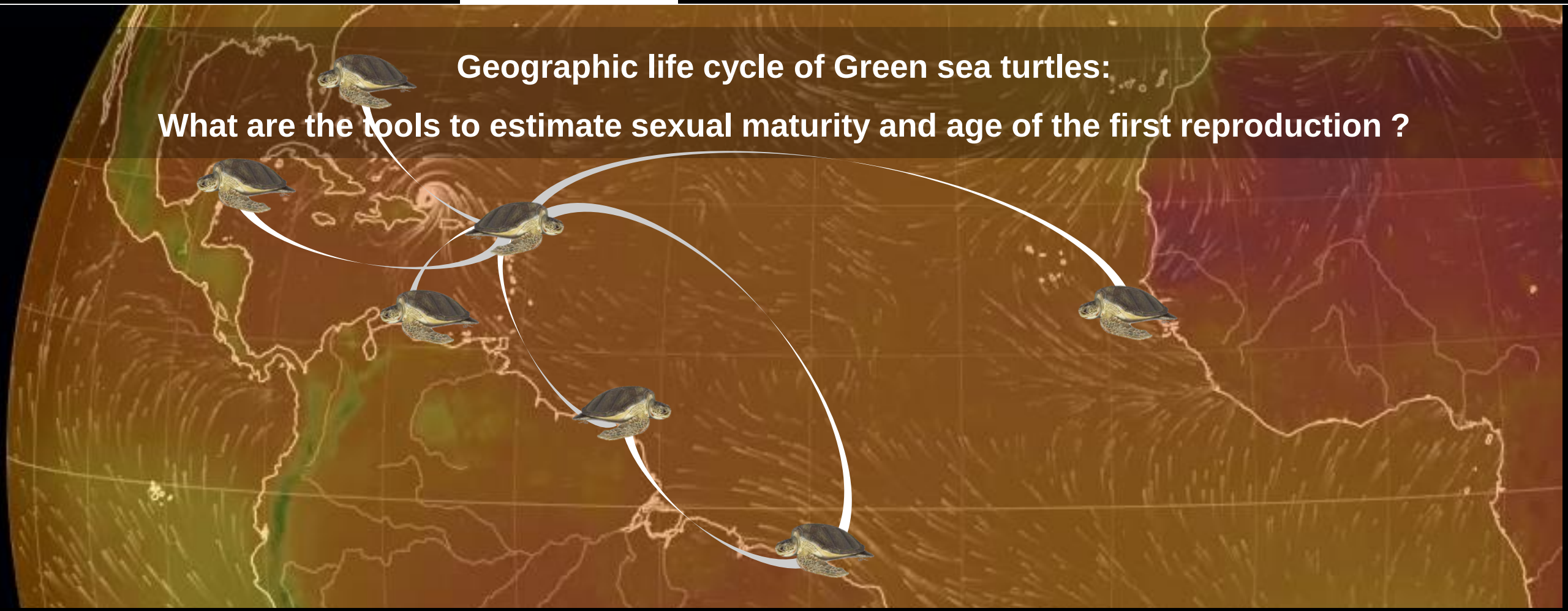
Geographic life cycle of Green sea turtles:

What are the tools to estimate sexual maturity and age of the first reproduction ?



Chevallier Damien
(CNRS IPHC)

Context

A complex life cycle

Coastal / Oceanic waters
Atlantic / Caribbean

Oceanic waters
Atlantic / Caribbean

♀

♀ ♂

Musick & Limpus (1997)

Nesting beach
French Guiana/Suriname

♀

♀

Coastal waters
French Guiana/Suriname

Migration of sea turtles is directly related to their complex life cycle which encompasses neritic, coastal and/or oceanic habitats

Context

A complex life cycle

Coastal / Oceanic waters
Atlantic / Caribbean

?

?

Oceanic waters
Atlantic / Caribbean

♀

?

Nesting beach
French Guiana/Suriname

♀

Coastal waters
French Guiana/Suriname

?

Musick & Limpus (1997)

It's pretty difficult to determinate the sexual maturity in sea turtles, that could explain why in Green turtle, **age of sexual maturity is so inaccurate** (15-50 years), **as the age of the first reproduction which is unknown**

Context

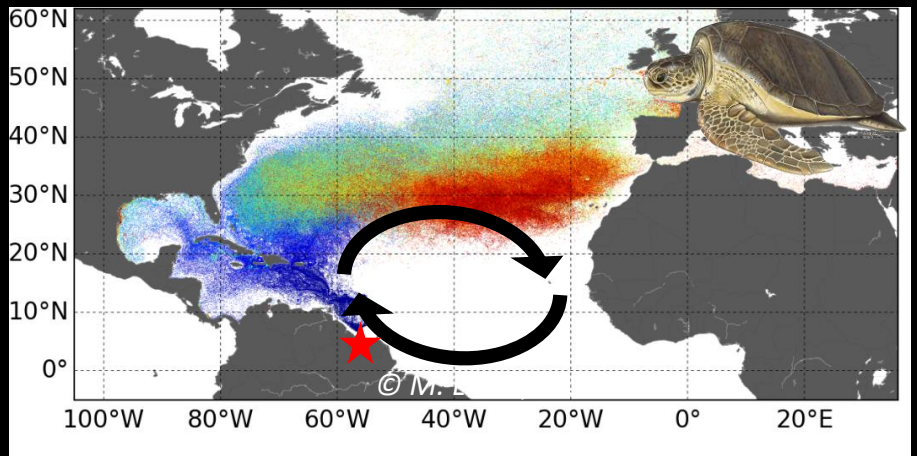
Sea turtles are usually considered as long-living species, with slow-growth, migratory behavior and **late sexual maturity.**

Age at Sexual maturity ≠ Age of 1st reproduction
(it's confusing)

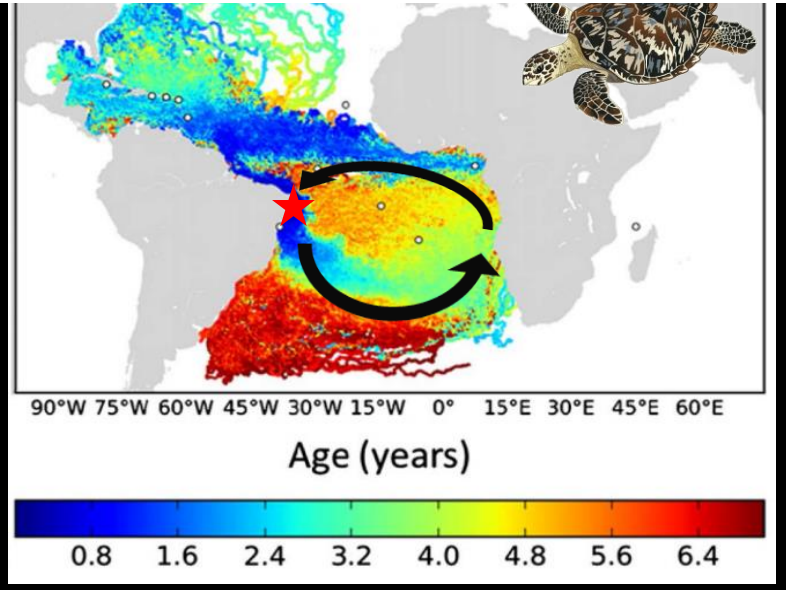
In this context, few parts of the life cycle of sea turtles are still poorly understood, especially the age of the 1^{rst} reproduction and what happens after they leave their developmental habitat.

Avens & Snover, 2013; Bell et al., 2005; Bjorndal, Bolten, & Martins, 2000; Patricio, Diez, & van Dam, 2014, *Luke et al. 2003, Makowski et al. 2005; Hart & Fujusaki 2010; Meylan et al. 2011*),

Context: First years of life of newborns



Different models exist to study the dispersion of newborns, and to determine their age when they arrive on the developmental areas



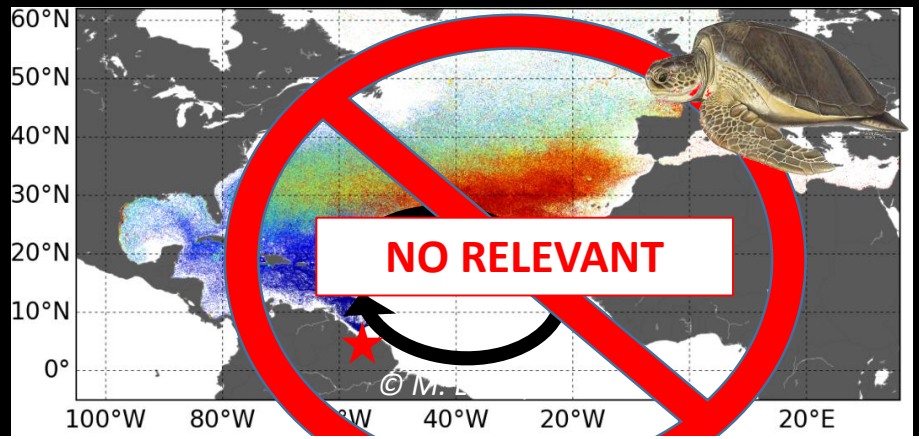
Phillips et al. (2002), Boles & Lohmann (2003), Gaspar et al. (2012), Putman et al. (2012a & b), Scott et al. (2012b & a), Burke et al. (2013), Putman et al. (2014)

Context: First years of life of newborns

Dispersion models

- **Theory of passive dispersion:**

Under the action of marine currents
'Learned migration goal'

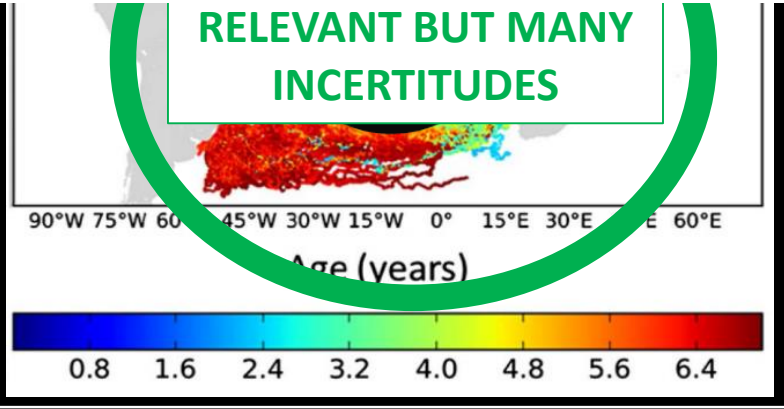


Needs new data to improve dispersion models

Salmon of Pacific

Triton

Crayfish



Phillips et al. (2002), Boles & Lohmann (2003), Gaspar et al. (2012), Putman et al. (2012a & b), Scott et al. (2012b & a), Burke et al. (2013), Putman et al. (2014)

In order to understand the life cycle of green turtles, so many questions to answer !

