Investigating the effect of temporal variation upon reproductive performances of green sea turtles (*Chelonia mydas*) by using an individual based model.

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Structure of the presentation

- **Sea turtles : critical features**
- **Purpose of the study**
- **Model description**
- **Results**
- **Concluding remarks**

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Sea turtle species

biological and behavioral characteristics :

- long lived animals
- high fidelity to specific nesting areas
- only mature females come ashore for nesting
- great variability in reproductive performance
  - Variable remigration interval (duration between two successive nesting seasons)
  - Variable renesting interval (duration between two successive nesting attempts)
- great variation in reproductive output
  - Number of clutches laid
  - Number of eggs per clutch

Sea turtle species

some critical features:

- Somatic growth rate is significantly reduced as animals get older (after maturation time)

- High reproductive value of each nesting individual
  – During a nesting season an individual turtle may lay more than 600 eggs

- High mortality rates during the first years of their lives
  – ‘from 1000 hatchlings entering the sea one of them will probably survive to adulthood’

Sea turtle species

problems arising when modeling sea turtles:

- Assessment of population trends is based on the number of nesting females
- Lacking information regarding:
  - survival rates
  - life span
  - age of maturation
  - re-nesting behaviour
  - density dependence mechanisms
  - population structure
  - population size
  - age-specific distribution

Sea turtle species

population dynamics of green turtles:

- Re-nesting interval 1-6 yrs
- Predominantly herbivorous species

Migratory routes

Somatic growth

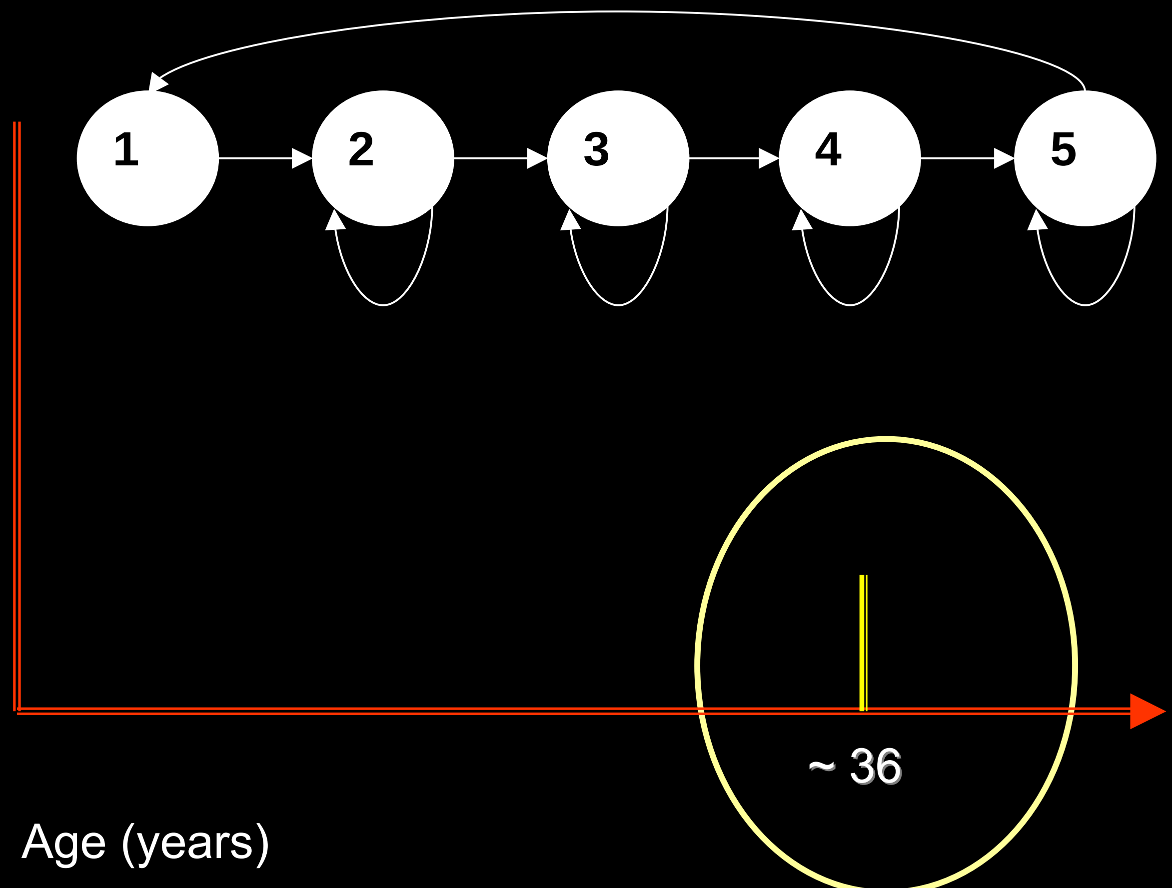
Transition to next stages

Are controlled by diet changes

- Life history can be easily divided into five stages

Sea turtle species

population dynamics of green turtles:



1st: ***eggs / hatchling***
2nd: ***pelagic stage***
3rd: ***benthic stage***
4th: ***immature***
5th: ***mature***

Structure of the presentation

- Sea turtles : critical features
- **Purpose of the study**
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Purpose of the study

- How variability at the age of first reproduction influences population persistence?
- How re-nesting patterns linked with extinction probabilities?

