May 2019

Final report on the green sea turtle nesting season of 2018-2019 *(Chelonia mydas)* on Tetiaroa atoll

- French Polynesia -

Final report on the green sea turtle egg-laying season of 2018-2019 *(Chelonia mydas)* on Tetiaroa atoll

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Citation

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With the support of: *Sven Lindblad et Kristin Hettermann*

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Abstract

The monitoring of green sea turtles on Tetiaroa atoll is a continuous research program, which strated in 2007, under the management og the Te mana o te moana association. Within the convention's framework, monitoring carried out during the 2017-2018 egg-laying season, benefitted from the support of The Brando and the Tetiaroa Society.

Cette saison, la première montée de tortue femelle a été estimée au 1er juillet 2018 et la dernière au 1er avril 2019, soit **un total de 274 jours.** Au cours de cette période, **190 traces ont été recensées dont 88 nids,** pondus majoritairement sur les *motu* Tiaraunu et Horoatera (hébergeant plus de 65 % des évènements de ponte).

This season, the first ascension of female turtles is estimated to have occurred on July 1tst 2018 and the last one on April 1st 2019; the egg-laying season lasted **274 days.** During this time period, **190 tracks were recorded, among which featured 88 nests,** most of which were found on the Tiaraunu and Horoatera, where more than 65 % of egg-laying events took place).

26 cases of adult female turtles observations were made at night, mainly on the beaches accounting for **11 individuals**. This season, the size of the entire atoll's sea turtle population has been estimated to **20 - 30 females**.

Thanks to in depth fieldwork, more than **90% nests were dug** which enabled the acquisition of reliable, valuable information regarding nest and hatchlings characteristics. Nests contained an average of **76 eggs** of which **72 hatched - 94% hatching success rate**.

Introduction

French Polynesia is composed of 118 islands (high volcanic islands and low coral islands), divided into five archipelagos (Society, Tuamotu, Gambier, Austral and Marquesas). Its total land area is 3 521 sq. km and it is part of an Exclusive Economic Zone (EEZ) of about 5 030 000 sq. km. (equivalent to the area of Europe). Five species of sea turtles can be found within this vast territory: the loggerhead sea turtle (*Caretta caretta*), the hawksbill sea turtle (*Eretmochelys imbricata*), the leatherback sea turtle (*Dermochelys coriacea*), the olive ridley sea turtle (*Lepidochelys olivacea)* and the green sea turtle (*Chelonia mydas*). The latter is, alongside the hawksbill sea turtle, the most common species found in French Polynesia (Petit & Gaspar, 2011). When it comes to sea turtle populations' biology and ecology in French Polynesia, our knowledge is fragmented. A major constraint is the vastness of the territory, which poses difficulties when it comes to the implementation of regular research programs.

To this day, only the green sea turtle is known to regularly lay eggs on the shores of French Polynesia. The major sites are located in the Society Islands, such as Tetiaroa (Petit et al., 2013), Scilly, Motu One and Mopelia (Balazs et al., 1995). Other less important sites have also been described, such as Tikehau (Tayalé, 2007), Maupiti and Fakarava (association Te Honu Tea).

Since 2007, the association Te mana o te moana conducts, with the valuable support of the atoll's owners, annual onshore monitoring on the egg-laying site of the Tetiaroa atoll, and since 2014, with the additional support of The Brando Hotel and the Tetiaroa Society. The high number of egg-laying events observed on the atoll in the last few years has contributed in making it one of French Polynesia's major sea turtle egg-laying sites. The purpose of monitoring is to catalogue the laying periods, gather data as complete as can be regarding the different criteria characterising the egg-laying events (tracks, females, nests, eggs, emerging turtles, immediate environment…), provide an index of the stock amounts and their evolution in time, and finally identify major sites for sea turtle egg-laying, to enable the establishment of conservation actions and adapt the relevant areas. Add to this, some studies are currently realised on the climate change impact on sea turtles.

During the nesting season 2018-2019, the monitoring were be done thanks the financial support of Tetiaroa society, The Brando, Vilebrequin, Hinerava, IFBD, Esri, Fondation Prince-Albert-II-de-Monaco et Sven Lindblad et Kristin Hettermann.

Materials and Methods

I. Study area

Tetiaroa is a private atoll located in French Polynesia. It is part of the Society Islands and belongs to the Brando family. Situated 53 sq. km north of Tahiti, it is the only atoll of the Winward Islands. It has a total surface of 6 sq. km, about 585 hectares of sand, and is divided into the following 12 *motu* (small islands): Onetahi, Honuea, Tiaraunu, Tauini, Auroa, Hiraanae, Horoatera, Aie, Reiono, Tahuna rahi, Tahuna iti and Rimatuu (Figure 1). Except in for Onetahi, the *motu* are not inhabited. Since July 1st 2014, the latter hosts the eco-resort The Brando. Presently, more than 300 people live there permanently, the majority of whom works for the hotel. The atoll also receives the daily visit of charter companies, which enable tourists to discover the *motu*'s beaches, such as Rimatuu and Tahuna iti.

During the 2018-2019 season, these 12 *motu* were prospected at least once by the Te mana o te moana association.

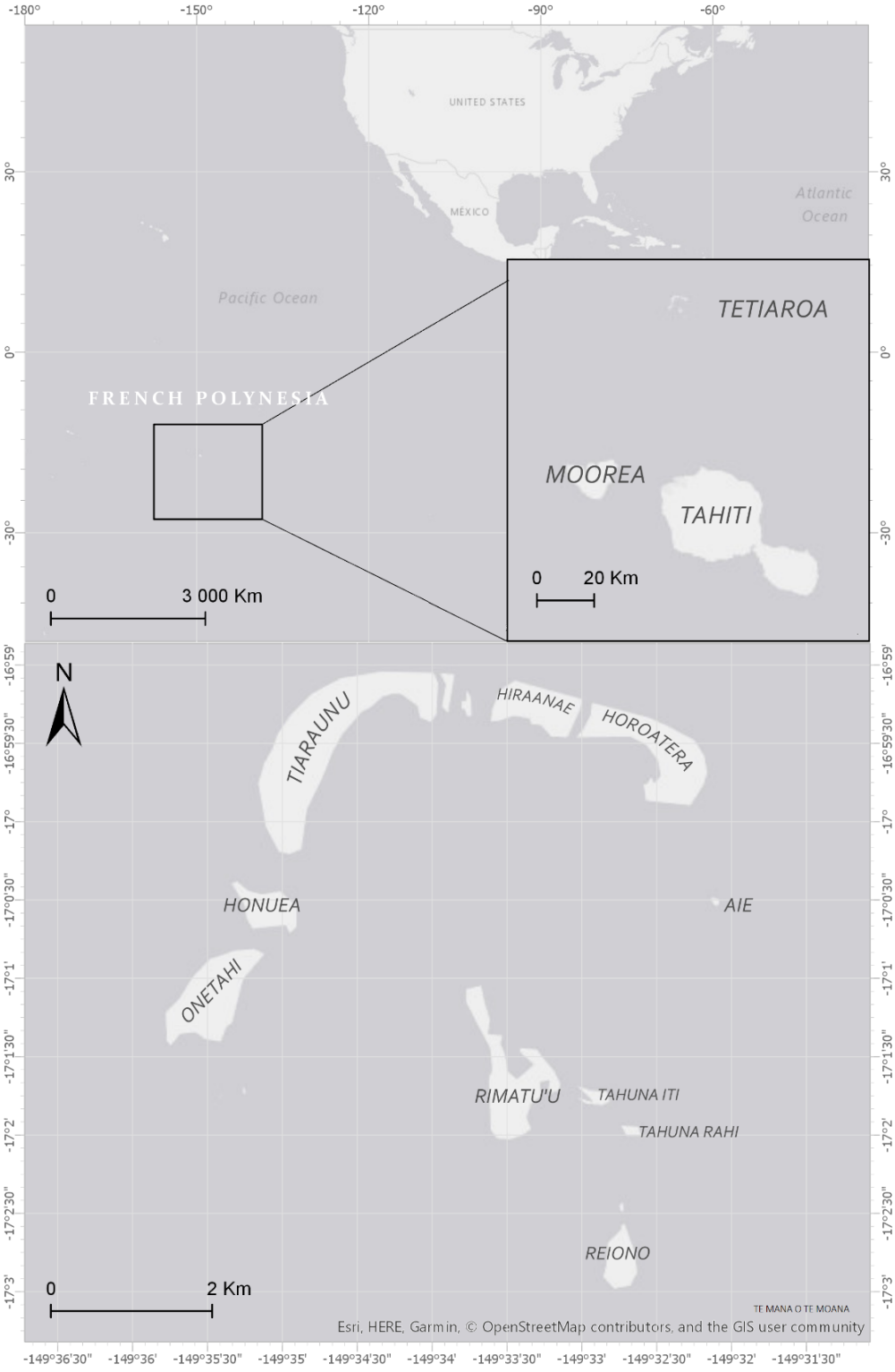


Figure 1 : Tetiaroa atoll

II. Field T

During the 2017-2018 season, 20 people took turns in collecting data on the field, three of which remained permanently on-site. These people underwent a training program at the Moorea care centre, led by Dr. Cécile Gaspar (certified for sea turtles by Direction of Environment DIREN from French Polynseia Gouvernment), which focused on teaching them how to handle egg-laying turtles (baggage, measures, genetic sampling).

- **Touron Margaux**: Marine biologist – Head coordinator of the nesting season.
- **Genet Quentin**: Marine biologist -

Volunteers were able to assist the permanent team, for time periods varying from one to a few months.

