg^{-1} fw);

$C_{f,x}$ - the OBT concentration in food of animal x (Bq kg^{-1} fw);

a_x - the transfer coefficient from the HTO in the water to OBT in the animal x;

b_X - the transfer coefficient from OBT in food to OBT in the animal x;

$K_{05,x}$ - the loss rate of OBT from animal x (d^{-1})

- For a proper mass balance we have

$$C_f = \sum_{i=1}^{n} C_{prey,i}\, P_{prey,i} \frac{Dryf_{pred}}{Dryf_{prey,i}}$$

$C_{prey,I}$ - the OBT concentration in prey I

$P_{prey,i}$ - the preference for pray I

$Dryf_{pred}$ dry matter fraction in animal

Dry_{fpray} dru matter fraction in preyi

C_{prey} food preference for pray i

- Experimental data shows that at equilibrium, animal OBT concentration depends on intake (only HTO or only OBT>> Specific activity

Specific activity ratio

- The specific activity (SA) of tritium = the ratio between the tritium activity and the mass of hydrogen corresponding to the specific form.
- The specific activity ratio (SAR) = SA OBT in the animal divided by SA of HTO or OBT in media water or food
- Based on analysis of available experimental data we have

Aquatic organism	SAR (HTO source)
Zooplankton	0.4±0.1
Mollusks	0.3±0.05
Crustaceans	0.25±0.05
Planktivorous fish	0.25±0.05
Piscivorous fish	0.25±0.05
Terrestrial mammals	0.25±0.05

a_x - the transfer coefficient from the HTO in the water to OBT in the animal x;
b_x - the transfer coefficient from OBT in food to OBT in the animal x;

$$a_x = (1-SAR_x) * K_{05,x};$$

$$b_x = 0.54*10^{-3}\ SAR_x * Dryfx * K_{05,x}$$

NO BIOCONCENTRATION, NO DIRECT UPTAKE OF DOT

- OBT is formed through metabolic processes involving HTO in the water

OBT loss rate-DEPENDS ON TEMPERATURE, relative growth rate and metabolic rate

- Zooplankton (Ray 2001)

$K05=(0.715-0.13\log(V))+(0.033-0.008\log(V))*\ 1.06^{(T-20)}$ $V(\mu m3)$ - zooplankton volume $10\text{-}10^4$

K_{05} = 0.19 - 0.7 d^{-1} (average 0.3) at 20 C

- Zoobenthos large range of species contributing, and large range of loss rate as an average
- Loss rate 0.05 (d^{-1}) at 15 °C – assessed by us as a compromise between components:

Larvae - Chironoma - 0.06-0.2 (*Heling 1995* , Casteaur IRSN)

Small mollusks and crustacean - 0.007-0.05 (mixt of data)

Use the temperature dependence as for Tridacna !

- Mollusks *Mitilus Edulis (Sukhotin2002).* $K_{05}=0.024W^{-0.246}$ at 10 C

  Energy content of Mitilus soft tissue (2386 J per g wet tissue),

Eliptio Complanata (EMRAS) ~0.01 mature mussels, higher than Mitilus

Table Mitilus metabolism and OBT loss

W g wet	Respiration μ mol h–1 g–1	maintenance J/d gwet	OBT lossrate d^{-1}	T1/2 d
5.00	2.60	28.36	1.19E-02	58.30
10.00	2.19	23.88	1.00E-02	69.23
20.00	1.85	20.11	8.43E-03	82.22
30.00	1.67	18.19	7.62E-03	90.91
50.00	1.47	16.02	6.72E-03	103.19
80.00	1.31	14.26	5.98E-03	115.95

More on mollusk !

