Simulation to the migration of Anchovy in the Yellow Sea by Individual-based model

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Introduction

- There are abundant resource of anchovy in the Yellow Sea , but it is dramatically decrease in recent years . It is very significant to study its evolution processes and the mechanism. It can help us to recognize how to prevent such matter in the future.
- Model of anchovy is an important method in the study. An Individual-based model of anchovy migration was created preliminary .

- After coding the model will be applied to study the response of the population of anchovy to the human activity and the change of environment.
- Now the model was coded and calibration experiment was made. The model should realize: the population of anchovy in steady environment can reproduce steadily; the mean length of specifically age group agree with observation and the migration of population can be simulated.

- The individual-based model (IBM) is popular in recent years(Kenneth A.Rose, Heather L.Haas , Jarl.Giske , Geir.Huse). Their study provide the basic idea to my model. The model combine the life history of anchovy with the environment to simulate the distribution and migration.
- Individuals and the circumstance are different. Those differences are emphasized and new properties of the ecosystem which called emergent properties can be discovered in IBM.

- My work not only describe the phenotype differences of individuals, such as weight and length, but also describe the intrinsic differences of individuals.
- By biology, the phenotype of individual is decided by its genotype and the circumstance. The differences between individuals not only on phenotype but also on genotype. Even if in asexual reproduction , the genotype of descendant is different from its predecessor because of gene mutation.

- In my model, the properties of every individuals include two sections, first section is genotype and the other is phenotype. The genotype is immobile and the phenotype is time-variation
- The genotype of individuals inherit from its parent and occur mutation. So the genotypes of individuals are unique in the model. Genotype is immobile in its lifetime.
- In a word, there are parameters and variables in the function of develop of individuals, some parameters have relation to individuals , those parameters are defined as genotype.

