**Supporting Information**

**Climate change in fish: effects of respiratory constraints on optimal life-history and behaviour**

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**Matlab Code**

close all;

clear all;

%Flags

RunClimateWarming = 0;

RunOptimization = 1;

%FIGURES to plot

PlotStrategies = 1;

PlotForward = 1;

% DEFINE PARAMETERS

%Resolution of model

LengthMax = 200; LengthStep = 2;

ForagingBehMin = 1; ForagingBehMax = 10; ForagingBehStep = 0.2;

AllocationStep = 0.05;

AgeMin = round(1); AgeMax = round(30);

EMax = 11;

IMax = 1000;

StepsWithinYear = 24;

K = 0.95; WeightMax = (K/1E5)\*(LengthMax^3);

JKg= ((1104.538\*4.1868)\*1000); %J per Kg wet weight cod tissue (1cal=4.1868J)(Converting Cal.g wet weight to J.Kg wet weight). Data on cod body composition from Holdway and Beamish 1984, Table 2.

%Physiology

CostOfForaging = 0.15;

SDACoeff = 0.17; %J Kg y-1 Hansson et al 1996

%COT (Cost of Transport) - Migration

%Ware et al 1978 J KM

a = 4.18e+01;% J Yr-1

r = 0.138; %s-1

e = 0.43; %No Units - Scaling factor for optimal cruising swimming speed

b= 1.02; %No units - Scaling with length for cost of transport

ee =2.42; %Scaling with swim speed for COT

%Fisheries selectivity

UseSelectivity = 0;

Slope = 0.1; L50 = 30.;

%Natural Mortalities

SizeMVariable = 1;

SizeMCoeff = 0.33; SizeMExp = -0.75; %Size dependent mortality yr-1

SpawningMFactor\_value = 0; %Extra mortality when spawning, yr-1

SizeIndependentM = 0.07; % Baseline mortality yr-1

O2M\_coeff = 11; O2M\_exp = 3; %Used Scope mortality yr-1

ForagingM\_coeff = 0.030; ForagingM\_exp = 3; %Foraging mortality

%Parameter Values - NEA Cod Parameters

LengthMin = 16;%Length when introduced to model at age 1 (cm)

Fishing = 0.17;%Annual mortality rate from fishing

DM = 780;% Spawning migration distance (km)

TMean = 4.0;%Mean experienced temperature (degC)

TPeak = 0.66;%Time of peak temperature (the year goes 0 to 1)

TAmp = 1.04;%Amplitude of annual temperature cycle (degC)

TOffsetMax = 3;%Maximum climate change offset to run

Productivity = 1;%Environmental Mean - Productivity

%Other physiological and ecological parameters

GSImax = 0.10; GonadExp = 2.5;

CostOfGonadTissue = 1.5;

ConversionEfficiency = 0.5;

if RunClimateWarming == 1;

ClimateChangeOffset = (0:1:TOffsetMax);

else

ClimateChangeOffset = 0;

end

%Temperature Seasonality

d = (0:1/StepsWithinYear:1);

Seasonality =(TMean+0.5\*TAmp\*cos((d-TPeak)\*2\*pi()));

[Seasonality,ClimateChangeOffset]= meshgrid(Seasonality,ClimateChangeOffset);

Temp = ClimateChangeOffset+Seasonality;

%Array dimensions

LMax = (LengthMax-LengthMin)/LengthStep+1; %Length

BehMax = (ForagingBehMax-ForagingBehMin)/ForagingBehStep+1; %Behaviour

AMax = 1/AllocationStep+1; %Allocation

% DECLARE VARIABLES

%Fitness and strategy matrices

F(1:EMax,1:LMax,AgeMin:AgeMax) = 0.;

Strategy(1:2,1:EMax,1:LMax,AgeMin:AgeMax) = 0.;

Fitness(1:AMax,1:BehMax) = 0.;

%Other variables

Age=round(0); L=round(0); B=round(0); A=round(0); Harvest=round(0); Step=round(0);

Length(1:EMax,1:AMax,1:BehMax)=0.; intL(1:EMax,1:AMax,1:BehMax)=round(0); dL(1:EMax,1:AMax,1:BehMax)=0.; NewL(1:EMax,1:AMax,1:BehMax)=0.;