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↓

How individual variation is associated with population persistence?

Individual variation is reflecting different patterns of env. variability with temporal consideration

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Dynamic simulation model

Why sea turtles?

- Underlying processes and environmental implications upon population dynamics are widely questioned
- Due to lacking information the development of theoretical model is strongly encouraged (i. e. extrapolation – modification of critical demographic variables)

Dynamic simulation model

Why sea turtles?

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Why green turtles?

- In compare to other sea turtle species:
  - biology and behaviour are well documented
  - existence of useful demographic information
- Density dependent growth has been documented

Dynamic simulation model

Model structure:

- Modular stochastic IBM

  objects:

  Superinvidiviuals

  Individual animals

  Stage packs

Dynamic simulation model

Model structure:

Primary units of the simulation:

Superinvidiviuals:

The concept

- Newborns are modeled as an aggregation of animals sharing the same characteristics (age, growth, mortality rates etc)
- When individuals are born decisions about physiology, behaviour and development are made

Advantages

- Reduce computational burden
- Model abundant first age classes

Dynamic simulation model

Model structure:

Primary units of the simulation:

Individual turtles:

The concept

- Whether the age of S.I. exceeded the minimum maturation age (36 yrs) each animal tracked individually
- Each animal was individually subjected to all processes (growth, mortality, reproduction)

Advantages

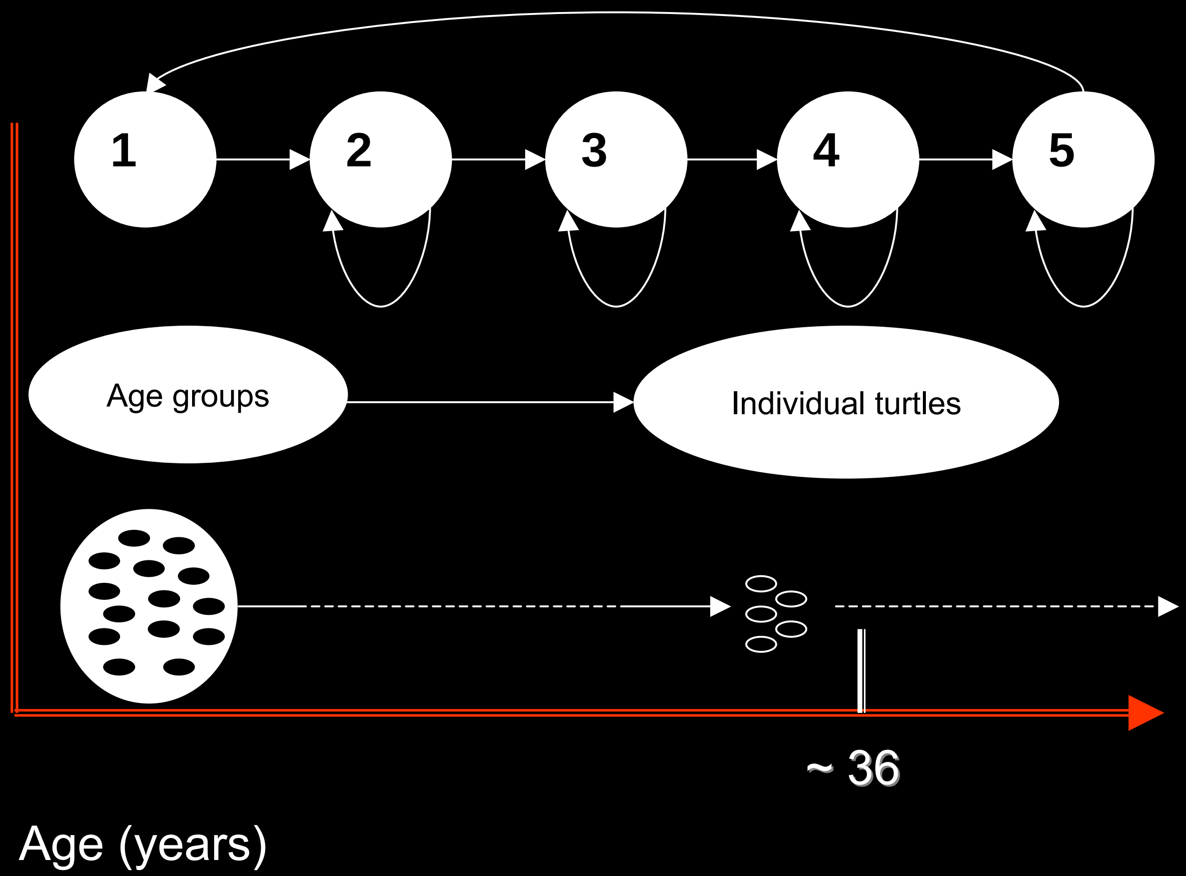
- Do not underestimate the reproductive value of breeding females