- **Deroo Julien:** Geography student at University of Quebec.
- **Gabri Lucie:** Ecology student at University or Bordeaux
- **Raynal Aude:** Student at ENSAT engineering school of Toulouse
- **Poly Virginie:** Ecologist, and ex-volunteer during the nesting season 2016-2017 on Tetiaroa atoll
- **Monsinjon Jonathan:** Doctor in ecology, and specialist on climate change impact on sea turltes
- **Driver Malik :** Athlete
- **Brémont Didier:** Professional photographer

III. Field protocol

Based on the Polynesian environmental code, the green sea turtle species is classified under the B Category. Hence, since 2007, all administrative requests concerning the scientific monitoring of green sea turtles have been assigned to the Direction for the Environment.

This year, the main focus of the study was nocturnal prospection on 3 *motu*: mostly on Onetahi & Tiaraunu and less continuously on Horoatera. Regular monitoring has enabled the registration and identification of egg-laying females, thanks to the Capture-Mark-Recapture

(CMR) method. The fact of ringing turtles monitored during the night time has enabled to acquire information regarding their egg-laying frequency, the time span before each new egg-laying event, the geographical distribution of nests created by the same turtle, but also the incubation time period of each nest.

Alongside nocturnal missions, daytime prospection was also carried out on a daily basis, dedicated to recording tracks and nests located on the various *motu*, in order to know the exact number of events, which occurred on the entire atoll this season.

1. Morning survey

Since the beginnings of monitoring on Tetiaroa in 2007, the method has remained the same. Daytime monitoring, taking place on the 12 *motu*, is executed in twos and aimed at locating turtle tracks (ascending/descending tracks, turned over sand, diggings...). In order to optimise the research, a first observer is in charge of monitoring the lower part of the beach, at the foreshore level, whilst a second observer prospects the higher part of the beach, located at the vegetation's edge.

The purpose of daytime monitoring is to identify the tracks left on the beach. All turtle species leave different kinds of tracks. This helps determine the species, which laid the eggs. On Tetiaroa, all the tracks discovered had been made by green sea turtles. The front flipper prints were deep and asymmetrical, which is typical of their moving patterns. The prints of the hawksbill sea turtles, commonly found in French Polynesia, are less deep and less asymmetrical.

When tracks or diggings are discovered, various characteristics are written down:

- ✓ **General characteristics of observation**: for each new track/digging, the observers' names, the date of the observation and the *motu*'s name are taken down.

- ✓ **Characteristics of the track and diggings:** upon the discovery of the track, the kind of ascension must be determined. The tracks are interpreted as follows: it can either be a simple track **(T)**, demonstrating that the turtle ascended and then descended without

performing further actions; the track can be found alongside one or more diggings, which didn't lead to any egg-laying events, we call these "attempts" **(TN0)**; it can be found next to successful diggings, which led to egg-laying and in this case, either we can only suspect that there has been an egg-lay **(TN1)** or we are almost sure that it took place **(TN2)** or we are absolutely certain that it occurred **(TN3)**. The fact that eggs were laid can only be confirmed, if it has been observed or if the nest has been dug up and the eggshells counted after the hatching phase. (Figure 2).

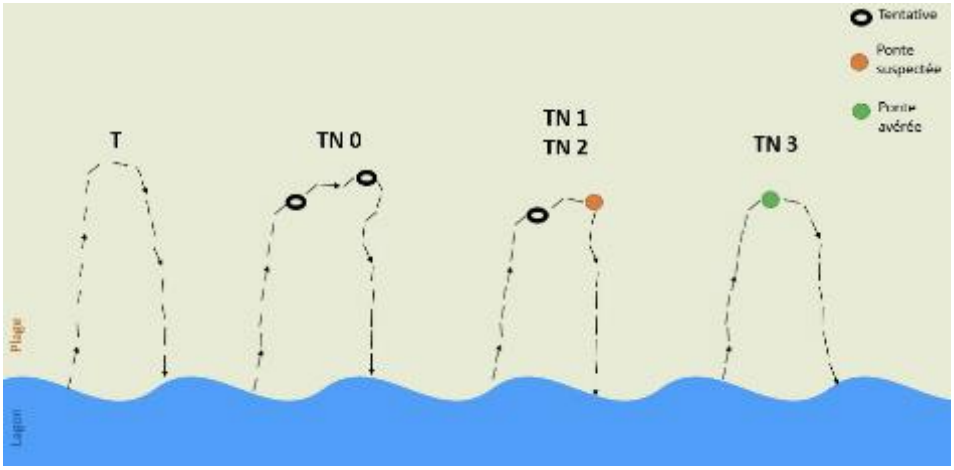


Figure 2: Diagram featuring the different kinds of recorded tracks

For each track, the number of attempts is counted and written down.

When a turtle track is spotted and the presence of a nest cannot be deduced, the GPS coordinates of the track's highest point are written down. If one or multiple diggings have been found, the last digging's GPS point is taken down. Hereafter, the objective will be to determine the last nest by figuring out the turtle's progression, based on the orientation of the prints left by its flippers.

Then, the track's degree of freshness will be assessed and put in the following categories: "fresh", "partially erased" and "erased". Based on the category, it will be possible to estimate the date of ascension. The degree of difficulty found in estimating the freshness of the tracks is correlated with the monitoring frequency of the site.

- ✓ **Environmental characteristics:** regardless of the type of ascension being considered, a few environmental parameters will be assessed, in order to collect information concerning their influence on the success of egg-laying and egg incubation.

Thereby, qualitative measures are taken at the surface, such as the sand's grain size. If much of sand particles is inferior to 1 mm, the grain size is put into the "thin" category, and if the diameter of many these is superior to 2 mm, it will be put into the coarse category. In between these two numbers, the grain size was described as "medium".
The light exposure of the nest or of the top of the track was also qualitatively assessed. The vegetative cover, from which resulted the light exposure, was divided into three categories, based on a 5m radius around the nest or from the track's top: "shady" (more than 50% of vegetative cover), "half-shady" (between 25 and 50% of vegetative cover) and "direct sunlight" (less than 25%).

The quality of the coastline facing the nest or of the last digging is also taken into account. This criterion is broken down into 3 categories: « sand », « coral slab » and « rugged».

The distance from the nest or from the track's summit to the highest line of the tide is measured using a double decametre. Furthermore, in order to know the total distance of the egg-laying beach, we measure the distance from the first line of vegetation to the highest tide's line.

- ✓ **Marking the diggings and recording the nests:** when new diggings are observed, iron stick is driven into the sand as a mark, 1m behind the potential incubation chamber, in order to avoid hindering the access of emerging turtles to the beach. The main cavity (the one containing the eggs or, if the presence of eggs is uncertain, the last cavity before the descent) is called a "nest" and assigned a number.

2. Night survey on Onetahi

Given the great amount of turtle ascensions observed since the beginning of the season, and thanks to the great accessibility of observation sites, facilitated by the implementation of a permanent field team on the Onetahi *motu*, nocturnal prospection on Onetahi has been systematic (5 times per night, each night). Five patrols were carried out at fixed hours: 20h30 / 22h / 23h30 / 1h00 / 3h00. The association Te mana o te moana's field teams were aided by

volunteers of the hotel and by the staff from the security company of The Brando Hotel. When it came to handling the turtles, each person involved had received training and was accompanied by the staff of Te mana o te moana.

During patrols, field teams cover the coast to identify female green sea turtles in their ascending or egg-laying phase. If the turtle has already returned to the water and hence, has failed, the same protocol applies as during nocturnal prospection. However, if the turtle is still present on-site, in addition to gathering the aforementioned information, the following protocol applies:

- ✓ **Taking photographs of the animal:** each turtle has a unique layout of scales on its head profiles (Schofield et al., 2008), which is an exceptional tool for photo-identification (classified in the TORSOOI data base). De facto, a picture of both head profiles is taken, when encountering a turtle, as well as a general picture of the body. In order to better respect the animal, it is preferable to take pictures without flash and to use a red light.

- ✓ **Measures:** the length and curved width of the shell (CCL and CCW) are written down.

- ✓ **Ringing:** the turtles are ringed at the edge of the front flippers, between the two first scales. The rings are "Monel Tag", numbered on one side and provided by the Direction for the Environment in French Polynesia.

- ✓ **Genetics:** a skin sample is taken from the hind flippers' area for genetic analyses, led by the Direction for the Environment.

- ✓ **Other:** all details observed regarding the animal are meticulously written down, such as physical injuries on the body or a specific attitude of the animal towards external factors (hotel constructions, light, surrounding people, etc.…).

- ✓ **Nest protection:** when the turtle gets back to the lagoon and if the event led to the laying of eggs, solely in the case of Onetahi, a grid is set up to protect the active nest. Due to the implementation of The Brando Hotel, and despite the fact that a specific lighting

policy has been put in place during the nesting period, negative effects of disorientation have been noticed numerous times amongst emerging turtles, when exiting the nest. To minimise the impact, the decision was made to set up a circular grid around the nest, during the entire incubation time period. These protections have proved efficient in many ways. They ensure a precise identification of nesting cavities, enable us to watch out for potential predators, and help us observe the emergence of turtles and their descent to the lagoon.

Patrols are carried out to observe the emergence of turtles. Teams will either let them descend to the lagoon naturally or they will decide to bring them to a protected area, away from the artificial lights, and from there, let them get to the lagoon in the most natural way as can be. Active protection has enabled us to meticulously observe emerging turtles, their health condition and their energy. Our presence has played a big part in fighting off predators in the sand and on the beach, when they descend to the lagoon (birds, crabs, hermit crabs…).

