Comment évaluer une menace ?

Marc Girondot

Laboratoire Ecologie, Systématique et Evolution
ESE – UMR8079

Les changements en réponse à une menace

- Imaginez deux situations, A et B, avec B la situation où la menace est présente: la présence de la menace ne permet jamais de conclure sur l'impact démographique de la menace pour deux raisons:
  - Toute différence d'un paramètre démographique entre les groupes A et B ne peut pas être interprétée comme étant dû à la présence de la menace. A et B diffèrent par beaucoup d'autre facteurs;
  - Si la menace est bien la cause d'une différence, comment se traduit-elle en terme démographique ?
    - Dire qu'une menace existe ne suffit pas à conclure sur l'importance de la menace.

Intégrer une menace dans le fonctionnement d’une population

- Quantifier la menace ne suffit pas: on doit quantifier les conséquences de cette menace.

La dynamique des populations vue par une matrice de Leslie

- Une matrice de Leslie est formée en augmentant ou en joignant un vecteurs ligne contenant les taux de natalité de chaque groupe d'âge et une série de vecteurs lignes qui contiennent le taux de survie des colonnes et des zéros partout ailleurs.

Âge

$$\begin{array}{rc}
 & \begin{array}{cccccc} 0 & 1 & 2 & 3 & 4 & 5 \end{array} \\
\begin{array}{r} \\ \hat{a}ge\ 0\ vers\ 1 \\ \hat{a}ge\ 1\ vers\ 2 \\ \hat{a}ge\ 2\ vers\ 3 \\ \hat{a}ge\ 3\ vers\ 4 \\ \hat{a}ge\ 4\ vers\ 5 \end{array} & \begin{bmatrix} 0 & f_1 & f_2 & f_3 & f_4 & f_5 \\ s_0 & 0 & 0 & 0 & 0 & 0 \\ 0 & s_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & s_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & s_3 & 0 & 0 \\ 0 & 0 & 0 & 0 & s_4 & 0 \end{bmatrix}
\end{array}$$

Taux de fécondité par âge

Taux de survie par âge

La dynamique des populations vue par une matrice de Leslie

- Une matrice de Leslie est formée en augmentant ou en joignant un vecteurs ligne contenant les taux de natalité de chaque groupe d'âge et une série de vecteurs lignes qui contiennent le taux de survie des colonnes et des zéros partout ailleurs.

Âge

$$\begin{array}{r|cccccc|}
 & 0 & 1 & 2 & 3 & 4 & 5 \\
 & 0 & f_1 & f_2 & f_3 & f_4 & f_5 \\
\text{âge } 0 \text{ } vers \text{ } 1 & s_0 & 0 & 0 & 0 & 0 & 0 \\
\text{âge } 1 \text{ } vers \text{ } 2 & 0 & s_1 & 0 & 0 & 0 & 0 \\
\text{âge } 2 \text{ } vers \text{ } 3 & 0 & 0 & s_2 & 0 & 0 & 0 \\
\text{âge } 3 \text{ } vers \text{ } 4 & 0 & 0 & 0 & s_3 & 0 & 0 \\
\text{âge } 4 \text{ } vers \text{ } 5 & 0 & 0 & 0 & 0 & s_4 & 0
\end{array}$$

Taux de fécondité par âge

Taux de survie par âge

Vous croyez vraiment qu'on peut résumer la dynamique des populations d'une tortue marine par une matrice…

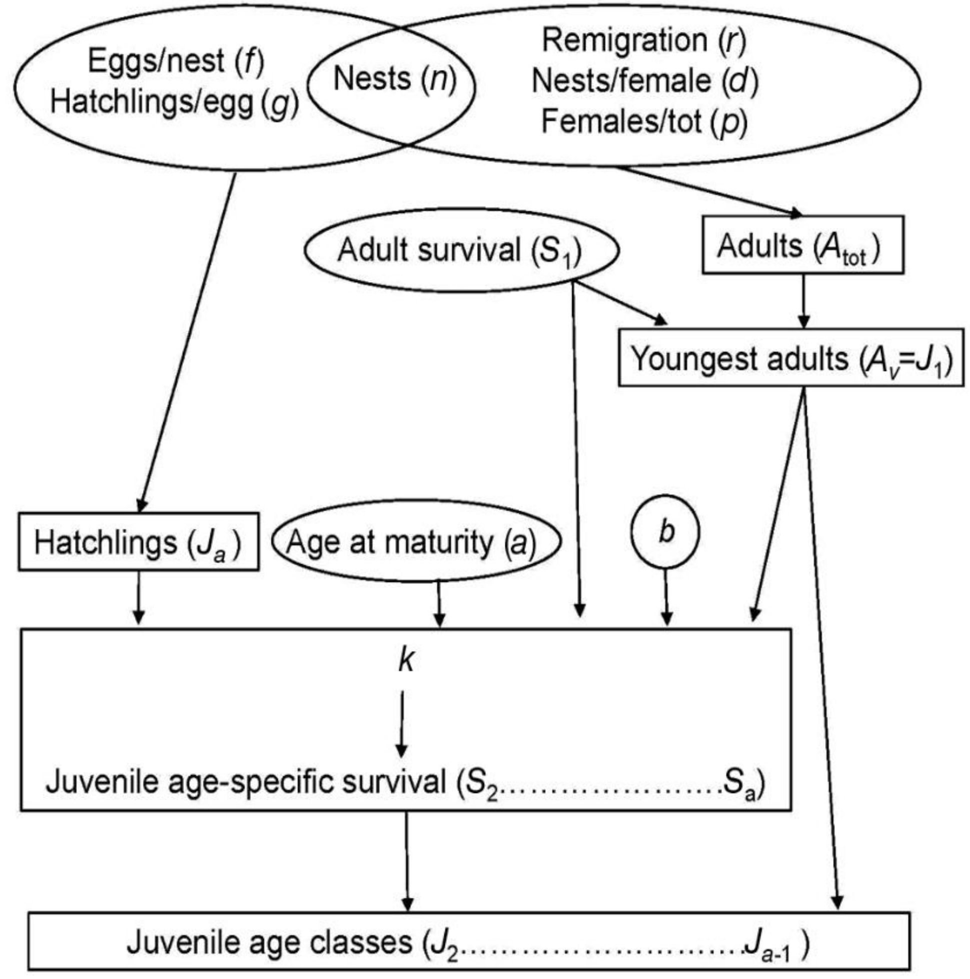
La biologie des tortues marines

- The biology of marine turtles is studied by over 500 researchers worldwide who published around 500 scientific publications per year.
- All the aspects of the biology of the 7 species of marine turtles is studied
- *A contrario*, the population dynamics of these species is poorly known.

Why?

Marine turtles population dynamics

- The classical tool to study marine turtle population dynamics is to use Leslie (age) or Lefkovitch (stage) matrix. However, many simplifications must be done. The consequences of these simplifications is not understood.
- *« Although many turtles exhibit an increase in dutch size with female body size (Wilbur and Morin, 1988; Congdon and Gibbons, 1990; Van Buskirk and Crowder, 1994), most of the life tables gave an average fecundity for all adults, and all had a constant annual survival rate for adults. »*
  - In Heppell SS (1998) Application of life-history theory and population model analysis to turtle conservation. Copeia 1998: 367-375



Casale P, Heppell SS (2016) How much sea turtle bycatch is too much? A stationary age distribution model for simulating population abundance and potential biological removal in the Mediterranean. Endangered Species Research 29: 239-254 doi 10.3354/esr00714

Marine turtles population dynamics

- An alternative is to model population dynamics at the finest possible level (genet=egg and then individuals) to reproduce the best the subtilities of life-history parameters of the modelled population.
- The time scale is the year except during a nesting season for nesting females where the time scale is the day and the embryos where the time scale is the minute.
- The basis of the model is to model life-histories as reaction norms.

The virtual Turtles project

Why reaction-norms?

- In ecology and genetics, a reaction norm, also called a norm of reaction, describes the pattern of phenotypic expression of a single genotype across a range of environments.
  - The « environments » can be any factor linked with the individual:
    - Habitat quality
    - Temperature of nest
    - Size of female
    - Rank of clutch
    - etc