1. In Martinique, where do the juvenile green turtles come from ?

2. How many years do they spend in development areas ?

3. Do they show fidelity to their feeding areas in development areas ?

4. Where do they migrate after their development phase ?

5. Do they breed in the year they leave their development areas ?

6. Do they return to the beaches where they were born ?

In order to understand the life cycle of green turtles, so many questions to answer !

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Understanding the life cycle of green turtles needs many study sites !

Martinique (Juveniles)

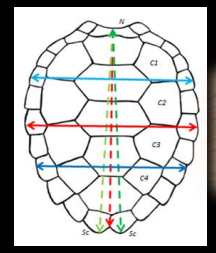
French Guiana (Adult females)

Understanding the life cycle of green turtles needs many approaches !

1. In Martinique, where do the juvenile green turtles come from?

Mixed Stock Analyses

2. How many years do they spend in development areas ?



3. Do they show fidelity to their feeding areas in development areas ?

CMR campaign 2009-2019

4. Where do they migrate after their development

5. Do they breed in the year they leave their devel

Understanding the life cycle of green turtles needs many approaches !

1. In Martinique, where do the juvenile green turtles come from?

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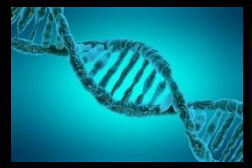
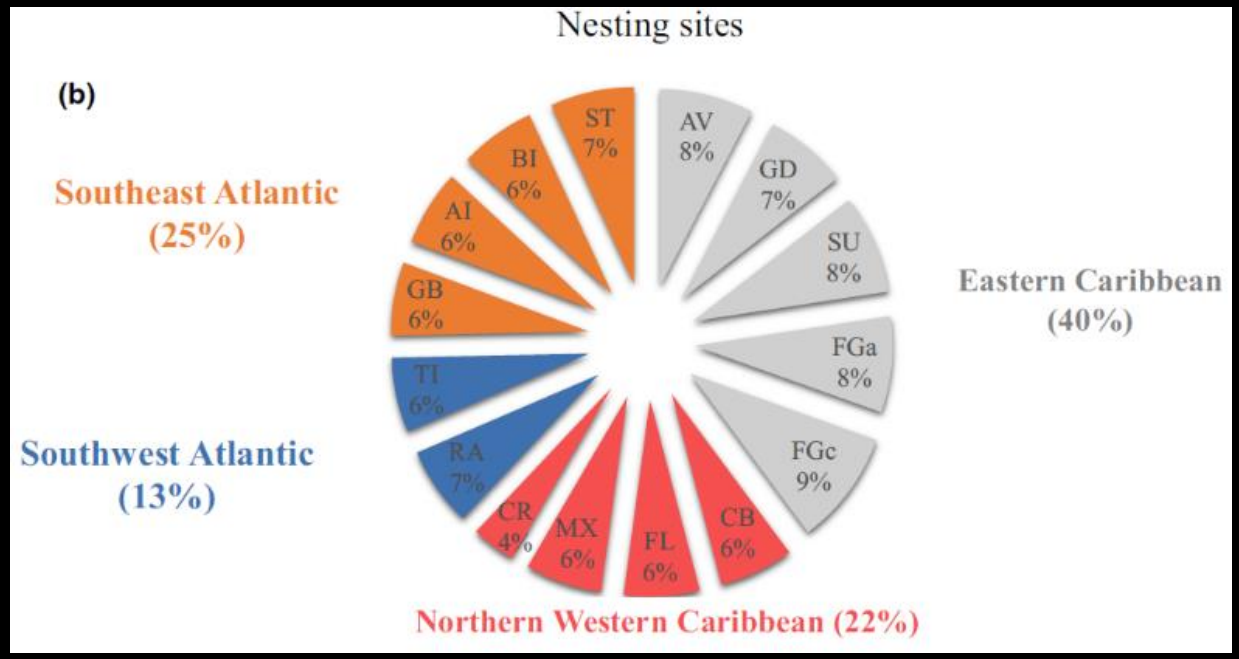


Results 1 : In Martinique, where do juvenile green turtles come from ?

Mixed Stock Analyses shows that **French Guyana**, **Suriname** and **Aves Island** were the most important source populations for the juveniles of Martinique

----> **40% of the contribution**

These juveniles are descendants of female population from several beaches in the Caribbean and the Atlantic, mainly from Suriname and French Guiana, but also from beaches in southern Brazil.



Chambault et al. 2018. *Ecol. Evol*. 8 : 12790–12802

Results 2 : How many years do they spend on development areas ?

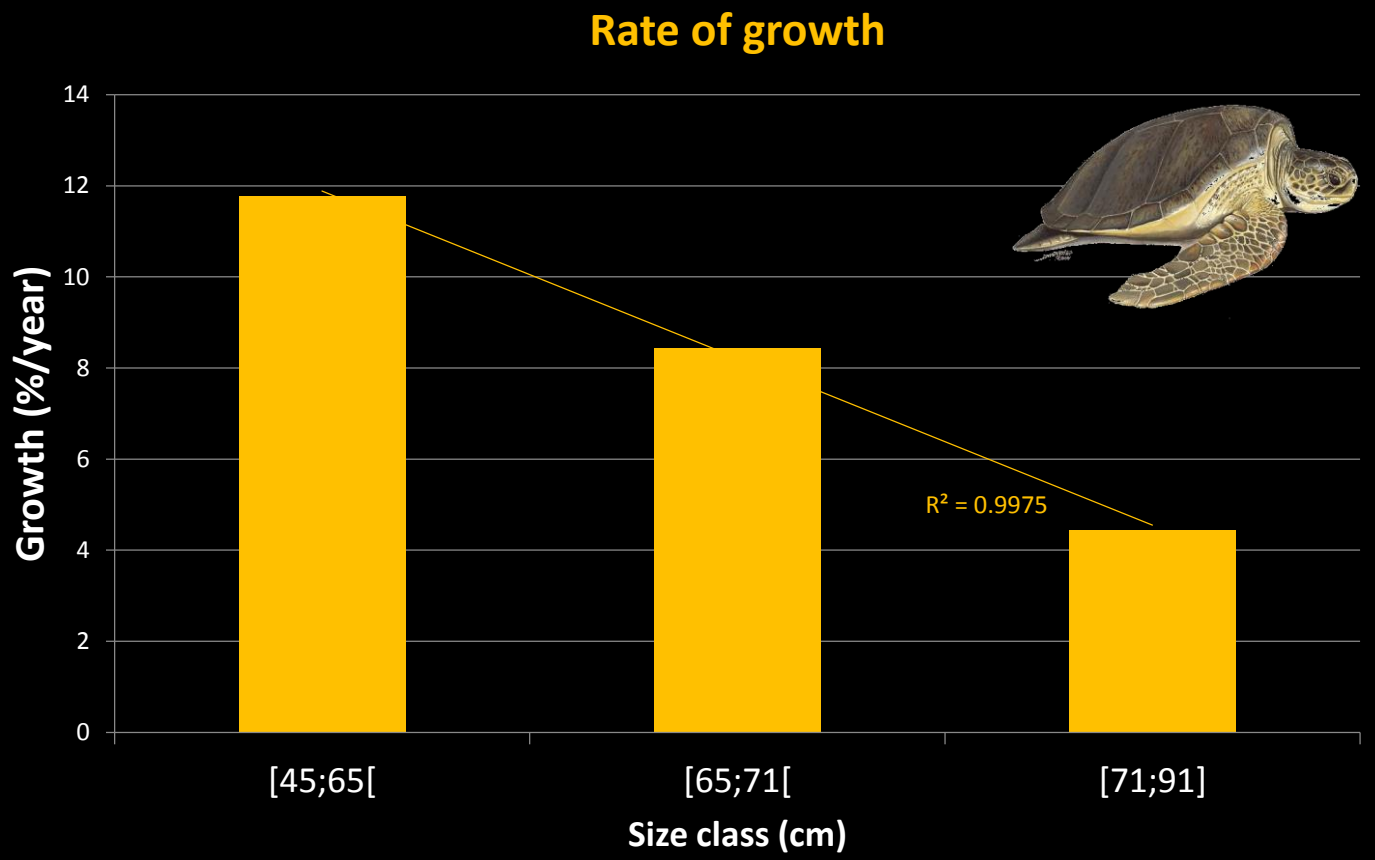
Theoretical evolution of the growth of a lambda individual in Martinique

- 500 individuals captured and measured

- 200 individuals recaptured

- Mean of growth : 4.4 ± 1.1 cm/year (n= 200)

(Analyzes in progress)



➢ **Very fast growth in developmental area**

Results 2 : How many years do they spend on development areas ?

