Photo-identification Characterization of the Humpback Whale Population (*Megaptera novaeangliae)* around Tubuai Island in the Austral Islands and Influence of Temperature on its Temporal Distribution in 2019 and 2020[1]

Léa Picon[2]

Abstract: The humpback whale (*Megaptera novaeanglaie*) is a migratory cetacean species, which comes to Polynesia each winter to carry out part of its life cycle. Its conservation requires a knowledge of the species, its habitat, and the way it occupies it. Studying humpback whale demography is crucial to understand the structure and the dynamics of the population frequenting South Pacific waters, and facing multiple and increasing threats. The methods used here are based on photo-identification, to evaluate some characteristics of the population, whose individuals are identified thanks to their fluke. The results suggests that the island of Tubuai is a stopover on the migratory route of humpback whales, because although groupings probably associated with reproductive behaviors were noted, few mother-calf pairs were recorded. Perhaps because this area does not gather optimal environmental conditions for calving. We investigated the influence of temperature on the temporal distribution of individuals. Results showed no significant effect of temperature on the presence of individuals, although the literature has already shown a correlation between these two elements. It would therefore be interesting to increase and homogenize the sampling effort in terms of space and time in this archipelago, with several study sites over several years, in order to look for a link between environmental factors and habitat use by humpback whales.

Characterized by its geographical isolation, its geomorphological and climatic characteristics, French Polynesia harbors a very particular biodiversity, especially marine. Thus, among the 87 species of cetaceans recorded in the world, scientists estimate that nearly 16 frequent polynesian waters (Gannier 1999, 2000, 2002, Laran et al. 2016, Pool et al. 2013a, b). However, some authors agree that more than 20 cetacean species may frequent French Polynesian waters, at least seasonally (Reeves et al. 1999). In the Austral Islands, 10 cetacean species have been reported, although these tend to become scarcer as the waters of the Polynesian EEZ cool (Laran et al. 2017) : Humpback whale (*Megaptera novaeangliae*), large sperm whale (*Physeter macrocephalus*), dwarf sperm whale (*Kogia sima*), Cuvier's beaked whale (*Ziphius cavirostris*), Blainville's beaked whale (*Mesoplodon densirostris*), orca (*Orcinus orca*), short-finned pilot whale (*Globicephala macrorhynchus*), peponocephalus (*Peponocephala electra*), bottlenose dolphin (*Steno bredanensis*) and spinner dolphin (*Stenella longirostris)* (Van Canneyt et al. 2011). The presence of humpback whales (*Megaptera novaelangliae*) was first reported in 1993 in four of the French Polynesian archipelagos (Poole 2002, 2006). As with many mysticete species, there is a disparity between breeding and feeding areas. Thus, both males and females undertake an annual seasonal migration of nearly 6,000 km to link the breeding and feeding areas. The species forms several distinct populations in the two hemispheres of the globe, between which exchanges are limited, and there are seven breeding areas in the tropical Pacific (stocks A to G) and six Antarctic polar feeding areas (stocks I to VI) in the southern hemisphere. Each year, from July to November, French Polynesia is visited by the humpback whale population belonging to the F2 stock, located north of the VI feeding area, which demonstrates a limited demographic exchange and a high degree

1 Manuscript accepted 02 June 2021
2 Université de la Polynésie Française, BP 65 70, Faaa 98702, French Polynesia (email : leapicon@gmail.com ; phone : +689 89 52 52 17)

of fidelity to the breeding areas (Olavarría et al. 2007).