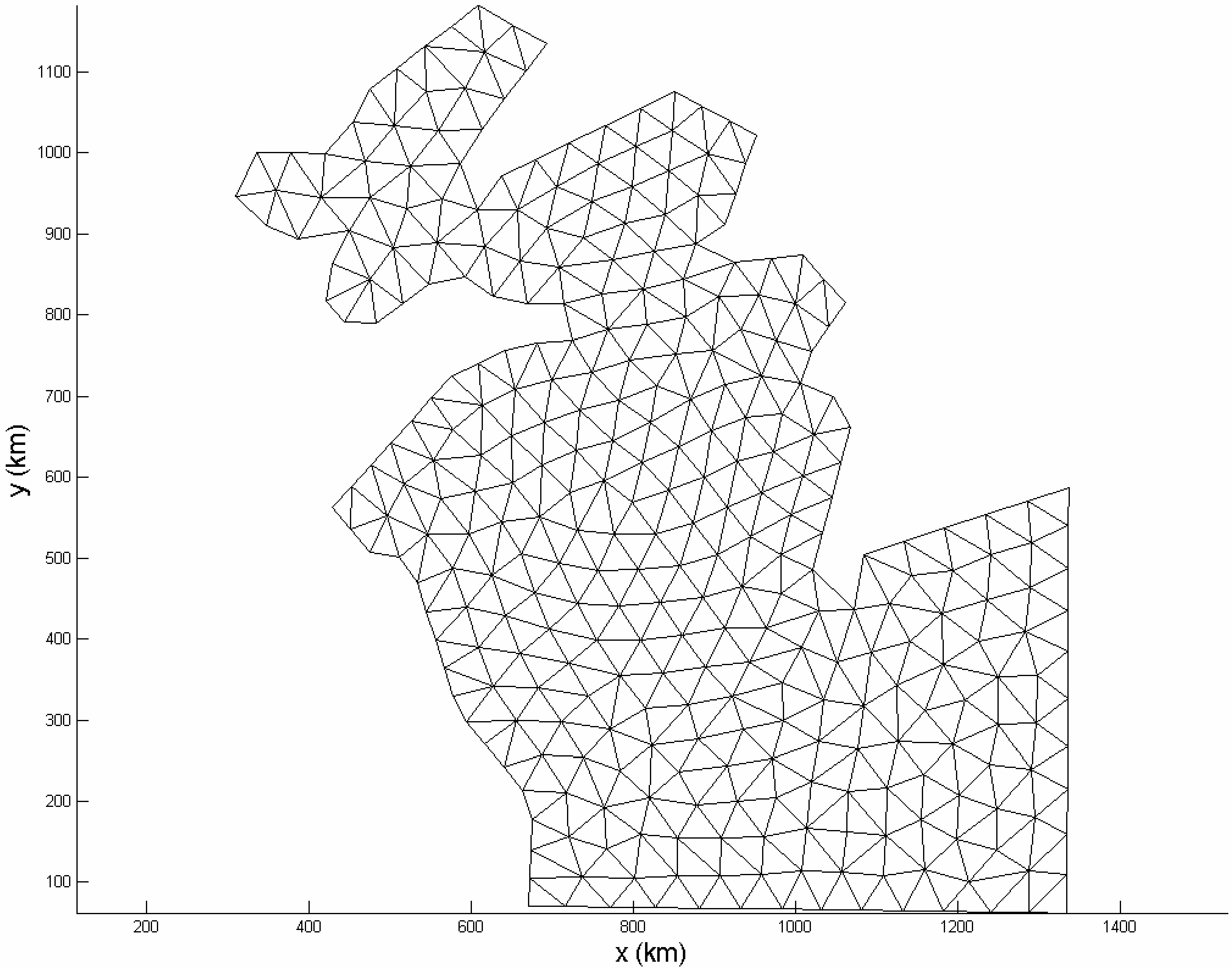
Methodology

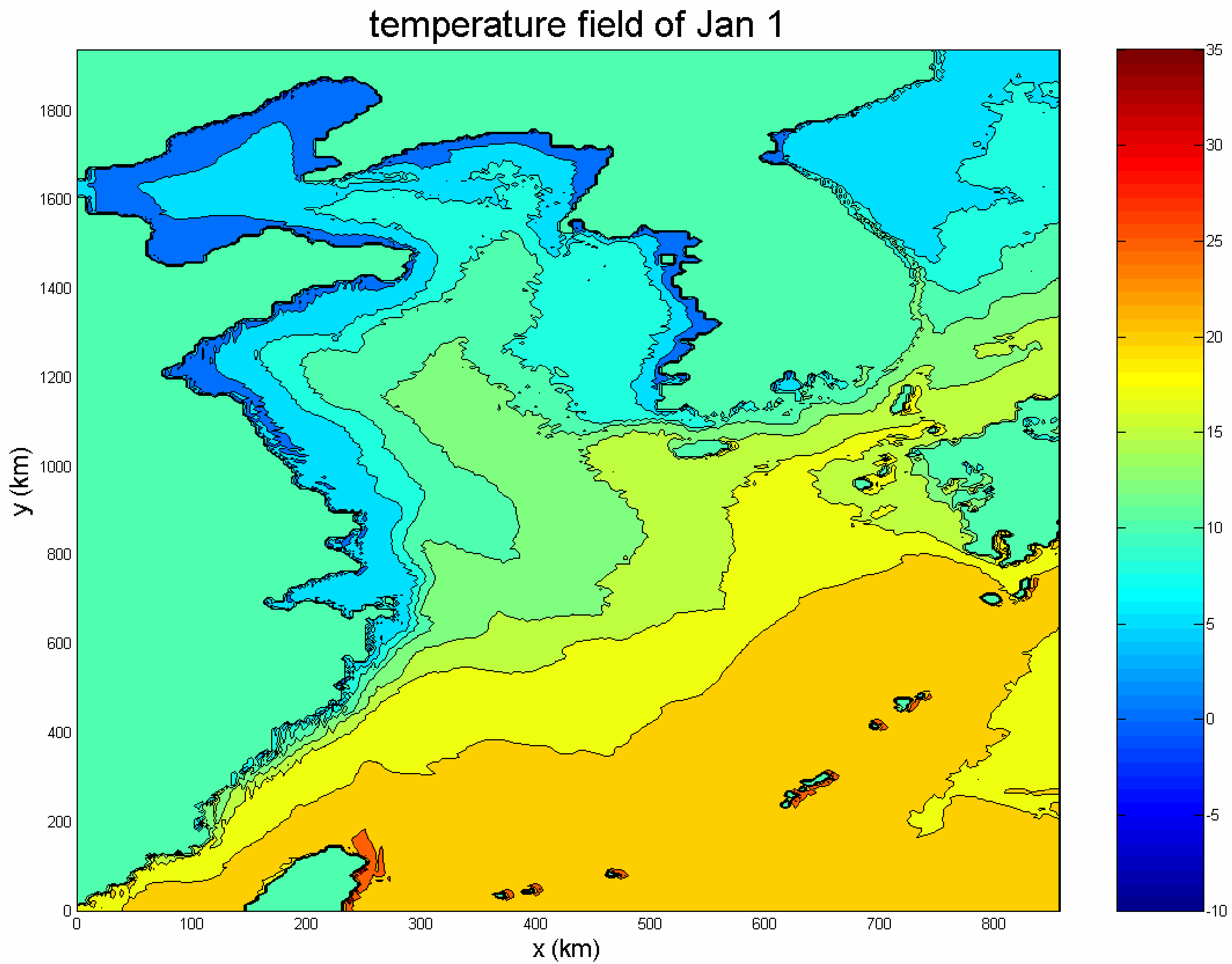
- Physical field
- The lower trophic level
- Anchovy
- About the genotype
- Flow chart of the model

