# FINAL REPORT PROGRAM LEFE

| Program LEFE/CYBER | Project Title: GUANACO<br>Guano influence on coral reef functioning | Years<br>2020-2021 |
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Participating Laboratories :
UMRs ENTROPIE, EIO, IMBE, LOCEAN, UNIMIB and Max Planck Institute for Chemistry

Other funding sources : EC2CO, IRD

*Context*

Seabirds, feeding exclusively at sea and breeding on islets, play an important ecological role in transferring nutrients between terrestrial and marine ecosystems. If nutrient enrichment of the coastal environment surrounding seabird islets has been recognized, few studies have been looking at the impacts of seabird-derived nutrients on coral reefs (Thibault et a. 2019).

*Objectives / scientific questions*

The GUANACO project had 3 objectives: 1) understand how nutrients from seabird guano are transferred to the reef, 2) evaluate if we can establish an historical record of seabird enrichment through the analysis of nitrogen isotopes in coral cores organic matrix and 3) study the impact of seabird-derived nutrients on coral physiology.

*Main results*

Obj. 1. We demonstrated, through the $\delta^{15}N$ analysis of nitrates and of their concentration (lens, offshore water and on the shore/wide gradient), the dominant role of the lens of water present under the island (Fig. 1). This brackish water lens acts as a powerful bioreactor, oxidizing 99% of the total dissolved nitrogen from seabirds into nitrate. The $\delta^{15}N$ of the nitrate-rich groundwater (13.47 ± 0.01‰) corresponds to the $\delta^{15}N$ of the guano, and is markedly different from both the surrounding ocean surface (6.00 ± 0.10‰), and the deeper water (6.90 ± 0.06‰). The lens then percolates into the reef approximately 25-50 m from shore and would account for over 80% of the nitrate pool. Infiltration of groundwater into the lagoon remains the dominant source of nitrogen within 100m of high tide, and is mainly controlled by the tidal regime (maximum percolation at low tide). Enrichment of the surrounding waters is therefore via the brackish water lens and not by direct input of guano when the seabirds return to the colony, nor by offshore inputs (Choisnard et al. To be submitted. See list of publications).

Obj. 2. Only two *Porites sp.* cores have been analyzed and partially (due to laboratory closure/COVID crisis). The observed record in the cores, however, very clearly demonstrates a difference (x2) in the $\delta^{15}N$ values of the coral organic matrix between the reference site (6‰) and the guano site (12‰) attesting the persistence of these nitrogen inputs from guano throughout the year (Fig. 1, 2). These observations also demonstrate that seabird-derived N is integrated into the coral organic matrix with very little fractionation ($\delta^{15}N$ values of the coral organic matrix close to those of the lens), allowing the impact of seabird-derived N sources to be tracked at a given study site. The difference in nitrogen recycling between sites appears to follow a yearly pattern, confirming that CS-$\delta^{15}N$ allows us to assess how these processes may have changed over long periods of time. Historical CS-$\delta^{15}N$ records could provide insight into changes in N inputs over time due to seabird abundance changes or natural climate or oceanographic forcing (paleoenvironmental proxy).

Obj. 3. We first demonstrated that coral nutrition was modulated (season, site and distance from the coastline) by the intensity of nitrogenous inputs from guano with more autotrophy (increased assimilation of inorganic matter through symbionts) in the presence of high amounts of nitrate (Thibault et al. 2022). We then demonstrated that nitrogen inputs from guano significantly boosted coral metabolism: Coral photosynthesis (in situ Diving PAM measurements and ex-situ experiments on the boat) was significantly higher at the guano site compared to the control site, as well as symbiont and chlorophyll density of *P. damicornis* branching corals. This confirms that nitrogenous discharges from seabirds promote the acquisition of inorganic nutrients by corals. Finally, analyses of cores of the massive coral *Porites sp*. revealed that calcification rates were increased twofold at the guano site (Thibault et al. to be submitted).

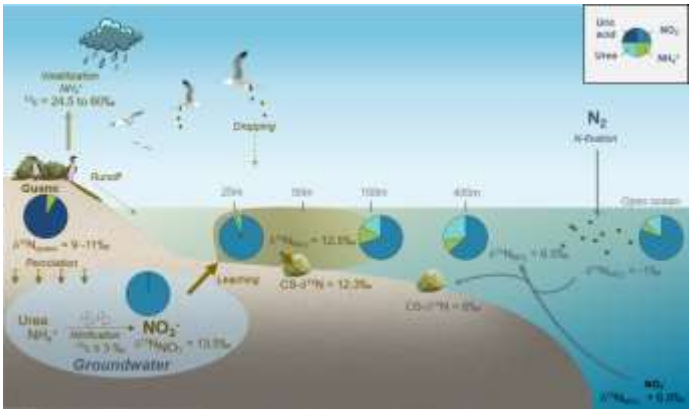


Fig. 1. Suggested distribution of N species and $\delta^{15}N$-$NO_3^-$ on the reef flat and $NO_3^-$ sources. Seabird-derived N is indicated by brown arrows while blue arrows account for oceanic inputs. As discussed in the text, seabird-derived N mostly percolates in the groundwater lens where it is transformed in $NO_3^-$ through nitrification. Leaching on the reef-flat induces inputs of enriched $\delta^{15}N$-$NO_3^-$ up to 100m from shore and seems to be consumed by corals. At locations exempt from seabird's influence, $NO_3^-$ is mainly supplied from N-fixation and the deep ocean. The light $\delta^{15}N$-$NO_3^-$ of these two sources is also recorded in CS- $\delta^{15}N$. The pie charts present the nutrient content at each site.