Dynamic simulation model

Model structure:

Primary units of the simulation:

Superindividuals -Individual turtles:



Dynamic simulation model

Model structure:

Secondary units of the simulation:

Stage packs:

The concept

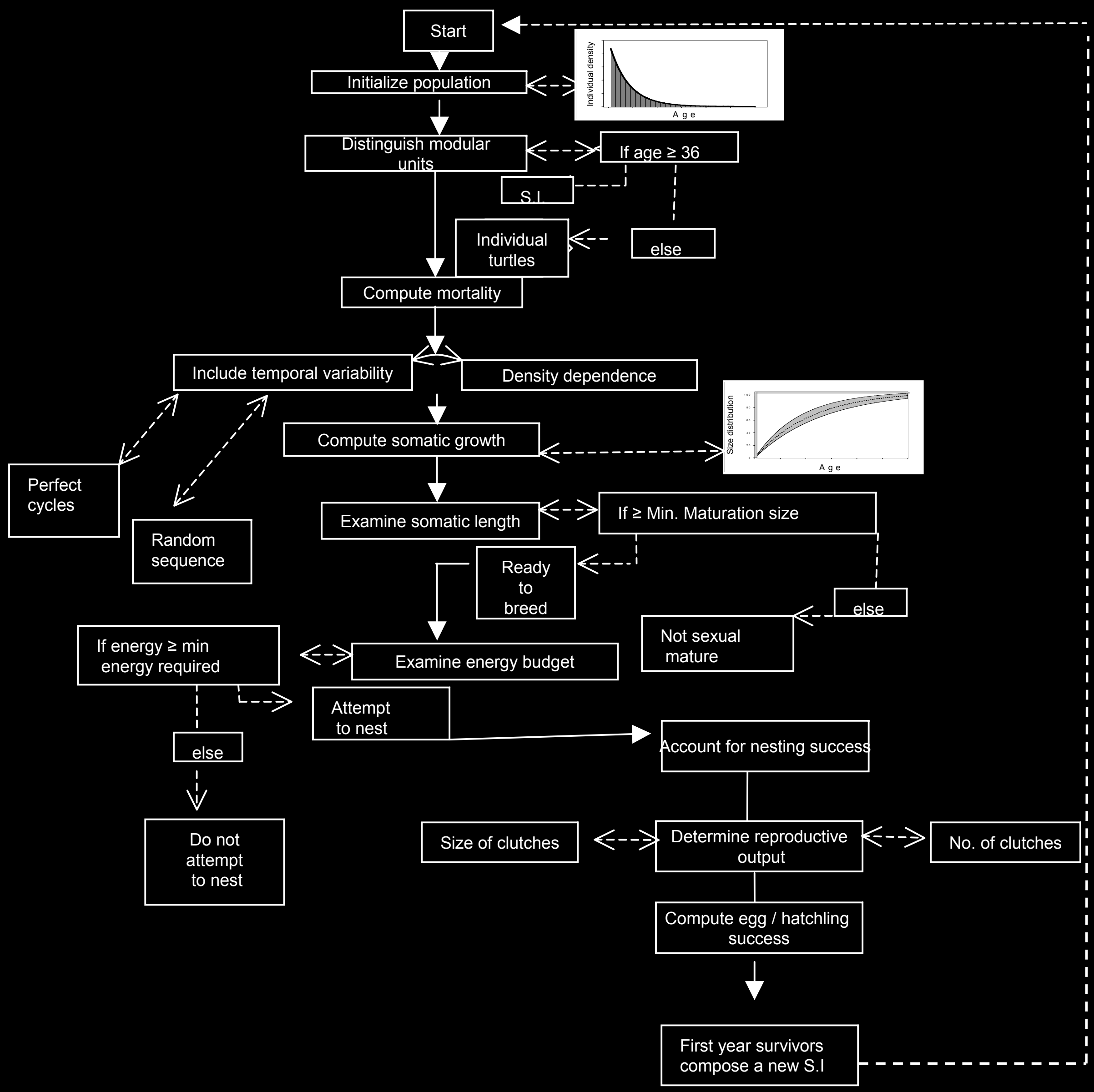
- Three stages (juveniles, subadults, adults) used for the description of stage-based packs
- Based on stage specific biomass, a density dependent effect on growth was modeled
- Based on stage specific biomass , a density dependent effect on reproductive performance was modeled

Advantages

- Design and apply switching rules

Dynamic simulation model

Processes:



Dynamic simulation model

Processes:

- Growth model
- Reproduction
- Temporal variation
- Density dependence

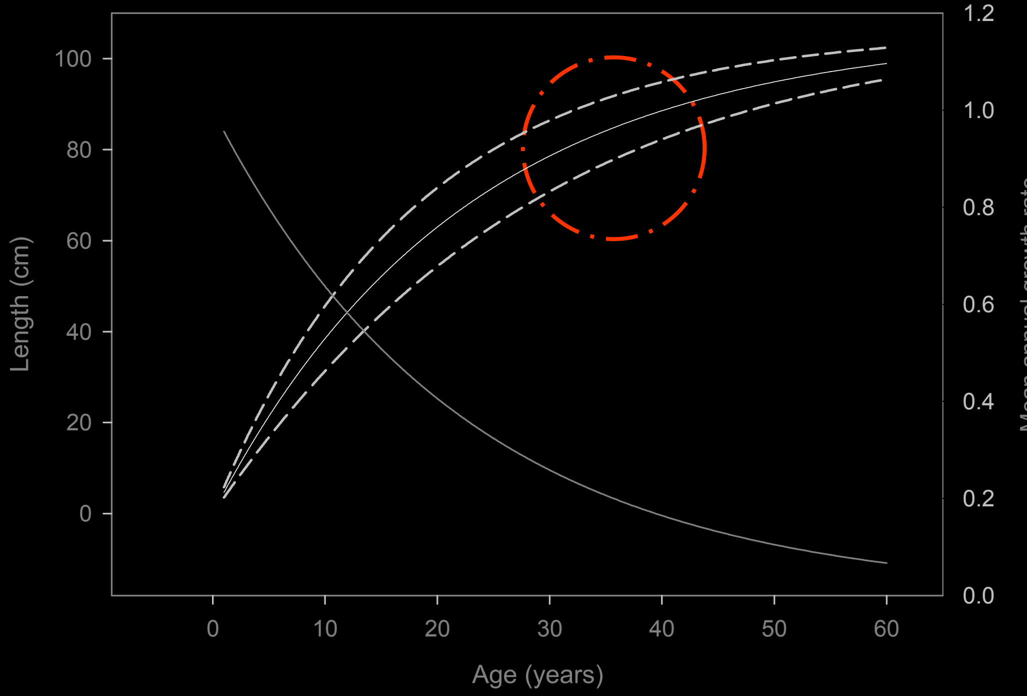
Dynamic simulation model

Growth model

- Exponential function
- Assumed a maximum life span of 60yrs
- Used a mean approximation of the maturation age
- Used size data of nesting females
- We assumed that mean and minimum (observed) lengths correspond to maximum and mean lengths of first breeders

➢ Develop a size to age distribution

➢ Individual variation by sampling from a uniform distribution



Dynamic simulation model

Reproduction

- *First breeding*
- *Re-nesting interval*
- *Reproductive output (number of clutches & size of clutches)*
- *Nesting success*

Dynamic simulation model

Reproduction

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Dynamic simulation model

Reproduction

- *First breeding*

The first breeding attempt was assumed to occur only if the individual had reached a threshold body condition

When entering the mature stage it was assumed that they have already started to accumulate energy to be devoted to their first breeding.

Dynamic energy budget of an individual was given by:

$$E_{i,t} = E_{initial,i} + E_{incr,i,t-n} + E_{incr,i,t}$$

Thus, first breeding attempt is defined as:

$$\begin{cases} L_{i,t} \geq L_{mature} \\ and \\ E_{i,t} \geq E_{crit} \end{cases}$$

Dynamic simulation model

Reproduction

- *Re-nesting interval*

An energy accumulation component was used to determine successive nesting attempts

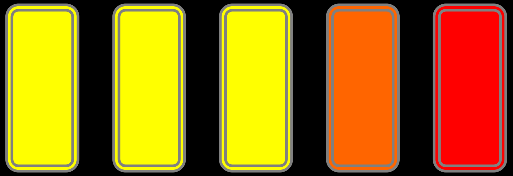
It was assumed that the time between successive non - breeding periods has a cumulative effect upon the energetics.

Energy status, described by the function:

$$B_{i,t} = B_{i,t_{env}} + B_{i,t-\mu} + B_{mean} + B_{i,o}$$

Therefore, completion of the energetic requirements for breeding occurred when individuals' energy budgets exceed critical threshold level when.

$$B_{i,t} \geq B_{crit}$$



Dynamic simulation model

Reproduction

- *Reproductive output*

Number of clutches laid sampled within the range of observed values

Dynamic simulation model

Reproduction

- *Reproductive output*

Number of clutches laid sampled within the range of observed values

Clutch size (no. of eggs / clutch) was determined as a power function of individuals length

$$Egg_{i,n,t} = a \cdot e^{(b \cdot lth(i))}$$

Dynamic simulation model

Temporal Variability on growth and reproductive performances

Each simulation years was distinguished between good and bad year

Dynamic simulation model

Temporal Variability

Whether a good year occurred:

- The annual of energy increment would be sufficient to secure breeding every three successive years
- Maximum (age-specific) somatic growth increment

Dynamic simulation model

Temporal Variability

Whether a bad year occurred:

- The energy increment was equal to the value of energy needed for re-nesting after 6 successive years

- Minimum (age-specific) somatic growth increment

Dynamic simulation model

Temporal Variability

Whether a bad year occurred:

An autocorrelated type of disturbance was also assumed:

sampled growth rate -25%	(After 1 yr)
sampled growth rate -50%	(After 2 yrs)
sampled growth rate -75%	(After 3 yrs)