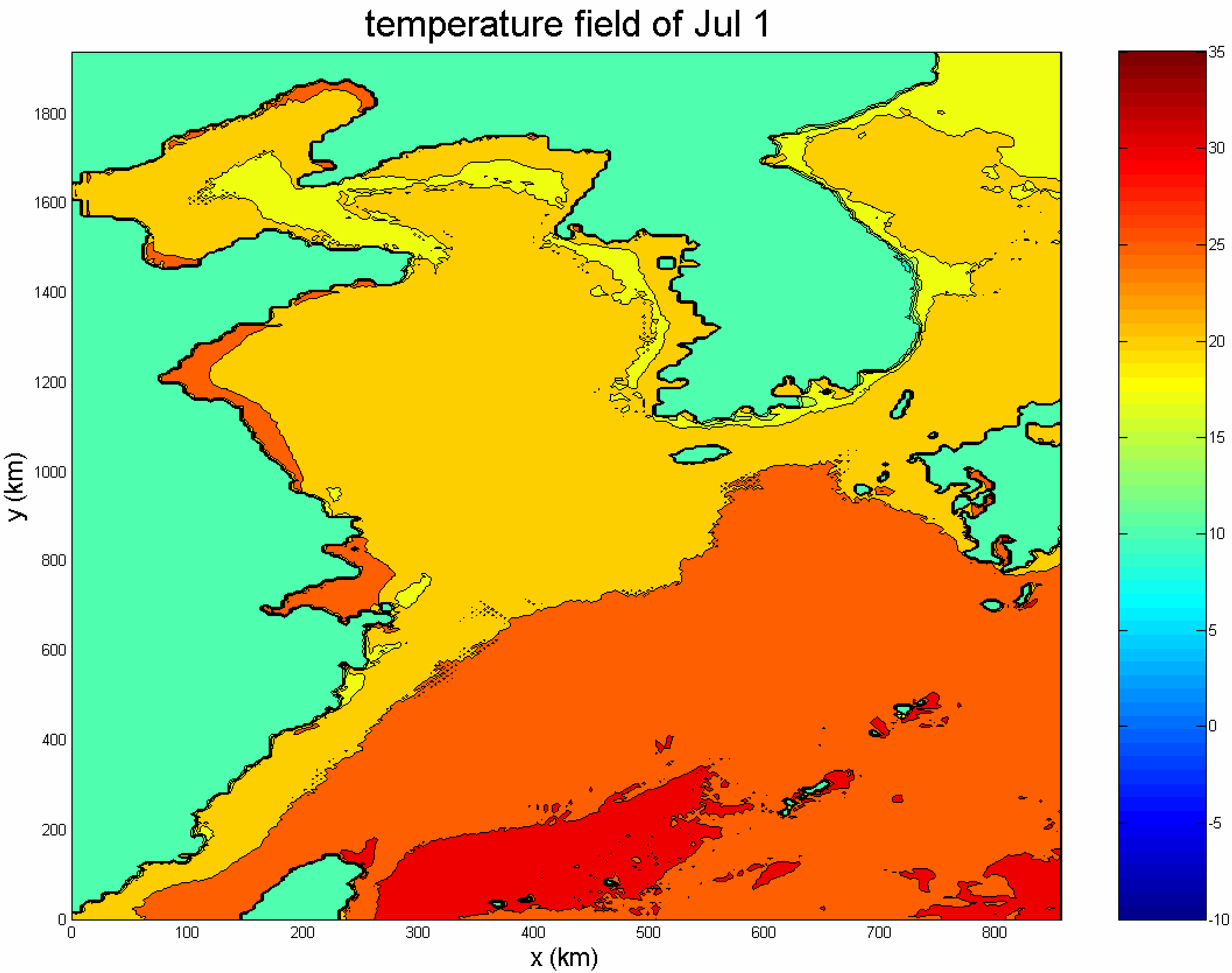
Physical field

- The space structure of the model use two-dimension unstructured mesh.
- Temperature field which calculate by POM is introduce to the mesh. The temperature use mean value of five years and daily update .

The mesh on which calculate




temperature field of Jan 1
y (km)
x (km)
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1400
1600
1800
-10
-5
0
5
10
15
20
25
30
35


temperature field of Jul 1
y (km)
x (km)
0
200
400
600
800
1000
1200
1400
1600
1800
0
100
200
300
400
500
600
700
800
35
30
25
20
15
10
5
0
-5
-10

The lower trophic level

- The lower trophic level use NPZ model, the function as following :

$$\frac{dN}{dt} = -P \cdot Ph_{Max} \cdot r_{NP} \cdot r_{IP} \cdot r_{TPh} \cdot Ra_{NP} + Rc_{N}\left(X, t\right)$$

$$\frac{dP}{dt} = P\left(Ph_{Max} \cdot r_{NP} \cdot r_{IP} \cdot r_{TPh} - \mathrm{Re}\, s_{PB} \cdot r_{TPR} - CPZ_{Max} \cdot r_{PZ} \cdot r_{TZC}\right)$$

$$\frac{dZ}{dt} = Z\left(CPZ_{Max} \cdot r_{PZ} \cdot r_{TZC} \cdot r_{ASZ} \cdot Ra_{NP} / Ra_{NZ} - \mathrm{Re}\, s_{ZB} \cdot r_{TZR}\right) - \sum R_{F_i} Con_{F_i}$$

Variables and parameters

- N—nitrogen concentration.
- P—phytoplankton biomass.
- Z —zooplankton biomass.
- Ph_{Max} —maximal rate of photosynthesis at baseline temperature
- Res_{PB}—respiration rate of phytoplankton at baseline temperature
- CPZ_{Max}—maximal rate of consumption at baseline temperature

- Res_{ZB} —respiration rate of zooplankton at baseline temperature .
- Rc_N —recruit rate of nitrogen .
- r—influence coefficients of light ,temperature, nutrition(food) concentration.
- Ra_{NP} —content of nitrogen phytoplankton
- Ra_{NZ} —content of nitrogen zooplankton

Anchovy’s life behaviors

- Consumption and respiration
- Weight and length
- Swim
- Spawn
- Hatch
- Mortality

Consumption and respiration

$$Con_F = W \cdot Con_{FMax} \cdot r_{ZF} \cdot r_{TFC}$$

$$\mathrm{Res}_F = W \cdot \mathrm{Res}_{FB} \cdot r_{TFR}$$

- W —weight of anchovyindividual.

Con_F —rate of consumption of anchovy individual.

Res_F —rate of respiration of anchovy individual.

Con_{FMax} —maximal rate of consumption at baseline temperature.

Res_{FB} —rate of respiration at baseline temperature

r—influence coefficients of temperature and food concentration.

Weight and length

$$\frac{dW}{dt} = Con_F \cdot r_{AsF} \frac{Ra_{NF}}{Ra_{NZ}} - \mathrm{Re}\, s_F$$

$$L = \alpha W^{\beta}$$

W —weight of anchovyindividual

L —length of anchovyindividual

r_{AsF} —Ratio of absorption

α β —coefficent

- Length will not decrease as the weight decreasing, but it will increase only at the weight come back to the maximum in its history.

Swim

$$\overline{S}\overrightarrow{p}_{Sw} = Ab_{Sw} \cdot \nabla Fi$$

$$Ab_{Sw} = K_{Sw} \cdot L + C_{Sw}$$

$$Fi = e^{\left(r_{FiT} \cdot \ln Fi_T + \ln Fi_{Con}\right)}$$

$$Fi_T = \begin{cases} e^{-\left(T - T_{ideal}\right)} & T > T_{ideal} \\ e^{r_{ec}\left(T - T_{ideal}\right)} & T < T_{ideal} \end{cases}$$

$$Fi_{Con} = \frac{Z}{Z + K_{FZ}}$$

Ab_{Sw} —Swim ability.