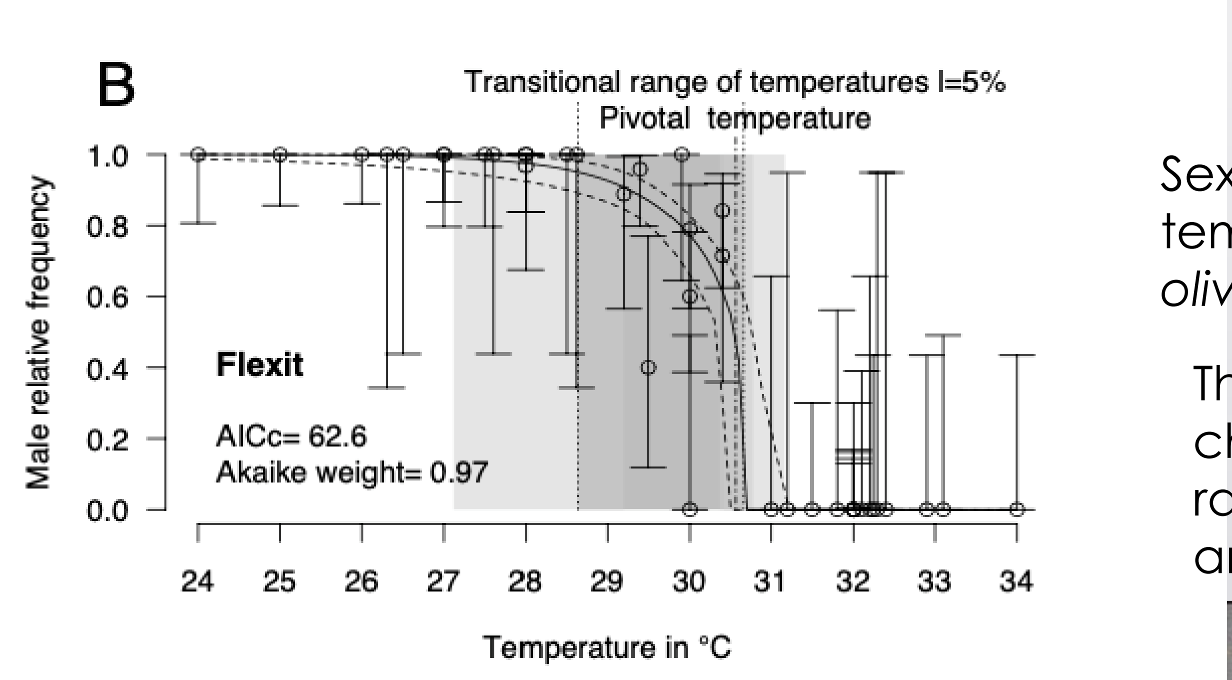
The reaction-norms

Stage	**Life-history**	**Environment**
Egg	Number of eggs	SCL and rank of clutch
	Hatching success	Temperature
	Sex determination	Temperature
Juvenile	Survival	SCL
	Sexual maturity	SCL
	Growth	Habitat and SCL
Male	Survival	SCL
	Growth	Habitat
	Remigration interval	Cumulative effect of habitat
Female	Survival	SCL, nesting status
	Growth	Habitat
	Remigration interval	Cumulative effect of habitat
	Clutch frequency	Cumulative effect of habitat
	Number of eggs	SCL and rank of clutch

Egg stage

Temperature-dependent sex determination

- Abreu-Grobois, F.A., Morales-Mérida, B.A., Hart, C.E., Guillon, J.-M., Godfrey, M.H., Navarro, E. & Girondot, M. (2020) Recent advances on the estimation of the thermal reaction norm for sex ratios. *PeerJ,* **8,** e8451.

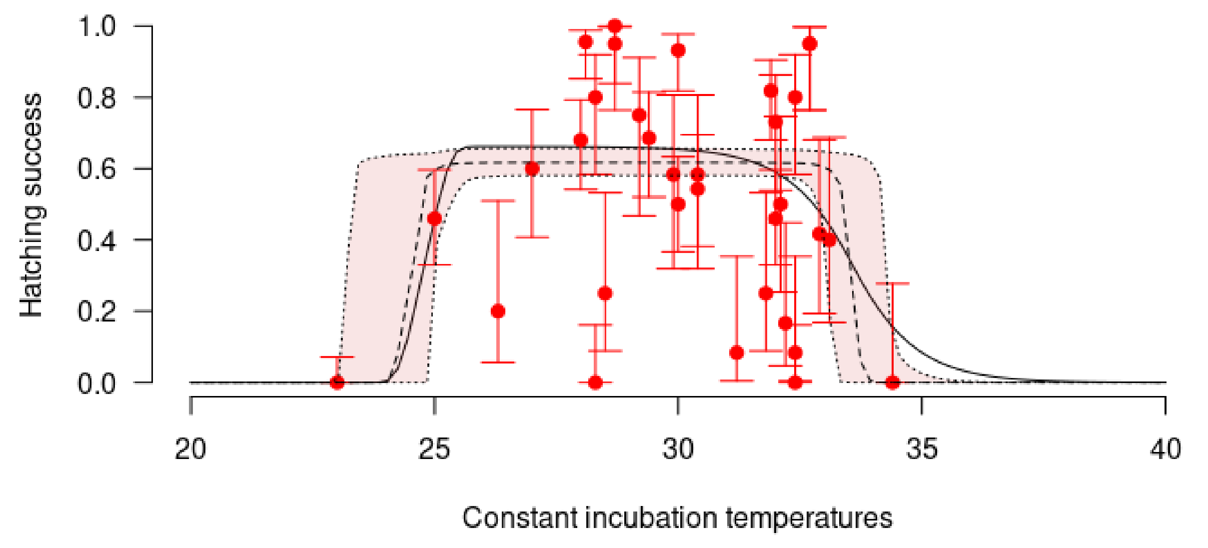


Sex ratio according to incubation temperature for *Lepidochelys olivacea*

The constant temperature equivalent is chosen for each clutch based on random number with a intra-annual and a inter-annual SD.

Temperature-dependent hatching-success

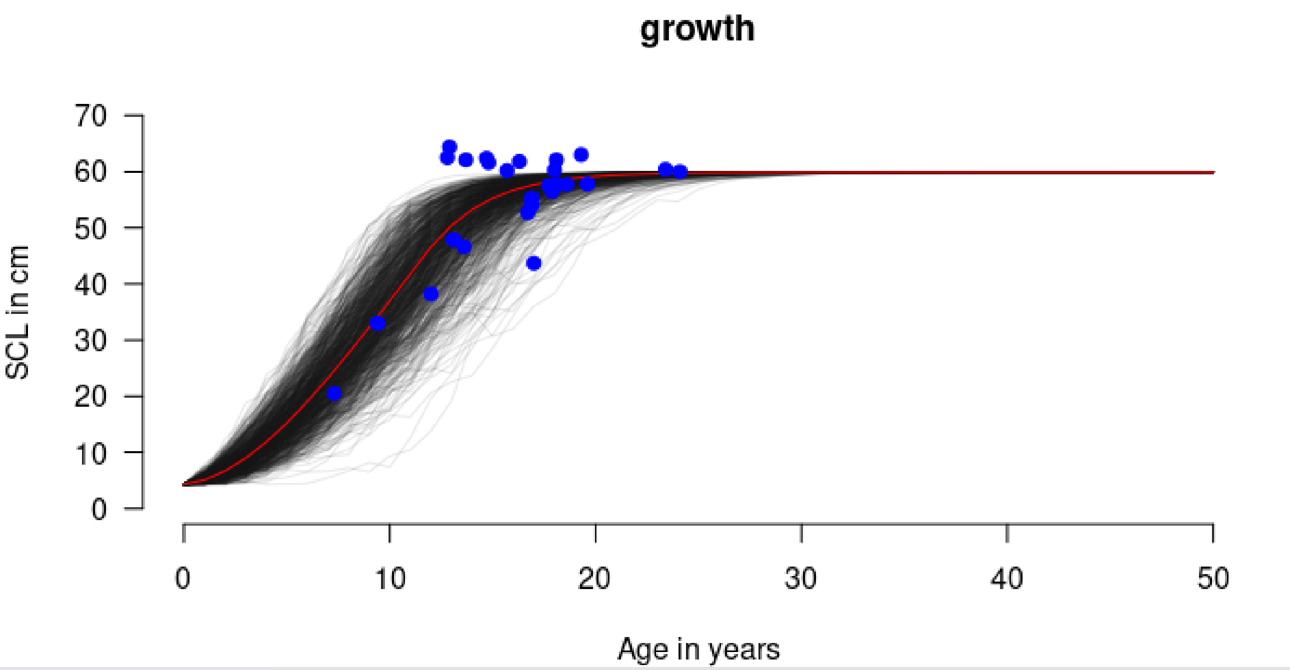
- Laloë, J.-O., Monsinjon, J., Gaspar, C., Touron, M., Genet, Q., Stubbs, J., Girondot, M. & Hays, G.C. (2020) Production of male hatchlings at a remote South Pacific green sea turtle rookery: conservation implications in a female-dominated world. *Marine Biology,* **167,** 70.