- A marine clams (Mya arenaria) (average temperature 15 C) The average mass of soft tissue was 40 g OBT Halftime >150 d (Bruner 1972).
- ((Mytilus edulis) (Bonotto 1983). Food phytoplankton grown in HTO> a mussel of mass 8 g shows a half time of 16 d but one of mass 2 g have a halftime of only 6 days. FOOD tritiated leucine mussel of mass 0.5 grams half time of 36 days
- Crayfish, as from literatue ~100 d

Because mollusks have a low factorial aerobic scope (Wilmer 2000) the field metabolic rate is about 50 % higher than the basal one. The relative growth rate is also low (Heling 1994), and finally we can assess the biological half time in close relation with basal metabolic rate. While operculate mollusks have the interspecific value of basal metabolic rate $W=0.2M^{0.67}$ (M in grams and metabolic rate W in J/h), the intraspecific relationships can differ up to a factor of ten (Comparative.. 1992). For various species with mass of 10-40 grams we obtain a biological half time between 15 and 500 days using data in (Wilmer 2000,Comparative.. 1992) and the low relative growth rate (Heling 1994) **Because mollusks are eaten by aquatic organism or man with muscle, viscera and gills together, an overall biological half time must be used :**

Small, eaten by fish half time ~50 D

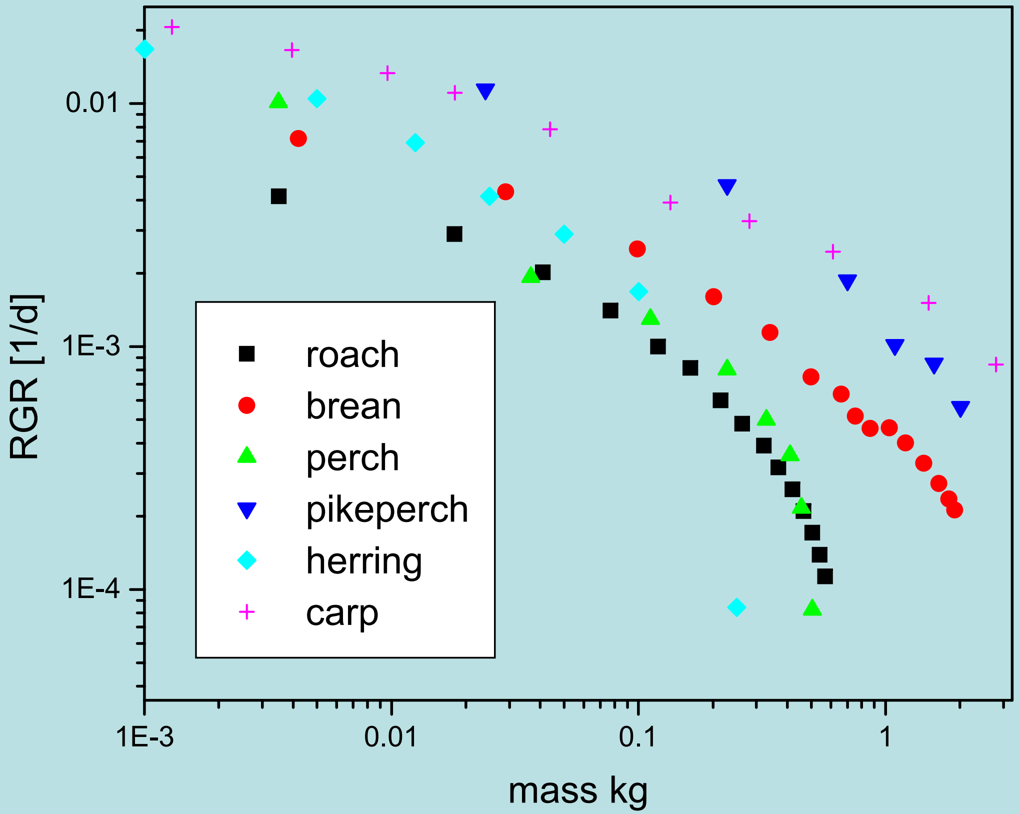
Large, eaten by humans Half time ~100

Temperature dependence to be adapted by user.