$\overline{S}\overrightarrow{p}_{Sw}$ —Swim speed

Fi —fitness

Fi_T —temperature influence to fitness

Fi_{Con} —food concentration influence to fitness

T, T_{ideal} —temperature of circumstance and optimum temperature.

r_{FiT}, r_{ec} — coefficient.

Spawn

- Individual spawn only four condition be met. Those condition are:

1. current time is in spawn season;
2. the individual is in spawn field;
3. length of individual attain to a criterion;
4. the interval from last spawn attain to a criterion.

$$Num_{Egg} = Ra_{hat} \cdot W \cdot Ra_{Egg} / W_{Egg}$$

$$\Delta W = W \cdot Ra_{Egg}$$

Num_{Egg} —The number of eggs.

ΔW —Weight of sum eggs which spawn by a individual.

W_{Egg} —weight of a egg

Ra_{Egg} —proportion of eggs to whole weight

Ra_{hat} —ratio of hatch.

Hatch

- Individual grow through the following life stages: egg, yolk-sac larva, larva, young-of-the-year(YOY), adult . The former four stages are not simulate to simplify the model. So eggs hatch to YOY directly at 45 days after being spawned.

Mortality

- Individual die because of following four reason :

1. the individuals which have abnormity phenotype die forcedly
2. some individuals starve to death
3. some individuals is winterkilled
4. individuals which age arrived at their natural life.

- The criterion of abnormity phenotype: the standard length of individual calculated by following function

$$L_S = 16.3\left(1 - e^{-0.8(Age+0.2)}\right)$$

- Individuals which length exceed the 1.2 times standard length or less than 0.8 times standard length will be regarded as abnormity.

About the genotype

- Definition of genotype
- Mutation of genotype

Definition of genotype

- Genotype is defined as a aggregate of parameters which are used in the differential equations or algebra equations mentioned before.
- Some parameters are studied at length, and it is reported that they are similar among individuals. So they can be regarded as the parameters of the whole population .

- Some parameters in the equations are time-variation or state-variation. So they are not agree with the invariability of genotype.
- Suppose those parameters are continuous function of age or state. The function is divided into some sections and every sections are liner function. Values of dividing point agree with the invariability of genotype. So the values of dividing point can be regard as genotype.
- Those parameters in the equations are update at every steps and be named half-genotype.

- Discuss as preceding, the parameters in the equations of fish be divided three class: population parameter, genotype and half-genotype.

Mutation of genotype

- As start of run of the program, A template fish be initialized. The template be copy and the genotype of every copy random mutate.
- At the process of reproduction, the genotype of offspring inherit from its parent and occur random mutation.
- The process of reproduction and phenotype update called training of population .

- The mutation control by two parameters: first is maximal amplitude(Am), the other is frequency (Fr)of the greater mutation.
- Great Am and Fr be adopted At start of training to form a diversity group, so that the probability of exist individuals which agree with observation is greater.
- The small Am and Fr be adopted At end of training so that individuals in group will have similar genotype and can be regard as a population.

Flow chart of the model

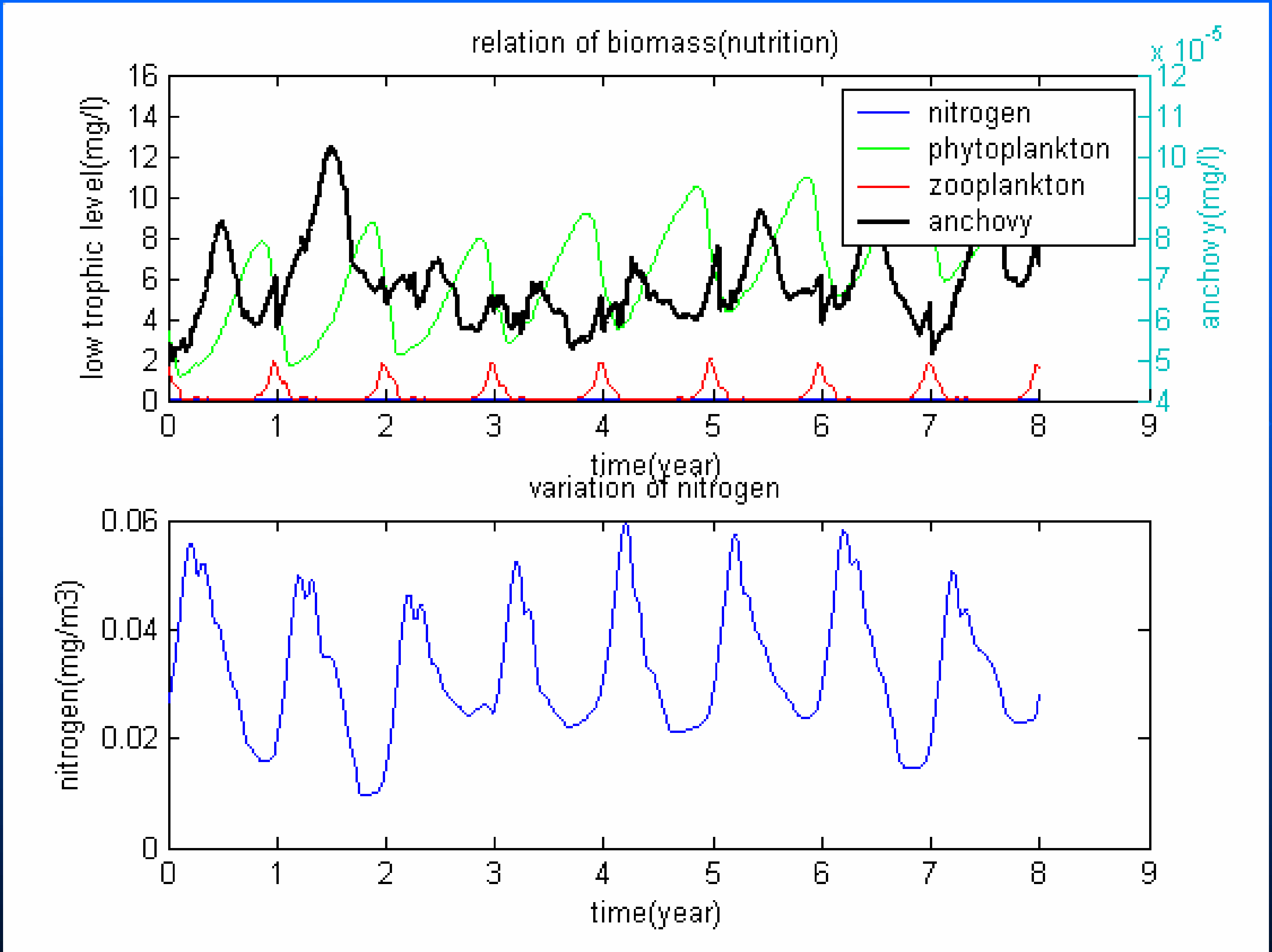
- At start of the program,a template fish be initialized and be copy . The genotype of every copy occur mutate. The copies be collocated in calculation field random. Then carry the cycle which include following steps