Rules concerning the behaviour to adopt are very strict and need to be respected, when it comes to approaching and handling laying females. All handlings take place either after the turtle has laid its eggs or during the animal's descent to the lagoon.

3. Night survey on other *motu* (Tiaraunu and Horoatera)

Besides daily nocturnal monitoring on Onetahi, near daily night watches take place on the Tiaraunu *motu* and regularly take place on the Horoatera *motu*. In the course of these expeditions, field teams follow the exact same protocol as the one carried out on Onetahi, apart from the nest protection phase, which is not applied on other *motu*. Teams benefitted from basic on-site camping structures.

4. Protocol used during the hatching period on the other *motu*

Upon the discovery of an active nest, the estimated egg-laying date is determined. Based on previous years' collected data, the incubation time period of green sea turtle eggs on Tetiaroa was estimated between 50 and 80 days. Nest monitoring starts at this time, in anticipation of the emerging turtles. On the Onetahi *motu*, during the hatching time period and due to the

protecting grids, the field team carries out a minimum of 2 to 4 patrols per night. The first one takes place at 20h30 and the last one at 5h, before the sun rises. Monitoring enables to observe the emergence of all protected nests on Onetahi.

After the main phase of emergence, a minimum of a two-day time period of animal security is respected. Following this time period, field teams dig up the nest to obtain precious information, regarding the hatching success rate, and intervene on weakened, deformed or emerging turtles, which are stuck, and unable to leave the nest. If no sign of emerging turtles is detected during the monitoring phase, the nest is dug up following the theoretically maximum amount of time, wherein the hatching should take place (+ 80 days).

If an incubation chamber and shells are discovered, the following measures are taken:

- ✓ **General information:** the date, hour, as well as the nest's number are written down

- ✓ **Counting the number of emerging turtles, which reached the surface:** when a hatched clutch is discovered, the number of emerging turtles is written down. We check each individual's energy in the umbilical area and if need be, assistance is brought to the juveniles, stragglers and wounded turtles.

- ✓ **Counting the eggs:** once the nest is excavated (minimum 48h after the hatching phase), the number of empty shells and the number of unhatched eggs are both written down. It is important to check the inside of unhatched eggs, in order to distinguish infertile eggs, from non-fertilised eggs and embryos, which died in the course of their development. We also take note of the number of deaths among the emerging turtles, which managed to exit the egg, and the number of live, emerging turtles, which could not get out of the nest.

- ✓ **Measures:** once the nest has been excavated, the maximum depth of the incubation chamber is measured (by hand, with gloves or using a small garden shovel).

- ✓ **Genetics:** in order to be able to proceed to genetic analyses, a skin sample is collected at the level of the emerging turtles' flippers, from dead individuals only (embryos or emerging turtles).

- ✓ **Predation:** observing and counting the predators in and around the nest. An infrared video camera was set up a number of times on the Tirana *motu*, in order to watch the behaviour of predators, when the emergence was occurring without the presence of field teams.

Results

I. Nesting seasons evolution since 2007

Along the years, the monitoring program of green sea turtles on Tetiaroa initiated by the association Te mana o te moana has gathered 11 seasons' worth of data. Regular monitoring has enabled the acquisition of precious information regarding the evolution of their presence on the atoll with the passing of seasons.

1. Phenology of nesting events

In French Polynesia, the green sea turtle egg-laying season runs from November until April (Lebeau, 1985). When taking into account the egg-laying phenology of the last eleven seasons on Tetiaroa, one can notice great differences between the time at which the season begins and ends, the length of the nesting season, as well as the length and time period, wherein the nesting peak occurs (Figure 3).

Despite this striking variety, its has also been noticed that increasingly, nesting seasons have been starting earlier and earlier, since the first monitoring operations, which took place in 2007: from November 5th in 2007 to July 12th in 2017, which amounts to a near 4 months' difference.

Also, the length of nesting seasons has changed greatly, from 156 days in 2007-2008 to 289 days in 2017-2018. With the passing of years, it seems that the nesting season has lengthened.

Likewise, the time of the nesting peak has changed. The latter is defined as the time period, in which the most nesting events have been observed. In 2007 and 2008, it used to take place around the months of January and February. Now and since 2009-2010, it draws towards the months of November, December and January. In the last four seasons, it seems to have been remaining so (Figure 3).

This season, we estimated to have occurred on July 1st 2018 and the last one on April 1st 2019; the egg-laying season lasted **289 days**

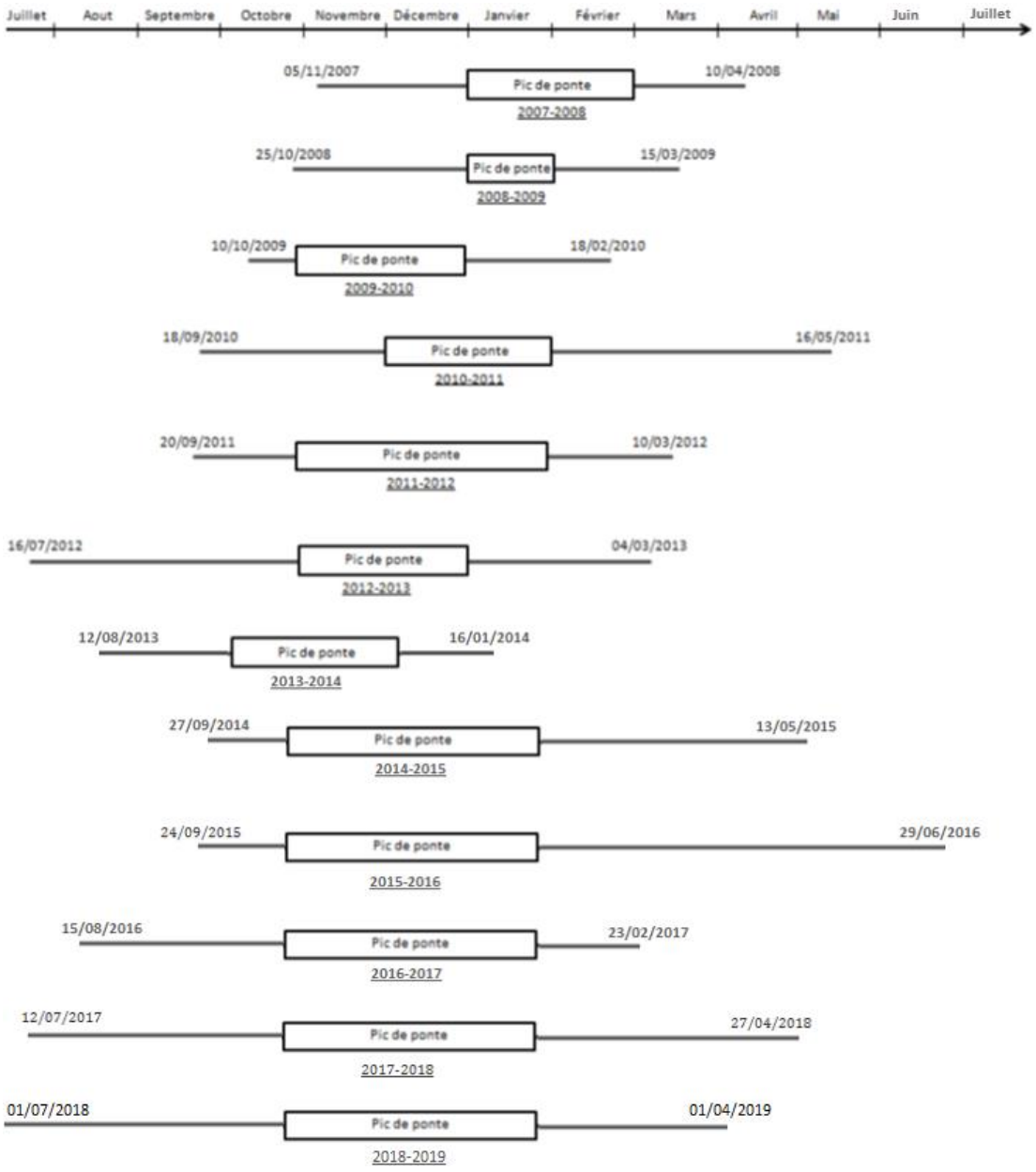


Figure 3 : Spread of the nesting seasons from 2007 until 2019

2. Nesting events

The number of egg-laying events is also very heterogeneous and varies depending on the egg-laying season, from 53 ascensions during the 2009-2010 season to 1316 during the 2017-2018 season (Figure 4).

However, thanks to twelves years' worth of collected data regarding turtle nesting on Tetiaroa, the profile of a **three-year nesting cycle** seems to be shaping up. From the 2009-2010 season

until the 2011-2012 season, an increased growth in the number of tracks has been observed. The same pattern has been observed from 2012 until 2015 and from 2015 until 2018.

In the following years, it will be possible to confirm the length of the nesting cycle, by recapturing the female in question, which will either be identified thanks to the tags, the photo-identification of either head profiles, or genetic samples.