Weight(1:EMax,1:AMax,1:BehMax)=0.; Gain(1:EMax,1:AMax,1:BehMax)=0.; Gonads(1:EMax,1:AMax,1:BehMax)=0.; GSI = 0.;

SizeM(1:EMax,1:AMax,1:BehMax)=0.; SizeM\_step(1:EMax,1:AMax,1:BehMax)=0.;

O2M(1:EMax,1:AMax,1:BehMax)=0.; O2M\_step(1:EMax,1:AMax,1:BehMax)=0.; UsedScope(1:EMax,1:AMax,1:BehMax)=0.;

GonadM(1:EMax,1:AMax,1:BehMax)=0.; ForagingM(1:EMax,1:AMax,1:BehMax)=0.; SpawningM(1:EMax,1:AMax,1:BehMax)=0.; SpawningMFactor(1:EMax,1:AMax,1:BehMax)=0.;

FishingM(1:EMax,1:AMax,1:BehMax)=0.; Selectivity(1:EMax,1:AMax,1:BehMax) = 0.;

Survival(1:EMax,1:AMax,1:BehMax)=0.; Intake(1:EMax,1:AMax,1:BehMax)=0.; NetIntake(1:EMax,1:AMax,1:BehMax)=0.;

SDA(1:EMax,1:AMax,1:BehMax)=0.; EnergeticCostOfForaging(1:EMax,1:AMax,1:BehMax)=0.;

Strat1(1:LMax,1:AgeMax-1) = 0.; Strat2(1:LMax,1:AgeMax-1) = 0.;

EnergeticForagingRateCoeff(1:EMax,1:AMax,1:BehMax) = 0.; EnergeticForagingCostCoeff(1:EMax,1:AMax,1:BehMax) = 0.;

%Forward simulation

Ind(1:16,AgeMin:AgeMax,1:IMax,1:size(Temp,1)) = 0.;

MeanInd(1:19,AgeMin:AgeMax,1:size(Temp,1)) =0.;

iLength = 0.; iintL = round(0); idL = 0.;

iWeight = 0.; iGonads = 0.; iGSI = 0.;

iAllocation = 0.; iForagingBehaviour = 0.; iForagingRate = 0.; iIntake = 0.; iROSM = 0.;

iSizeM = 0.; iSizeM\_step = 0.; iForagingM = 0.; iGonadM = 0.; iSpawningM = 0.; iSurvival = 0.;

iFishingM = 0.; iSelectivity = 0.; iRespiration = 0.; iNetIntake=0.;

%FIGURE handles etc

hStrat = 1; hStrat1 = 0.; hStrat1surf = 0.; hStrat2 = 0.; hStrat2surf = 0.;

hForward = 2;

hFigure2 = 3;

hFigure1a = 3;

hFigure1c = 3;

hFigure1b = 3;

hSeasonality = 3;

%Calculating foraging risk and allocation matrices for array-based

%optimization

clear('ForagingBehaviour');

ForagingBehaviour(1:AMax,1:BehMax) = 0.;

for A = 1:AMax;

ForagingBehaviour(A,1:BehMax)=ForagingBehMin:ForagingBehStep:ForagingBehMax;

end

Allocation(1:AMax,1:BehMax) = 0.;

for B = 1:BehMax

Allocation(1:AMax,B)=0:AllocationStep:1;

end

%Respiration Physiology

% Clarke & Johnston 1999 - General teleost fish

SMR\_exp\_CJ = 0.80;

SMR\_coeff\_CJ = exp(-5.43); %mmol O2 g-1 h-1

SMR\_coeff\_CJ = SMR\_coeff\_CJ \* 434 \* 24 \*365; %J g-1 y-1

SMR\_coeff\_CJ = SMR\_coeff\_CJ \* (0.001^(-SMR\_exp\_CJ)); %J kg-1 y-1

%Correction acording to new exponent

SMR\_exp = 0.70;