Hatching success according to incubation duration in *Lepidochelys olivacea*

Juvenile and adult stages

Juvenile and adult biphasic growth

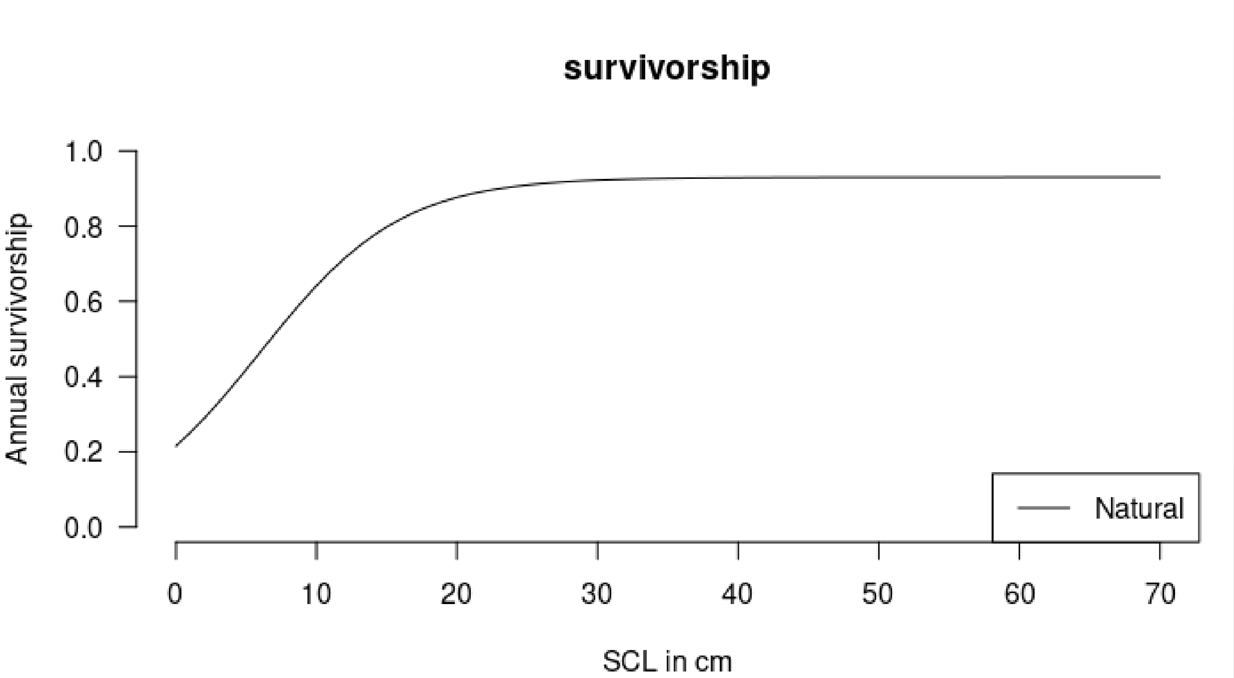


Indeterminate growth for *Lepidochelys olivacea*

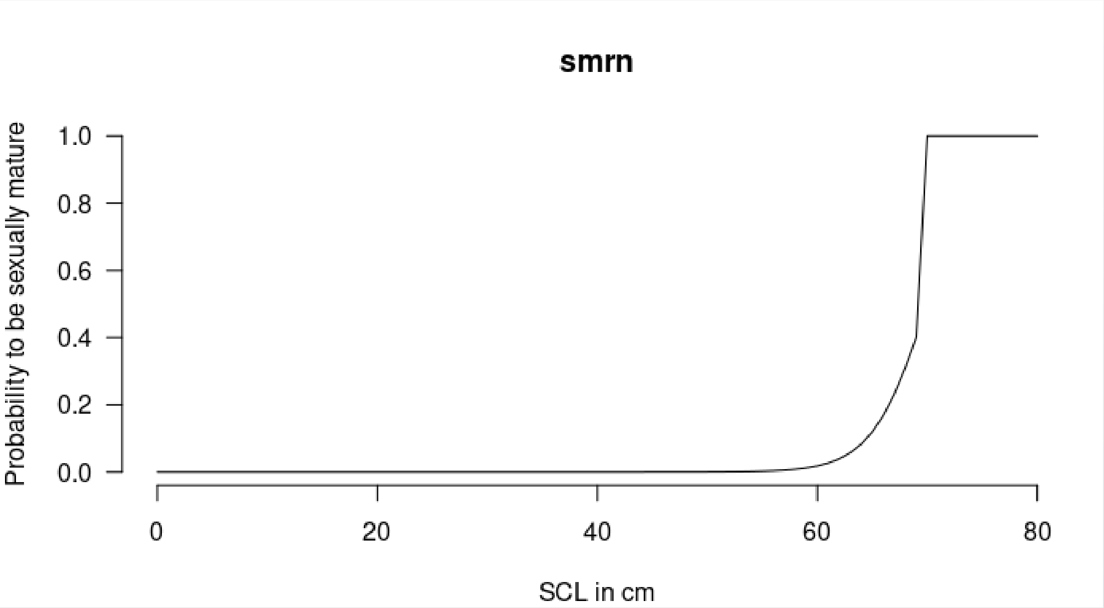
Chevallier, D., Mourrain, B. & Girondot, M. (2020) Modelling leatherback biphasic indeterminate growth using a modified Gompertz equation. *Ecological Modelling,* **426,** 109037.

Survival

- The annual survival is dependent on SCL of individual.
- It is possible to define natural annual survival and human effect on annual survival.
- Survival can be different for a female during a nesting season as compare to female that do not nest this year.



Sexual maturity



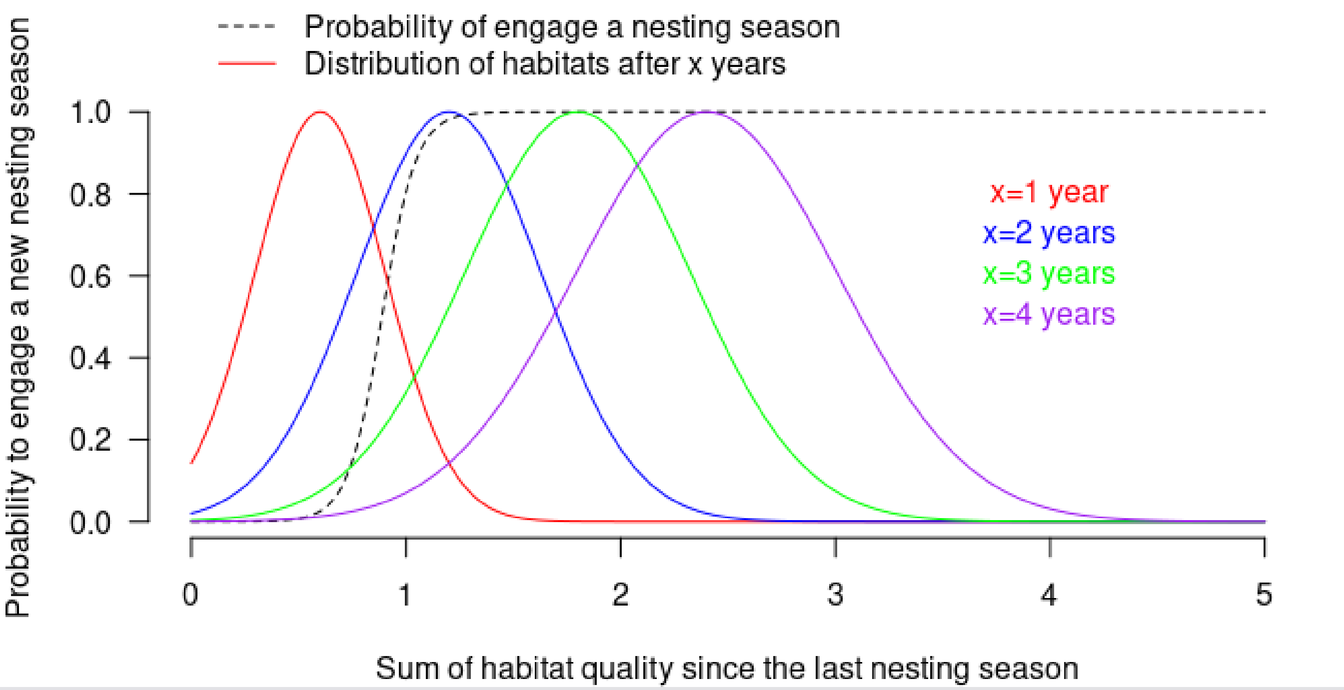
Probability that a *Lepidochelys olivacea* is mature according to its size

Girondot M, Mourrain B, Chevallier D, Godfrey MH (2021) Maturity of a Giant: Age and size reaction norm for sexual maturity for Atlantic leatherback turtles. Marine Ecology 42: e12631

Males and females

The remigration interval

- The probability to engage to a new nesting season is modeled as a logit function (P_RI and S_RI parameters) dependent on the sum of habitat quality since the last nesting season or the sexual maturity.



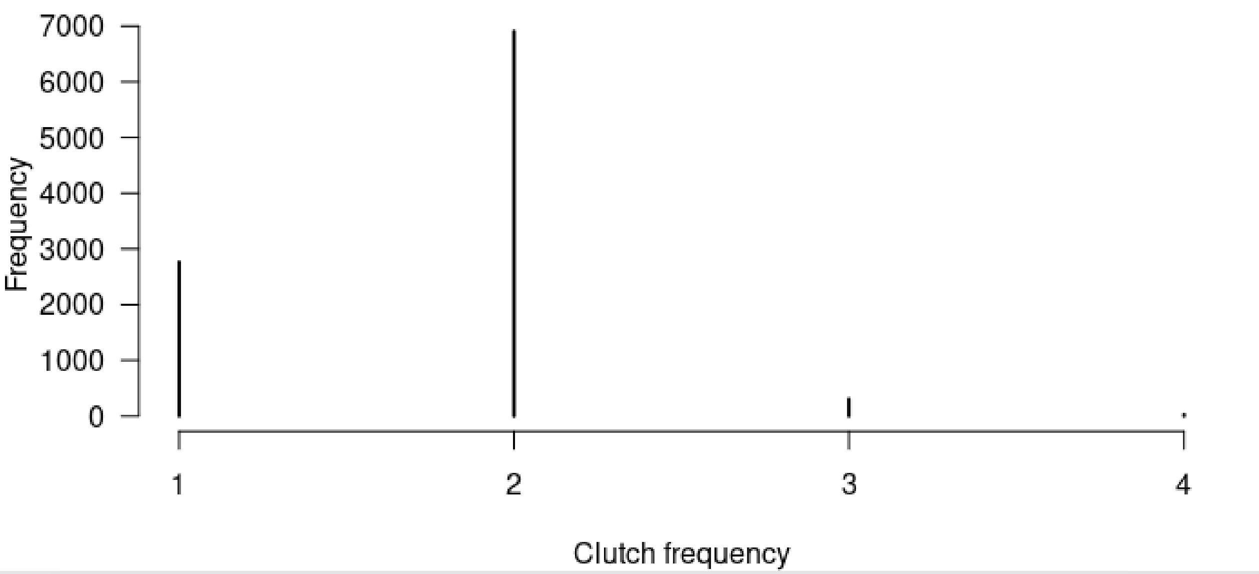
The remigration interval

- The probability to engage to a new nesting season is modeled as a logit function (P_RI and S_RI parameters) dependent on the sum of habitat quality since the last nesting season or the sexual maturity.
- The distribution of remigration interval can be adjusted by changing the value of P_RI and S_RI.