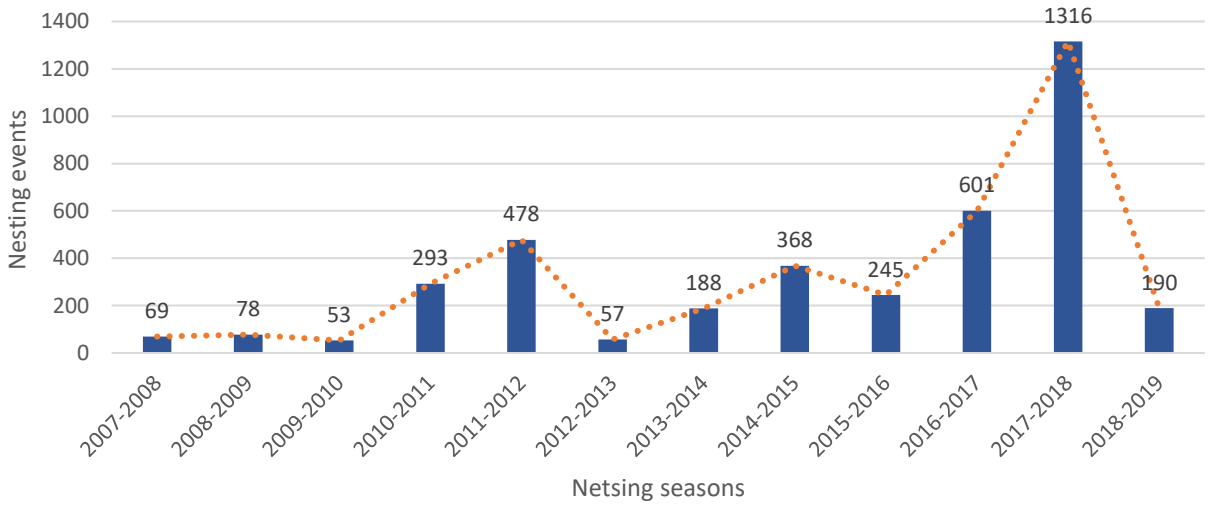


Figure 4 : Evolution of the number of nesting events from 2007 until 2019

3. Nesting females

Over the 12 years, **161 nesting females** were identified by the field team. Identification could be done thanks to tags instaled on front flippers L'identification a pu être faite soit par la pose de bagues sur les nageoires antérieures, photography of either head profiles, or by sample genetic. The identification variation over the seasons are link with the night prospection effort lead by the team (Figure 5).

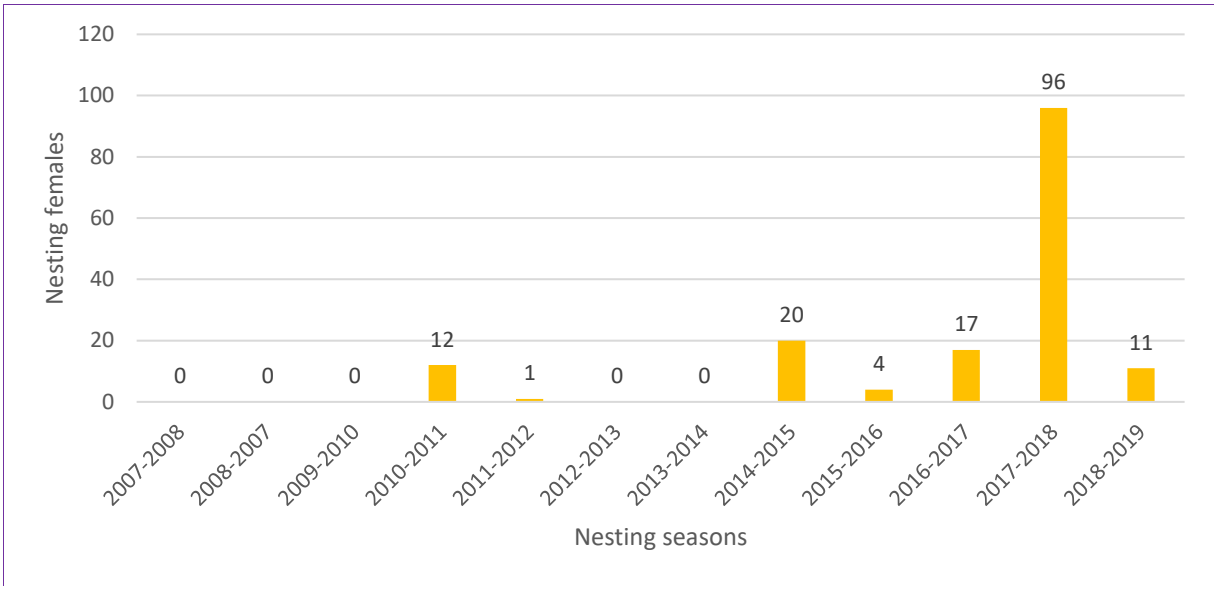


Figure 5 : Evolution of the number of nesting females from 2007 until 2019

II. Nesting season 2018-2019

1. Prospection efforts

The prospection was led from July 13th 2018 until May 6th 2019, which corresponds to **210 day patrols** on the 12 *motu* and **170 night patrols (**Table 1**)**.

On account of The Brando Hotel's implementation on Onetahi, which made its access easier, the number of patrols carried-out on the *motu* increased to a number of 4 per day (20h30 / 22h / 23h30 / 3h). Tiaraunuu and Horoatera *motu*, known to preferably welcome the green sea turtles' nesting events on Tetiaroa (Petit et al. 2013), were regularly prospected during the day, at least twice a week, but also at night (31 night patrols on Tiaraunu and 8 nights spent on Horoatera). Regarding the 9 remaining *motu*, Honuea, Rimatu'u, Tahuna Rahi, Tahuna iti, Reiono, Aie, Tauvini, Auroa and Hiraanae, nearly each of these were kept under surveillance on average twice a month, except for the 4 last ones, which were only once visited due to the absence of green sea turtle tracks.

In total and throughout the entire atoll, teams covered more than **1 130 km**

Tableau 1: Effort de prospection durant la saison 2018-2019

	Day patrol	Night patrol	Prospection efforts *(km)*
TIARAUNU	62	31	320
HOROATERA	51	8	200
ONETAHI	22	128	455
AUTRES	75	3	156
TOTAL	210	170	1131

2. Nesting events

2.1. Type of recorded tracks

190 crawls were identified during the 2018-2019 nesting season, on the Tetiaroa atoll. 101 attempts (among which feature 22 simple tracks (T) and 79 abandoned cavities (TN0)), which represent 53% of the total number of events. 89 nesting events were recorded, with **81 were proven true** (TN3 – the egg-laying was witnessed or the nests were excavated and the eggs counted), which amounts to 43% of events, and 8 remained a hypothesis (the presence of eggs in the nest wasn't confirmed (TN2)), accounting for 4% (Figure 6).

Tableau 2: Number of tracks

	TOTAL	PERCENTAGE
T	22	12%
TN0	79	42%
TN1	0	0%
TN2	8	4%
TN3	81	43%
TOTAL	190	100%

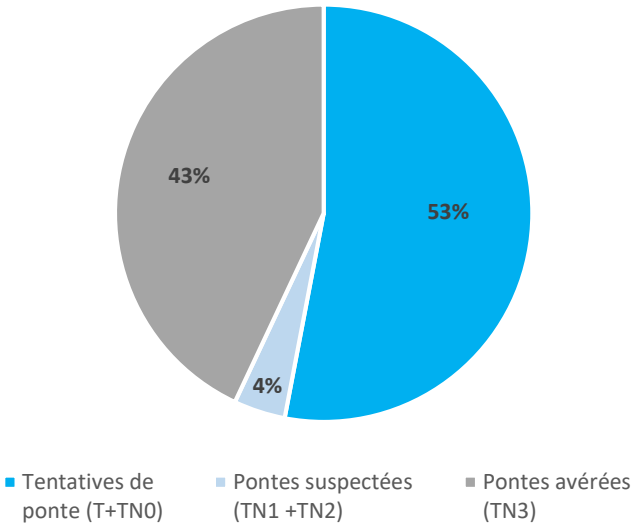


Figure 6 : Type of recorded ascensions during the 2017-2019 nesting season

2.2. Temporal distribution

Nesting events occurred between July 1st 2018 (estimated date of the first ascension) and April 1st 2019 (estimated date of the last ascension), in the course of **274 days**. This season, **the nesting peak occurred in December and January**, based on the fact that 54% of egg-laying events this year took place during this time period (Figure 7).

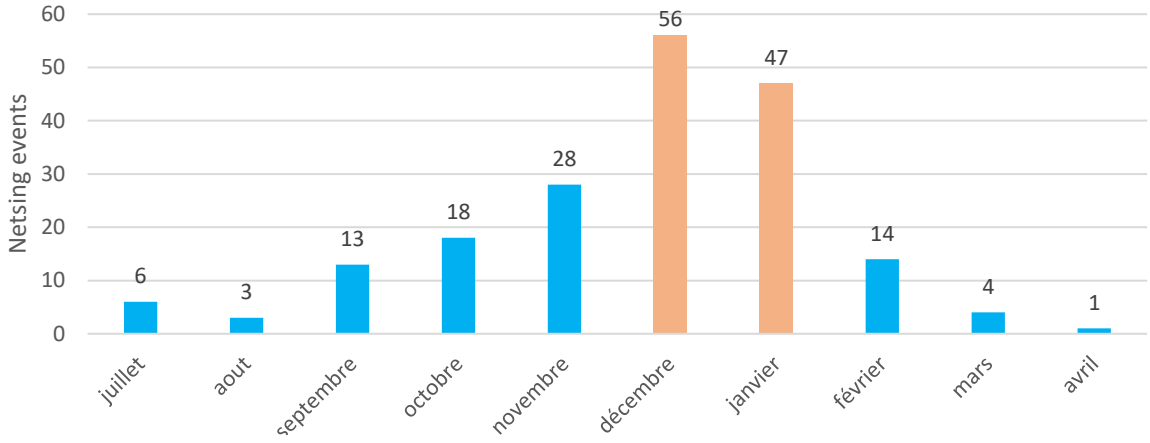


Figure 7 : Temporal distribution of egg-laying events during the 2018-2019 season

2.3. Spatial distribution

The 2 main nesting areas of this season, which **accounted for more than 65% of events**, were found on the two great *motu* in the north, **Horoatera and Tiaraunu**. These sites had already stuck out in the course of previous seasons, as being areas with regular and high presence of green sea turtles, when compared to the rest of Tetiaroa.