Emblematic species, these animals are classified as category B species by the local environmental code, and the Polynesian EEZ became in 2002 one of the largest marine mammal sanctuaries in the world. However, its management is based on a still too limited knowledge of the cetacean populations of Polynesia. Indeed, the most recent studies including French Polynesia were conducted at the South Pacific scale (Albertson et al. 2015, 2018, Carroll et al. 2015, Constantine et al. 2012, Garland et al. 2015, Garrigue et al. 2020, Schmitt et al. 2014), and data for the Polynesian sanctuary have been spatially and temporally incomplete since 2002 (Carroll et al. 2015, Laran et al. 2016, Poole 2002, 2006, Poole et al. 2013a, b, 2014). Gaps remain in terms of the demographic structure and migratory dynamics of populations frequenting Polynesian waters. Although population size estimates have been made locally (Poole 2002, 2013a, b, 2014), these data lack spatial and temporal regularity and need to be centralized. This lack of knowledge compared to the rest of the world can be explained by technological barriers: despite the fact that humpback whales are mostly found (83%) less than 2 km from the coast (Gannier 2004), the megapteres of French Polynesia are distributed in an immense maritime space of five million km², which makes their study all the more complex. The last census data date back to 2012 with an estimate of 440 individuals based on photo-identification and 934 individuals based on genetic inputs (Constantine et al. 2012). This was then a study of the entire South Pacific. The last study devoted to a census including the Austral Islands was in 2006 (Poole 2006) and focused only on the island of Rurutu, and the most recent including a larger sampling effort was in 2001 (Bourreau and Gannier 2001). The most recent humpback whale survey focusing on the Australs was in 2014 (Poole et al. 2014).

It was therefore deemed relevant to focus on the humpback whale population frequenting the Austral Islands, in order to propose a preliminary study for the characterization of the population in the entire Polynesian EEZ, planned by the Oceania Association from 2021. The available data directed this study towards the island of Tubuai, where the sampling effort was the most important and regular over the last two years. Until now, the most used method in French Polynesia for the study of humpback whales (*Megaptera novaeangliae*) is based on photo-identification. This method is based on the variable natural pigmentation patterns and scar marks on the tail fin of individuals (Lillie 1915, Katona et al. 1979). Initiated by researchers in the 1970s (Mizroch et al. 1990, Katona et al. 1979), this technique has since been widely used on humpback whale populations worldwide to determine many aspects of their biology, ecology and behavior. Finally, it was considered interesting to contrast biological and physical data in order to establish a first observation on the possible influence of environmental factors on the demographic dynamics of individuals. Temperature is the dimension that was chosen here, with respect to what has already been found in the South Pacific (Derville et al. 2019), and the data at our disposal.

MATERIAL AND METHODS

1. Studied area

Tubuai (23° 27' S and 149° 30' W) is the largest island of the Australs archipelago, in French Polynesia, about 620 km south of Moorea. With its 8 km length and 5.5 km width, its surface area is 45 km². It is a high island made up of two ancient volcanic mountains, the highest of which reaches an altitude of 422 m (Mount Taita'a), separated by the Huahine Pass, and at the foot of which is a coastal plain dotted with floodplains. The coast is formed by a raised reef platform, and the island is surrounded by a shallow lagoon (6 m on average) 3 km wide, which makes it the largest lagoon of the Austral Islands with its 85 km² surface. The lagoon is delimited by a reef barrier which is pierced by a large channel and two smaller channels (Poole 2002). The waters are constantly renewed thanks to a rather strong and constant marine current. This contributes, among other things, to the preservation of the ocean floor and coral organisms that do not suffer from bleaching as in other islands, the freshness of the waters and the very low pollution explaining this effect. The island's climate is the coolest in French Polynesia, with an annual average temperature of between 21 °C and 26 °C (https://meteo.pf/fr), with the water temperature in the lagoon at 26 °C in summer and 23 °C in winter (https://www.ncdc.noaa.gov/). In terms of geomorphology, the Austral archipelago offers a great diversity, from recent volcanic islands without lagoon (Rapa and Marotiri islets), to islands with a large lagoon (Tubuai and Raivavae), to an atoll profile (Maria), through islands raised by a second phase of volcanic activity (Rurutu and Rimatara). These extremely varied geomorphological characteristics and the particular climate of the Austral Islands, between tropical and temperate zones, have given these islands particular habitats and marine ecosystems, distinguishing them from the other archipelagos of French Polynesia, and sometimes presenting similarities with the Cook Islands, Pitcairn and the Gambier.

2. Data collection

2.1. Photographic data

Photographic data were collected by an experienced independent observer based in Tubuai and manager of the diving center "Tubuai plongée", which conducts "whale watching trips" during the season. Established on the island of Tubuai in the Austral Islands since 2018, this center was the first whale watching provider on the island, now accompanied by a second provider that started its activities in 2020 but does not offer launching with the animals.