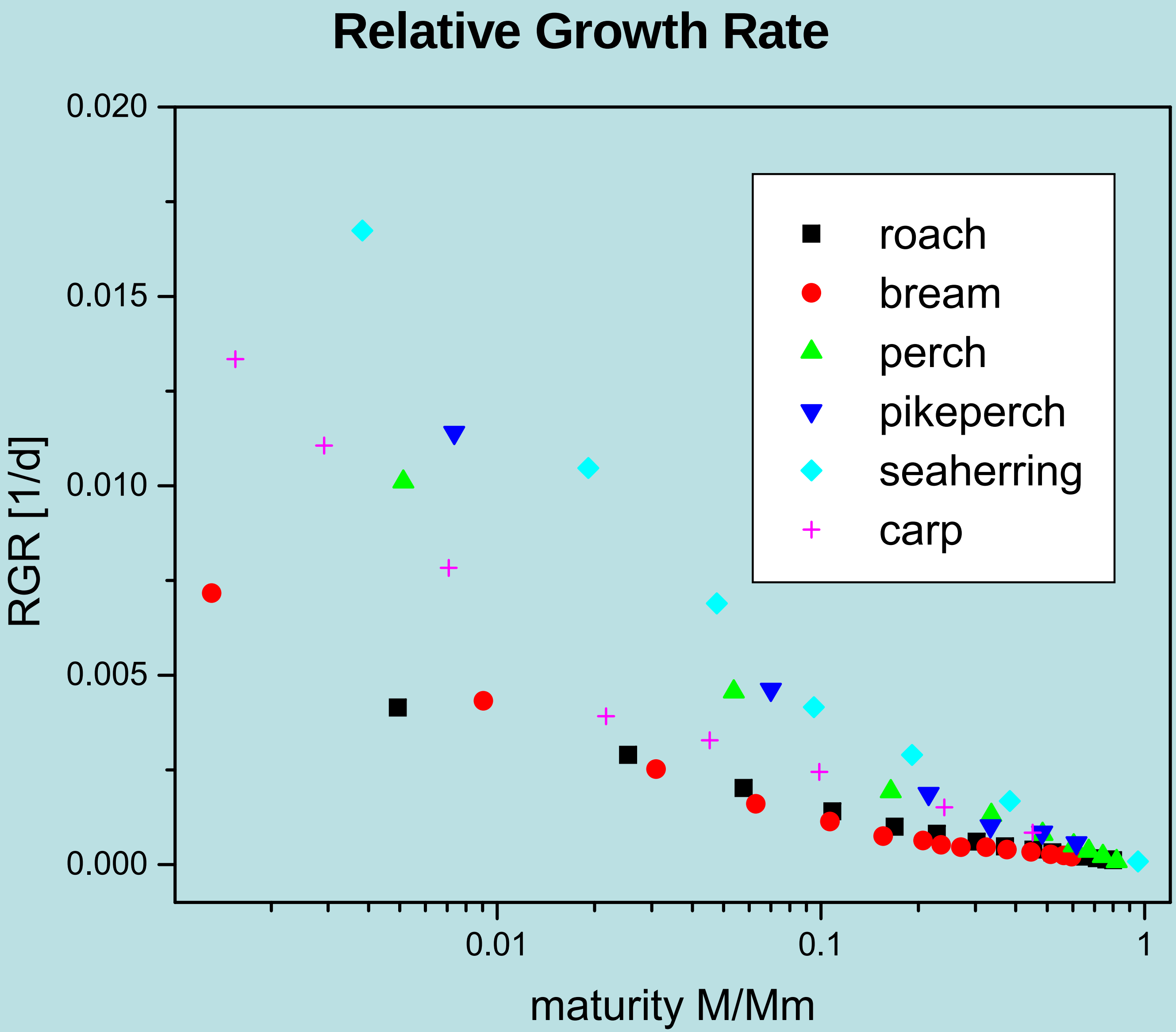
FISH

- (Elwood 1971) (small goldfish!~10 g?) Carassius auratus) The “OBT” half time was determined to be 8.7 days . Fish grown previously in a contaminated lake.
- (Rodgers 1986) involving juvenile rainbow trout of mass around 12 g (7 g at start 16 g at end) When fish were feed with tritiated amino acids, after 56 days OBT loss rate was close with 25 days . OBT loss rate was close with 25 days experiment at 15 C
- NO MORE DATA ….Will be from AECL
- WE USE FISH BIOENERGETICS AND METABOLIC MODEL
- Loss rate = RGR + metabolic rate
- Some details presented in Chatou (A Melintescu)

Relative Growth Rate, experimental data Nederland (Helling)



RGR, with normalised mass (maturity degree)