StandardWeight = 3; %kg

SMR\_coeff\_changedexp = SMR\_coeff\_CJ \* (StandardWeight^(SMR\_exp\_CJ-SMR\_exp));

%Temperature effect on SMR

SMR\_std = SMR\_coeff\_changedexp\*(0.05^SMR\_exp); %50g fish

SMR\_TempFunction = exp(15.7-(5.02.\*1000./(Temp+273.15))).\* 434 .\* 24 .\*365;

SMR\_TempFunction = SMR\_TempFunction./SMR\_std;

SMR\_coeff=SMR\_coeff\_changedexp\*SMR\_TempFunction;

%Adapted Claireaux et al. 2000

AMR\_TempFunction = (3.15\*10^7 - 2.9\*10^7.\*exp(-0.12.\*Temp) - 660\*exp(0.5\*Temp));

% AMR\_TempFunction = (3.15\*10^7 - 2.9\*10^7.\*exp(-0.12.\*Temp) - 600\*exp(0.1\*Temp)); %Sensitivity Analysis

AMR\_exp = SMR\_exp;

AMR\_coeff = AMR\_TempFunction;

%Temperature effect on foraging Input

StdTemp = 4; Magnitude = 0;

SMR\_TempFunctionAtStdTemp = exp(15.7-(5.02.\*1000./(StdTemp+273.15))) .\* 434 .\* 24 .\*365/SMR\_std;

SMR\_AtStdTemp = SMR\_coeff\_changedexp \* SMR\_TempFunctionAtStdTemp; %J kg-SMR\_exp y-1

Foraging\_TempFunction = ((1-Magnitude) + Magnitude.\*(SMR\_TempFunction./SMR\_TempFunctionAtStdTemp)).\*SMR\_AtStdTemp;

%Environmental Stochasticity

EStDev = 2.5;

EMean = 1+(EMax-1)/2;

ProbE(1:11) = 0.; ValueE(1:11) = 0.;

ScaleE = 0.3;

for E = 1:EMax;

ProbE(E) = (1/(EStDev\*sqrt(2\*pi())))\*exp(-((E-EMean)^2)/(2\*(EStDev^2)));

ValueE(E) = 1+ScaleE\*(2\*((E-1)/(EMax-1))-1);

end

sumProbE = sum(ProbE);

ProbE(:) = ProbE(:)/sumProbE;

for E = 1:EMax;

EnergeticForagingRateCoeff(E,:,:) = ValueE(E) .\* Productivity .\* ForagingBehaviour(:,:);

EnergeticForagingCostCoeff(E,:,:) = ForagingBehaviour(:,:) .\* CostOfForaging ;

end

clear ('ForagingBehaviour', 'Allocation');

ForagingBehaviour(1:EMax,1:AMax,1:BehMax) = 0.;

Allocation(1:EMax,1:AMax,1:BehMax) = 0.;

for E = 1:EMax;

for A = 1:AMax;

ForagingBehaviour(E,A,1:BehMax)=ForagingBehMin:ForagingBehStep:ForagingBehMax;

end

for B = 1:BehMax

Allocation(E,1:AMax,B)=0:AllocationStep:1;

end

end

%Backwards Iteration and Optimization

for TemperatureNo = 1:size(Temp,1);

if (RunClimateWarming == 1) || (RunOptimization == 1);

F(:,:,:) = 0.;

Strategy(:,:,:,:) = 0.;

SpawningMFactor(:,:,:) = SpawningMFactor\_value;

SpawningMFactor(:,1,:) = 0.;

if PlotStrategies == 1;

hStrat1 = subplot(1,2,1);

[X,Y] = meshgrid(AgeMin:AgeMax-1,LengthMin:LengthStep:LengthMax);

hStrat1surf = surf(X,Y,Strat1);

set(hStrat1surf,'ZDataSource','Strat1');

xlabel('Age (years)');

ylabel('Length (cm)');

title('Allocation');

axis([AgeMin AgeMax-1 LengthMin LengthMax 0 1]); axis square; caxis([0 1]);

hStrat2 = subplot(1,2,2);

hStrat2surf = surf(X,Y,Strat2);

set(hStrat2surf,'ZDataSource','Strat2');

xlabel('Age (years)');

ylabel('Length (cm)');

title('Foraging risk');

axis([AgeMin AgeMax-1 LengthMin LengthMax 0 10]); axis square; caxis([0 2]);

end % PlotStrategies

for Age = AgeMax-1:-1:AgeMin

for L = 1:LMax;