The data used for this study are from observations made in 2019 and 2020. The survey effort differs slightly from year to year. In 2019, approximately 30 field days were spent in August, September and October, with between four and eight hours of observation per day. In 2020, over these same three months of observation, between 45 and 50 days were spent prospecting with outings lasting between 4 and 8 hours, except for the fortnight that joins the end of September to the beginning of October, where days of 10 hours of observation were conducted. In terms of area covered, it is located in the band between 50 and 2,000 m from the reef, with a survey that was done on average at 1 km from the reef off the island [Figure 1]. As far as field data collection is concerned, an observation form transmitted by the DIREN was completed daily in 2019, and for the year 2020 only photo and video data were reported (Macri Antoine, pers.comm., February 2021).

The equipment used was a 22-foot aluminum boat with a maximum capacity of 10 people and a 200 horsepower outboard motor. The equipment used for photo-identification is a Nikon D5200 camera with an 18/250 mm lens, a pair of binoculars used for prospecting and verification, and a Go pro camera (Hero 7 in 2019 and Hero 8 in 2020) for taking out-of-water and underwater videos. In addition, an Aquarian hydrophone H2A with 10m of cable was deployed systematically in 2020 as a complementary survey tool.

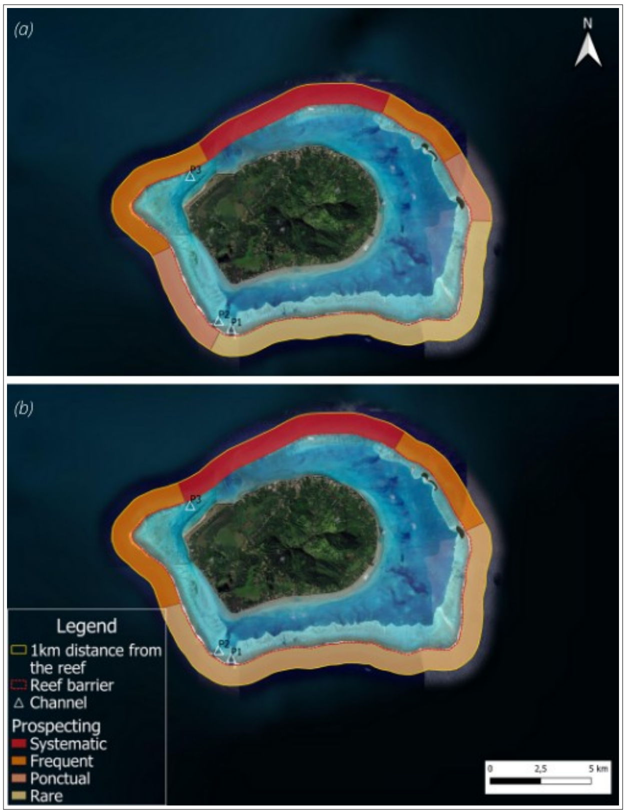

Figure 1. *Map of prospected areas around Tubuai in 2019 (a) and 2020 (b)*
(Channels : P1=Avarahi ; P2=Avaiti ; P3=Anamoana ; Prospecting :Frequent=3 out of 4 field trips ; Ponctual=1 out of 4 field trips ; Rare=1 out of 8 field trips)
(Map created the free and open source Qgis 3.16.0)

2.2. Temperature data

The temperature data come from the CRIOBE observatory database. An agreement was signed with the center for the use of its data, collected in April 2021 on the probe deployed in Tubuai (Chancerelle Yannick, pers.comm., March 2021). The thermograph, type SBE56, is located at -14 meters depth on the outer slope of Tubuai reef, at GPS coordinates 23°20.660'S/149°24.220'W.

3. Data processing

3.1. Photo-identification

The photo-identification technique is based on key features of cetacean fins. These include, for the humpback whale, the measurement of key tail fin features, including fin shape, distribution of black and white pigments in different regions of the tail fin, and other distinguishing features that allow identification (Kniest et al. 2009). The characteristics used to identify individuals are all observable on the animal when it is at the surface: singularity of the caudal fin, notches in the fin, scars or pigmentation on the top of the body, etc., which may be due to the natural life cycle of the animal but also to anthropogenic activities. In French Polynesia, since launching in the presence of one or more humpback whales is authorized, the acquisition of underwater images allows us to enrich the photographic databases. The first step is to obtain photos of the animals, mostly from a boat, and then to sort them to determine if they contain details that can be used to identify the individual. The next step is to describe precisely each individual photographed: shape and pigmentation of the tail, number, size and position of the scars, shape of the fin, notches, pigmentation, etc. This step of description is reproduced for each photograph comprising the individual, and constitutes a profile of the animal. All the profiles form a photo-identification catalog. Subsequently, when new photos of cetaceans are taken at sea, they can be compared to the photos in the catalog to try to recognize previously identified individuals: this is the very principle of the photo-identification method.