Sexual maturity in Caribbean: range: 86.6-122 cm CCL (Meylan et al. 2011)

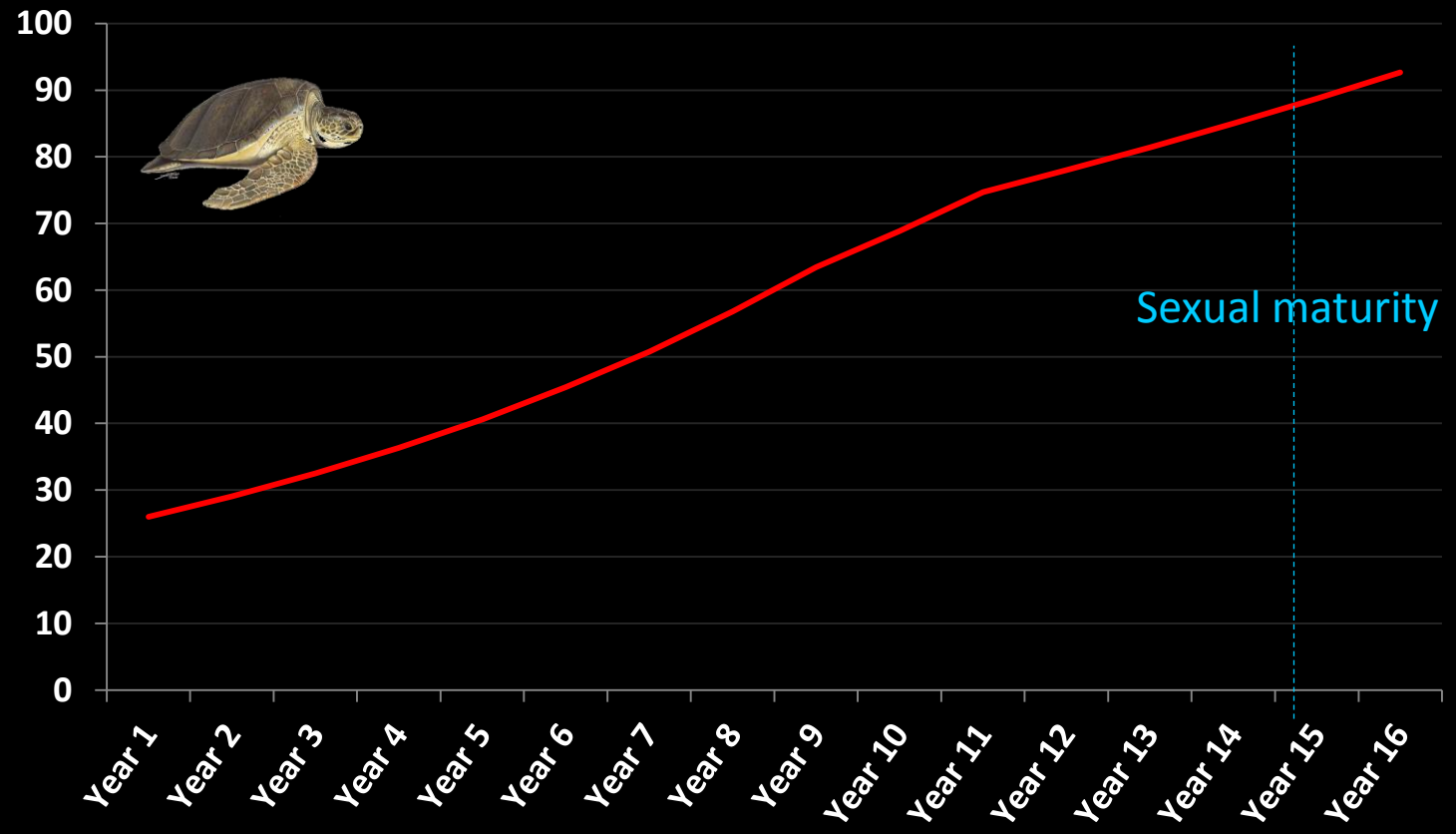
Brazil: 22 years to go from a length of 30 to 87 cm ; mean 2.6 ± 1.6 cm / year (Almeida et al. 2011)

- **16 years to go from a length of** 26 to 93 cm

- **Diminution of growth relatively constant:**
  3.6 ± 0.2 cm the 5 last year
  before sexual maturity

(Analyzes in progress)

Theoretical evolution of the growth of a lambda individual in Martinique



➢ **~ 15 years to reach sexual maturity in developmental area**

Results 3 : Do they show fidelity to their feeding areas in development areas ?

3.2. Habitat use

31 green turtles equipped with tags:

- 21 residents: **142 ± 91 days** (min: 42; max: 383 days)
- 10 migratory

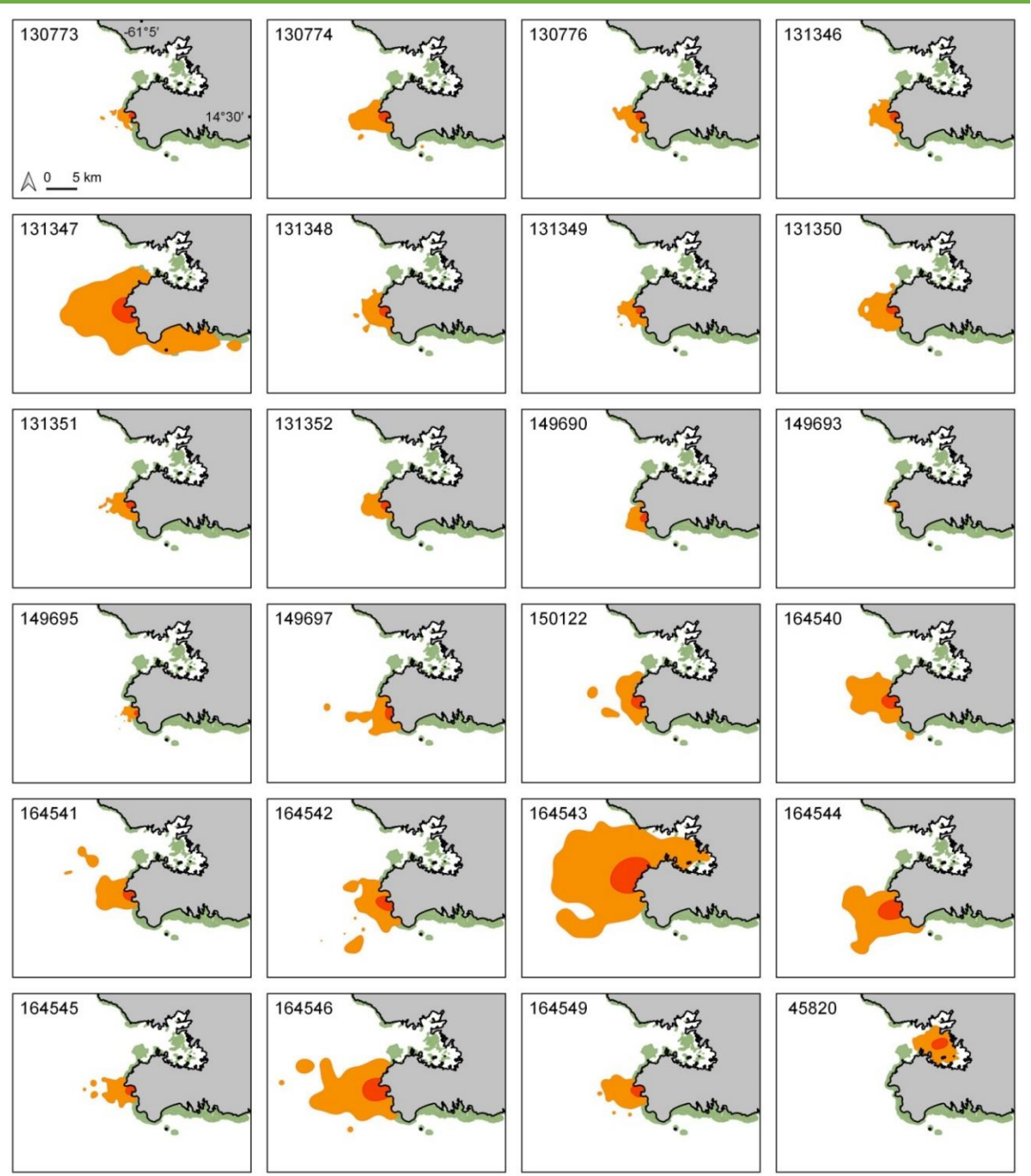
Home-range

- Few variations in home range shape and location across 21 individuals: **1.8 to 250 km²**.

- Small core areas centered mainly on 2 Bays (Grande Anse or Anse du Bourg): **0.2 to 24 km²**