Length(:,:,:) = LengthMin + (L-1)\*LengthStep; %cm

Weight(:,:,:) = (K/1E5).\*(Length(:,:,:).^3);

Gonads(:,:,:) = 0.;

SizeM(:,:,:) = 0.;

FishingM(:,:,:)=0.;

GonadM(:,:,:) = 0.;

O2M(:,:,:) = 0.;

for Step=1:StepsWithinYear;

SizeM\_step(:,:,:) = (1./StepsWithinYear).\*SizeMCoeff .\* (Length(:,:,:).^SizeMExp);

SizeM(:,:,:) = SizeM(:,:,:) + SizeM\_step(:,:,:);

if UseSelectivity == 1

Selectivity(:,:,:) = 1./(1+exp(-Slope.\*(Length(:,:,:)-L50)));

else

Selectivity(:,:,:) = 1.;

end

FishingM(:,:,:) = FishingM(:,:,:) + (1./StepsWithinYear).\*Fishing.\*Selectivity(:,:,:); %Fishing mortality y-1

EnergeticCostOfForaging(:,:,:) = EnergeticForagingCostCoeff(:,:,:).\* SMR\_coeff(1, Step).\*(Weight(:,:,:).^SMR\_exp); %J y-1.

Intake(:,:,:) = EnergeticForagingRateCoeff(:,:,:) .\* Foraging\_TempFunction(TemperatureNo, Step) .\* (Weight(:,:,:).^SMR\_exp); % J y-1.

SDA(:,:,:) = SDACoeff.\*Intake(:,:,:); %J y-1

SMR(:,:,:) = SMR\_coeff(TemperatureNo, Step).\*((Weight(:,:,:)+Gonads(:,:,:)).^SMR\_exp); %J y-1

SMR\_somatic(:,:,:) = SMR\_coeff(TemperatureNo, Step).\*((Weight).^SMR\_exp); %J y-1

SMR\_gonadal(:,:,:) = SMR\_coeff(TemperatureNo, Step).\*((Gonads.^SMR\_exp)); %J y-1

AMR(:,:,:) = AMR\_coeff(TemperatureNo, Step).\*(Weight(:,:,:).^AMR\_exp); %J y-1

NetIntake(:,:,:) = (Intake(:,:,:) - SMR(:,:,:) - EnergeticCostOfForaging(:,:,:) - SDA(:,:,:)); %J y-1

NetIntake\_somatic(:,:,:) =(Intake(:,:,:) - SMR\_somatic(:,:,:) - EnergeticCostOfForaging(:,:,:) - SDA(:,:,:)); %J y-1

NetIntake\_gonadal(:,:,:) =(Intake(:,:,:) - SMR\_gonadal(:,:,:) - EnergeticCostOfForaging(:,:,:) - SDA(:,:,:)); %J y-1

EnergeticCostOfGrowth(:,:,:) = (1-ConversionEfficiency).\*NetIntake(:,:,:); %J y-1

EnergeticCostOfGrowth\_somatic(:,:,:) = (1-ConversionEfficiency).\*NetIntake\_somatic(:,:,:); %J y-1

EnergeticCostOfGrowth\_gonadal(:,:,:) = (1-ConversionEfficiency).\*NetIntake\_gonadal(:,:,:); %J y-1

NetIntake(:,:,:) = NetIntake(:,:,:) - EnergeticCostOfGrowth(:,:,:); %J y-1

PositiveIntake(:,:,:) = (NetIntake(:,:,:) > 0);

%Simple Oxygen Budget

UsedScope(:,:,:) = SMR(:,:,:) + EnergeticCostOfForaging(:,:,:) + SDA(:,:,:) + EnergeticCostOfGrowth(:,:,:); %J y-1

O2M\_step(:,:,:) = O2M\_coeff.\*(UsedScope(:,:,:)./AMR(:,:,:)).^O2M\_exp;

O2M(:,:,:) = O2M(:,:,:) + O2M\_step(:,:,:).\*SizeM\_step(:,:,:);

%Allocation and growth

Weight(:,:,:) = Weight(:,:,:) + ...