RGR, from Nederland data

- For Fish consumed by man, RGR is 0.0017 (carp, herring), 0.0005 (perch), 0.001 (pikeperch), 0.0005 (bream), using the target weight in MOIRA>>
- Piscivore RGR =0.0007; carp 0.0017;, planktivore 0.0005 !!
- For prey fish, we can assess RGR of 0.001 (roach), 0.01 (perch0+), 0.005 (perch1+), 0.0025 (bream2) and 0.004 (herring 0+)

Fish metabolism and growth

the regular decrease in the mass-specific rate of metabolism with increasing body mass can be explained principally by a combination of a decrease in the rate of tissue respiration and an increase in the relative size of tissues of low metabolic activity with increasing body mass

Shin OIKAWA*a AND Yasuo ITAZAWA **FISHERIES SCIENCE** 2003; **69**: 687–694

$$RGR = c \cdot E \cdot C_a W^{C_b} \cdot F_c(T) - R_a W^{R_b} \cdot F_r(T) \cdot A$$

$$K_{05} = c \cdot E \cdot C_a W^{C_b} \cdot F_c(T)$$

Definition in Chatou, A. Melintescu
The daily consumption rate depends also on the food availability (abundance, competition) and is a fraction “c” of the maximum, potential one Cmax- can be obtained only in optimal, laboratory conditions.
In field condition, primary production depends on trophic level and is highly seasonal

Available model inputs for fish

yelow perch	perca flavescens
walleye	stizostedium vitreum
northern pike	esox lucius
bluegill	lepomis macrochirus
white bass	morone chrysops
cisco	coregonus artedii
carp	*Cyprinus carpio*

Parameters can be adjusted for local conditions if growth dynamic is known

USING IAEA TECTOC

C_{OBT}(fw) = (1–WC) *WEQ * R f*C_W
WC~0.78 WEQ~0.65(0.61-0.71) RF~0.66(0.34-1.3 !)
C_{OBT}(fw) ~0.1CW (0.05- 0.2)

Aquatrit planctivore, bentivore 0.115, pike 0.156

Dry matter fractions (IAEA TECDOC, 2009)

Phytoplankton	0.2
Vascular plant	0.25
Bivalve mollusks, crustacean, insect larvae	0.25
Amphibians (whole body)	0.21

Dry matter of benthic algae is ~0.11

Nutrient	Pike	Carp (Bullhead)	Clam
Protein	18.2	18.9	10.5
Fat	1.2	7.1	1.3
Carbohydrate	0	0	3.1
Water equivalent factor	0.645	0.709	0.577