Dynamic simulation model

Temporal Variability

Succession of good and bad years:

1. *Perfect cycle model*
2. *Random model*

Perfect cycle model (a)
1 bad year
6 good years

Perfect cycle model (b)
1 bad year
10 good years

Random model
Good / bad years

Dynamic simulation model

Density dependence

a) D.d effect on somatic growth is likely to occur whether pop. fluctuates near the 40% of its highest density (Bjorndal et al., 2000)

b) The model was run - no temporal variation included

c) Abundance of the different stages (juveniles, immature, mature) was evaluated

d) Density (with respect to total population size of the different stages) was determined

e) We set a threshold by counting for the 40% of the maximum proportional contribution of the former stages to the total population size

Dynamic simulation model

Density dependence

D.d. was modeled as an additional form of variability in environmental conditions rather than a distinctive and independent process

Dynamic simulation model

Density dependence

Juvenile – immature stages:	Mature individuals:
Reduction in growth rates (alike bad years)	Reduction in <u>growth rates</u> (alike bad years) & Delayed in re-nesting interval

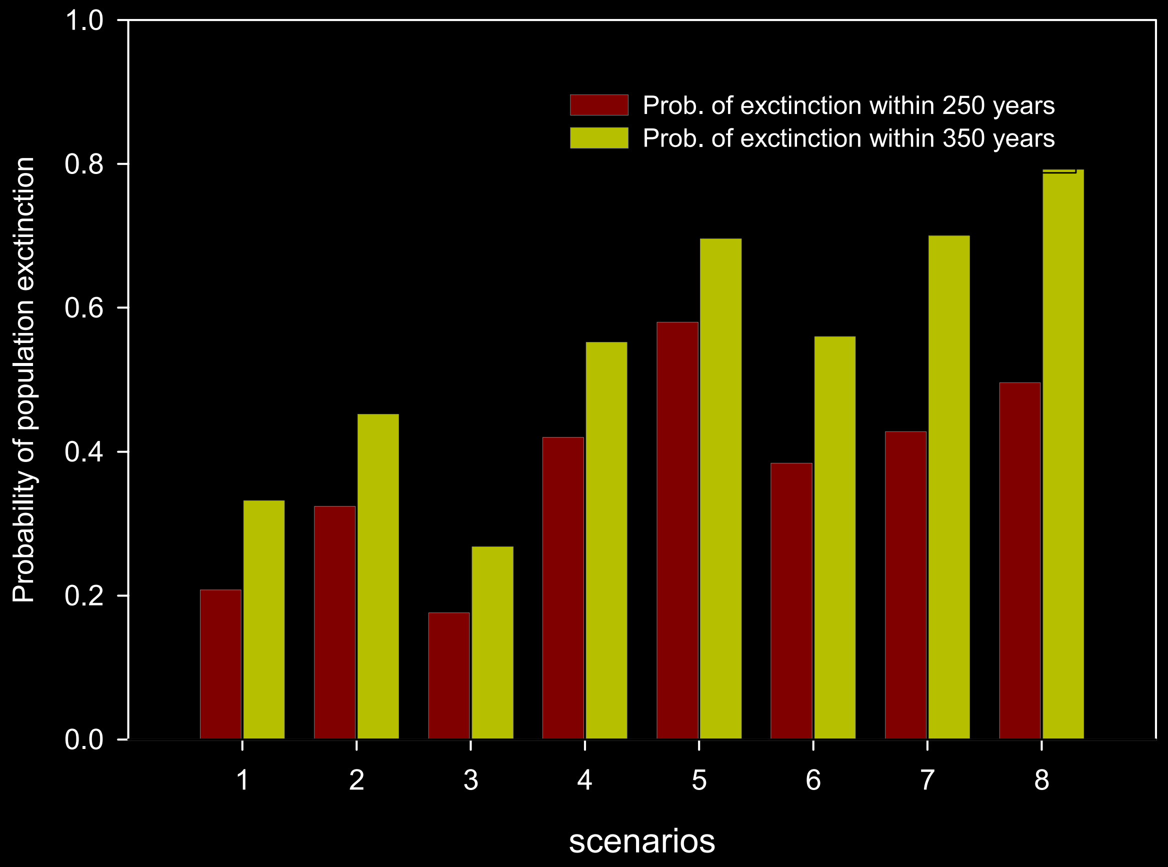
Dynamic simulation model

- Population was initialised by using an exponential function with extreme values closely related to observed data (hatchings – nesting ind.)
- We modelled only female ind.
- Sex ratio 1:1
- Model was run in a 350 yr horizon
- Each simulation set was run 500 times.