PositiveIntake(:,:,:) .\*(1./StepsWithinYear).\*(1-Allocation(:,:,:)).\*NetIntake(:,:,:)./JKg + ...

(1-PositiveIntake(:,:,:)).\*(1./StepsWithinYear).\*NetIntake(:,:,:)./JKg; %kg step-1

Length(:,:,:) = min((1E5.\*Weight(:,:,:)./K).^(1/3), LengthMax);

Weight(:,:,:) = min(Weight(:,:,:), WeightMax);

Gonads(:,:,:) = Gonads(:,:,:) + PositiveIntake(:,:,:).\*(1./StepsWithinYear).\*max(0, (1./CostOfGonadTissue).\*Allocation(:,:,:).\*NetIntake(:,:,:)./JKg); %kg step-1

GonadM(:,:,:) = GonadM(:,:,:) + SizeM\_step(:,:,:).\*(((Gonads(:,:,:)./(Weight(:,:,:)+Gonads(:,:,:)))./GSImax).^GonadExp);

end %Steps within year

%Energetic Cost of Migration

UOpt(:,:,:)= (r.\*(Length(:,:,:).^e)); %Optimal swimming speed dependent on length of fish taken from Ware 1978

COTware(:,:,:) =(a.\*(Length(:,:,:).^b).\*(UOpt(:,:,:).^ee)); % J/Km - using length at the end of the year (Energetic Cost of Transport)

Migration(:,:,:) = (1./CostOfGonadTissue).\*(COTware(:,:,:).\*(2\*DM))/JKg;% was J - divided by Jkg to convert to kg GONADS step-1 - Migration occurs at the end of the year

Migration(:,1,:) = 0.;

Gonads(:,:,:) = max(0., (Gonads(:,:,:) - Migration(:,:,:)));

ForagingM(:,:,:) = ForagingM\_coeff.\*(ForagingBehaviour(:,:,:).^ForagingM\_exp).\*SizeM(:,:,:);

SpawningM(:,:,:) = SpawningMFactor(:,:,:).\*(SizeMCoeff .\* (Length(:,:,:).^SizeMExp));

Survival(:,:,:) = exp(-ForagingM(:,:,:) - FishingM(:,:,:) - SizeIndependentM - SizeM(:,:,:) - GonadM(:,:,:) - O2M(:,:,:) - SpawningM(:,:,:));

intL(:,:,:) = max(1, min(floor((Length(:,:,:)-LengthMin)./LengthStep)+1, LMax-1));

dL(:,:,:) = ((Length(:,:,:)-LengthMin)./LengthStep)+1-intL;

for E = 1:EMax

Fitness(:,:) = 0.;

for A = 1:AMax;

for B = 1:BehMax;

for EnextT = 1:EMax

Fitness(A,B) = Fitness(A,B) + ProbE(EnextT)\*(dL(E,A,B)\*F(EnextT,intL(E,A,B)+1,Age+1) + (1-dL(E,A,B))\*F(EnextT,intL(E,A,B),Age+1)); %Residual reproductive value = future fitness

end

end

end

Fitness(:,:) = squeeze(Survival(E,:,:)) .\* (Fitness(:,:) + squeeze(Gonads(E,:,:))); %Reproduction at the end of year, gonads added to residual fitness, everything discounted by survival

[OptAFitness,OptA] = max(Fitness); %First find optimal A (for each B)- matlab stores optimal fitness and index of optimal fitness in the two arrays

[OptFitness,OptB] = max(OptAFitness,[],2); %Then find optimal B as maximum of the many values from previous line.