➢ **In "Short term" : High site fidelity of immature green turtles to one bay**

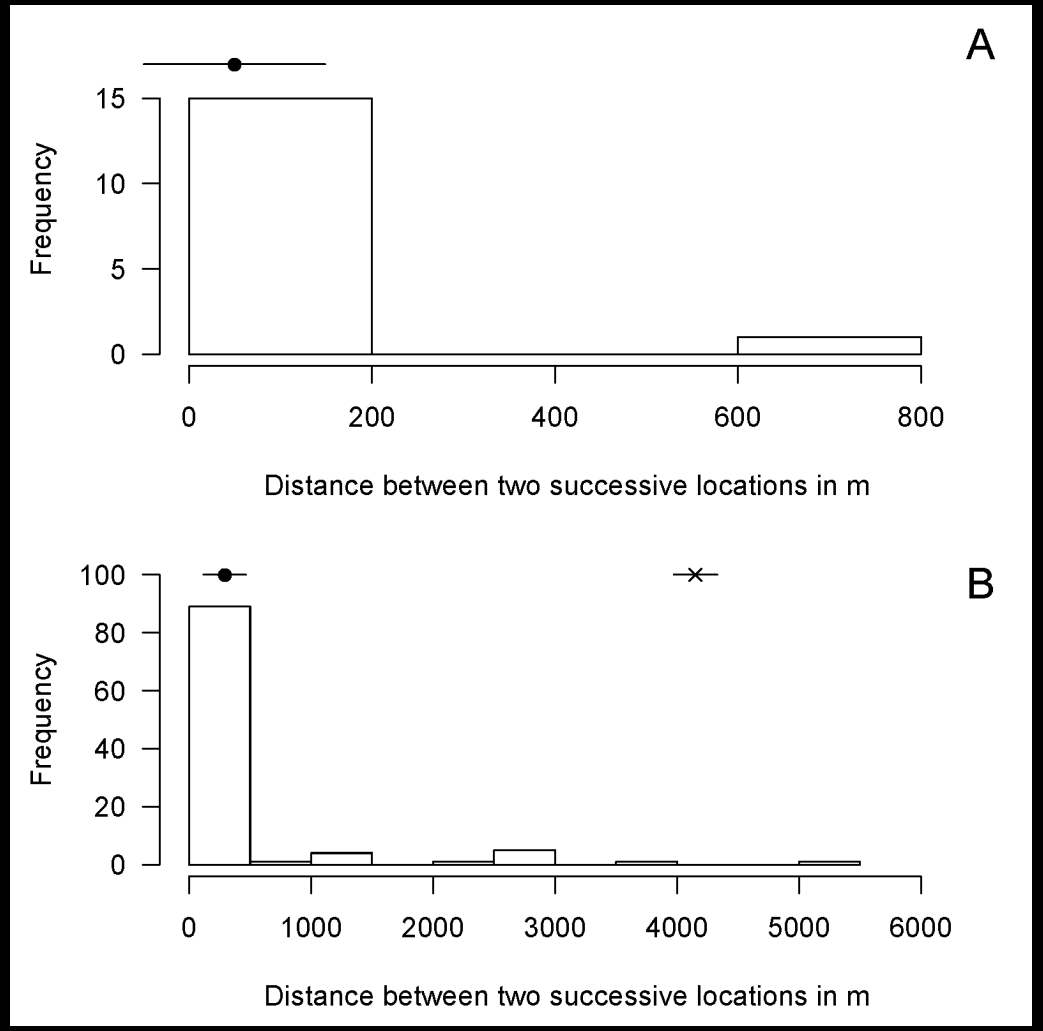
Siegwalt et al. *In prep.*



Results 3 : Are they fidel to their feeding areas on development areas ?

3.2 Site fidelity analysis using Capture-Mark-Recapture data

- The average distance between 2 capture locations is:
  - **49 m** (SE: 49 m) **within 12 months (A)**
  - **292 m** (SE: 87 m) **over > 12 months (up to 9 years) (B)**



➢ **In "Long term" : High site fidelity of immature green turtles to one bay**

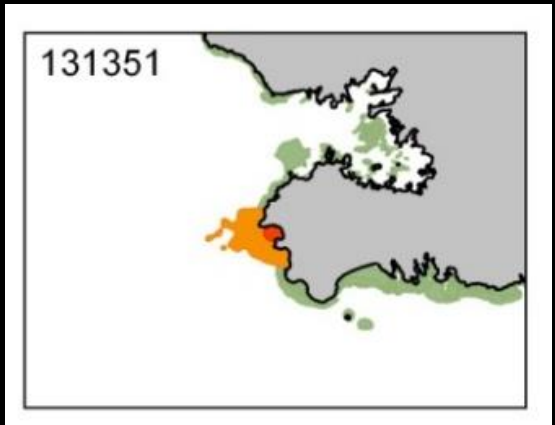
Siegwalt et al. *In prep.*

Results 4: Where do they migrate after their development phase ?

Tracks of the 10 green turtles having reached sexual maturity

	Residents (n=21)	Migratory (n=10)
Length (cm)	75.5 ± 10.5	85.9 ± 3.8
Weight (Kg)	54.6 ± 9.6	81 ± 9.3

≠



Sexual maturity in Caribbean: range:

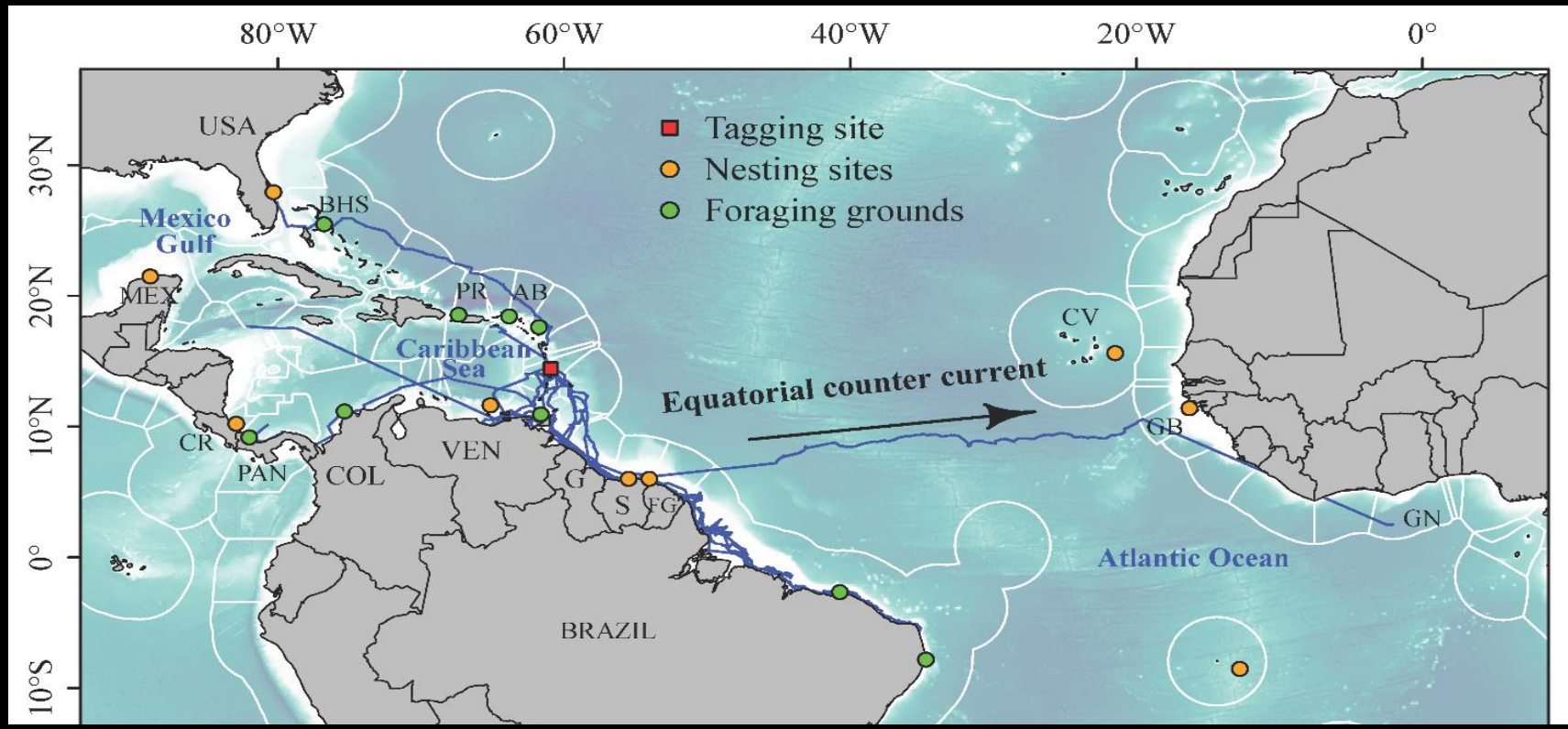
86.6-122 cm CCL (Meylan et al. 2011)

Chambault et al. 2018. *Ecol. Evol*. 8 : 12790–12802

Results 4: Where do they migrate after their development phase ?

Tracks of the 10 green turtles having reached sexual maturity

- Tracking duration : **166 ± 79 days**
- Total distance travelled: **4 394 ± 1964 km** (min: 1370 km, max: 7821 km)



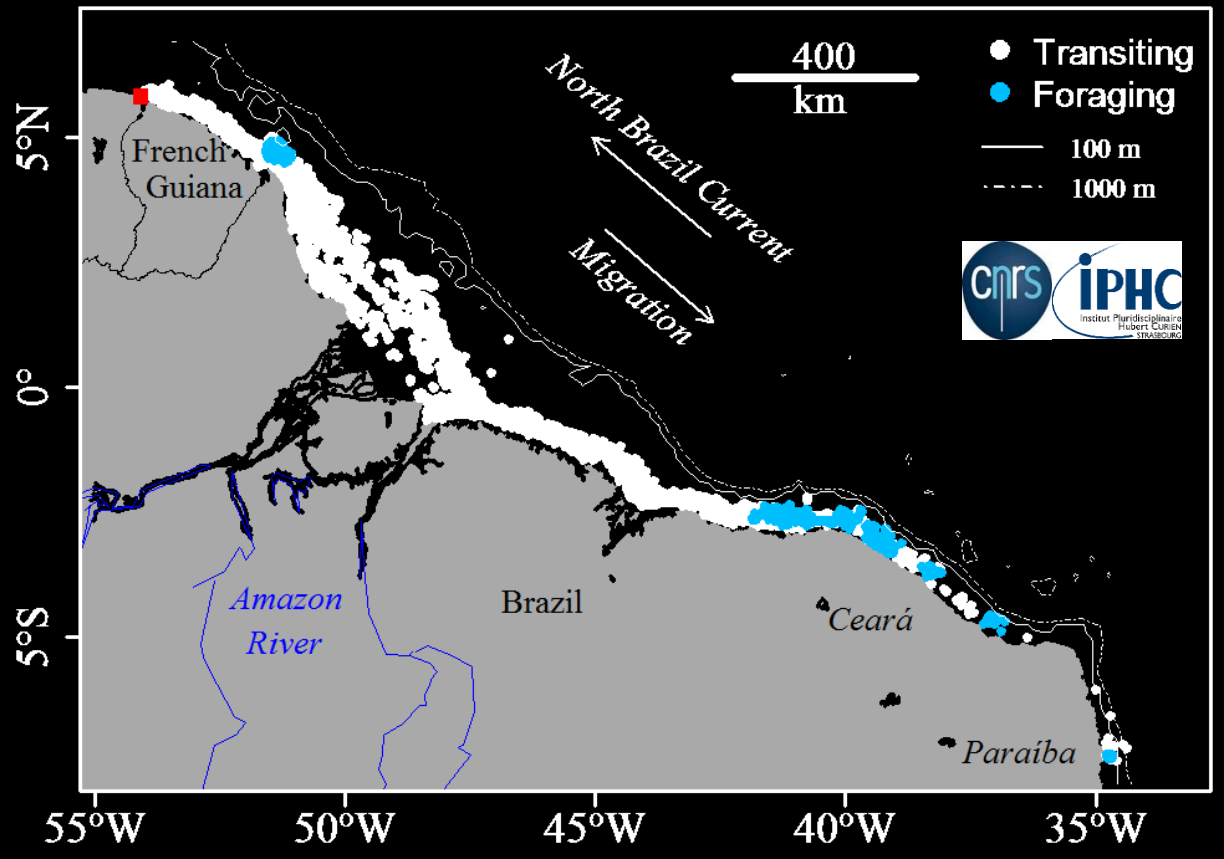
➢ **Multidirectional migration: 6 different destinations**

Results 4: Where do they migrate after their development phase ?