Results

Probability of population extinction

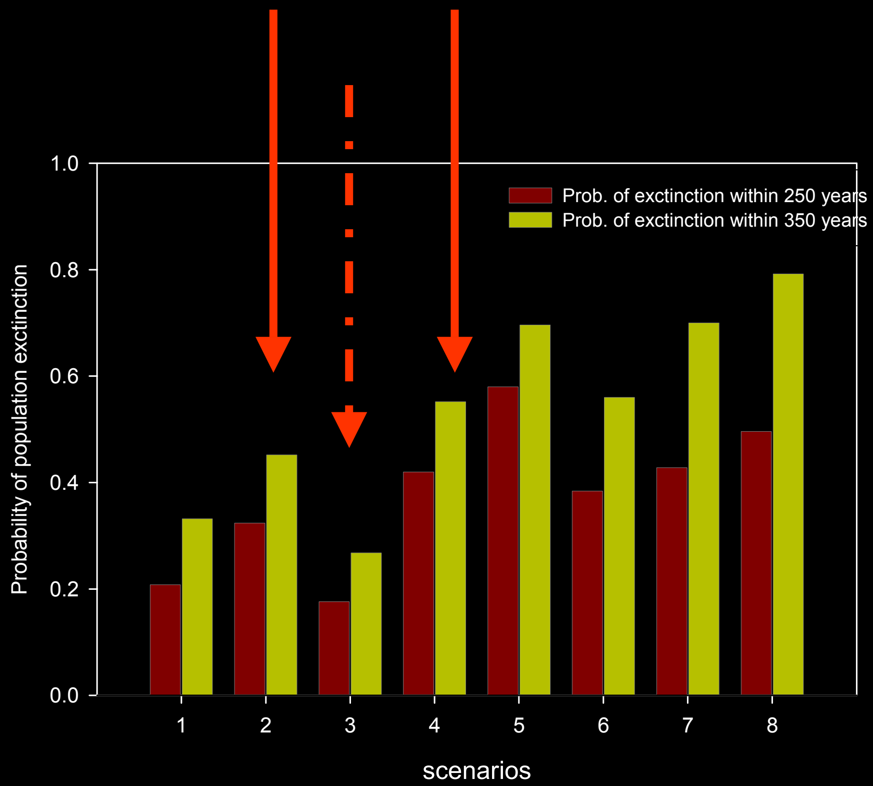
1: no temporal variability
2: AC cycle 6:1, applied to the age of first breeding
3: AC cycle 10:1 applied to age of first breeding
4: random model of temporal variation applied to the age of first breeding
5: AC cycle 6:1, applied to both age of first breeding and re-nesting interval
6: AC cycle 10:1 as above
7: random model of temporal variation as above
8: D.d buffer mechanism modeled to describe both age of first breeding and re-nesting interval.



Results

Probability of population extinction

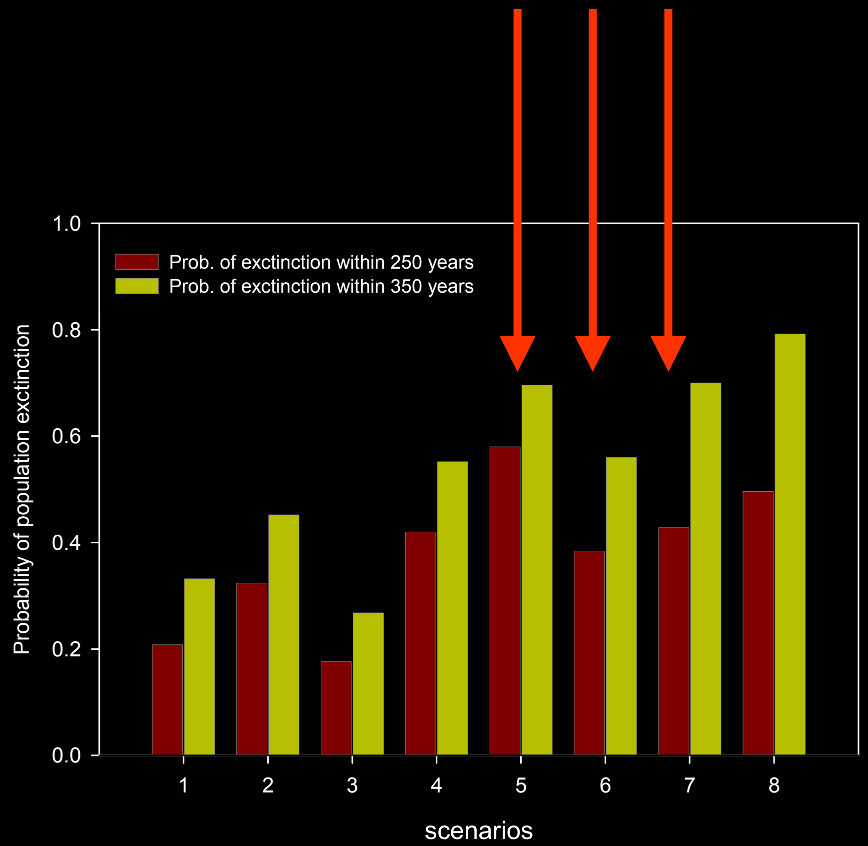
Temporal variability as a buffer mechanism upon the age of first breeding has only a slight effect