The photos transmitted by the observer were processed according to the photo-identification protocol developed with the scientific committee of the association. The raw data was organized in files by date of exit. For each date, the processing consisted first of the visualization of all the photos and a first sorting to select only the photos likely to be used for identification purposes. Then, sub-folders by visually differentiated individuals ("Ind.1", "Ind.2"...) were created, duplicating and cross-referencing if necessary the photos with the presence of groups and/or mother/baby duets from each other after this first sorting. For each sub-file, the most qualitative photo and on which appears the most distinctly the bottom of the caudal fin was selected. The manual work of identification followed: visual determination of the similarities and differences between the photo of interest to identify and the photos of the Oceania catalog (approximately 300), which lists all the individuals already identified by the association in French Polynesia. For that, it was possible to help on the one hand with the type of caudal (from C1 to C9) [Figure 2], and on the other hand with the pigmentation, the cut of the trailing edge, particular marks (scars, holes, localized depigmentation...) [Figure 3]. Two cases were then encountered: either a resighting, *i.e.* a strong visual resemblance with an individual of the catalog, or the identification of a new individual, not recognized among those of the Oceania catalog.

Whatever the case, the next step was to submit the photo of the individual of interest to automatic recognition software: these allow for optimization of matching processes, with cetacean features of interest usually obtained by applying standard filters to the input image, based on experimentation and experience brought by manual individual recognition. The software selected for this study is Happy Whale, it is a participatory science tool, created in 2015 by Ted Cheeseman and Ken Southerland. Its use has demonstrated a reduction in image processing time by 98% and a decrease in error rate from 6-9% to 1-3% (Cheeseman et al. 2017). As the algorithm is not accessible, results are sent as a notification: the first informs that the output has been successfully recorded on the software, and the second that the observed individual is a resighting. At present, 355,276 observations have been submitted to the software, and 56,168 individuals identified, which makes this platform the one that records the most individuals among its competitors (https://happywhale.com/). Indeed, other automatic recognition computer platforms exist, however they are either no longer updated (*e.g.* Flukematcher, Kniest et al. 2009) or under development (*e.g.* Flukebook, Blount et al. 2019). For the present study, it was chosen to carry out a manual identification before a computerized identification, for reasons of processing time and data organization: indeed, although the software allows a faster identification, especially as the catalog is enriched in individuals, the photos are not always processed immediately, and only the resightings are subject to a notification on the software. Thus, if there was no resighting with the database of the software, the photo is not classified as a new individual, and the Oceania association loses data. The methodology was therefore to submit the photo of the individual of interest to the Happy Whale platform, accompanied by information on the capture (date, time, place). The objective of this submission was to provide a second verification by the algorithm, and an integration of the Oceania data in the Happy Whale catalog, with the aim of receiving later a confirmation / correction of the identification or resighting.

Finally, the last step consisted in completing two spreadsheets internally. The first one lists all the individuals of the Oceania catalog with their dates and places of first observation / possible resightings. The second one, used in the rest of this study for the statistical treatments, lists each observation in rows and includes in columns: place (island, associated commune, GPS coordinates), date, time, exit number, source of the photo (photographer, name of the boat), number of the individual (in the form "Mn" + number), sex if known, status if known, number of individuals present on this observation, presence of newborns.