Honuea and Onetahi represent 17% and 10% of events. This season, the presence of sea turtles on Tahuna Rahi, Rimatuu, Reiono's has been relatively low, accounting for only 8% of events. Not a single nesting event took place on Tahuna iti, Aie, Tauvini, Auroa and Hiraanae (Figure 8).

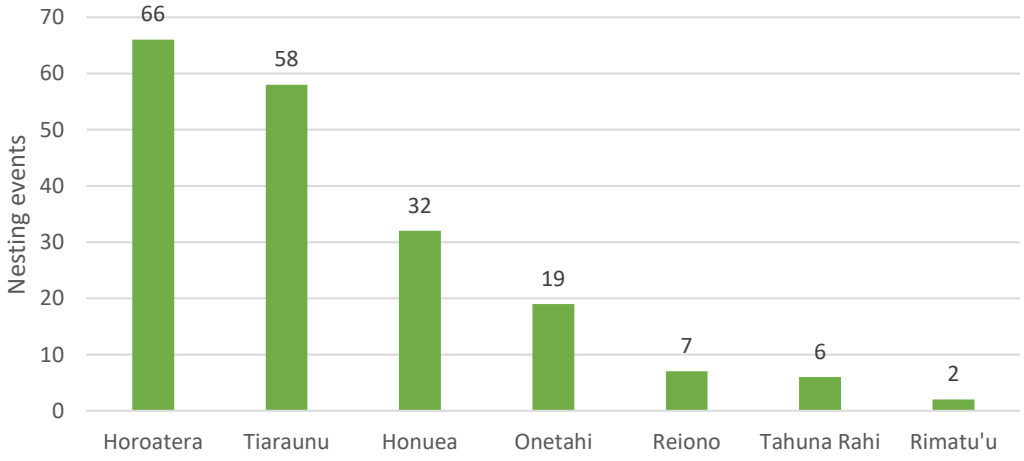


Figure 8: Number of recorded nesting events per motu during the 2018-2019 season

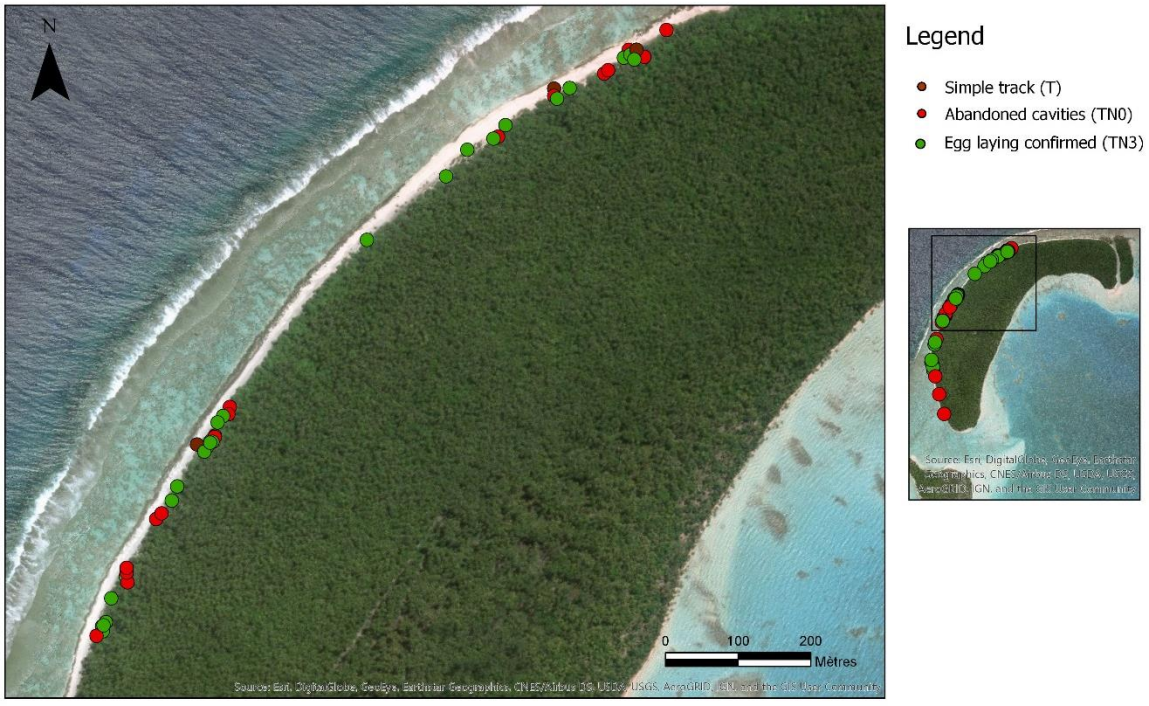
The details of the different types of tracks, as well as the location of the nesting events of each motu frequented are presented below:

- **TIARAUNU**

Tiaraunu *motu* accounted for **58 nesting events**. Among this nesting events there are: 30 egg-laying confirmed (TN3), 1 egg-laying almost certain (TN2), 24 unfinished nest digging attempts (TN0) and 3 simple crawls (T) (Tableau 3, Figure 9).

Tableau 2: Summary of egg-laying events on the Tiaraunu motu

	TN3	***TN2***	***TN1***	***TN0***	***T***	***TOTAL***
Number of tracks	30	1	0	24	3	58
Percentage	52%	2%	0%	41%	5%	100%



Cartographie Te mana o te moana 2019

Figure 9 : Cartography of green sea turtle egg-laying events on the Tiaraunu motu

- **HOROATERA**

66 nesting events took place on Horoatera, with 28 egg-laying confirmed (TN3), 4 egg-laying almost certain (TN2), 19 unfinished nest digging attempts (TN0) and 15 simple ascensions and descents (T) (Tableau 4, Figure 10).

Tableau 3: Summary of egg-laying events on the Horoatera motu

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	28	4	0	19	15	66
PERCENTAGE	42%	6%	0%	29%	23%	100%

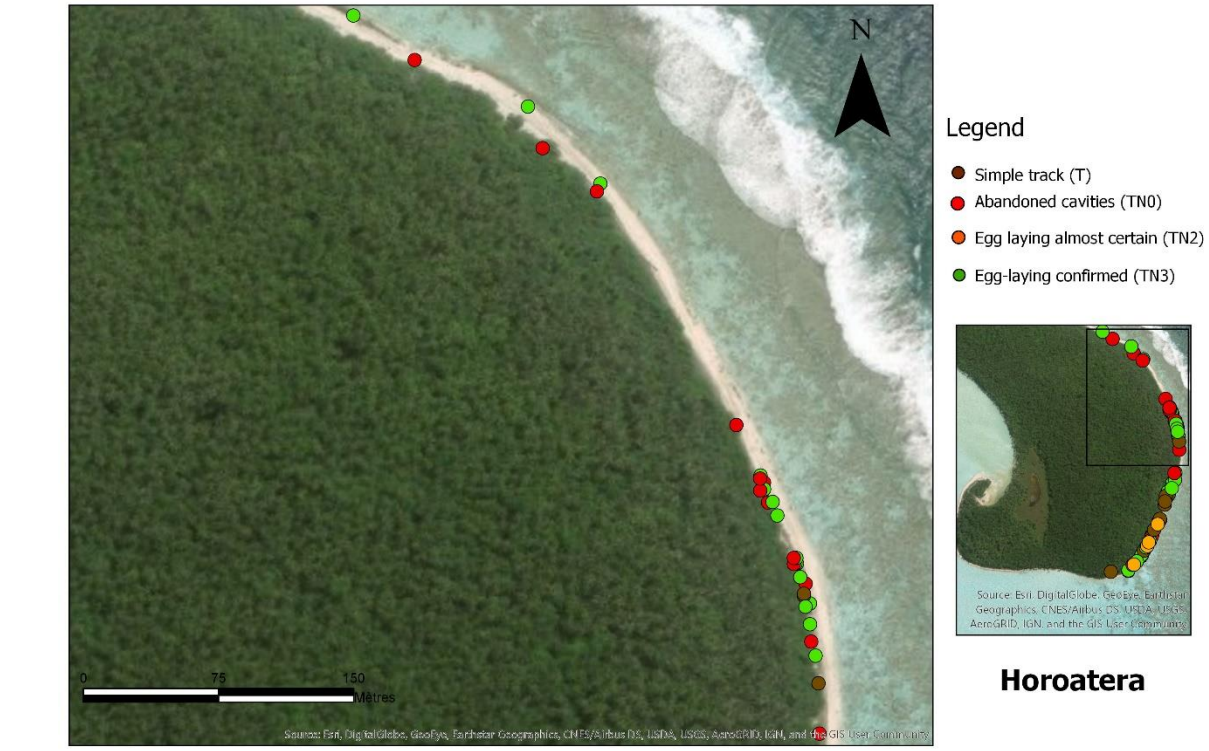


Figure 10 : Cartography of green sea turtle egg-laying events on the Horoatera motu

- **HONUEA**

32 egg-laying events took place on the Honuea *motu*, with 10 egg-laying confirmed (TN3), 19 unfinished nest digging attempts (TN0) and 3 simple ascensions and descents (T) (Tableau 5, Figure 11).