Results

Probability of population extinction

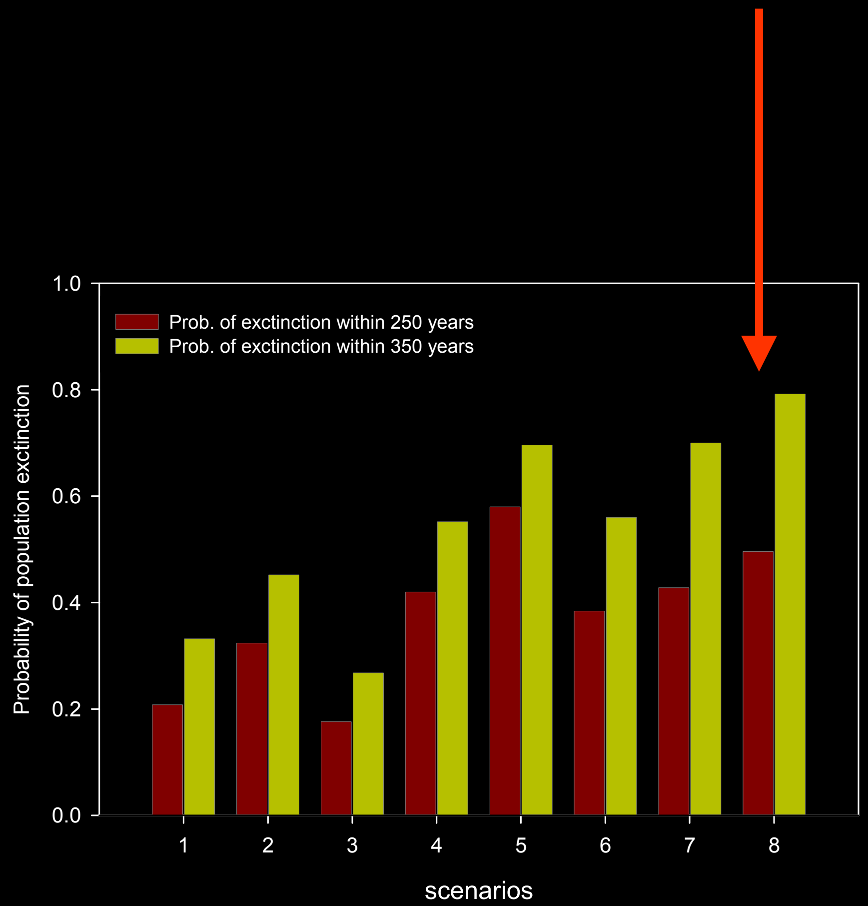
Variability in first breeding & re-nesting interval increased extinction probability



Results

Probability of population extinction

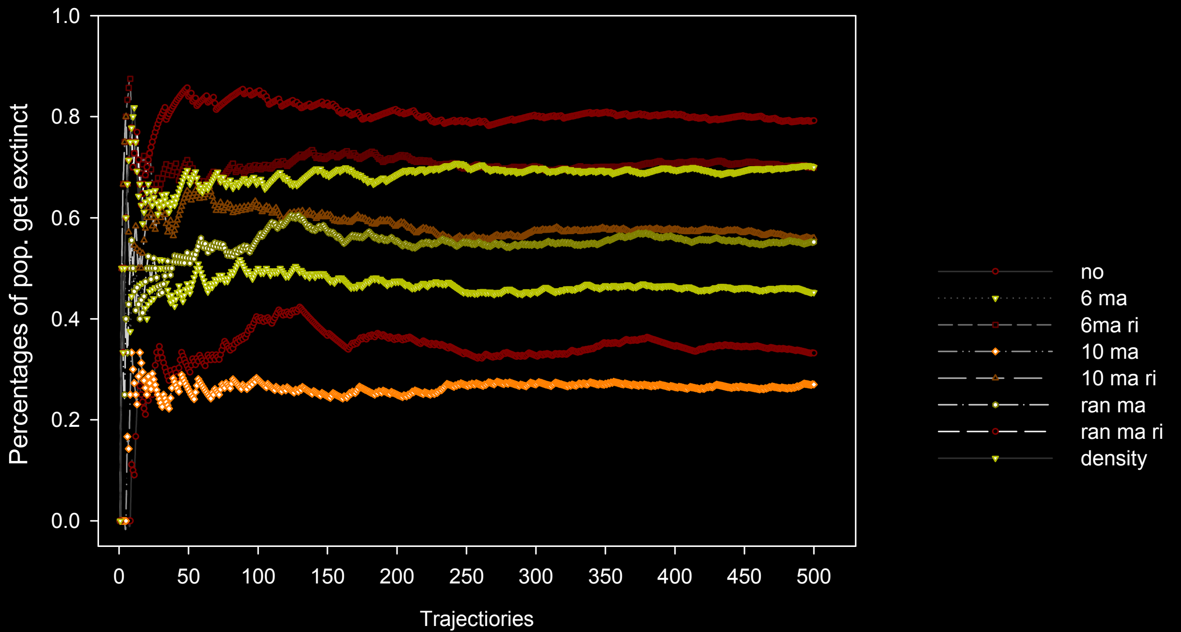
Density dependent effects on growth and reproduction resulted to increased extinction probability