Macronutrient Content

Macronutrient Content of Fish

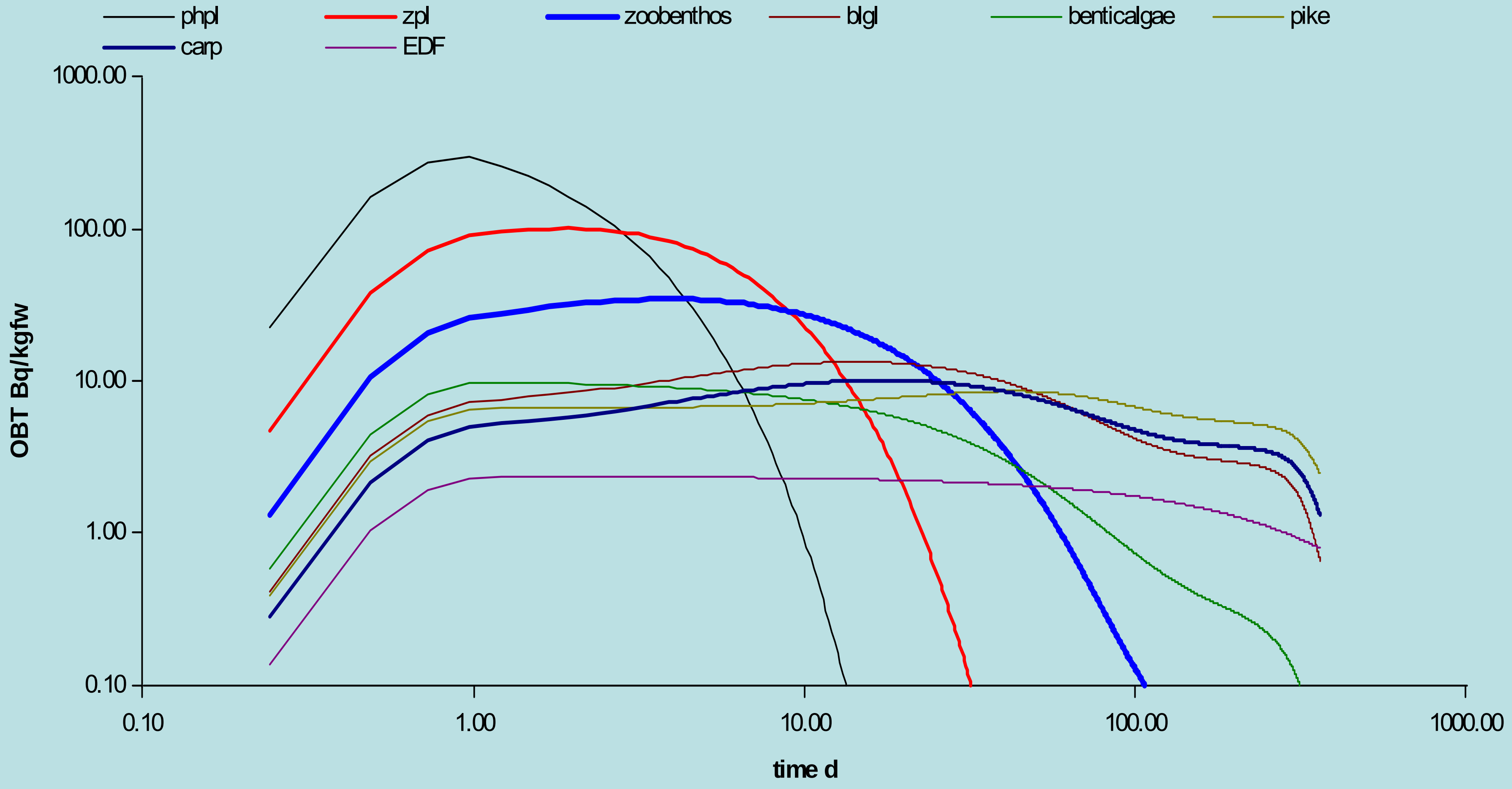
(Per 100g raw edible portion)

Type of Seafood	*Water g*	*Protein g*	*Lipid g*	*Energy kcal*	*Energy kJ*
Cod	*80.8*	*18.3*	*0.7*	*80*	*337*
Haddock	*79.4*	*19.0*	*0.6*	*81*	*345*
Plaice	*79.5*	*16.7*	*1.4*	*79*	*336*
Whiting	*80.7*	*18.7*	*0.7*	*81*	*344*
Sole	*81.2*	*17.4*	*1.5*	*83*	*351*
Monkfish	*83.8*	*15.7*	*0.4*	*66*	*282*
Herring	*68.0*	*17.8*	*13.2*	*190*	*791*
Mackerel	*64.0*	*18.7*	*16.1*	*220*	*914*
Tuna	*70.4*	*23.7*	*4.6*	*136*	*573*
Salmon	*67.2*	*20.2*	*11.0*	*180*	*750*
Trout (Rainbow)	*76.7*	*19.6*	*5.2*	*125*	*526*

Source: Holland, B., Brown, J., & Buss, D.H., 1993. Fish and Fish Products; the third supplement to McCance & Widdowson's The Composition of Foods (5th Edition), HMSO, London. Food Standards Agency (2002) McCance & Widdowson's The Composition of Foods Sixth summary edition. Cambridge: Royal Society of Chemistry.

Rodgers experiment

- juvenile rainbout trout exp
- av. Mass 11g RGR 0.0109, Kobt 0.0309 >> Kresp=0.02 at 15 C
- Rainbout trout not yet modled, if cisco (also salmonide) model can reproduce at a factor 2.


phpl
zpl
zoobenthos
blgl
benticalgae
pike
carp
EDF
1000.00
100.00
10.00
1.00
0.10
OBT Bq/kgfw
0.10
1.00
10.00
100.00
1000.00
time d

Selective uptake of DOT; Cardiff case

- Documented in literature for organics T and C, ignored as consequences in practice.
- Experiments done in 2000-2003 but not published .
- Depends on organic specie and animal type.
- More intense for phytoplankton and bacteria, lees for mussels
- WHAT TO DO? To include or not