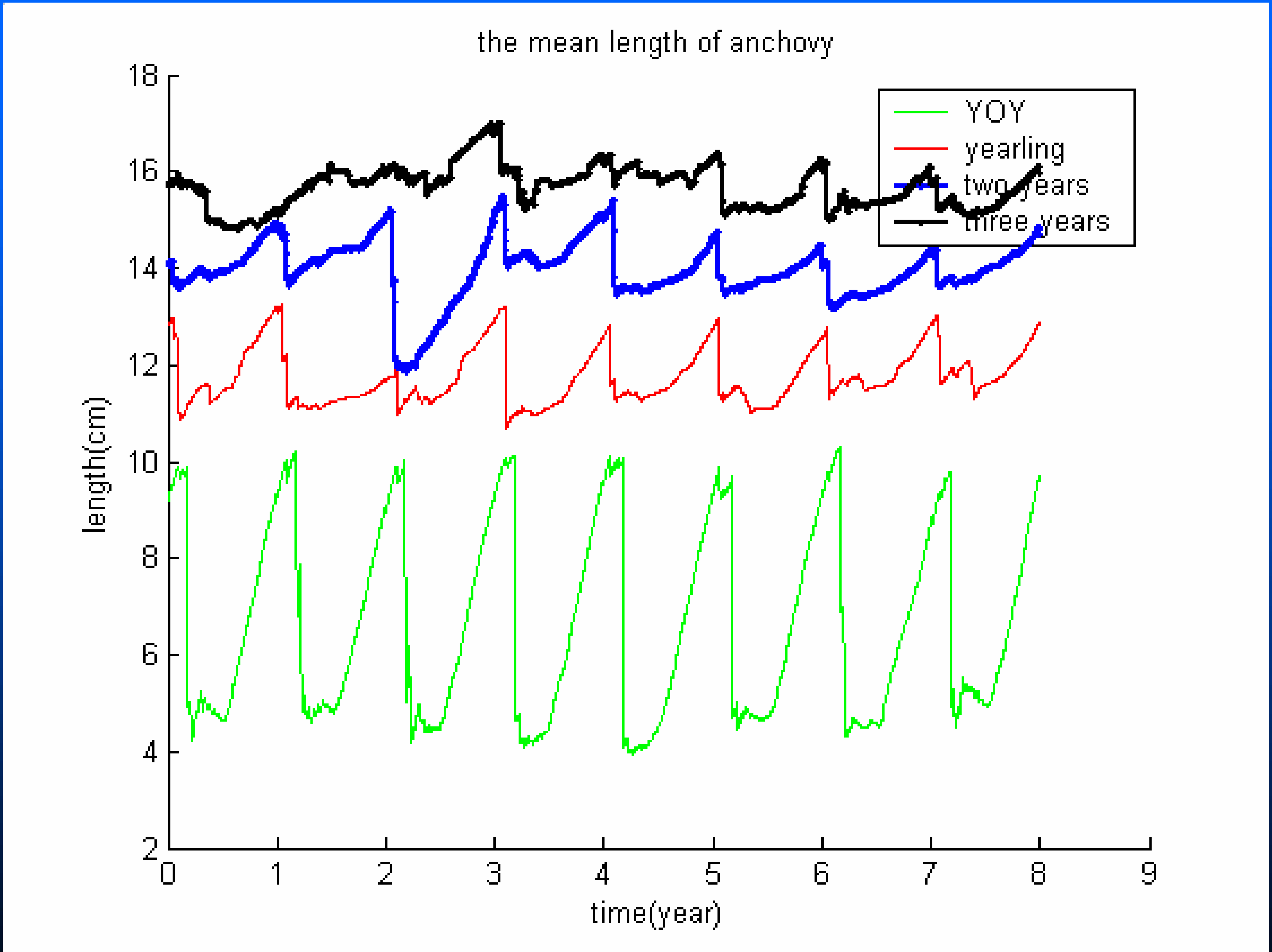
1. Update of temperature field which calculated by POM.
2. Update of The lower trophic level.
3. Update of phenotype of anchovy population.

The update adopt runge-kutta method.