Tableau 5: Nesting events' summary on Honuea

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	10	0	0	19	3	32
PERCENTAGE	31%	0%	0%	59%	9%	100%

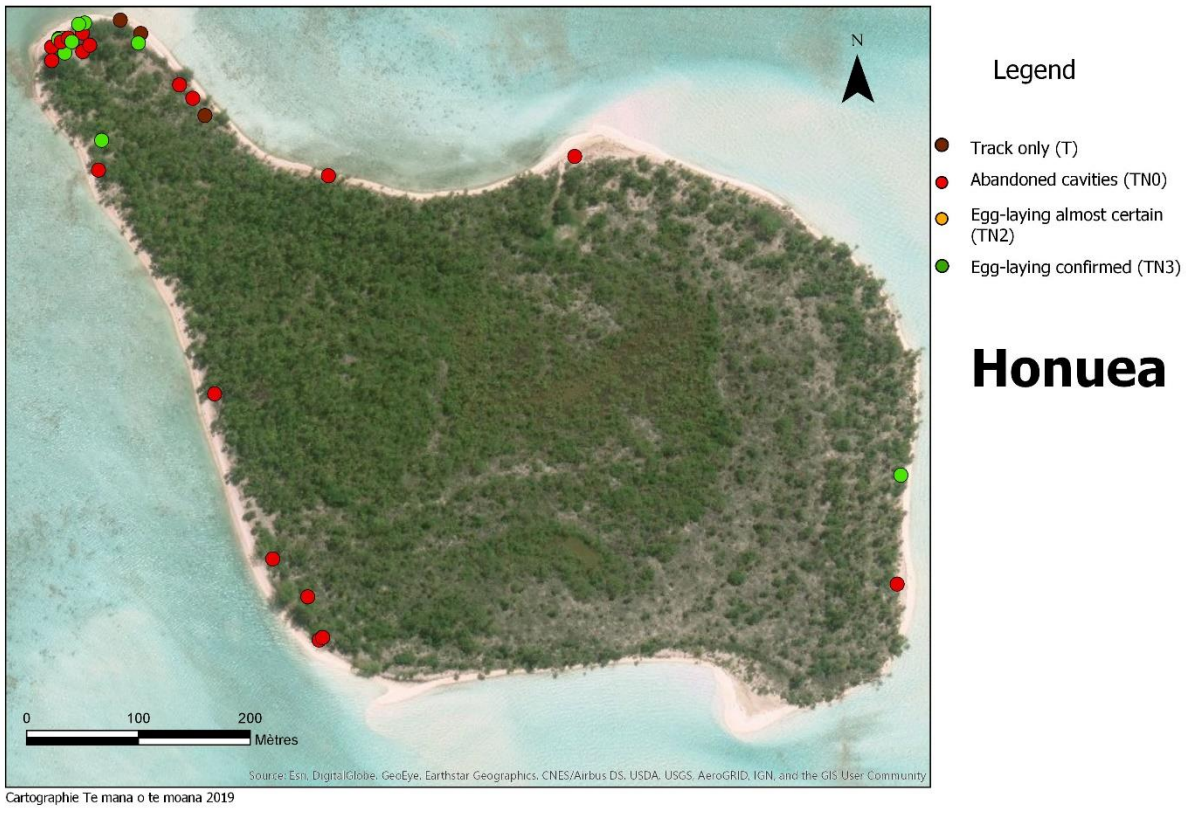


Figure 11: Cartography of green sea turtle egg-laying events on the Honuea motu

- **ONETAHI**

On the Onetahi *motu*, field teams counted **19 egg-laying events**. The egg-laying events were broken down as follows: 9 egg-laying confirmed (TN3), 9 unfinished nest digging attempts (TN0) and 1 simple ascensions and descents (T) (Tableau 6, Figure 12).

Tableau 6: Nesting events' summary on Onetahi

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	9	0	0	9	1	19
PERCENTAGE	47%	0%	0%	47%	6%	100%

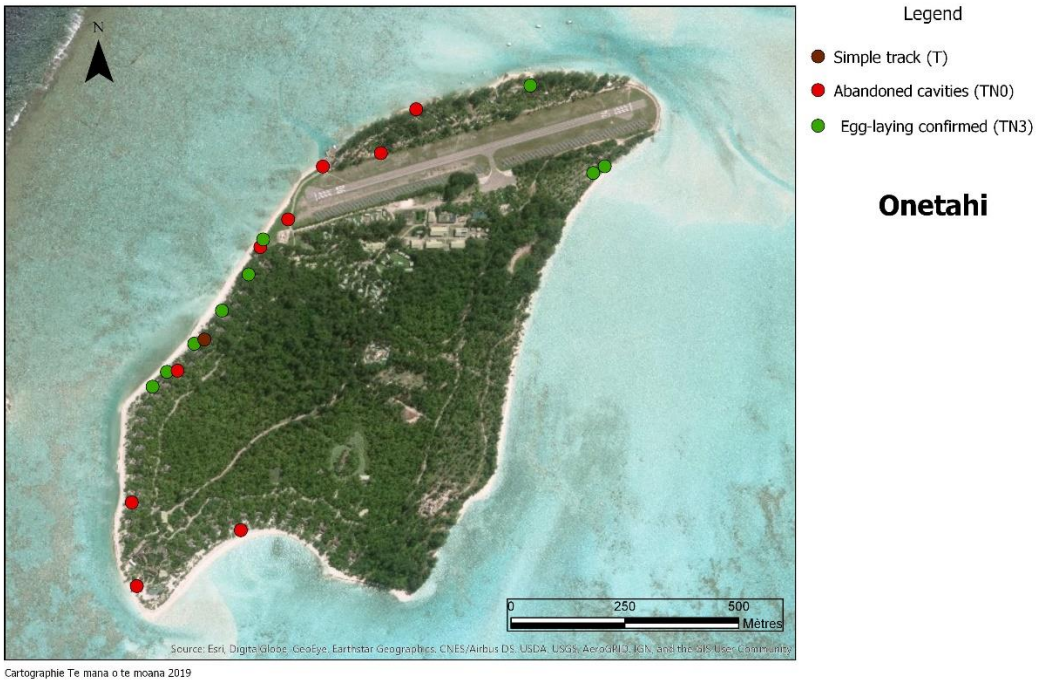


Figure 12 : Cartography of green sea turtle egg-laying events on the Onetahi motu

- **TAHUNA RAHI**

7 egg-laying events took place on the Tahuna *motu* with 3 egg-laying confirmed (TN3) and 4 unfinished nest digging attempts (TN0) (Tableau 7, Figure 13).

Tableau 4: Nesting events' summary on Tahuna Rahi

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	3	0	0	4	0	7
PERCENTAGE	43%	0%	0%	57%	0%	100%

- **REIONO**

6 egg-laying events took place on the Reiono *motu*, with 3 egg-laying confirmed (TN3) and 3 unfinished nest digging attempts (TN0) (Tableau 8, Figure 13).

Tableau 5: Nesting events summary on Reiono

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	3	0	0	3	0	6
PERCENTAGE	50%	0%	0%	50%	0%	100%

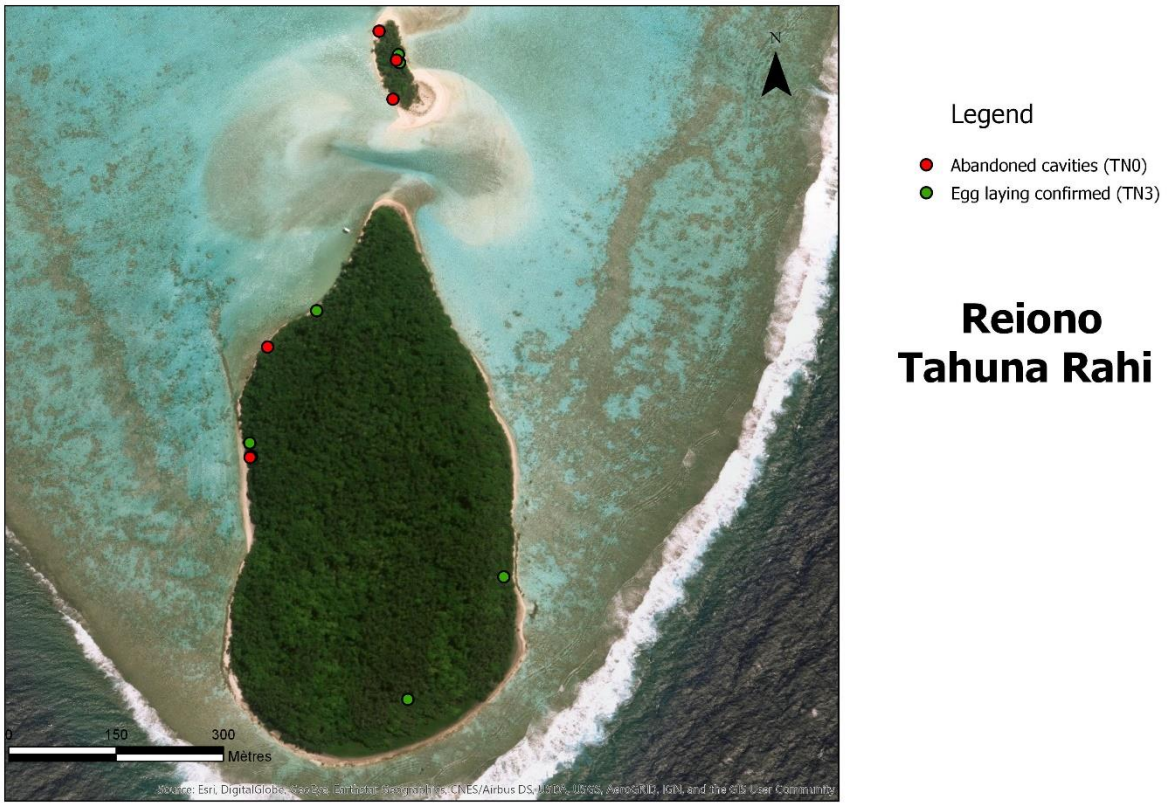


Figure 12 : Cartography of green sea turtle nesting events on Reiono et Tahuna Rahi

- **RIMATU'U**

2 nesting events took place on the Rimatu'u, with 1 egg-laying confirmed (TN3) and 1 unfinished nest digging attempt (TN0) (Tableau 8, Figure 13).