Females

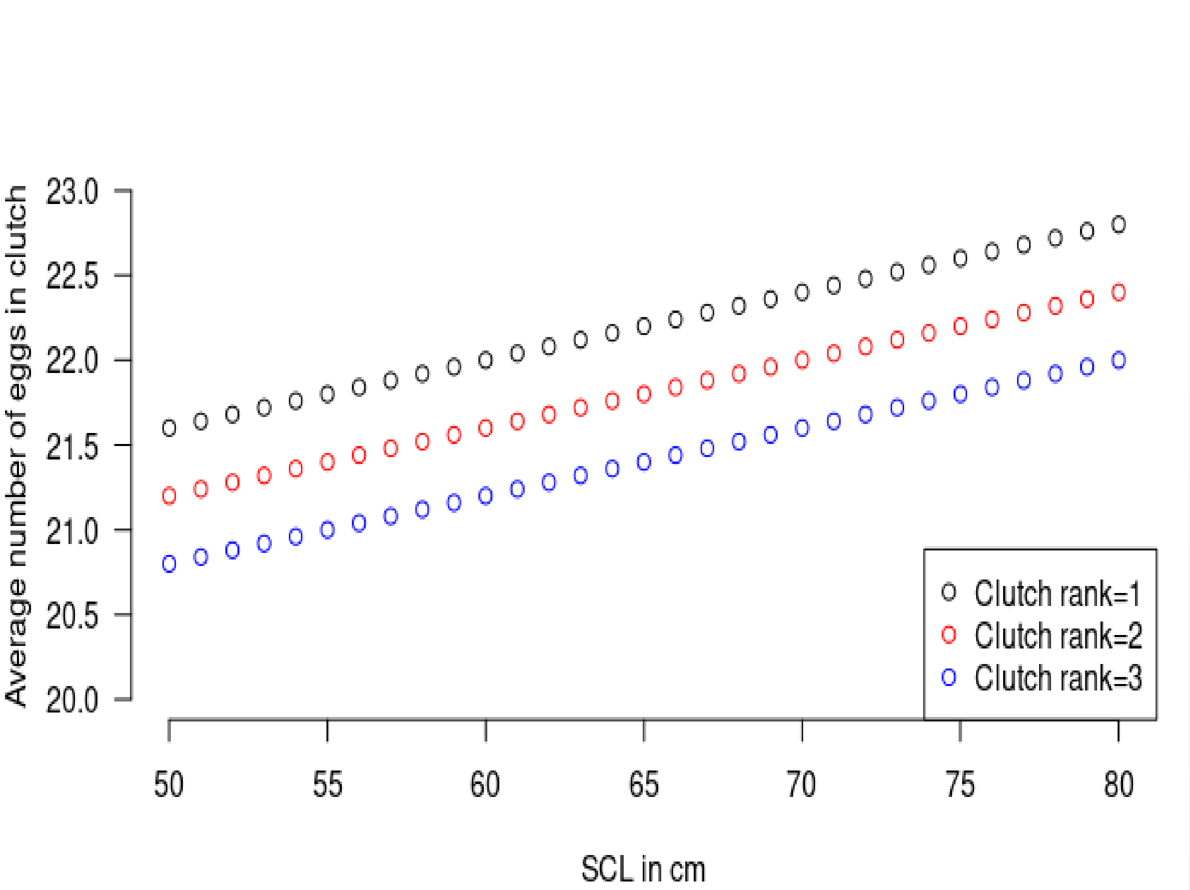
Clutch frequency

- The clutch frequency is modeled as a logit function (P_CF and S_CF parameters) dependent on the sum of habitat quality since the last nesting season or the sexual maturity.



Number of eggs per clutch

- The number of eggs per clutch is obtained using a random number with a mean dependent on the rank of the clutch (mean is decreased by 1 x rank of the clutch) and on the SCL of the female (mean is increased by 0.02 x SCL).



The reaction-norms

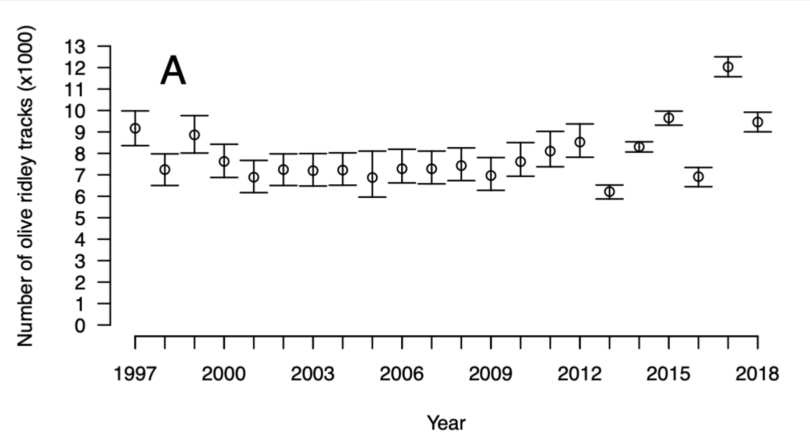
Stage	Life-history	Environment	Links
Egg	Number of eggs	**SCL and rank of clutch**	🔵 🟠
	Hatching success	**Temperature**	🔴
	Sex determination	**Temperature**	🔴
Juvenile	Survival	**SCL**	🔵
	Sexual maturity	**SCL**	🔵
	Growth	**Habitat and SCL**	🔵 🟠
Male	Survival	**SCL**	🔵
	Growth	**Habitat**	🟠
	Remigration interval	**Cumulative effect of habitat**	🟠 🟢
Female	Survival	**SCL, nesting status**	🔵 🟠 🟢
	Growth	**SCL, Habitat**	🔵 🟠
	Remigration interval	**Cumulative effect of habitat**	🟠
	Clutch frequency	**Cumulative effect of habitat**	🟠
	Number of eggs	**SCL and rank of clutch**	🔵 🟠