Results

- Relation of biomass
- Length of groups of every age
- Migration of anchovy
- Sensitivity analysis of two important parameters


relation of biomass(nutrition)
low trophic level(mg/l)
anchovy(mg/l)
x 10^-5
nitrogen
phytoplankton
zooplankton
anchovy
time(year)
variation of nitrogen
nitrogen(mg/m3)
time(year)


the mean length of anchovy
YOY
yearling
two years
three years
length(cm)
time(year)
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9

migration

- Play movie of migration

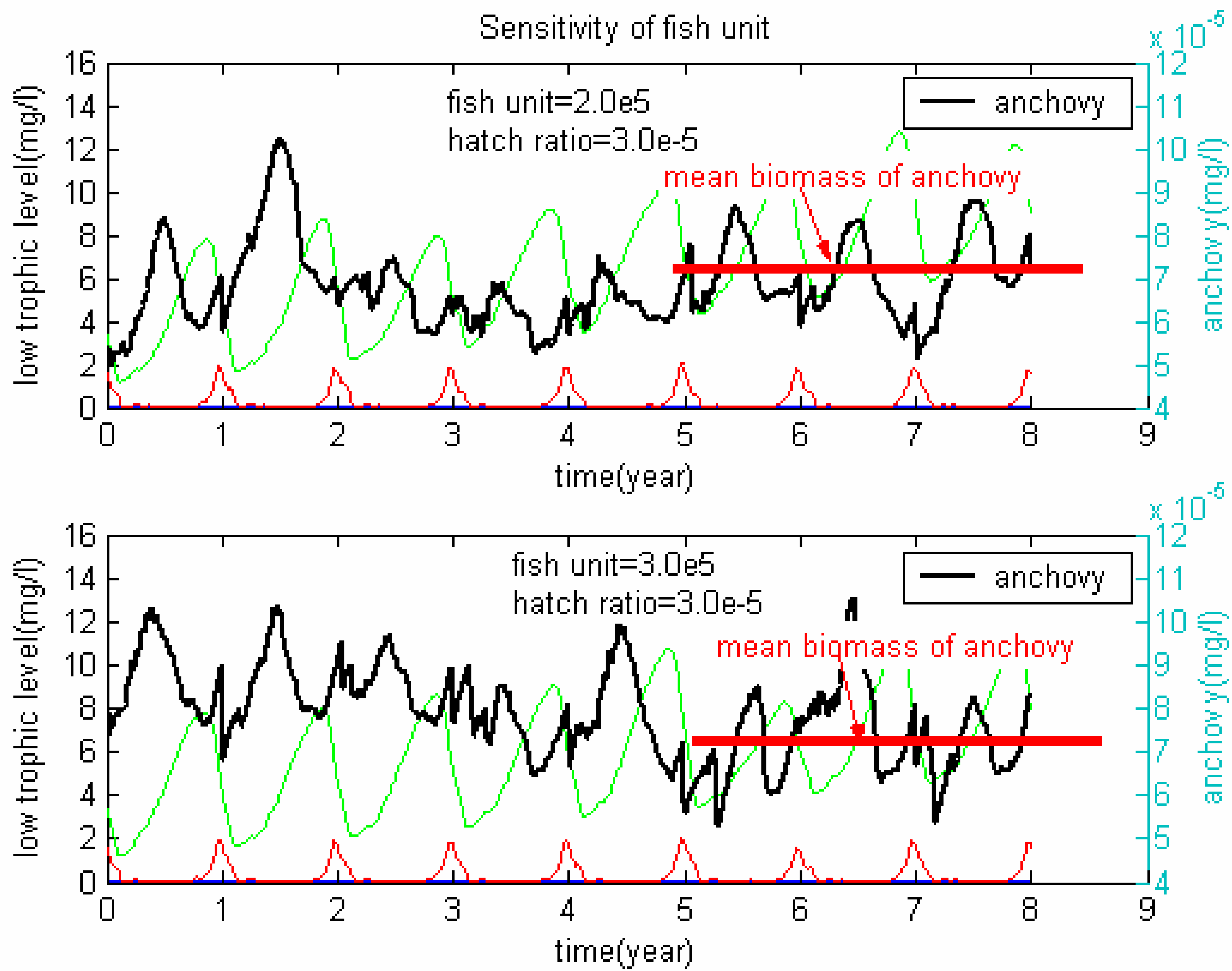
Animation disengaged

Sensitivity analysis