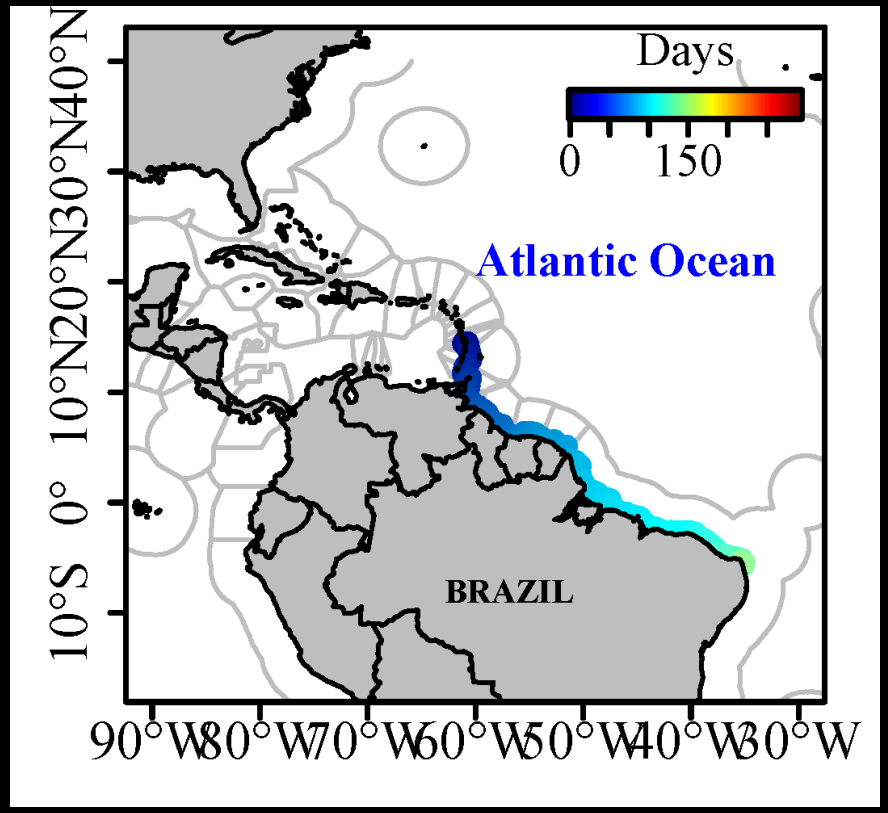
Tracks of the 10 green turtles having reached sexual maturity

➢ **50% of these turtles have reached Brazilian feeding areas used by adult green turtles in FG**

26 adult Green turtles from French Guiana



5 Immature Green turtles from Martinique



Baudouin et al. 2015. *Biol. Conserv.* / Chambault et al. 2015. *Plos One* / Chambault et al. 2018. *Ecol. Evol.*

Results 5 : Do they breed right after they leave their development areas ?

Size of gravide female green turtles in French Guiana (Yalimapo, West French Guiana)

Years	CCL± SD (range)	N
2012-2016*	**112.7±6.3** (91-138)	**1855**

New individuals (unmarked in 2015 & 2016) : **111.9±6.5 (91-129**)

Size of migratory green turtles from Martinique

CCL ± SD (cm)
85.9 ± 3.8

Gravide adult Females
112.7 ± 6.3 cm

≠

~ 27 cm

Immatures in Brazil
85.9 ± 3.8 cm

Bonola et al. *In prep*.

Results 5 : Do they breed in the year they leave their development areas ?

Gravide Adult Females
112.7 ± 6.3 cm

≠

Immature
~ 27 cm

Immatures in Brazil
85.9 ± 3.8 cm

Abstract—Skeletochronological data on growth changes in humerus diameter were used to estimate the age of Hawaiian green seaturtles ranging from 28.7 to 96.0 cm straight carapace length. Two age estimation methods, correction factor and spline integration, were compared, giving age estimates ranging from 4.1 to 34.6 and from 3.3 to 49.4 yr, respectively, for the sample data. Mean growth rates of Hawaiian green seaturtles are 4–5 cm/yr in early juveniles, decline to a relatively constant rate of about 2 cm/yr by age 10 yr, then decline again to less than 1 cm/yr as turtles near age 30 yr. On average, age estimates from the two techniques differed by just a few years for juvenile turtles, but by wider margins for mature turtles. The spline-integration method models the curvilinear relationship between humerus diameter and the width of periosteal growth increments within the humerus, and offers several advantages over the correction-factor approach.

Age and growth of Hawaiian green seaturtles (*Chelonia mydas*): an analysis based on skeletochronology

George R. Zug
Division of Amphibians and Reptiles

data. Mean growth rates of Hawaiian green seaturtles are 4–5 cm/yr in early juveniles, decline to a relatively constant rate of about 2 cm/yr by age 10 yr, then decline again to less than 1 cm/yr as turtles near age 30 yr. On

National Marine Fisheries Service, NOAA
2570 Dole St., Honolulu Hawaii 96822-2396

Denise M. Parker
Shawn K. K. Murakawa

Year elapsed before breeding for the first time (based on growth of 3.2 cm / year)

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
85,9	89,1	92,3	95,5	98,7	101,9	105,1	108,3	111,5

*New individual : **111.9 ± 6.5 cm (min: 91 cm, n= 1)**

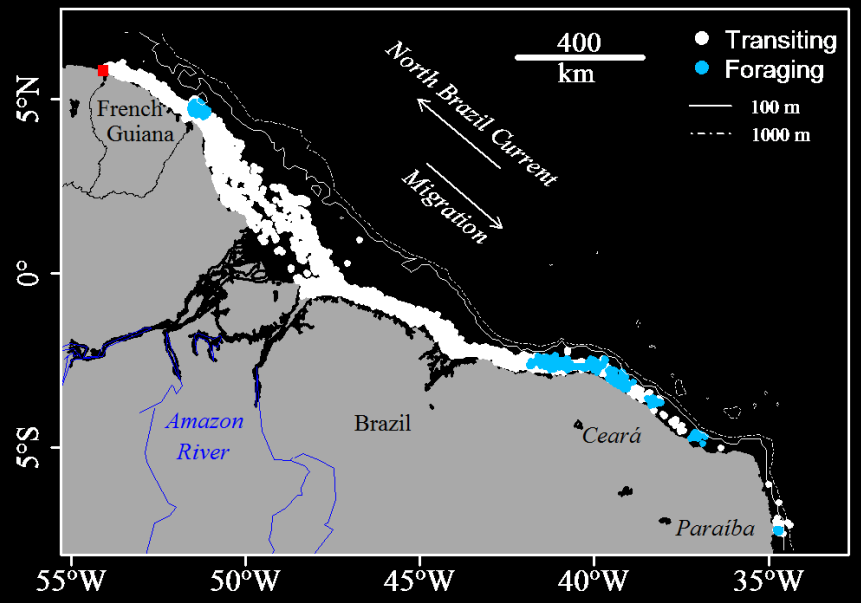
Results 5 : Do they breed in the year they leave their development areas ?

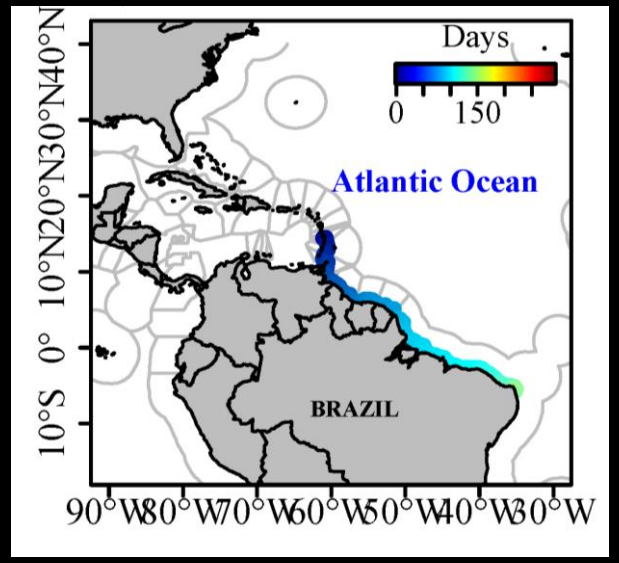
- **The first reproduction of green turtle after post-development migration : 3 to 9 years**

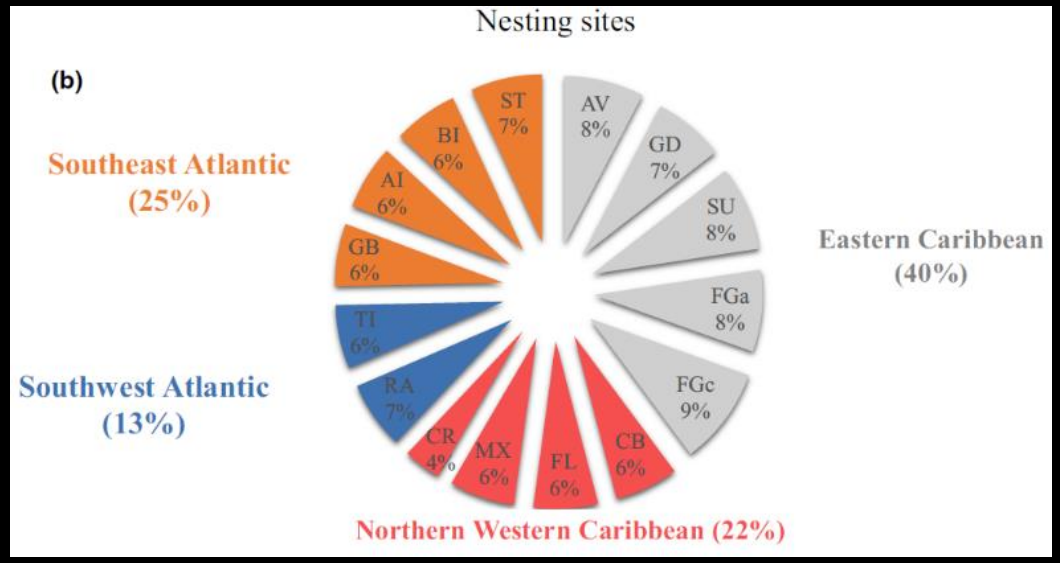
Results 6 : Do they return to the beaches they were born ?