F(E,L,Age) = OptFitness; %Optimal fitness (States age and lenght as well as the environment)

Strategy(1,E,L,Age) = (OptA(OptB)-1)\*AllocationStep; %Allocation strategy

Strategy(2,E,L,Age) = ForagingBehMin+(OptB-1)\*ForagingBehStep; %Foraging strategy

end %E

end %Length

if PlotStrategies == 1;

Strat1 = reshape(Strategy(1,6,:,AgeMin:AgeMax-1),LMax,[]);

Strat2 = reshape(Strategy(2,6,:,AgeMin:AgeMax-1),LMax,[]);

refreshdata(hStrat1surf);

refreshdata(hStrat2surf);

drawnow;

end

end %Age

end %Run optimization

% FORWARD SIMULATION - Allows visualization of the individual and population level characteristics emerging from the interaction of the life history strategy and the environment

%Initiate first cohort

iLength = LengthMin; %

iWeight = (K/1E5)\*(iLength^3);

iSurvival = 1.;

Ind( 1,AgeMin,:,TemperatureNo) = iLength; % 1: Length at age %Ind specifies the trait (1(length,for all age min to max,for all temps)

Ind( 2,AgeMin,:,TemperatureNo) = iWeight; % 2. Weight at age

Ind( 3,AgeMin,:,TemperatureNo) = 1.; % 3. Survival until age

% Ind( 4,AgeMin,I,TemperatureNo) = 0.; % 4. Gonads at end of age

% Ind( 5,AgeMin,I,TemperatureNo) = 0.; % 5. GSI

% Ind( 6,AgeMin,I,TemperatureNo) = 0.; % 6. Allcoation value

% Ind( 7,AgeMin,I,TemperatureNo) = 0.; % 7. Risk taken

% Ind( 8,AgeMin,I,TemperatureNo) = 0.; % 8. Intake

% Ind( 9,AgeMin,I,TemperatureNo) = 0.; % 9. Environmental value

% Ind(10,AgeMin,I,TemperatureNo) = 0.; %10. Size-dependent predation mortality

% Ind(11,AgeMin,I,TemperatureNo) = 0.; %11. Fishing mortality

% Ind(12,AgeMin,I,TemperatureNo) = 0.; %12. Foraging mortality

% Ind(13,AgeMin,I,TemperatureNo) = 0.; %13. Gonad mortality

% Ind(14,AgeMin,I,TemperatureNo) = 0.; %14. ROSM

% Ind(15,AgeMin,I,TemperatureNo) = 0.; %15. Total Natural Mortality

% Ind(16,AgeMin,I,TemperatureNo) = 0.; %16. Oxygen mortality

% Ind(17,AgeMin,I,TemperatureNo) = 0.; %17. SMR

% Ind(18,AgeMin,I,TemperatureNo) = 0.; %18. AMR

% Ind(19,AgeMin,I,TemperatureNo) = 0.; %19. SpawningM

%

for I = 1:IMax;

iLength = LengthMin;

iWeight = (K/1E5)\*(iLength^3);

iSurvival = 1.;

for Age = AgeMin:AgeMax-1;

EisOK = 0.;

while EisOK==0;

iE = EMean + EStDev\*randn(1);

if iE > 1;

if iE < EMax;

EisOK = 1;

end

end

end

EValue = 1+ScaleE\*(2\*((iE-1)/(EMax-1))-1);

%Look up optimal strategy

iintE = max(0.,min(floor(iE),EMax-1));

idE = max(0.,min(iE-iintE,1));

iintL = max(1, min(floor((iLength-LengthMin)./LengthStep)+1, LMax-1));

idL = (iLength-LengthMin)./LengthStep+1-iintL;

iAllocation = idE \*idL\*Strategy(1,iintE+1,iintL+1,Age) + idE \*(1.-idL)\*Strategy(1,iintE+1,iintL ,Age) + ...

(1.-idE)\*idL\*Strategy(1,iintE ,iintL+1,Age) + (1.-idE)\*(1.-idL)\*Strategy(1,iintE ,iintL ,Age);

iAllocation = max(0., min(iAllocation, 1.));

iForagingBehaviour = idE \*idL\*Strategy(2,iintE+1,iintL+1,Age) + idE \*(1.-idL)\*Strategy(2,iintE+1,iintL ,Age) + ...