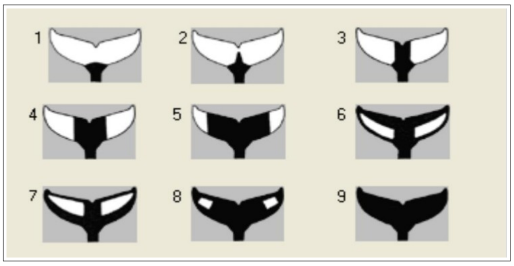

Figure 2. *Classification of tail types according to the 9-class system (https://www.globice.org/)*

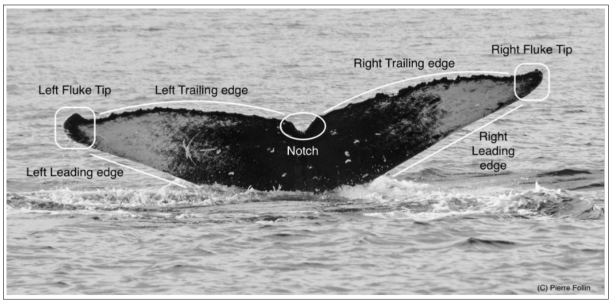

Figure 3. *Illustration of the different parts of the tail (https://www.asso-oceania.com/, Pierre Follin (Photographer))*

3.2. Statistics

Statistical processing of the data from photo-identification was then performed using R studio software version 1.2.5001 (RStudio Team, 2015). For demographic analysis, the total count as well as the sex ratio of the dataset were extracted by manipulation of the data table in R, with a graphical representation aided by the "ggplot2" package. A χ^2 test was performed on the 2019 and 2020 dataset to extract the proportion of individuals classified as "baby" and the proportion of individuals classified as "resighting". The study of the groups did not require statistical testing as it is purely qualitative. The analysis of the temperature data required a linear regression with the quasi-poisson distribution as the regression assumptions were verified but the over-dispersion of the residuals did not allow the application of a poisson regression (Qqplot, dispersion and distribution of residuals).

RESULTS

1. Demography and habitat

1.1. Study of identified individuals

Of the total number of identified individuals, (n=156), 110 individuals correspond to the year 2019, with the season running from 2019.08.09 to 2019.10.08 (61 days), and 46 to the year 2020, with the season running from 2020.08.13 to 2020.10.27 (76 days). Of the total individuals identified, 93% are adults and 7% are infants [Figure 6]. The seasonal distribution of the number of individuals visually identifies August and September as months of highest abundance [Figure 4].

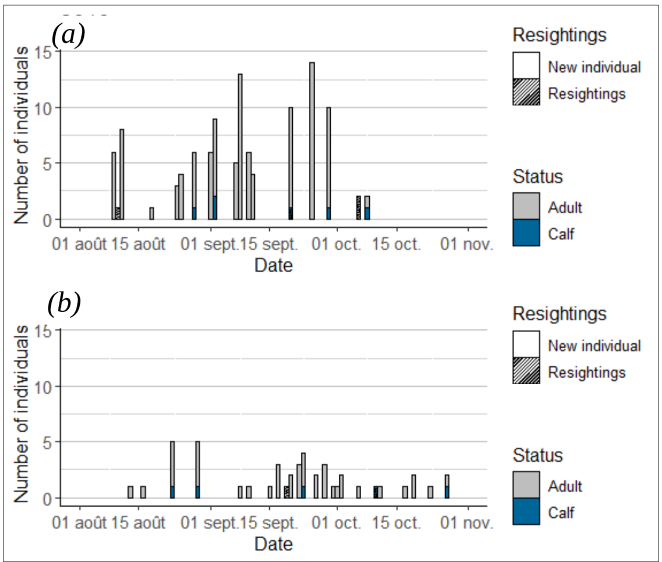

Figure 4. *Seasonal distribution of individuals in 2019 (a) and 2020 (b) according to their status and showing the resightings (only resighted individuals are hatched)*

1.2. Study of resightings and calf rate

In New Caledonia, the resighting rate during the same season varies between 15 and 50% depending on the year, with an average of about 25-30% (Garrigue et al. 2002, Garrigue Claire, pers. comm., 2021.05.10). The threshold for calculating the P-value was therefore set at 0.25. The X-squared proportion test (χ^2=5.3419; p-value<0.05) showed the resighting rate was significantly less than 25% in each of two years.