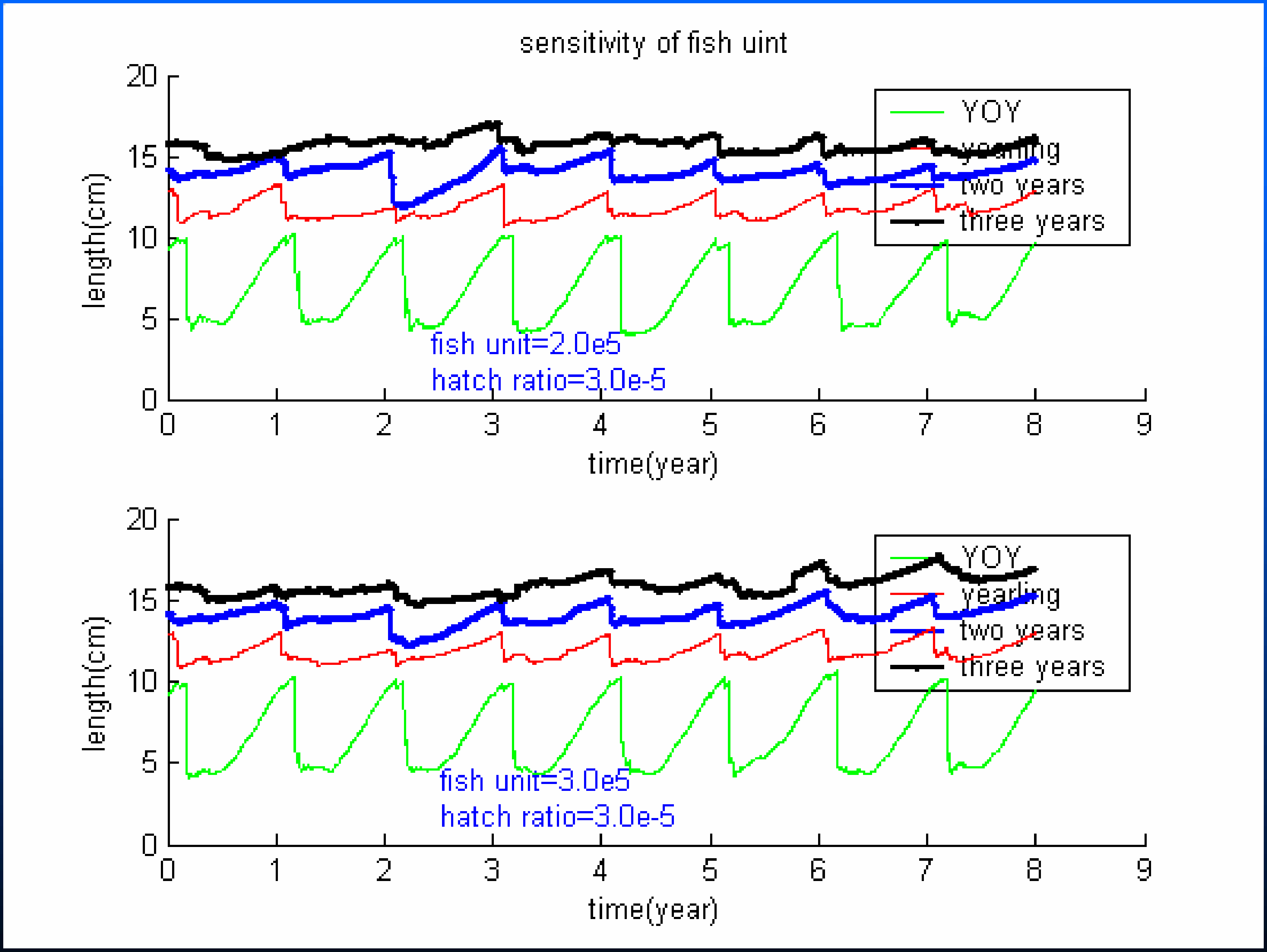
- Most parameters of anchovy is regards as genotype. Genotype may be mutation so discuss their sensitivity is not importance.
- But two parameters be configured fix values. Their values maybe influence the model. So it is importance to discuss them.

- One of the two parameters is fish-unit which mean a model individual represent the number of biology individuals.
- The other is hatch-ratio. eggs were hatched to YOY in the model. Hatch-ratio is defined as follow

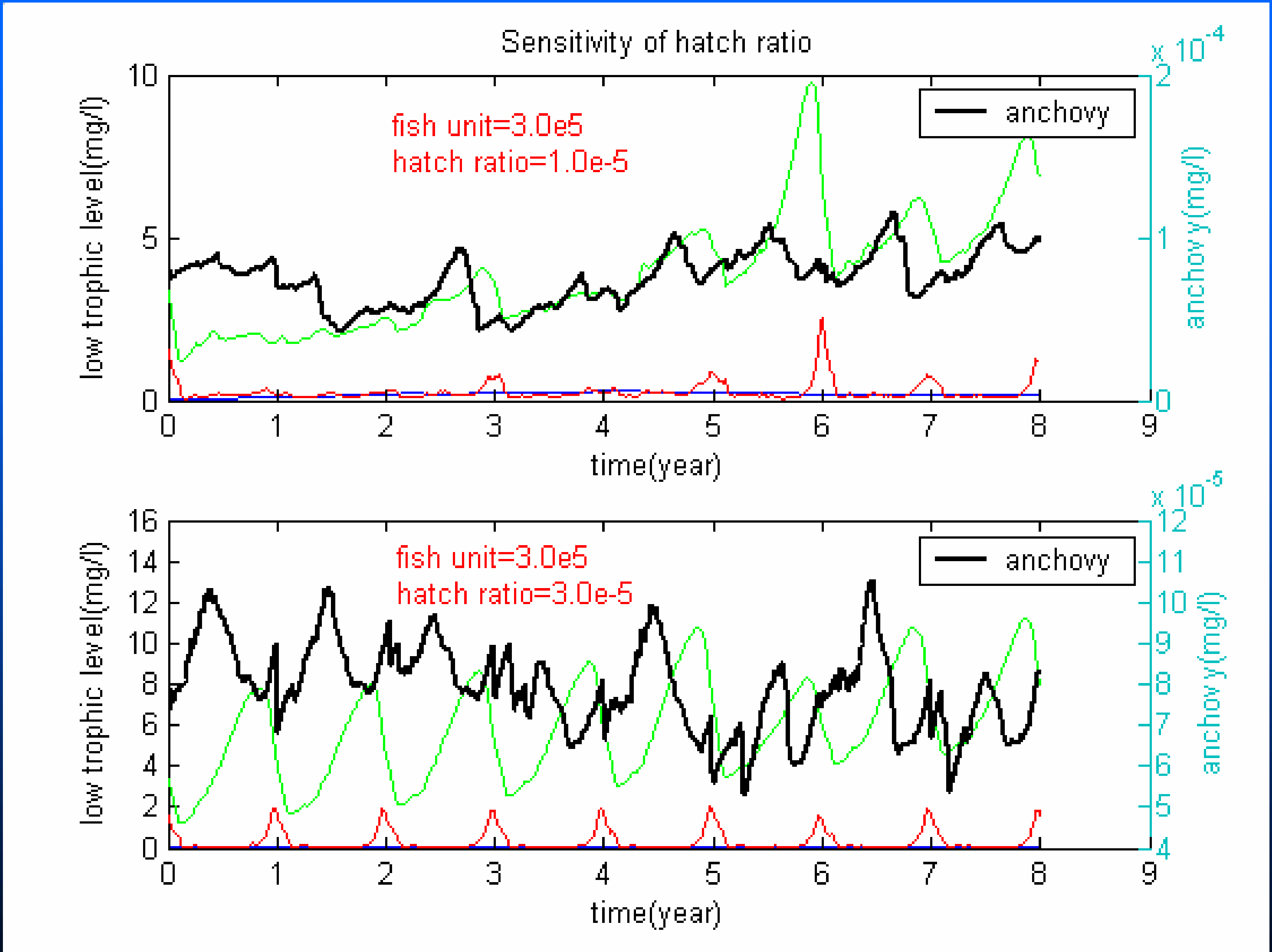
$$R_{Ha} = \frac{Num_{YOY}}{Num_{Egg}}$$