- 40% of immatures present in development areas in Martinique are born in French Guiana, Suriname, and Brazil

- 50% of migratory individuals have finished their migration in the same feeding areas of adult females in Brazil.







In this context, and given these results :

- **We can expect them to nest on their birth beach**
- **The simultaneous CMR monitoring Martinique-Guyane will allow us to confirm it ... soon ;-)**

Conclusion : How many years before sexual maturity and first reproduction ?

A complex life cycle

Oceanic waters
Atlantic / Caribbean

?

Coastal / Oceanic waters
Atlantic / Caribbean

?

♀

?

Nesting beach
French Guiana/Suriname

♀

Coastal waters
French Guiana/Suriname

Musick & Limpus (1997)

Conclusion : How many years before sexual maturity and first reproduction ?

Coastal / Oceanic waters
Atlantic / Caribbean

Oceanic waters
Atlantic / Caribbean

Nesting beach
French Guiana/Suriname

Coastal waters
French Guiana/Suriname

Musick & Limpus (1997)

A complex life cycle: to reconsider

Conclusion : How many years before sexual maturity and first reproduction ?

Immature
Development habitat

Coastal waters

2

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Adult breeding area

Coastal waters

4

Baudouin et al. 2015 / Chambault et al. 2015, 2016, 2018 / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

Immature
Development habitat

Coastal waters

2

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Days, months ?

Adult breeding area

Coastal waters

4

Baudouin et al. 2015 / Chambault et al. 2015, 2016, 2018 / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

~ 20 cm
4 to 5 years

Immature
Development habitat

Coastal waters

2

~ 15 years
(~ 20 cm to ~ 90 cm)

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Days, months ?

Adult breeding area

Coastal waters

4

Baudouin et al. 2015 / Chambault et al. 2015, 2016, 2018 / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

~ 20 cm
4 to 5 years

Immature
Development habitat

Coastal waters

~ 166 days

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

2

~ 15 years
(~ 20 cm to ~ 90 cm)

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Days, months ?

Adult breeding area

Coastal waters

4

Baudouin et al. 2015 / Chambault et al. 2015, 2016, 2018 / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

~ 20 cm
4 to 5 years

Immature
Development habitat

Coastal waters

~ 166 days

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

3 to 9 years

2

~ 15 years
(~ 20 cm to ~ 90 cm)

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Days, months ?

Adult breeding area

Coastal waters

4

Baudouin et al. 2015 / Chambault et al. 2015, 2016, 2018 / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

~ 20 cm
4 to 5 years

Immature
Development habitat

Coastal waters

~ 166 days**

Sub-adult/ Adult
Feeding habitat

Coastal waters

3

3 to 9 years

2

~ 15 years
(~ 20 cm to ~ 90 cm)

~ 118 days*,**

~ 118 days*,**

Juvenile Feeding habitat

Oceanic waters

1

5

Nesting beach

Days, months ?

Every 13 days**
(4 eggs lay / season)

Adult breeding area

Coastal waters

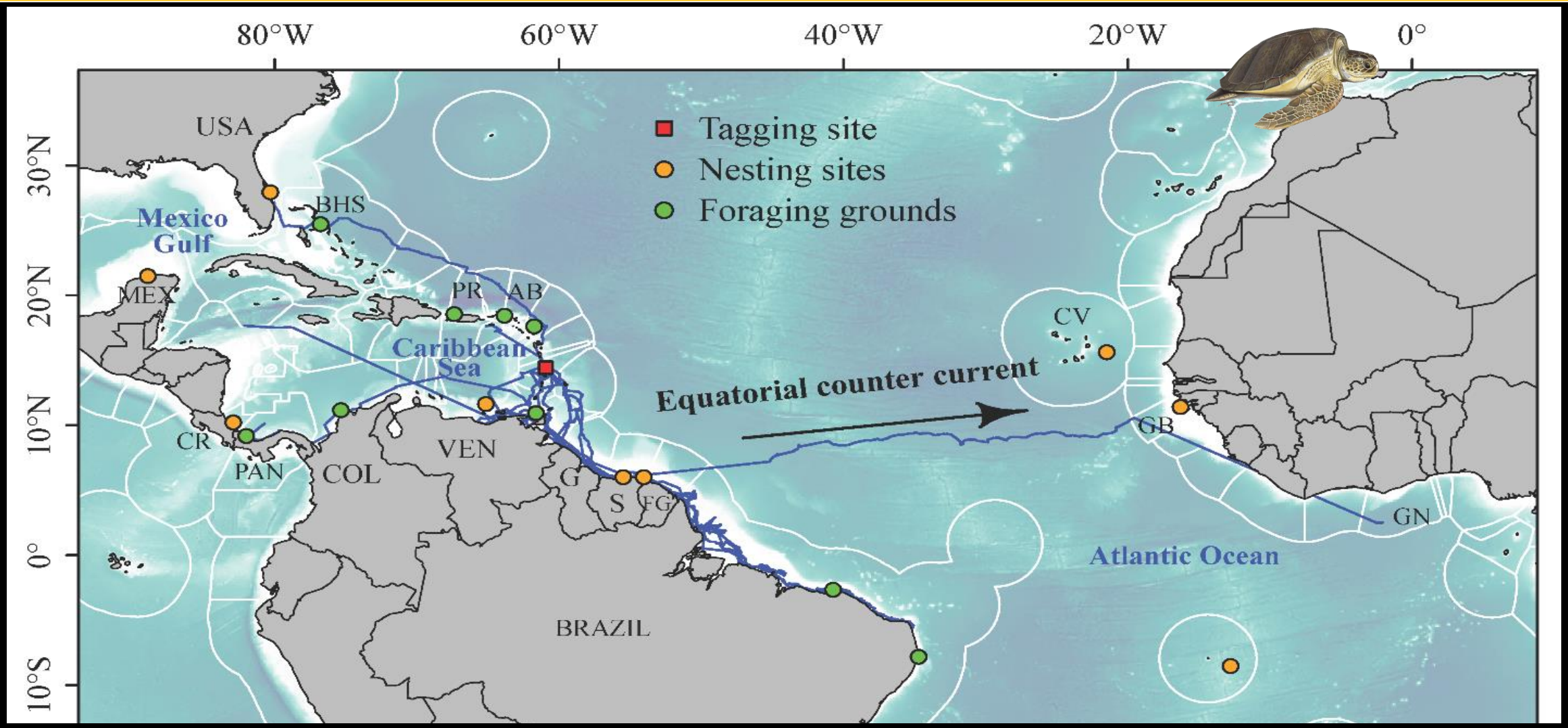
4

Baudouin et al. 2015* / Chambault et al. 2015, 2016, 2018** / Siegwalt et al. *In prep*. / Bonola et al. *In prep.*

Conclusion : How many years before sexual maturity and first reproduction ?

- **The sexual maturity should be around ~20 years old, but ...**
- **The age of first laying should be between 23 and 29 years old.**
- **Reduction of margin error : windows of 6 years** (23-29 y.) ***vs.*** **35 years** (15-50 y.)

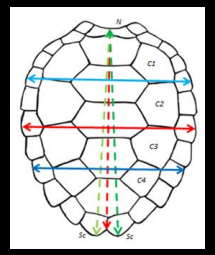
Conclusion : Protection in a Regional context and on all the life cycle ?



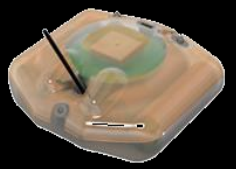
- ✓ **Sea turtles conservation will be efficient if lead on all the life cycle**
- ✓ **These results should be taken into account in RMU (Wallace *et al.* 2010)**