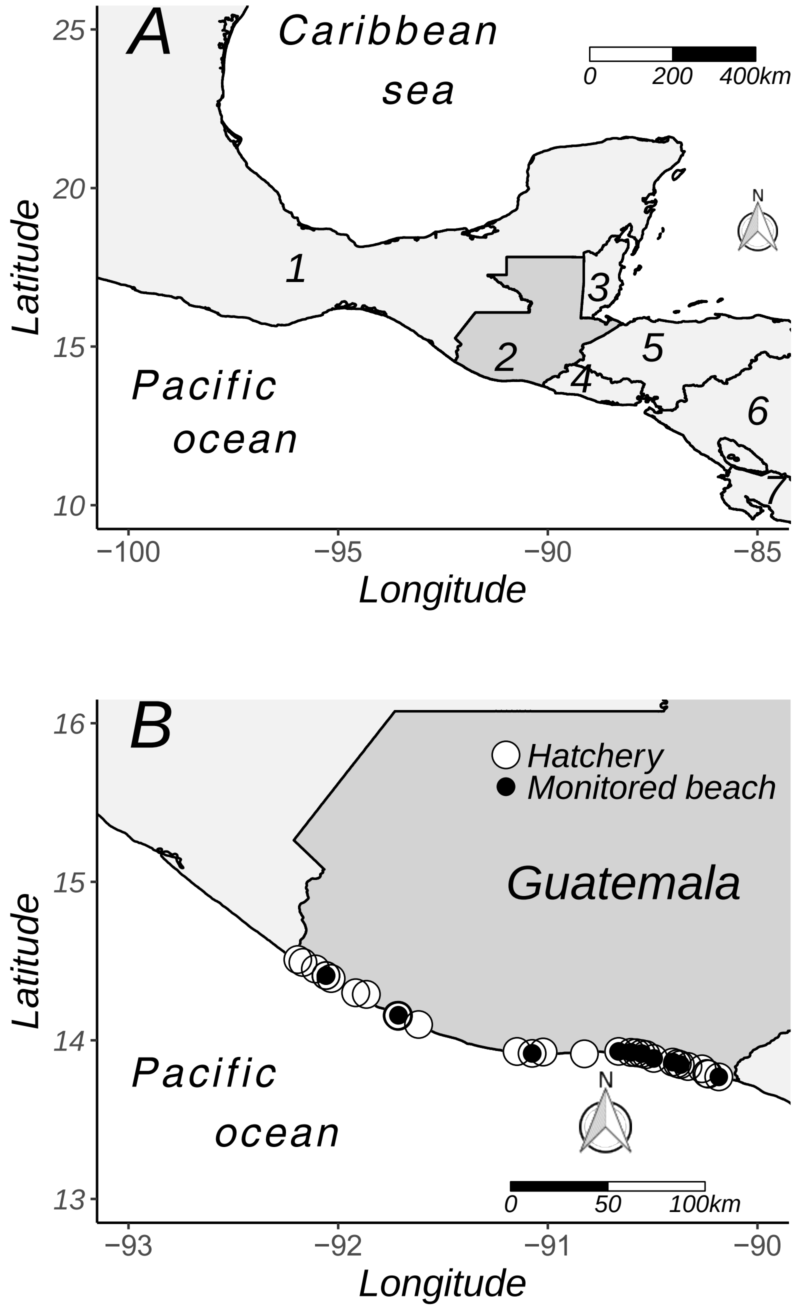
A case study

National managment of *Lepidochelys olivacea* in Guatemala

Situation in Guatemala

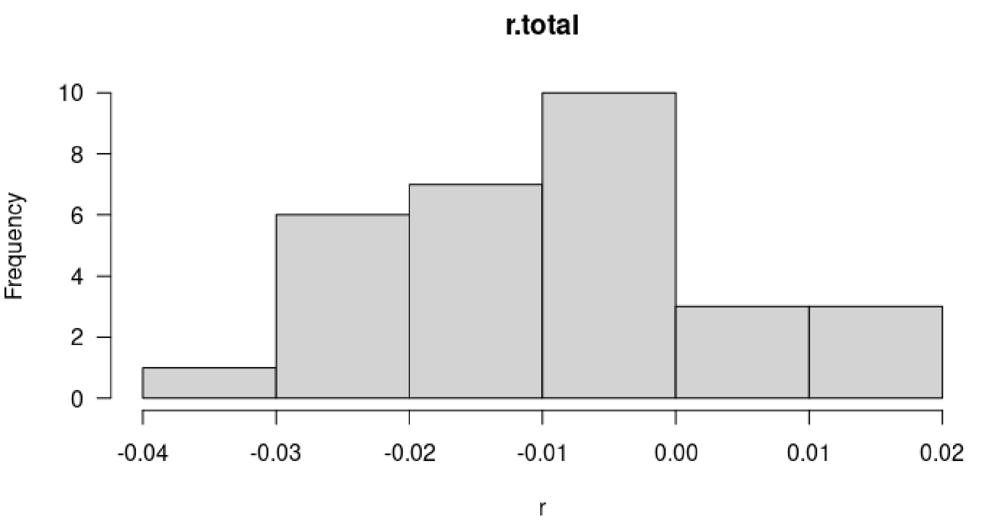
- All nests are taken legally by people. They must give 20% of eggs in national hatcheries.
- Eggs are incubated in shaded hatcheries and hatchlings are released. No control on the hatchling performance.
- Trend of nesting is stable for the last 20 years.

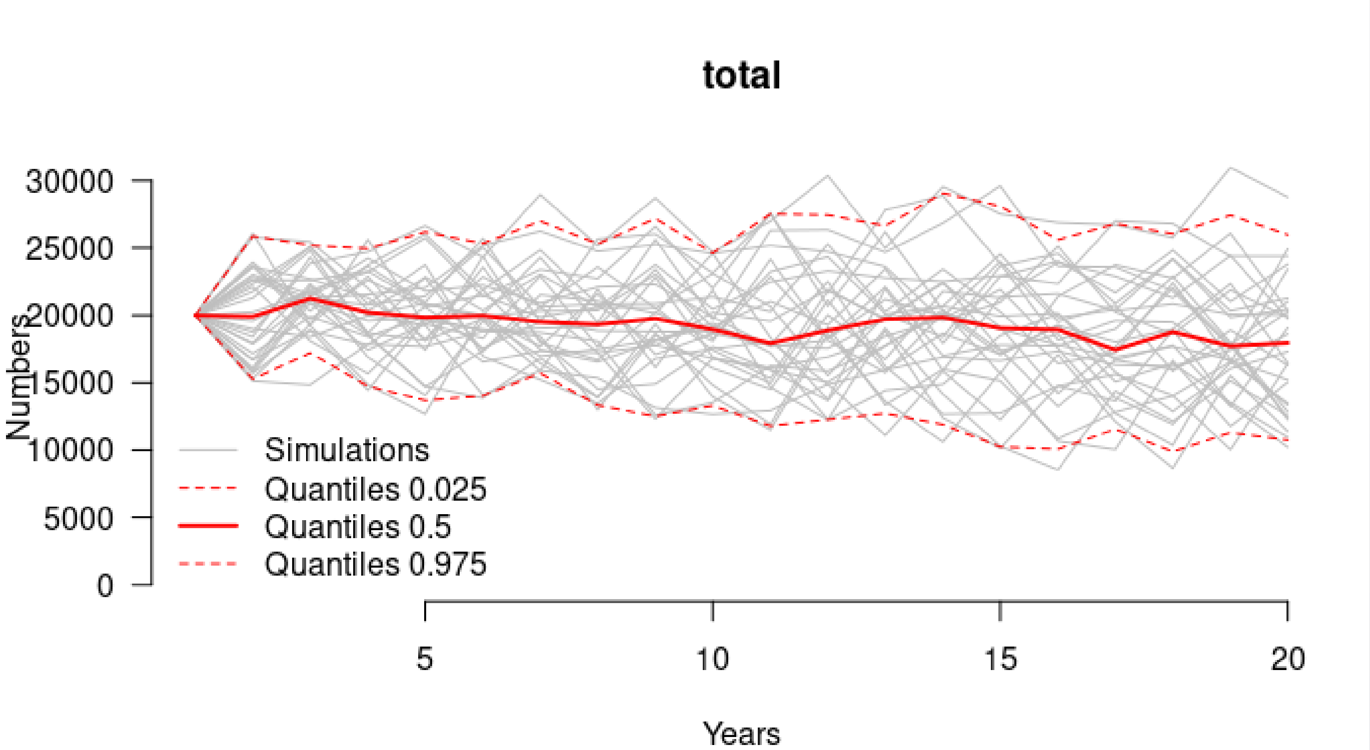




30 replicates: total number of individuals in the population

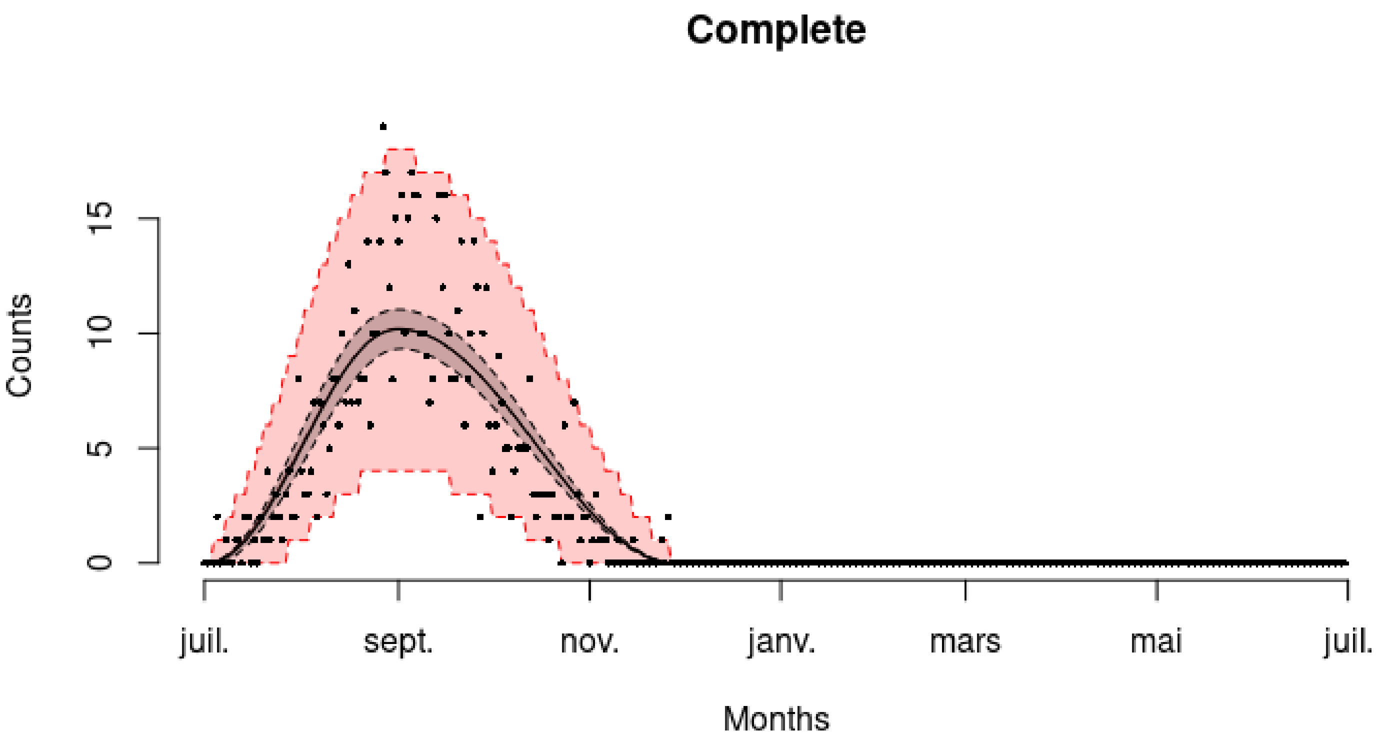
Adult annual survival 0.93
CTE = 30°C (SD 2)
20% of eggs are left in incubation