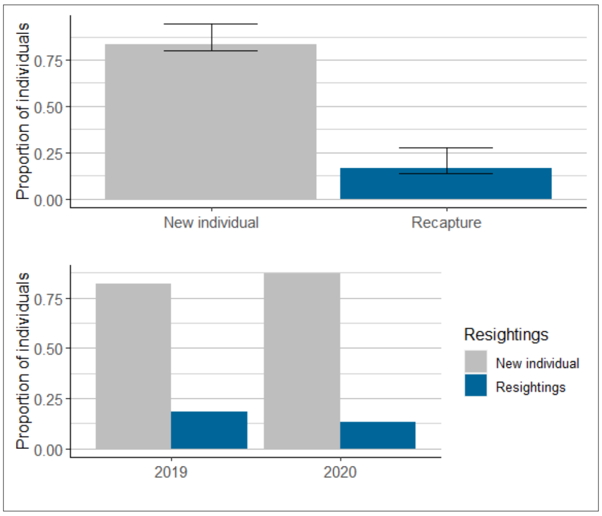

Figure 5. *Proportion of resightings in 2019 and 2020 with 95 % confidence interval*

According to the "sIM" model adopted by Chero et al. in a 2020 study, the average proportion of calves observed in the South Pacific is equal to 0.36. In this model, females are considered immature when first observed, unless they are nursing a calf (Chero et al. 2020, Barlow and Clapham 1997). The threshold for calculating the P-value was therefore set at 0.36. The X-squared proportion test (χ^2=55.492; p-value<0.05) showed the proportion of calves was significantly less than 36% in each of the two years.

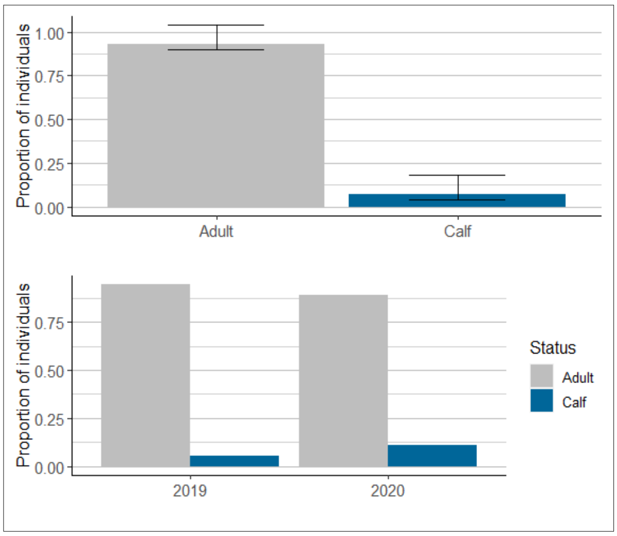

Figure 6. *Proportion of calves in 2019 and 2020 with 95 % confidence interval*

1.3. Study of groups

The study of the social structure of the observations made allows us to distinguish the number of individuals present by date and by observation [Figure 7]. From this figure, groups of individuals can be deduced. For the year 2019 (n=115), the beginning of the season is marked by the presence of groups ranging from 6 to 10 individuals, while the end of the season is rather characterized by smaller groups (one to five individuals). For the year 2020 (n=46), the same pattern is observed even if the values change quantitatively due to the total sample size: larger gatherings (three to five individuals) are observed at the beginning of the season compared to the end where solitary individuals are observed.

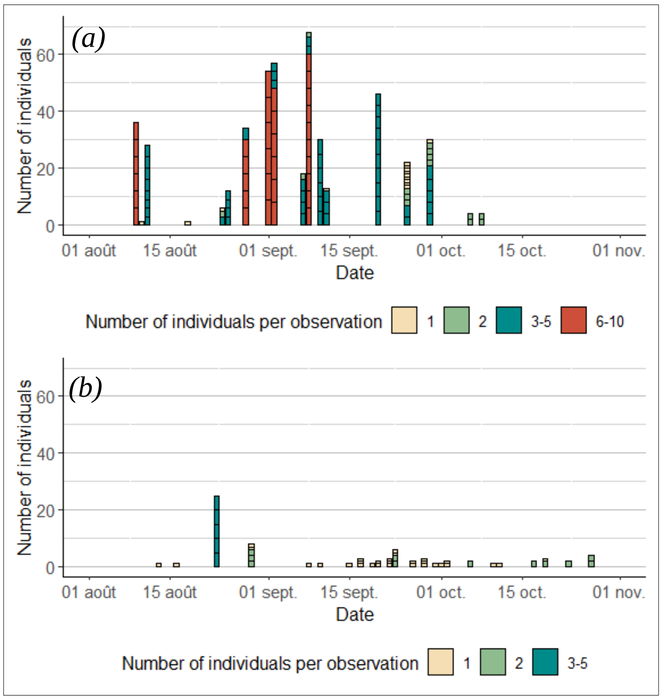

Figure 7. *Seasonal distribution of individuals in 2019 (a) and 2020 (b) according to the number of indiduals per observation and showing the constitution of the observations in groups*

2. Influence of temperature on the temporal distribution of individuals

Data from the CRIOBE observatory provided the water temperature profile at a depth of 10 m for the years 2019 and 2020 [Figure 8]. The calculated temperature averages over the observation days are 22.98 °C in 2019 and 23.04 °C in 2020.