Tableau 6: Netsing events' summary on Rimatu'u

	TN3	TN2	TN1	TN0	T	TOTAL
NUMBER OF TRACKS	1	0	0	1	0	2
PERCENTAGE	50%	0%	0%	50%	0%	100%

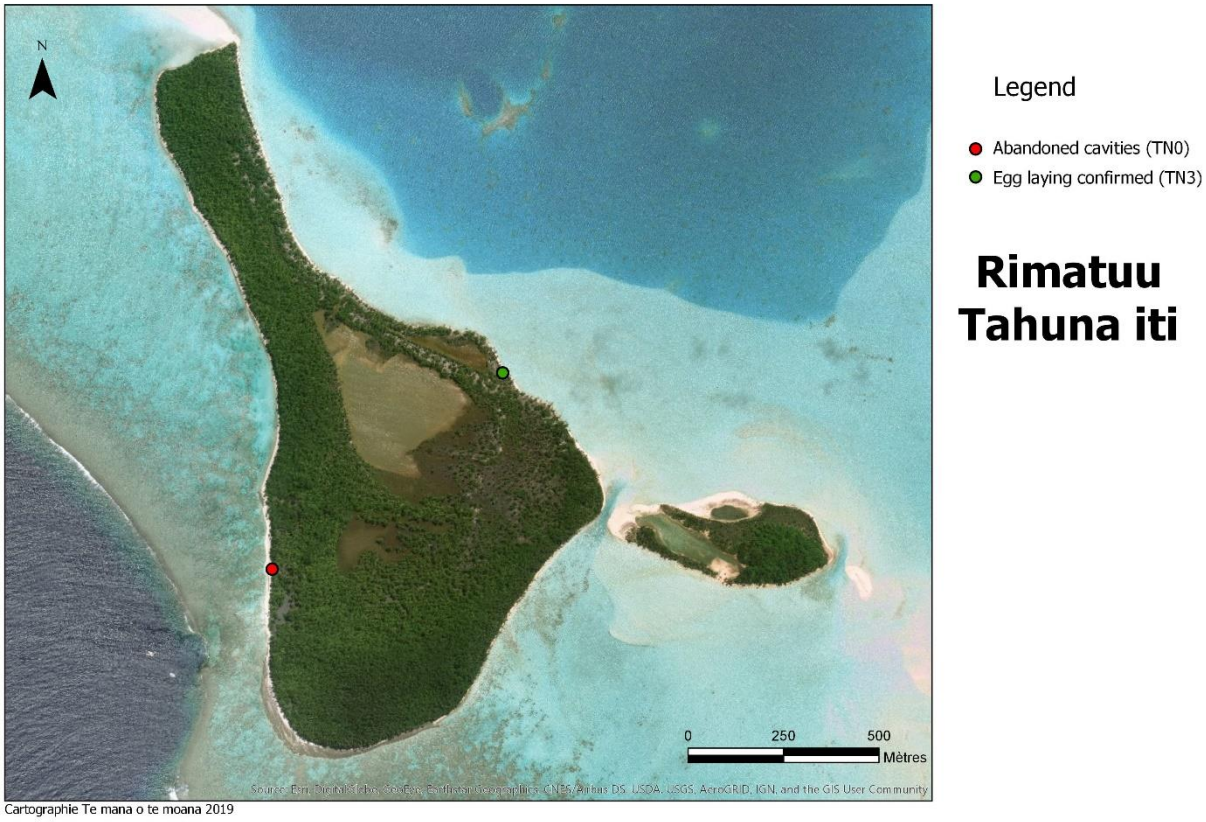


Figure 13: Cartography of green sea turtle egg-laying events on Rimatu'u et Tahuna iti

Key numbers :

- **190 nesting events** were recorder, corresponding to **47 % egg laying** and **53 % attempts**
- The nesting peack occurs in **December and January**
- Major nesting areas are located on the **Tiaraunu and Horoatera**

3. Females

3.1. Observations et identifications

During the 2018-2019 season, **26 female observations** occurred at night (13% of all recorded nesting events), 10 took place on Tiaraunu, 7 on Onetahi and 6 on Honuea and 3 on Horoatera.

Thanks to the Capture-Mark-Recapture method, **11 nesting females were identified**: 5 on Tiaraunu, 4 on Onetahi and 2 on Horoatera. Each individual's head profiles were photographed and tags (small Monel model of the DIREN,) were set on the front flippers. Genetic samples were collected from 9 females.

3.2. Nesting parameters

The average length of the shell is **100,6±5,0 cm** for an average width of **90,2±4,5cm.**

Before laying eggs, the female does on average **1.8 attempts.** On a sample of 453 nests, the minimum value observed equalled to 1 attempt and the maximum value to 5 (sample of 89 nest).

Upon the first ascension, the laying is not necessarily successful. Some females get back to the lagoon and come back to the beach in the following days**.**

The egg-laying interval lasts an average of 13 days and made an average of 6 nests (Touron et al., 2018).

The egg-laying time period, that is to say the time between the first and the last contact, was at mawimum 73 days, around 2 months and a half.

Fidelity to nesting sites is variable. Some green sea turtles could travel several kilometers between their differents nests. This season, **2 females were seen in the act of laying eggs on 2 different *motu*** (Onetahi and Honuea).

Key numbers :

- **26 female observations** were realised
- **11 different females** were identified
- Females can lay eggs on **different motu**

4. Nests and hatchlings

4.1. Nests

- **Depth**

The maximum depth of nests (in other words the deepest emplacement of egg shells) is about 54,85±8,2cm. On a sample of 82 nests, the extreme values of this variable fluctuate from 31 cm to 82 cm.

- **Number of eggs and hatching success**

The nests contained an average of 76,5±18,9 **eggs**. The minimum value observed is 44 eggs and the maximum value 137 eggs.

The average number of hatched eggs is 72±8,2 eggs/nest. Among the unhatched eggs featured an average of 0.2±0.1 infertile eggs, 6±5.1 non-fertilised eggs and 3±2.9 dead embryos.

The natural hatching success rate is 94%.

Field teams counted a total of **6 432 eggs on the entire atoll**, **of which 5 767 were empty shells**, in other words hatched eggs.

- **Incubation period**

The nesting and hatching estimated dates allow to determine the incubation time period with enough accuracy. The **average time of incubation was 60,7**±3,64 days, **the minimum being 53 days and the maximum 75 days**

- **Relocated nests**

This season, some nests had to be relocated due to their dangerous emplacements, which entailed high flood risks. In total, **2 nests were relocated**. (Tableau 10). This relocations were realized only when the nests where located in high flood risk areas.

A few nests were flooded on the Horoatera *motu*. Field teams discovered this when excavating the nests after the hatching phase.

Tableau 7: Paramètres des relocalisations effectuées durant la saison 2018-2019

Motu	Nest ID		Number of eggs	Hatching success	Relocation parameters	Comments
Onetahi	One 7	87	6	7%	3j after egg laying	Nest flooded
Onetahi	0ne 14	74	72	97%	< 3h after egg laying	-

Key numbers :

- Sea turtles dig nests **54.8 cm deep on average**
- They layed around **76 eggs per nest**
- **6 432 eggs** were counted, included **5 767 hatched**
- Hatching succes is around **94%**

4.2. Hatchlings

- **Hatchlings observed at the surface**

660 live hatchlings were observed at the surface, the main part of which was observed live on Onetahi. A few emerging turtles were observed on a deferred basis on Tiaraunu, thanks to trapping cameras.

- **Hatchlings stuck in the nest**

During the excavation of the nests, despite the fact that all eggs had hatched, **176 live hatchlings were found stuck in the nest** due to mechanical obstacles (root, coral…), or in a weakened or advanced dehydrated state with low chances of ever succeeding at getting out of the nest. Except for a few, all emerging turtles were saved and released in the lagoon. When turtles were found unable to swim well enough to reach the coral reef, they were brought to the laboratory of the Tetiaroa Society, in order to observe whether or not they would be able to recover. Those bearing signs of a worsening of their health condition were transferred to the Moorea care centre, to receive medical assistance before releasing them in the ocean. Out of 176 emerging turtles, 2 were taken to the Moorea care center.