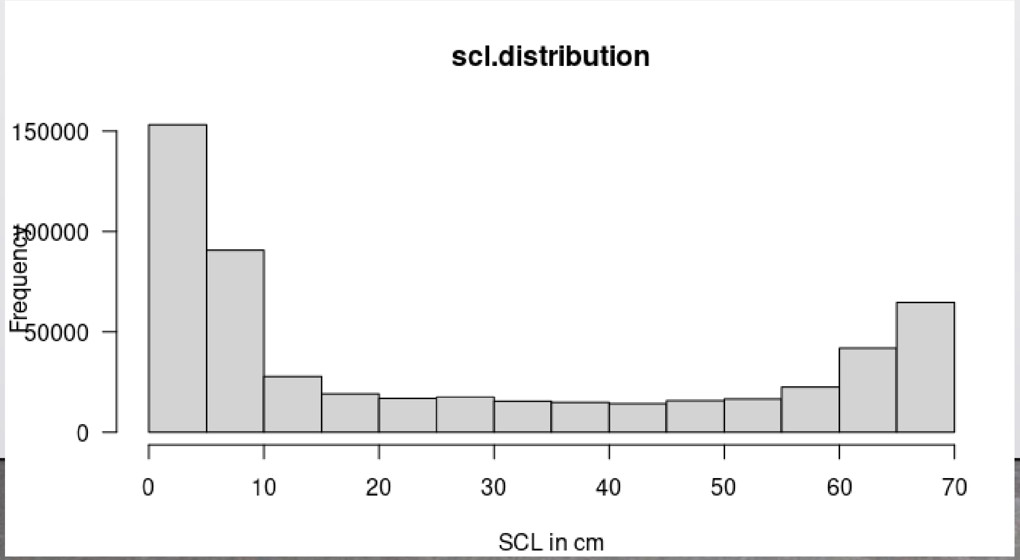
30 replicates: phenology

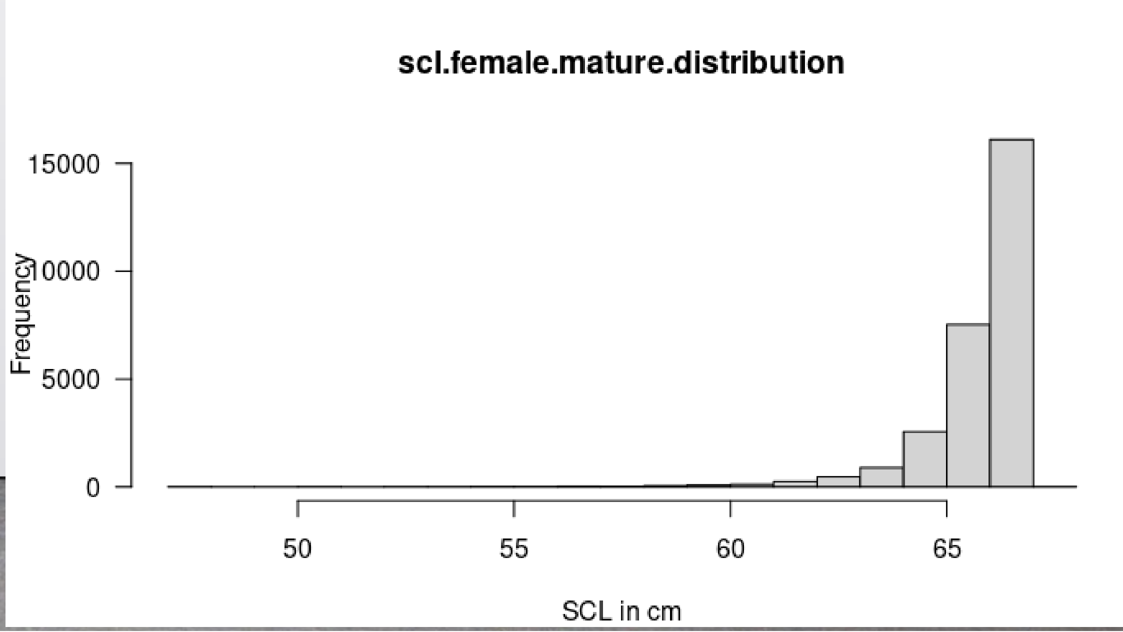
Adult annual survival 0.93
CTE = 30°C (SD 2)
20% of eggs are left in incubation