(1.-idE)\*idL\*Strategy(2,iintE ,iintL+1,Age) + (1.-idE)\*(1.-idL)\*Strategy(2,iintE ,iintL ,Age);

iSizeM = 0.;

iFishingM=0.;

iGonads = 0.;

iGonadM = 0.;

iO2M = 0.;

iEnergeticForagingRateCoeff = iForagingBehaviour\*EValue\*Productivity;

iEnergeticForagingCostCoeff = iForagingBehaviour\*CostOfForaging; % Same unit as SMR\_coeff: J kg-SMR\_exp y-1

for Step=1:StepsWithinYear;

iSizeM\_step = (1/StepsWithinYear)\*SizeMCoeff \* (iLength^SizeMExp);

iSizeM = iSizeM + iSizeM\_step;

if UseSelectivity == 1;

iSelectivity = 1/(1+exp(-Slope\*(iLength-L50)));

else

iSelectivity = 1;

end

iFishingM = iFishingM + (1/StepsWithinYear)\*Fishing\*iSelectivity; %Fisheries mortality %J y-1

iEnergeticCostOfForaging = iEnergeticForagingCostCoeff\*SMR\_coeff(1, Step)\*(iWeight^SMR\_exp); %J y-1

iIntake = iEnergeticForagingRateCoeff\*Foraging\_TempFunction(TemperatureNo, Step)\*(iWeight^SMR\_exp); %J y-1

iSDA = SDACoeff\*iIntake; %J y-1

iSMR = SMR\_coeff(TemperatureNo, Step)\*((iWeight+iGonads)^SMR\_exp); %J y-1

iSMR\_somatic = SMR\_coeff(TemperatureNo, Step)\*((iWeight)^SMR\_exp); %J y-1

iSMR\_gonadal = SMR\_coeff(TemperatureNo, Step)\*((iGonads^SMR\_exp)); %J y-1

iAMR = AMR\_coeff(TemperatureNo, Step)\*(iWeight^AMR\_exp); %J y-1

iNetIntake = iIntake - iSMR - iEnergeticCostOfForaging - iSDA; %J y-1

iNetIntake\_somatic =(iIntake - iSMR\_somatic - iEnergeticCostOfForaging - iSDA); %J y-1

iNetIntake\_gonadal =(iIntake - iSMR\_gonadal- iEnergeticCostOfForaging- iSDA); %J y-1

iEnergeticCostOfGrowth = (1-ConversionEfficiency)\*iNetIntake; %J y-1 taking into account assimilation efficiency

iEnergeticCostOfGrowth\_somatic = (1-ConversionEfficiency)\*iNetIntake\_somatic; %J y-1

iEnergeticCostOfGrowth\_gonadal = (1-ConversionEfficiency)\*iNetIntake\_gonadal; %J y-1

iNetIntake = iNetIntake - iEnergeticCostOfGrowth; %J y-1

iPositiveIntake = (iNetIntake) > 0; %J y-1

iUsedScope = iSMR + iEnergeticCostOfForaging + iSDA + iEnergeticCostOfGrowth; %J y-1

iO2M\_step = O2M\_coeff\*((iUsedScope/iAMR)^O2M\_exp); %Used scope respiration cost yr-1

iO2M = iO2M + iO2M\_step\*iSizeM\_step; %yr-1

if iNetIntake >0

iSomaticGrowth = (1/StepsWithinYear)\*(1-iAllocation)\*iNetIntake/JKg; %kg step-1

iGonadGrowth = (1/StepsWithinYear)\*max(0, (1/CostOfGonadTissue)\*iAllocation\*iNetIntake/JKg); %kg step-1

else

iSomaticGrowth = (1/StepsWithinYear)\*iNetIntake/JKg; %kg step-1

iGonadGrowth = 0.; %kg step-1

end

iWeight = max(0., min(iWeight+ iSomaticGrowth,WeightMax)); %kg

iLength = min((1E5\*iWeight/K)^(1/3), LengthMax); %cm

iWeight = min(iWeight,WeightMax);%kg

iGonads = iGonads + iGonadGrowth;%kg

iGonadM = iGonadM + iSizeM\_step\*(((iGonads/(iWeight+iGonads))/GSImax)^GonadExp); %yr-1