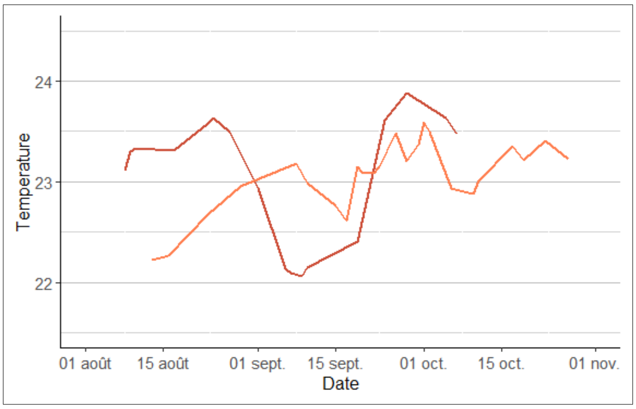

Figure 8. *Seasonal distribution of temperatures (in °C) in 2019 (a) and 2020 (b)*

A linear regression was performed (β=0.2326; $p>0.05$), the result of which was not significant [Figure 9]. Thus, the number of individuals identified is not positively correlated with water temperature in the first 10 meters of the water column.

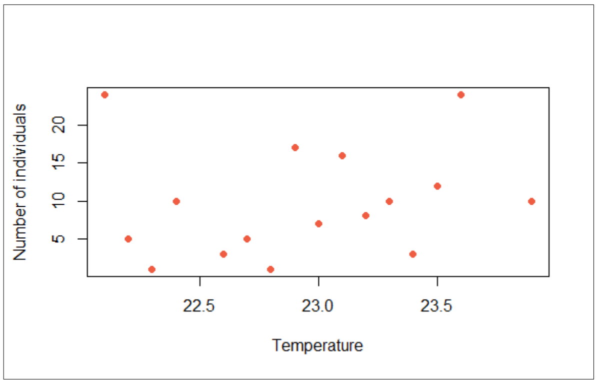

Figure 9. *Plot of the number of individuals according to the temperature (in °C)*

DISCUSSION

1. Limitations of the method

Photo-identification is a method that allows, to some extent, the study of the structure and dynamics of humpback whale populations. Indeed, this method has allowed to define and limit the stocks and sub-stocks of individuals in the breeding areas (Garrigue et al. 2007), as well as the feeding areas with which they are linked. It thus allows to study the size of a population in a given region, the rate of fidelity to certain regions due to the recurrence of observations, exchanges between regions, such as inter-island exchanges in

French Polynesia, but also the sex ratio or the proportion of juveniles within the population. The major advantages of photo-identification are the very long term monitoring of populations over time, which could allow multi-year studies and the identification of biological cycles for example. In addition, this method allows beyond the identification of individuals, the monitoring of their anatomy, through the evaluation of scars and other dermatological signs of the external health of the body: collisions with ships, entanglement in nets and fishing lines, etc.. (Barlow et al. 2011). Finally, the local context of French Polynesia, whose EEZ covers nearly five million km² of marine territories frequented by humpback whales, requires a multiplicity of observers in all the archipelagos frequented: Society, Australs, Tuamotus (Poole 2006). Participatory science is quite feasible and represents an asset in this method, which does not require the expertise that other methods require. However, photo-identification is not applicable to all species and requires a field effort that is quickly unattainable as we focus on estimating large populations with wide geographic distribution. Moreover, the assertion of the identity of an individual is sometimes limited with photography, hence the intervention of complementary methods such as genetics, which can provide certain information on the characteristics of the population. It is therefore important to consider this bias to the robustness of the dataset when studying it, before generalizing any statement to the population of interest.