30 replicates: SCL for total population and nesting females

Adult annual survival 0.93
CTE = 30°C (SD 2)
20% of eggs are left in incubation

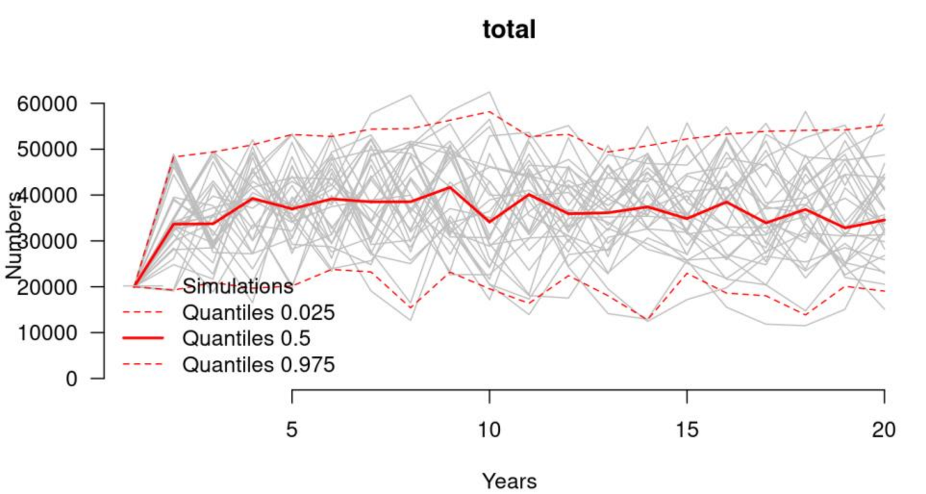


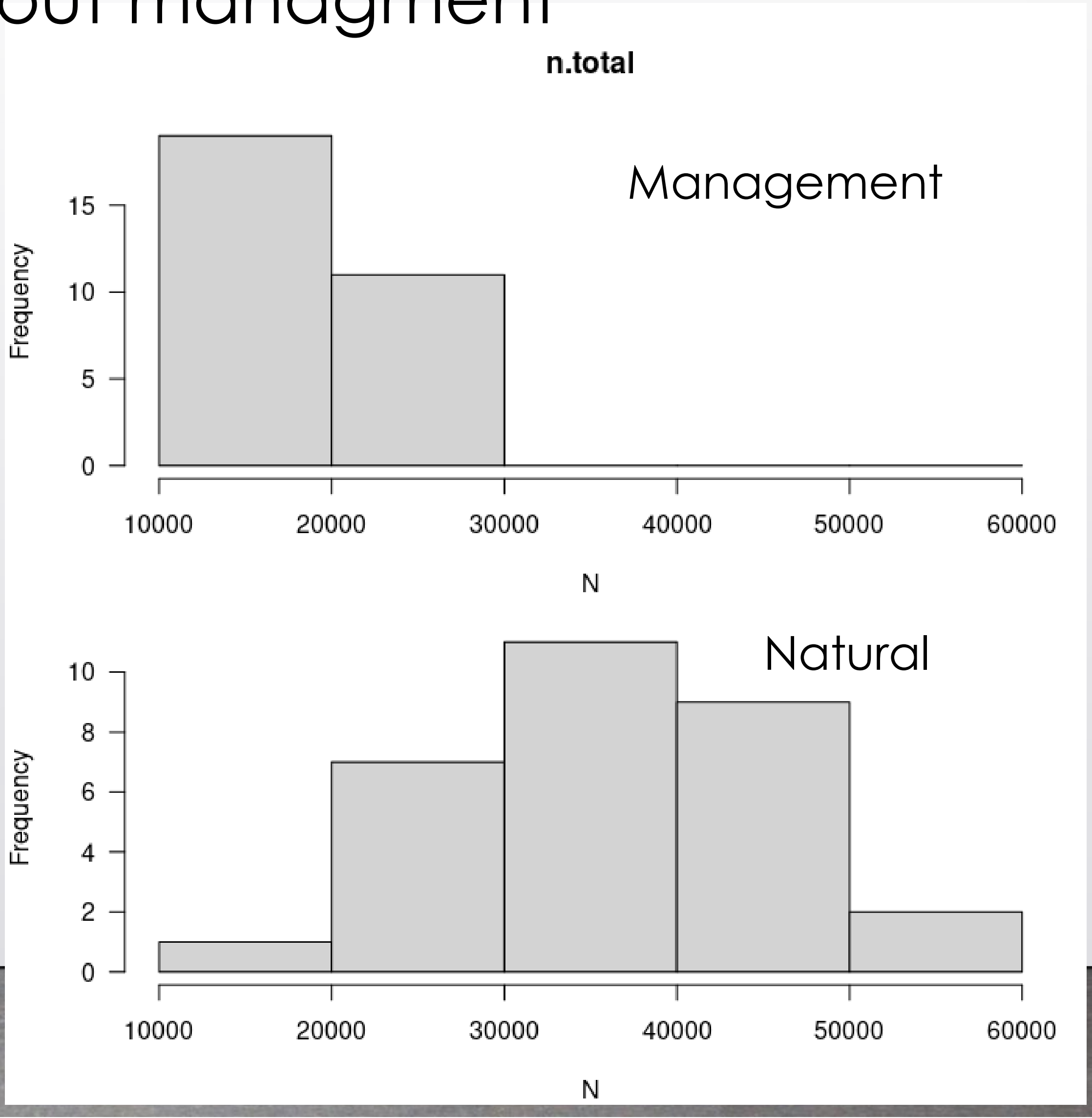


30 replicates: total number of individuals in the population without managment

Adult annual survival 0.93

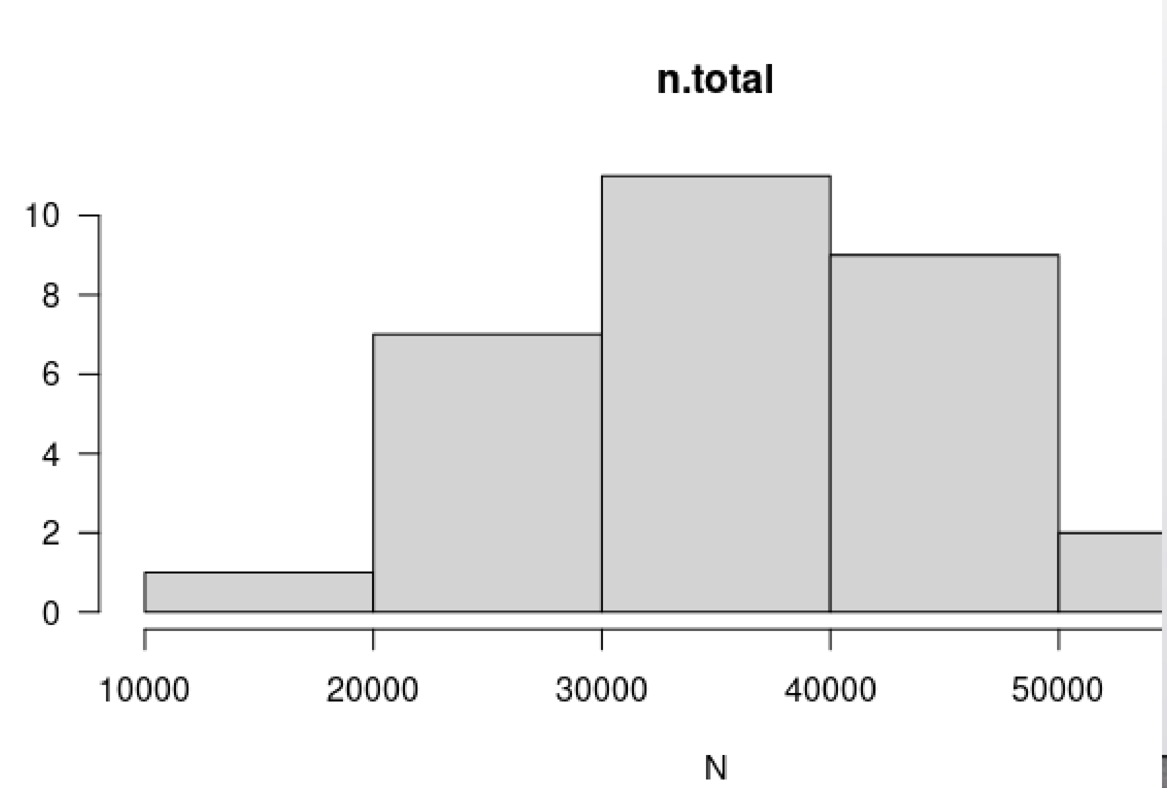
New hypothesis:
CTE = 34°C (SD 2) – No shaded hatcheries
100% of eggs in incubation

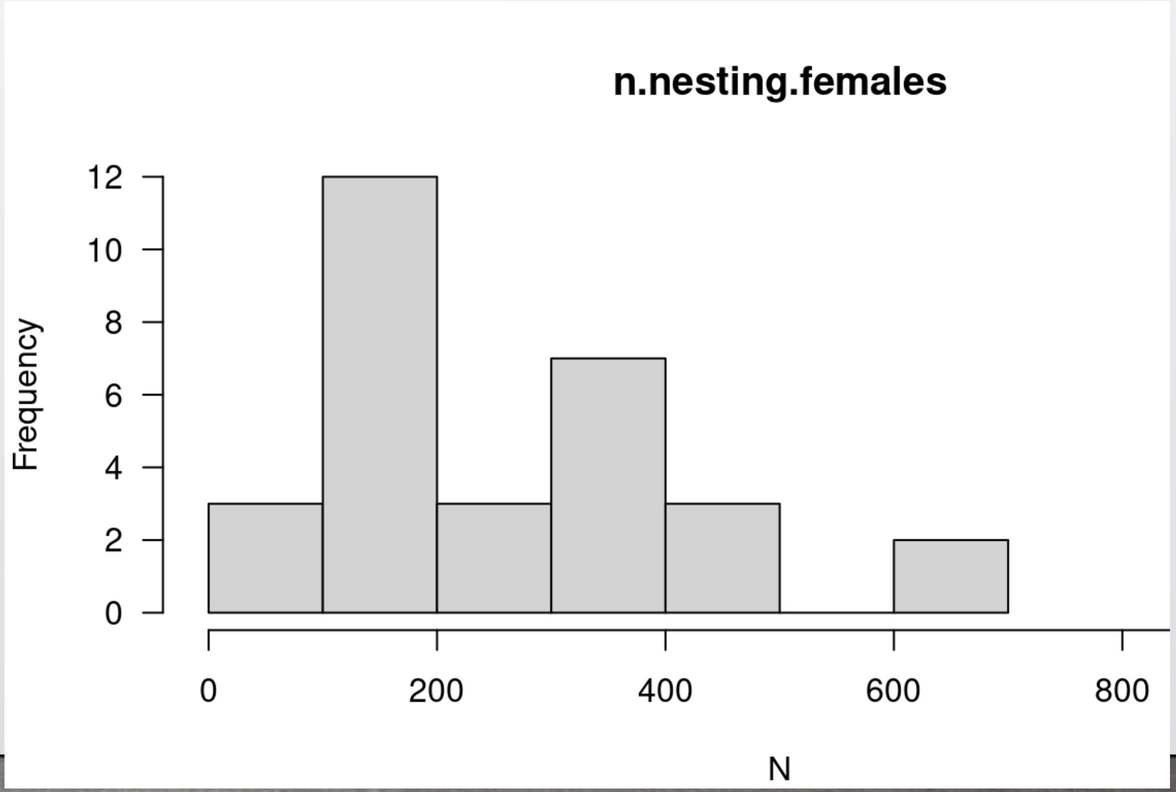




30 replicates: number of individuals in the population without managment

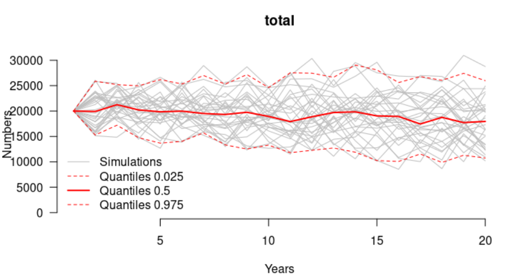
- Adult annual survival 0.93
- CTE = 34°C (SD 2)
- 100% of eggs in incubation





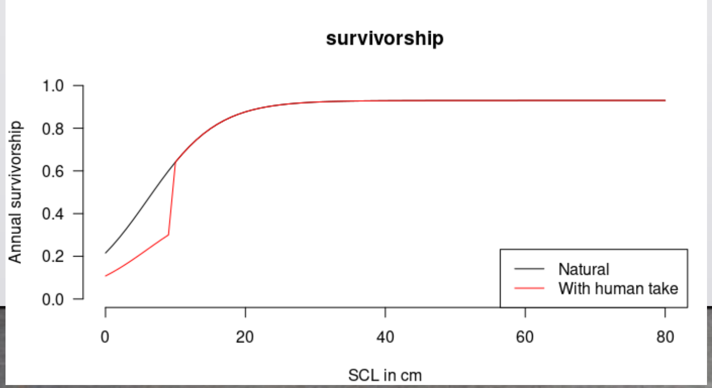
Nesting females are 1/100 of individuals in the population

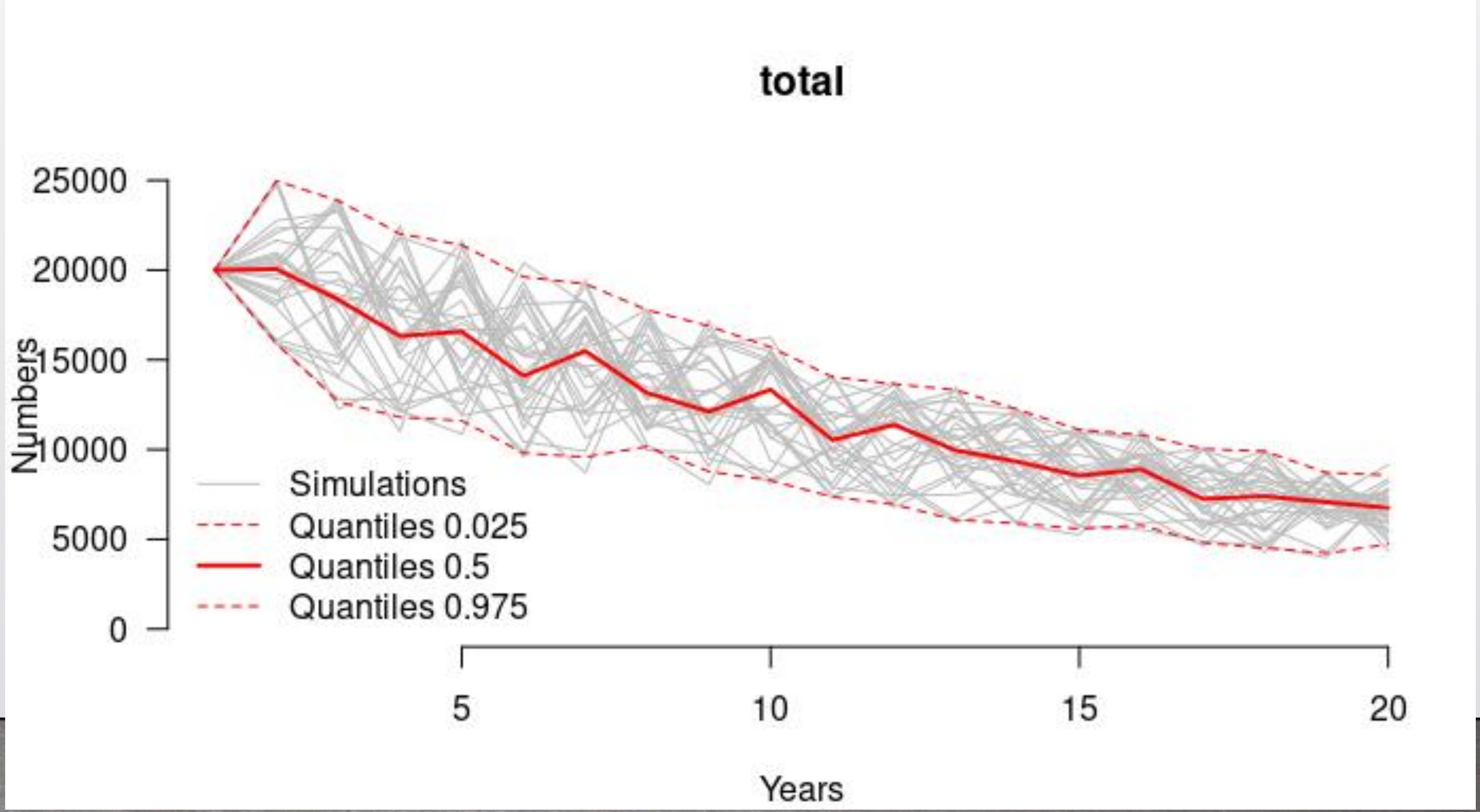
30 replicates: total number of individuals in the population