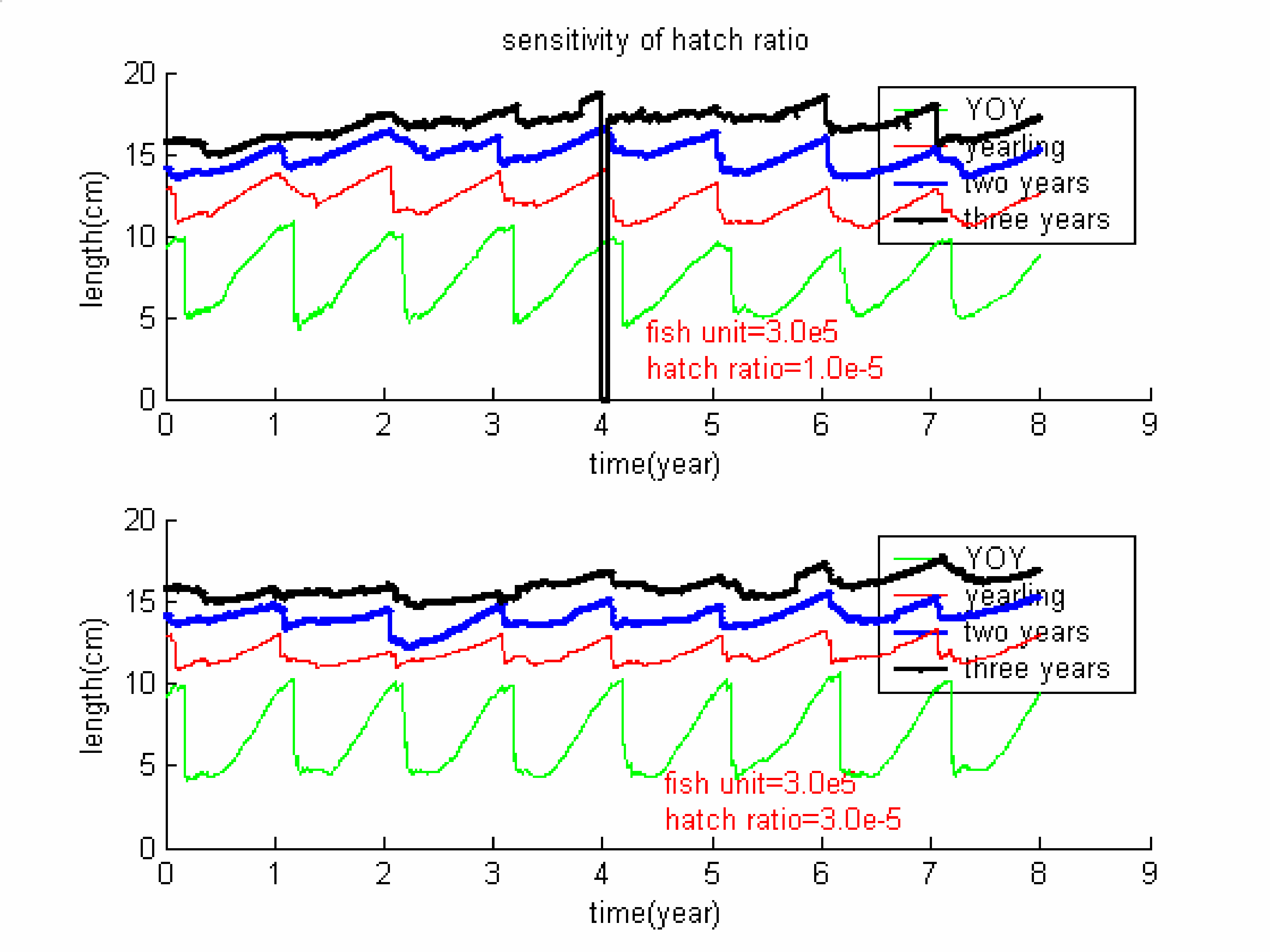


Sensitivity of fish unit
fish unit=2.0e5
hatch ratio=3.0e-5
anchovy
mean biomass of anchovy
low trophic level(mg/l)
anchovy(mg/l)
x 10^-5
time(year)
fish unit=3.0e5
hatch ratio=3.0e-5
anchovy
mean biomass of anchovy
low trophic level(mg/l)
anchovy(mg/l)
x 10^-5
time(year)



sensitivity of fish uint
length(cm)
time(year)
YOY
yearling
two years
three years
fish unit=2.0e5
hatch ratio=3.0e-5
fish unit=3.0e5
hatch ratio=3.0e-5


Sensitivity of hatch ratio
fish unit=3.0e5
hatch ratio=1.0e-5
anchovy
low trophic level(mg/l)
anchovy(mg/l)
x 10^-4
time(year)
fish unit=3.0e5
hatch ratio=3.0e-5
anchovy
low trophic level(mg/l)
anchovy(mg/l)
x 10^-5
time(year)



sensitivity of hatch ratio
YOY
yearling
two years
three years
fish unit=3.0e5
hatch ratio=1.0e-5
length(cm)
time(year)
YOY
yearling
two years
three years
fish unit=3.0e5
hatch ratio=3.0e-5
length(cm)
time(year)

Prospect

- Numerical experiments will be made aim at the response of the population to different fishing project and change of environment such as temperature and nutrition change.
- To Find the optimal fishing project which obtain maximal sustained fishery resources .

Thank you ！