There are other important biases to consider. One of the major biases of this study is that it refers to the number of individuals identified, and not to the number of individuals actually present at the time of the observation. Indeed, on certain observations where several individuals were present, it was not always possible to identify all of them, for reasons of quality of the photo, power of the lens, absence of photography of the caudal fin sometimes, etc. It is therefore not an estimation of the real size of the population, but more of its structure and its dynamics in time. Indeed, this work deals with temporality only, due to the lack of geographical data (no GPS coordinates taken by the observer, single parametric probe...). Another element that diminishes the scope of this study is the sampling effort, which differs from year to year, and only allows for inter-annual comparison to a certain extent. Finally, of the total individuals identified in years 2019 and 2020 (n=156), the sex of only 18.5% could be determined. This is a parameter that was therefore deliberately excluded from this study.

2. Demography and habitat

The study of the resighting rate for each year showed a lower rate than those observed in the South Pacific, in New Caledonia precisely. The hypothesis put forward here is that Tubuai would be located on the migratory route of the individuals, and would constitute a stopover before their ascent to even warmer waters, such as around the Leeward Islands. This would explain the low rate of intra-season resighting. To support this hypothesis, it is possible to look at the presence of calves, which at least testifies to the seasonal fidelity of pregnant mothers to their calving site. The study of the calf rate in each year showed a lower rate than those observed in the South Pacific. The whale population present in the Austral Islands in 2019 and 2020 was therefore probably moving to other lower latitudes, at least for the pregnant mothers that did not choose this archipelago to give birth. It is possible, however, that these same females may prefer to move farther offshore to breed and calve in deeper water and at a greater distance from shore (Trudelle et al. 2016).

If calving does not take place in the waters of the Australs, it is interesting to see if breeding behavior is still observed in this area. For this, a second hypothesis is put forward, according to which the presence of groups, testifying to interactions between adults, possibly linked to reproductive behavior. Indeed, the social organization of humpback whales is characterized by small, unstable groups, and even if there is no notable territoriality, more massive groupings are observed on feeding and breeding grounds (Clapham et al. 2009). Although the social behaviors associated with migration are less well described, it seems reasonable to assume that behaviors adopted on feeding and breeding grounds may be retained to some extent during migration. When migrating, whales swim primarily in small groups rather than individually, and, especially on the way back to the feeding grounds, continue to exhibit some of the behaviors characteristic of the breeding grounds (Valsecchi et al. 2002). However, if social organization exists, it is transient and probably based more on reciprocal altruism than kinship selection (Valsecchi et al. 2002). In the South Pacific, an increase in breeding groups has been observed in the months of September, with mother-whale duos but also companion groups (Garrigue 2001). The results of the present study seem to be consistent with the literature, with larger groups at the beginning of the season, reflecting interactions specific to the breeding areas, and more frequent observations of small groups at the end of the season, which may reflect individuals on the migratory route to high latitudes. However, the lack of information on sex makes the results difficult to interpret. Indeed, migrations are highly predictable in time and space, and it has been shown that within them, the different age, sex and breeding classes show a characteristic temporal segregation, and that the migratory schedules studied show consistency at the individual level as well (Craig et al. 2003, Burns et al. 2013). It would therefore be relevant to achieve sex assignment for the identified individuals in order to refine the results observed here.

The use of Tubuai waters by humpback whales is probably related to environmental factors that vary over the season and influence the distribution of individuals over time. Temperature is the physical factor that is studied here. The results of the present study did not show a significant relationship between the temporal distribution of individuals and water temperature in the top 10 meters of the water column. However, the literature reports that the average temperature of the South Pacific breeding area, which varies from 22.3 °C to 27.8 °C, would affect the predictability of reproduction due to its local variations. Indeed, temperature and its variability have been shown to affect the distribution of humpback whales on a small scale. For instance, their presence increased in waters with a low coefficient of variation of surface temperature, reflecting a preference for persistent temperature conditions over time in the southwest Pacific (Derville et al. 2019). Despite these results on the influence of surface water temperature, breeding habitat appears to be primarily determined by seafloor topography (Derville et al. 2019). Indeed, a recent study in New Caledonia showed that seamounts were staging and stopping points for humpback whales during the breeding season, as could be Mount McDonald east of the Australs EEZ, which would be an avenue to explore geographically, in order to better understand habitat use by individuals locally (Derville et al. 2020).

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