Perspectives: news investigations in 2019-2020

- Growth evolution linked habitat



- Habitat fidelity-selection / Food selection

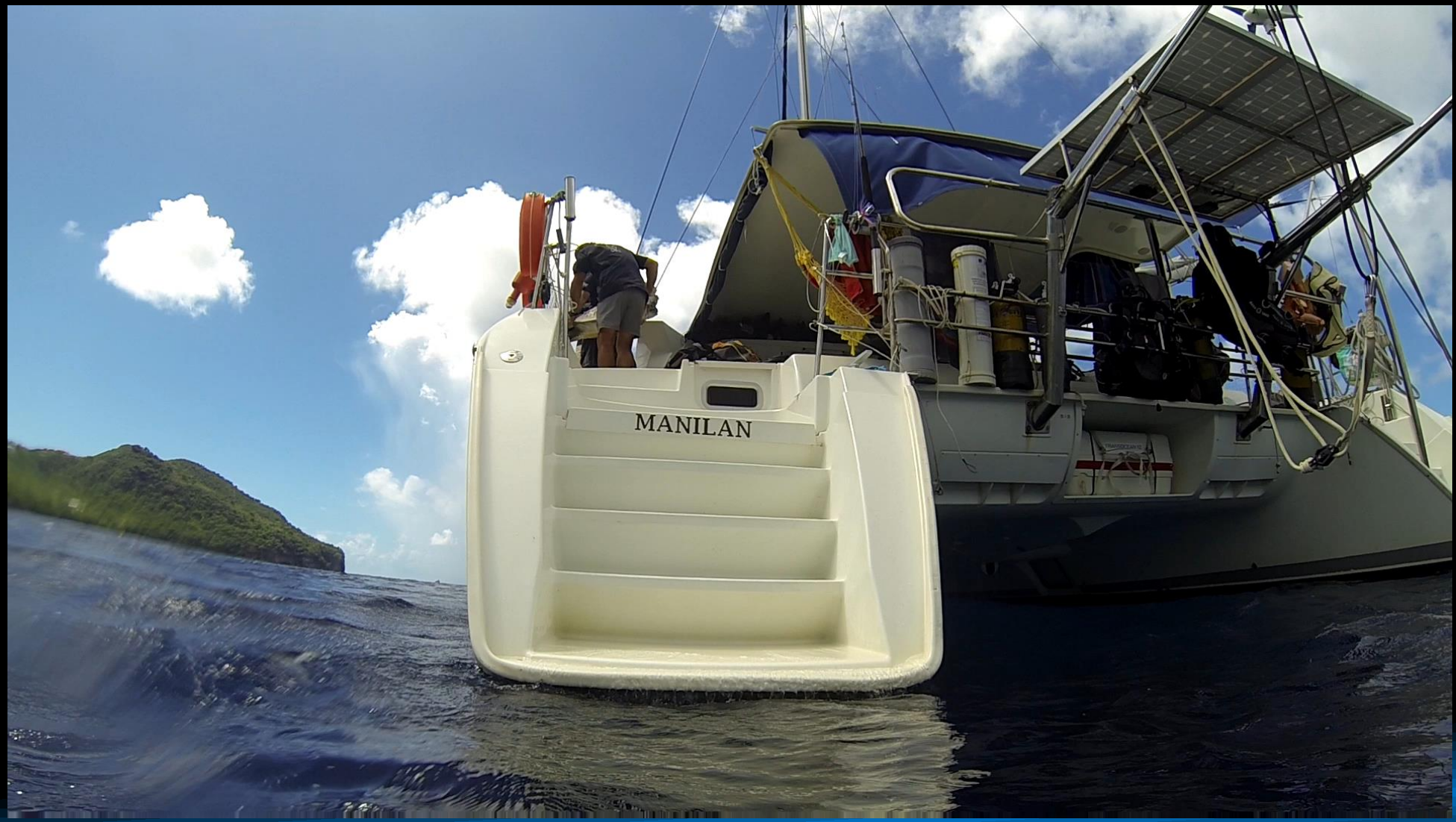


- Population trends in Martinique & French Guiana

- Annual contribution of adult females populations in Atlantic and Caribbean scale

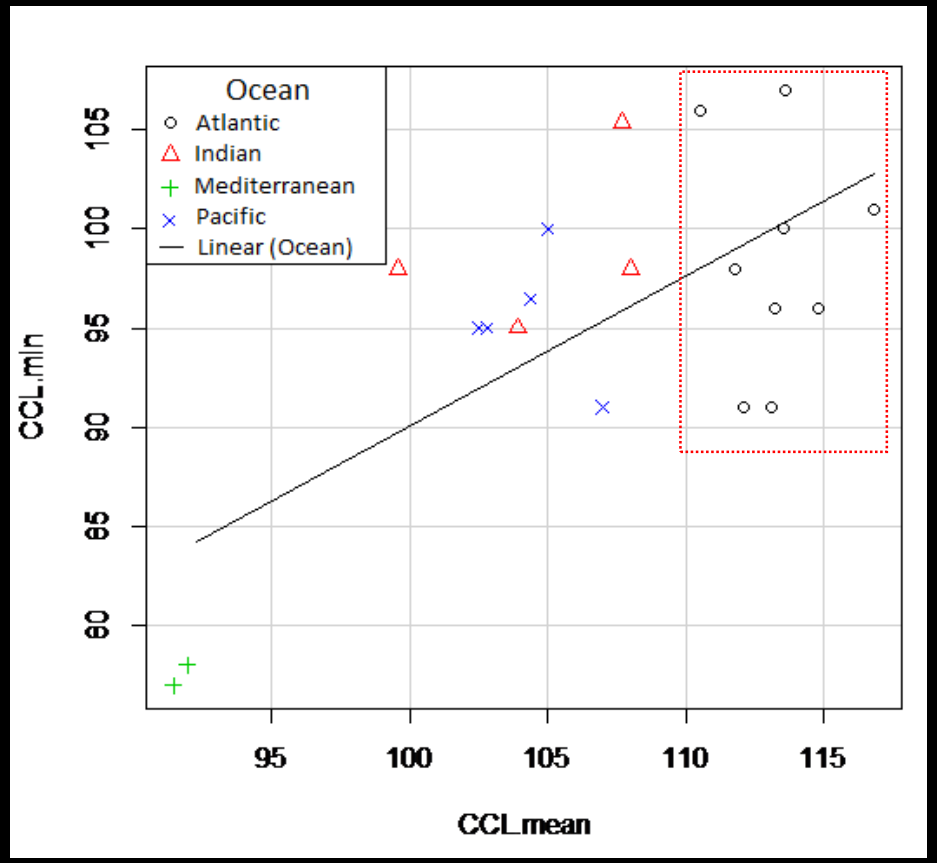
- Post-development Migration

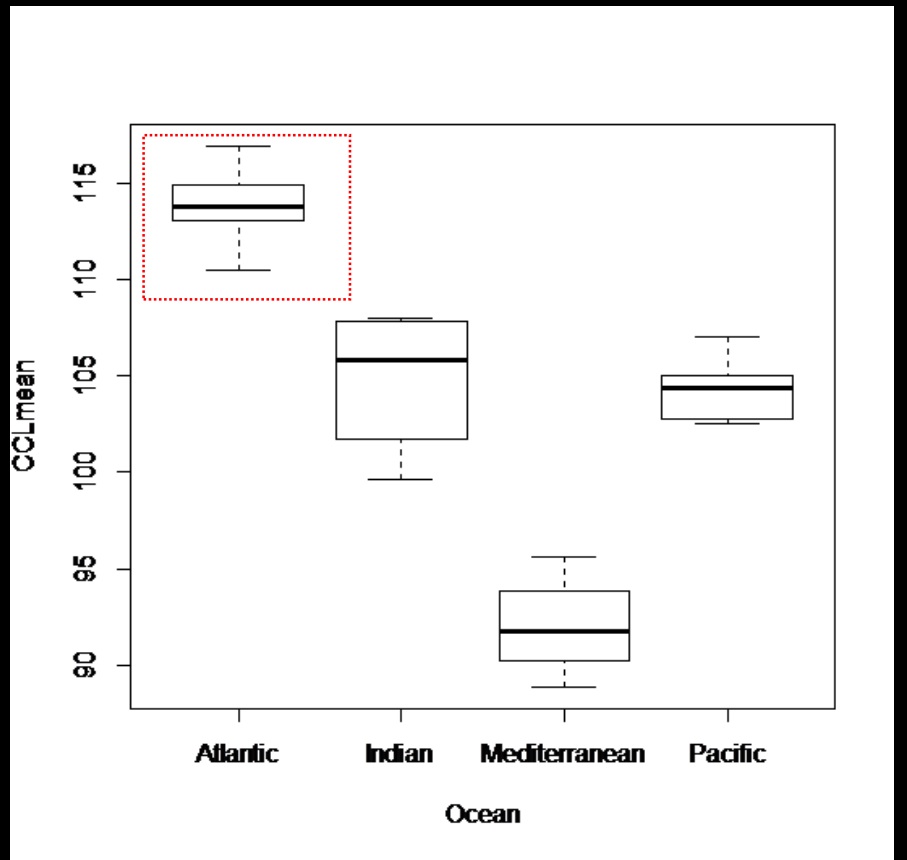
Thank you for your attention



ANNEXES

Représentation des tailles de tortues (taille minimum et taille moyenne) selon les regions

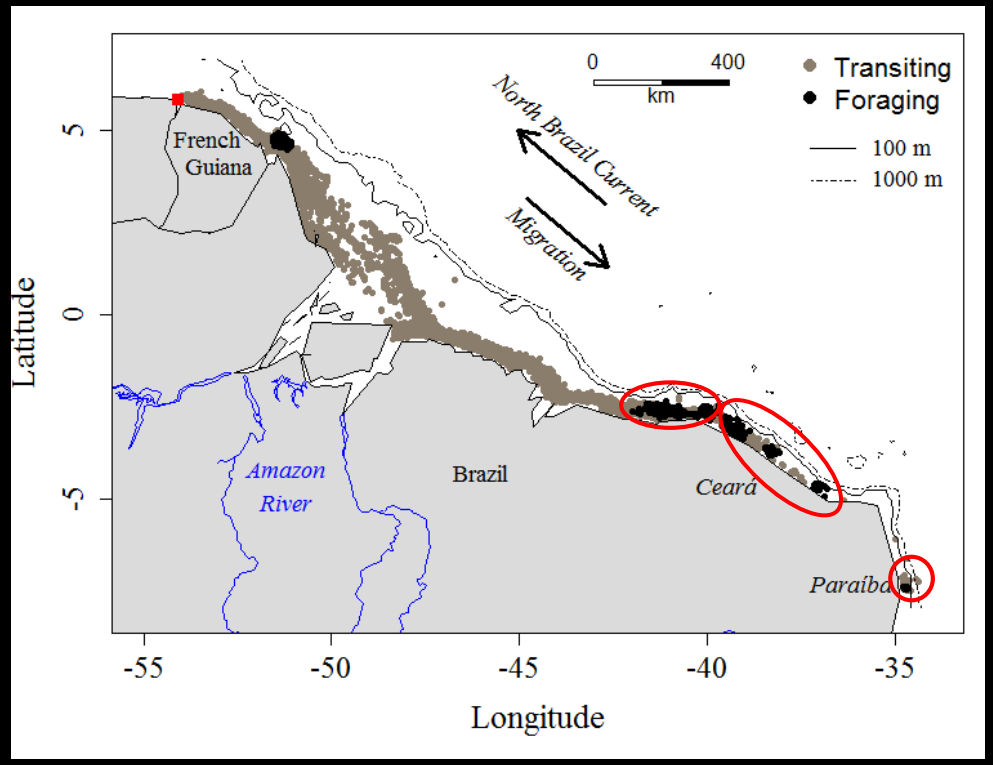




Bonola et al. *In prep*.