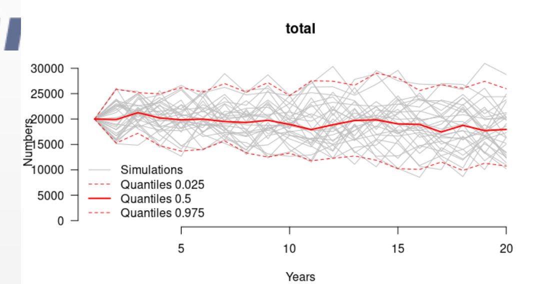


Adult annual survival 0.93
CTE = 30°C (SD 2)
20% of eggs in incubation

New hypothesis:
Juveniles from hatcheries with lower performance



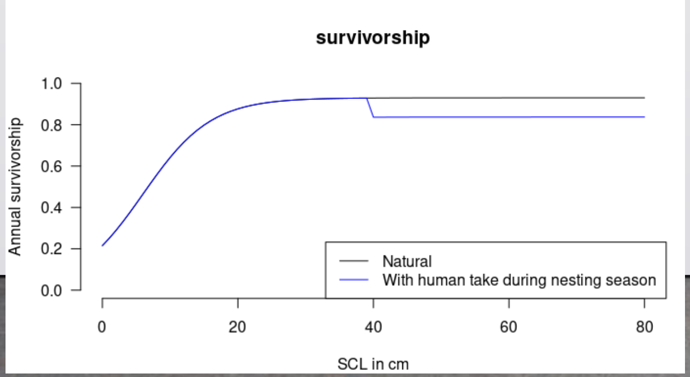


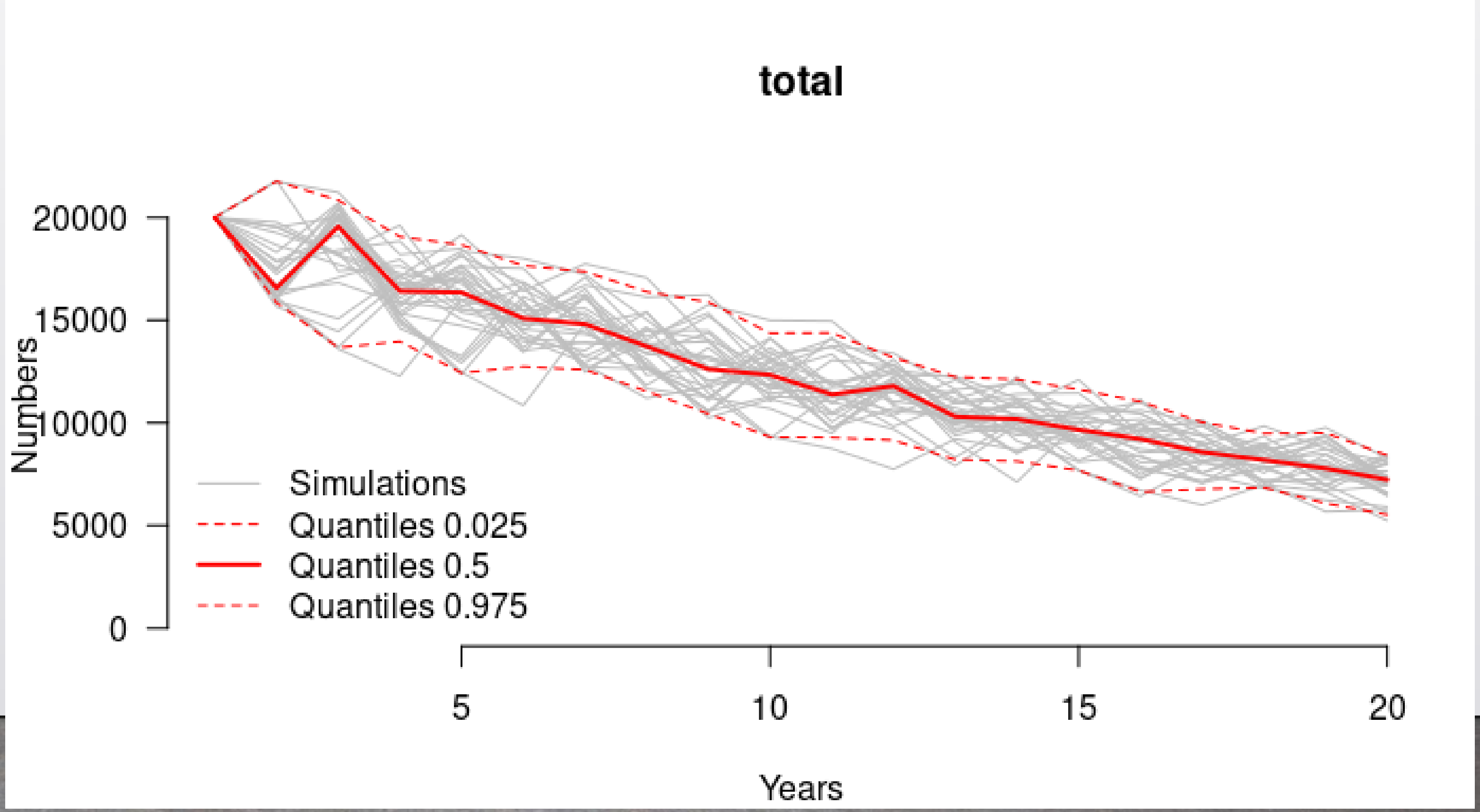


30 replicates: total number of individuals in the population

Adult annual survival 0.93
CTE = 30°C (SD 2)
20% of eggs in incubation

New hypothesis:
Mortality is 10% higher during the nesting season





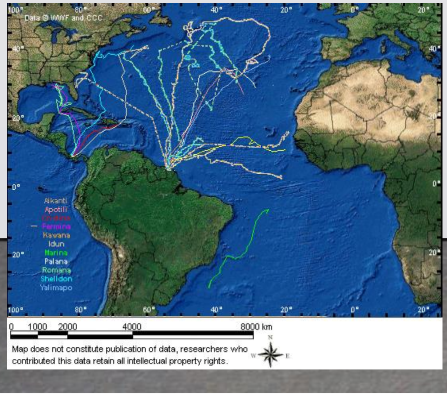
Conclusions

- The model well reproduces field observations for:
    - Phenology,
    - Size distribution of nesting females
    - Clutch frequency, Remigration interval
    - Growth of individuals
- It confirms the general observation that adult survivorship is the main driving force of population dynamics but sub-adults or eggs components are not negligible.
- The model already includes the possibility to have genetic component for sex determination, growth, phenology and hatching success (not used here).
- It takes 45 minutes to model 30 replicates of a population of 20000 individuals during 20 years on a 32-cores computer (the model is parallelized) then it is possible to test for a variety of models.

Future

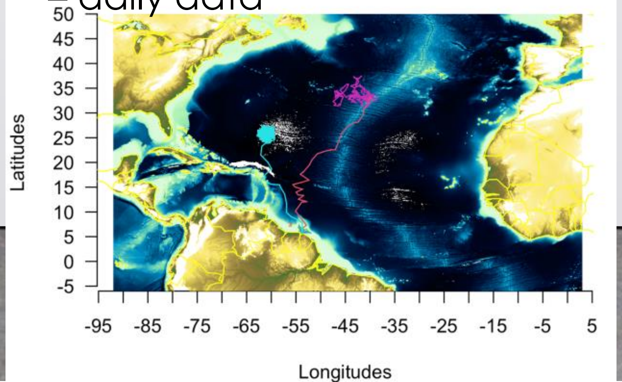
- Monitor neutral genetic markers to estimate effective size of population.
- Sensitivity analysis to better parametrize model (P and S are difficult to tune)
- The time scale is the year except during a nesting season for nesting females where the time scale is the day. But for embryos, the time-scale of the model should be the minutes to not use CTE.
- Model the movement of individuals to better define habitat quality:

Field observation of adult leatherbacks in the Atlantic



Map does not constitute publication of data, researchers who contributed this data retain all intellectual property rights.

IBM of Atlantic movement of 2 adult leatherbacks for 14 months – daily data



IBM of Atlantic movement of 100 adult leatherbacks for 14 months – daily data