Results

Mean percentages of pop. get extinct thought time

Increased variation during the first simulation years

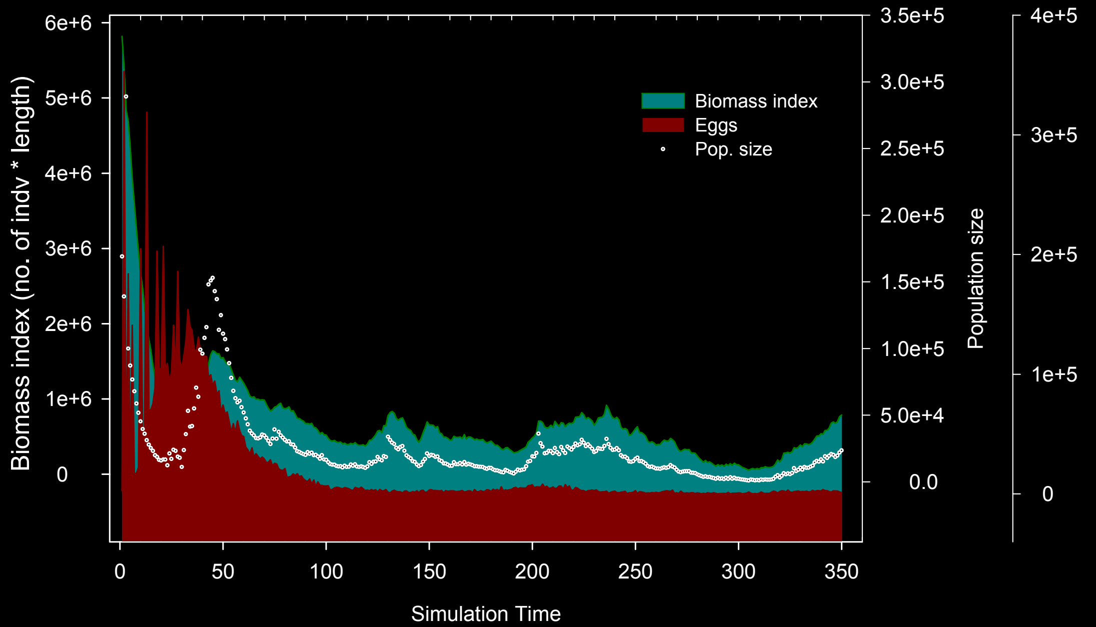


Results

Typical population trajectory

Sharp population decline

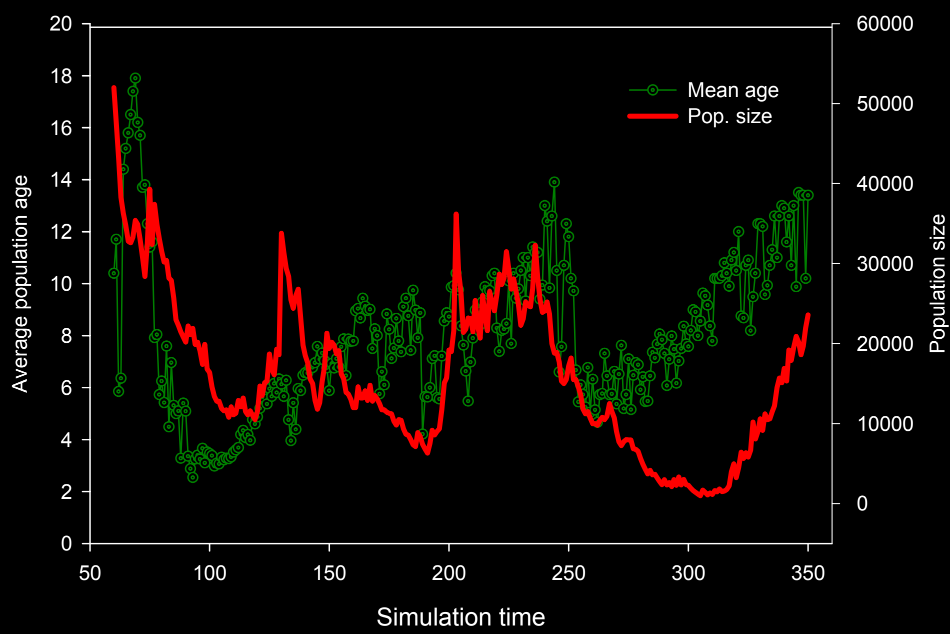
Increased egg production



Results

Population size and mean age distribution of the population.

Higher population declines are subjected to reduction in the lower age classes



Concluding remarks

The developed model stands apart from previous modelling techniques applied to sea turtle populations

- Highlight the importance of breeding cycles on population persistence
- D.d. mechanisms have a significant effect on population persistence

Concluding remarks

By using a modular type of a stochastic IBM

- We reduced computational burden
- We were able to simulate the abundant first age classes
- We integrated mechanism that it is strongly believed that act as population regulators
- We were able to provide some insights in frequently asked questions