- **Embryos and hatchlings featuring anomalies**

During the nest excavation phase, **243 dead embryos** were found, some of which featured strong anomalies, such as malformations or pigmentary deficits (albinism). In total, field team discovered 2 “albino”, 2 twin embryos, 2 two-headed embryos and 1 embryos with a shell curved in reverse. 60 genetic samples were taken from emerging turtles and embryos.

Key numbers :

- **660 live hatchlings** were observed **at the surface**
- **176 live hatchlings** were found **stuck in their nest**
- Various anomalies were observed on dead embryos: « Albino », two head, twins’ embryos…

5. Additional scientific studies

- **Thermologger**

Since the nesting season 2011-2012, the association Te mana o te moana, in partnership with Doctors Jacques-Olivier Laloé et Jonathan Monsinjon, studies the beaches tempertaures on Tetiaroa atoll nesting site. Thermologgers are regularly deployed inside incubation chambers, and also in "nest control".

During the 2018-2019 season, 8 loggers were inserted in 19 "real nests": 3 on Onetahi, 3 on Honuea and 2 on Tiaraunu.

Data collected from the temperature probes is currently being analysed. The information, which will arise from this data, will contribute to the development of a vast research program focusing on the long-term evolution of sand temperatures, in the context of climatic change.

Prédation

During the 2017-2018 nesting season, turtle nests were monitored using motion-triggered cameras resulting in direct evidence of repeated predation on green sea turtle hatchlings by ship rats (Gronwald et *al*., 2019). The observed behaviour indicate that green sea turtle hatchlings are a familiar food source

This season, 5 nests were equipped with cameras. The videos shown an important nests occupancy, and for 3 of them, 1 or several rat predations were recorded.

Datas collected will be used in a general research program on the impact of rat predation on green sea turtle hatchlings, and at the end, it will provide further scientific evidence for the necessity of rat management in turtle conservation.

- **Tide gauge and GPS system**

To improve the collection of satellite data, but also to know how the lagoon level is evolving, a differential GPS system (DGPS), as well as a tide gauge, were set up on the Tetiaroa atoll. The installation of the equipment was realised thanks to the collaboration of TMOTM and the Dutch company Van Oord, specialised in marine engineering. Their cutting-edge technology enabled the association's field teams to better evaluate risks related to rising waters and hence immediately adapt its conservation efforts (nest relocation…).

Discussion & Conclusion

2018-2019 was a season with few nesting events. These low figures support the hypothesis that a 3-year nesting cycle occurs. This hypothesis can be confirmed only when a female will be identified from one season to the next either through the tag, the photo identification or the genetic sample proofreading. For this, monitoring on the Tetiaroa Atoll should be maintained, with a sampling effort as intense as the last 3 years.

During the season, 11 different females were identified. Our field teams could not be present on various *motu* during the night time, the population of adult females on the atoll has been estimated between 20 and 30 individuals.

As in previous seasons, during nest excavations we found 76 eggs on average, which is a low number. Elsewhere worldwide, Green sea turtles laid an average of one hundred eggs per nest (Waqas et al, 2011; Hamann et al, 2006; Aureggi, 2001). In some regions, the average is even higher, like in the case of the Tromelin and Glorioso Islands, where an average of respectively 136 and 135 eggs were laid with a maximum value of 191 (Vergonzanne et al., 1976). Even though the number of eggs produced is relatively low in comparison with the rest of the world, Tetiaroa atoll has a very high hatching success rate, being superior to 90%. Numerous studies have recorded lower hatching success rates, for example 59% at Melbourne Beach in 1985 (Ehrhart et al., 1987), 80% on Surprise Island (Caut et al., 2007) and in 2007, during a mission

at Tikehau in Polynesia, an average of only 51 to 77% (Albar, 2007). Tetiaroas Green sea turtle population seems to adapt.

This year, we estimate that more than 6 400 hatchlings were born on the Tetiaroa atoll. This result, based on the number of hatched eggs, does not take into account the actual success rate of emerging turtles, given by the number of live emerging turtles divided by the total number of hatched eggs. The reason is that the latter was mainly impacted by ground predation (Ehrhart, 1987). On Tetiaroa, it is not easy to observe and quantify the impact of predation on emerging success. In fact, it is frequent for predators to extract emerging turtles from their nest before eating them (Dodd, 1988, Ali et al., 2002). This behaviour, common to crabs and other crustaceans, is also common to rats. Despite the fact that in the past, rat predation was considered negligible, when it came to emerging sea turtles (Vergonzanne et al, 1976), it is now considerable, reaching up to 45% of their diet (Caut et al., 2007). To this day, when monitoring green sea turtle egg-laying sites, this topic is not often taken into consideration. This year, thanks to the setting up of infrared video cameras to watch specific nests on the Tiaraunu *motu*, we could prove the presence of recurring black rat predation (*Rattus rattus*) on emerging turtles. The system of video cameras is an efficient means to observe this kind of predation. It has enabled us to take the decision of orienting our future efforts towards a better evaluation of the various impacts of predators on emerging turtles in the green sea turtle conservation program of Tetiaroa, and more specifically the impact of rats. A program of rat-disinfestation on one of the *motu* could emerge from this, with the support of the Tetiaroa Society.

Putting predation aside, the emerging success could be compromised by mechanical obstacles located in the nests, such as roots and stones, preventing the emerging turtles to get out of their nest. This year, during the nest excavation, 873 emerging turtles were found stuck in their nests by field teams of the Te mana o te moana association, the majority of which were saved in time and were immediately let go of, so that they could get to the ocean. Results point to the fact that excavating the nests, as fast as possible after the hatching phase, has highly contributed to conservation. As a matter of fact, it enabled nature to play its role in letting successful emerging turtles follow their path, but also enabled the emerging turtles, which encountered difficulties, to have a chance at life, by helping them just before they reached a state of advanced dehydration and the exhaustion of vitelline reserves.

Perspectives

Nesting monitoring on the Tetiaroa atoll needs to continue in order to keep acquiring data regarding this emblematic species. In fact, 10 years of monitoring has brought us answers concerning the phenology of egg-laying events, as well as nest, track, emerging turtle and adult female characteristics. In the meantime, the acquisition of valuable information regarding temperatures, genetics and satellites is starting to take shape. Over the years, the accumulated data acquired through monitoring could very well increase our scientific knowledge of Tetiaroa's green sea turtles and thus, help us protect the species in French Polynesia on a wider scale.

To do so, leading targeted studies focusing on key elements of the species' life cycle would be essential. The priority projects would be the following:

- **Marine monitoring**

Monitoring by using the manta-tow method, adapted by the teams of Te mana o te moana, has already proved its worth in the domain of sea turtle research (Petit and Gaspar, 2011). This method enables to cover a wide distance over a short amount of time and hence, record a great number of individuals, during several seasonal around the same islands.

The execution of numerous follow-ups at sea, during the entire egg-laying season, would allow the acquisition of new information regarding Tetiaroa's adult green sea turtles, and especially adult breeding males, the latter which at this stage are not well known. Also, this kind of monitoring would permit to correlate the data discovered on the ground with the data at sea.

- **Males migration**

Further pursuing the objective of getting to know more about breeding males, it would be interesting to equip one or more of them with a transmitting satellite. In fact, setting up satellites on sea turtles is a scientific tool enabling to follow their movements and better understand the population's distribution and migration. On Tetiaroa, laying females' migratory journey between the reproduction area and the feeding area is well known. However, the breeding male's journey and its comings and goings during the breeding season, whether it be in the surroundings of the atoll or pretty much anywhere, remain a mystery.

- **Sex-ratio and pivotal temperature**

In a context of climatic change, it becomes crucial to know the pivotal temperature influencing gender determination of green sea turtles on Tetiaroa. The latter has already been determined on many egg-laying sites and we know that there exist big differences from one site to the next (Refsnider, J.M., and Janzen, F.J., 2016). Studying the gender of emerging sea turtles does not require their killing anymore, thanks to new methods arisen in the 2000s, which have enabled to conduct research without hindering the species' conservation (Jensen et *al*., 2018).

Finding out the pivotal temperature on Tetiaroa's egg-laying site will finally allow us to give an accurate estimate of the *male/female* proportion of new-borns in the coming years. This also applies to all nests observed in previous years, wherein field teams inserted temperature probes (67 nests observed since 2011). From a conservation's perspective, this is an important matter. Australian researchers published their results in 2018 (Jensen et *al*., 2018), showing that egg-laying sites north of the great coral reef produced more than **99.1%** of females - a change observed in the last two decades. Such a high proportion presents a definite risk for the viability of the green turtle species.

- **Impact of predation on hacthlings**

Monitoring the impacts of predation on all *motu* of the Tetiaroa atoll, especially Tiaraunu and Horoatera, appears to be paramount. This does not include the Onetahi *motu*, where emerging turtles are protected and where while being monitored, 100 % of the turtles with sufficient energy get to the lagoon with no risk of predation. This season, footage filmed by the infrared video cameras confirmed that the *Rattus rattus* rat is a definite predator for emerging turtles

right from the moment they hatch. It has become highly necessary to evaluate their impact on the number of emerging turtles nested on the atoll, in order to determine the degree of emergency regarding the setting up of nest protection measures, or if need be, rat eradication measures. Presently, these measures seem to be the ones that would have the highest impact in terms of conservation and could, in addition to positive actions of protection performed on laying females, have the most crucial impact on emerging turtles and their survival rate on the beach before getting to the lagoon.

All these conservation actions will have immediate or long-term fundamental consequences on the conservation and survival of the green sea turtle species on Tetiaroa atoll.

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