end %Steps within year

%Energetic Cost of Migration

iUOpt= r\*(iLength^e); %Size dependent

iCOTware =(a\*(iLength^b)\*(iUOpt^ee)); % J/m

iMigration = 0;

iSpawningM = 0;

if iAllocation > 1.e-10;

iMigration = (1/CostOfGonadTissue)\*(iCOTware\*(2\*DM))/JKg;%kg gonads step-1

iSpawningM = SpawningMFactor\_value\*(SizeMCoeff \* (iLength^SizeMExp));

end

iGonads = max(0,(iGonads - iMigration));

iForagingM = ForagingM\_coeff\*(iForagingBehaviour^ForagingM\_exp)\*iSizeM;

iSurvival = iSurvival \* exp(-iForagingM - iFishingM - SizeIndependentM - iSizeM - iGonadM - iO2M - iSpawningM);

iGSI = (iGonads / (iWeight + iGonads));

Ind( 1,Age+1,I,TemperatureNo) = iLength;

Ind( 2,Age+1,I,TemperatureNo) = iWeight+iGonads;

Ind( 3,Age+1,I,TemperatureNo) = iSurvival;

Ind( 4,Age+1,I,TemperatureNo) = iGonads;

Ind( 5,Age+1,I,TemperatureNo) = iGSI;

Ind( 6,Age ,I,TemperatureNo) = iAllocation;

Ind( 7,Age ,I,TemperatureNo) = iForagingBehaviour;

Ind( 8,Age ,I,TemperatureNo) = iForagingRate;

Ind( 9,Age ,I,TemperatureNo) = iE;

Ind(10,Age ,I,TemperatureNo) = SizeMVariable\*iSizeM;

Ind(11,Age ,I,TemperatureNo) = iFishingM;

Ind(12,Age ,I,TemperatureNo) = iForagingM;

Ind(13,Age ,I,TemperatureNo) = iGonadM;

Ind(14,Age ,I,TemperatureNo) = iUsedScope/iAMR;

Ind(15,Age ,I,TemperatureNo) = iForagingM+SizeIndependentM+iGonadM+iO2M+iSpawningM+iSizeM;

Ind(16,Age ,I,TemperatureNo) = iO2M;

Ind(17,Age ,I,TemperatureNo) = iSMR;

Ind(18,Age ,I,TemperatureNo) = iAMR;

Ind(19,Age ,I,TemperatureNo) = iSpawningM;

Ind(20,Age ,I,TemperatureNo) = iSDA;

Ind(21,Age ,I,TemperatureNo) = iEnergeticCostOfForaging;

Ind(22,Age ,I,TemperatureNo) = iSMR\_somatic;

Ind(23,Age ,I,TemperatureNo) = iSMR\_gonadal;

Ind(24,Age ,I,TemperatureNo) = iEnergeticCostOfGrowth\_somatic;

Ind(25,Age ,I,TemperatureNo) = iEnergeticCostOfGrowth\_gonadal;

Ind(26,Age ,I,TemperatureNo) = iEnergeticCostOfGrowth;

end %Age

end % Individual

for Trait = 1:26;

for Age = AgeMin:AgeMax;

MeanInd(Trait,Age,TemperatureNo) = sum(Ind(Trait,Age,:,TemperatureNo))/IMax;

StDevInd(Trait,Age,TemperatureNo) = sqrt(sum((Ind(Trait,Age,:,TemperatureNo)-MeanInd(Trait,Age,TemperatureNo)).^2)/(IMax-1));

StDevPlus(Trait,Age,TemperatureNo) = (sum(Ind(Trait,Age,:,TemperatureNo))/IMax) + (sqrt(sum((Ind(Trait,Age,:,TemperatureNo)-Ind(Trait,Age,TemperatureNo)).^2)/(IMax-1)));

StDevminus(Trait,Age,TemperatureNo) = (sum(Ind(Trait,Age,:,TemperatureNo))/IMax) - (sqrt(sum((Ind(Trait,Age,:,TemperatureNo)-Ind(Trait,Age,TemperatureNo)).^2)/(IMax-1)));

end

end

end %Temperature