RESULTS – Foraging grounds and habitat

1. Trajectories & foraging grounds

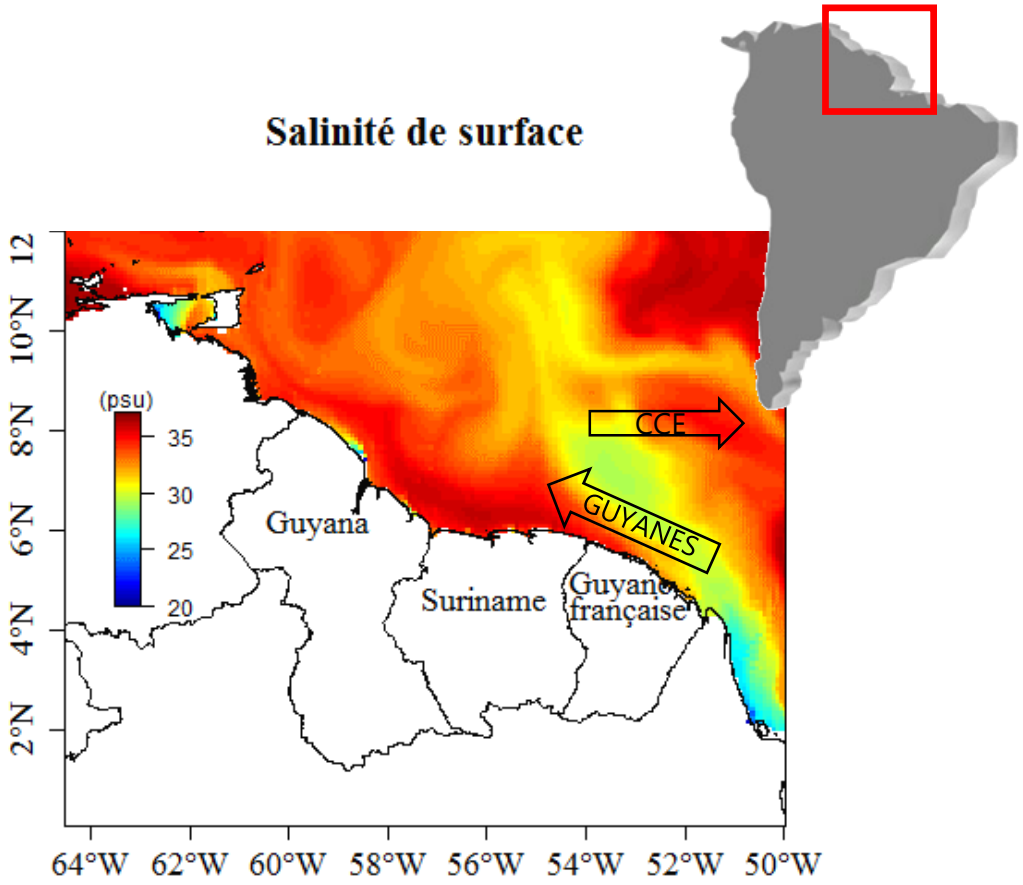


- Post-nesting migration (Apr-July)
- Direction: South-eastward
- Same foraging grounds both years
- ARS scale: 19.4±14.8 km radius
- Distance: 3681±729 km
- Duration: 118±37 days

Représentation des tailles de tortues (taille moyenne) individus marqués *vs.* non marqués

Année	Individu marqué PIT CCL±SD (range)	N	Individu non marqué NoPIT CCL±SD (range)	N
2015	112.6±6.1 (97-132)	197	**111.9±6.7** (91-129)	293
2016	114.3±5.1 (100-132)	113	**111.8±4.1** (101-125)	40
2015-2016	113.1±5.8 (97-132)	310	**111.9±6.5** (91-129)	333

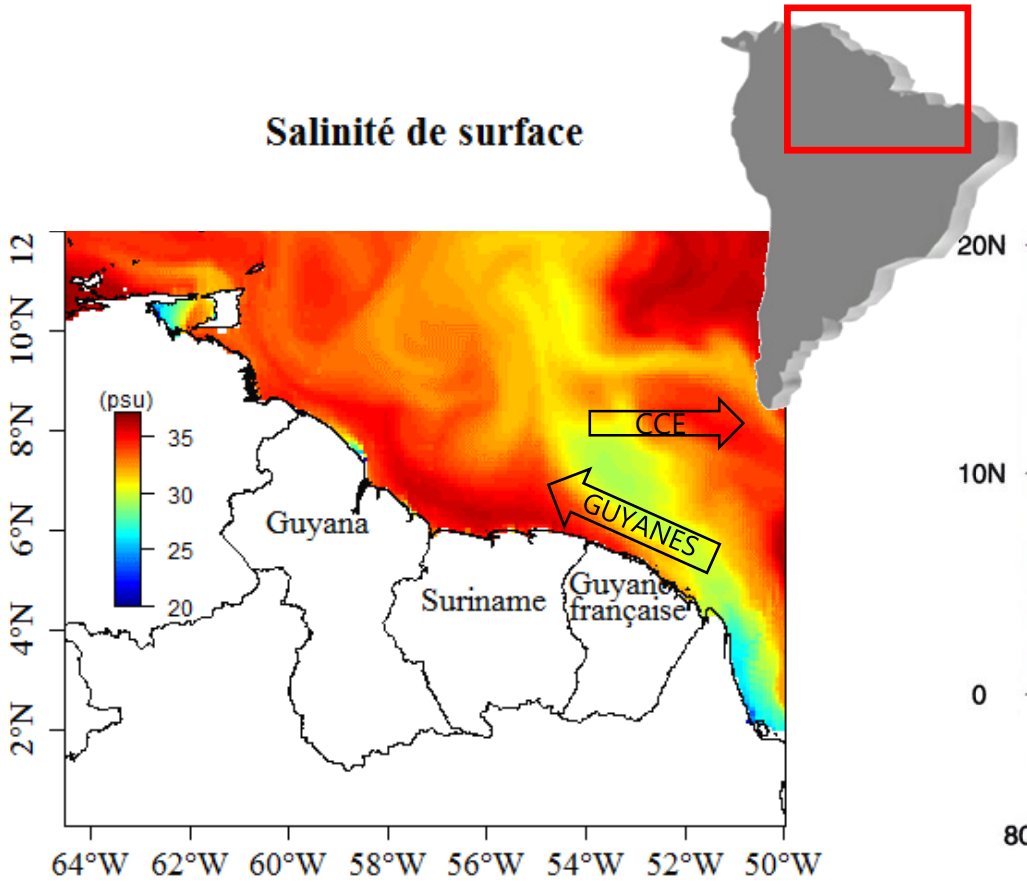
Contexte océanographique du plateau des Guyanes

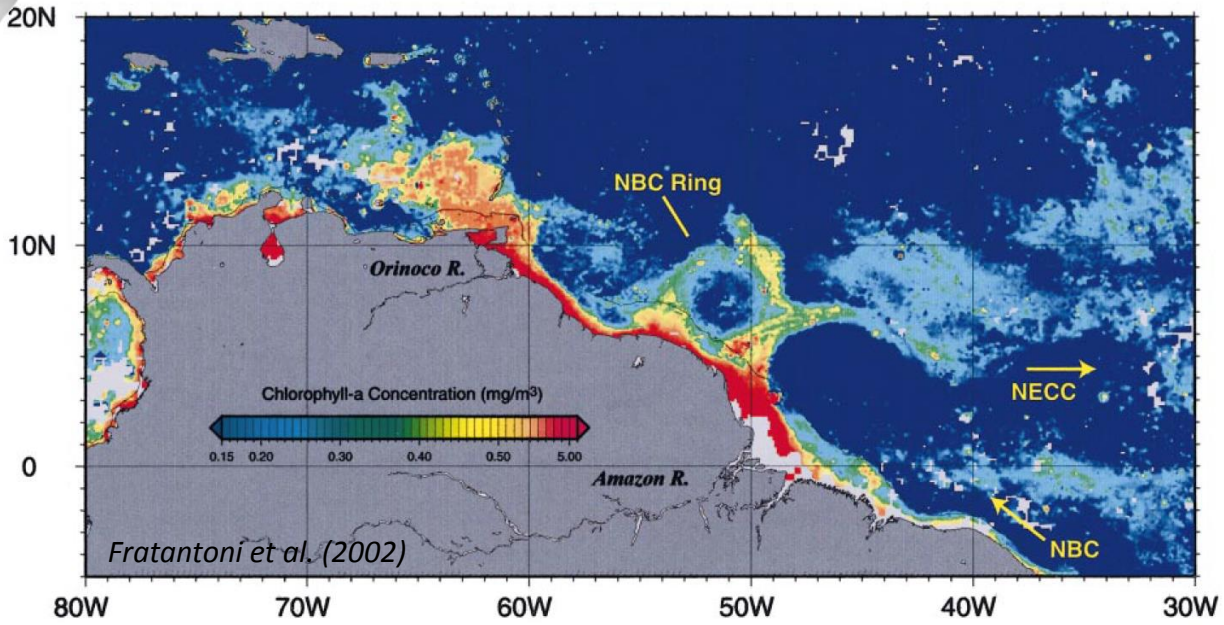


- 2 courants principaux [1]
- Tourbillons anticycloniques [2]

[1] De Master et al. (1996), [2] Fratantoni & Glickson (2002), [3] Baklouti et al. (2007)

Contexte océanographique du plateau des Guyanes





- 2 courants principaux [1]
- Tourbillons anticycloniques [2]

- Panache amazonien [3]
- Zone productive [3]

[1] De Master et al. (1996), [2] Fratantoni & Glickson (2002), [3] Baklouti et al. (2007)