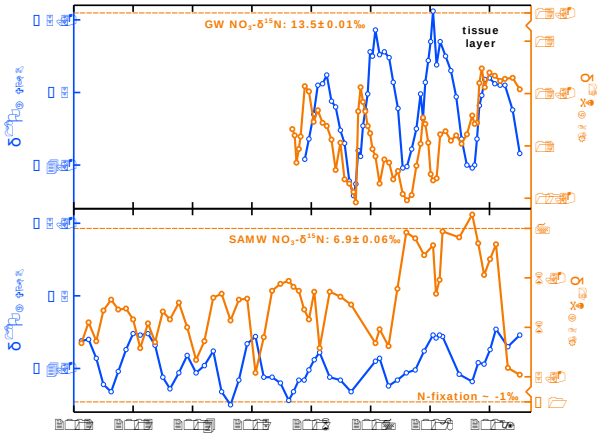


Fig. 2. Variation of coral skeleton CS-$\delta^{15}N$ (orange) and CS-$\delta^{18}O$ (blue) at the islet (upper panel) and control site (lower panel) over time. The grey band symbolizes the tissue layer of the coral. To unveil the spatio-temporal influence of different $NO_3^-$ sources on CS-$\delta^{15}N$, we plotted the $\delta^{15}N$-$NO_3^-$ of the possible N sources through orange dashed lines (Nitrogen fixation, offshore waters SAMW and GW: groundwater/brackish water lens).

*Future of the project :*

The GUANACO project has demonstrated that seabirds transfer nutrients from the ocean to their nesting sites via the brackish water lens present beneath the islets and boosting the physiology of adjacent reef-building corals. The link between seabird biomass and coral-available nitrogen, however, remains unclear. Our first measurements of $\delta^{15}N$ in the organic matrix of corals over only a few years have demonstrated the potential of these records to reconstruct nitrogen supply by seabirds over historical timescales. It is now essential to go back in time significantly to trace the fluctuations of seabird populations on a same site and the quantities of nutrients derived from guano. A PhD has just been funded in co-supervision with the Mack Planck Institute (sept. 2022/sept. 2025, and a cruise proposal has been submitted for 2023) to trace the fate and dynamics of nitrogen (N) derived from seabirds over the last 50/100 years in several Pacific atolls with different histories in terms of seabird populations related to the morphology of the islands but also to the presence or absence of rodents. Rodents such as rats have a strong impact on seabird populations, either by direct predation or by modification of their habitat; their presence thus leads to a decrease in their population and to guano inputs towards adjacent reefs. The measurement of the nitrogen isotopic composition ($\delta^{15}N$) of nitrates in seawater, groundwater under the islets, and organic matter bound to the coral skeleton on several sites (islets/atolls) contrasted in terms of morphology, number of seabirds and history of rodent presence should provide information on the still little explored role of seabirds on coral reef functioning.

*Nombre de publications, de communications et de thèses*


Publications (2 accepted, 2 to be submitted)

Thibault, M., Houlbrèque, F., Lorrain, A., Vidal, E. (2019) Seabirds: Sentinels beyond the Oceans. *Science*, *366* (6467), 813. https://doi.org/10.1126/science.aaz7665.

Thibault, M., Houlbreque, F., Duprey, N. N., Choisnard, N., Gillikin, D. P., Meunier, V., ... & Lorrain, A. (2022). Seabird-derived nutrients supply modulates the trophic strategies of mixotrophic corals. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.790408

Choisnard N, Duprey NN, Houlbrèque F, Thibaut M, Foreman AD, Cuet P, Guillaume MM, Martinez-Garcia A, Vonhof H, Crutzen PJ, Haug GH, Maguer JF, L'Helguen S, Lorrain A**.** Tracing the fate of seabird-derived N in a coral reef using nitrate and coral skeleton stable nitrogen isotopes. Limnology and Oceanography.

Thibault M., Houlbrèque F., Duprey NN, Choisnard N, Lorrain A. Seabird-derived nitrogen supply boosts coral metabolism. Biology letters.

Communications (2)

Thibault, M., Houlbreque, F., Duprey, N. N., Choisnard, N., Gillikin, D. P., Meunier, V., Benzoni, F., Ravache, A. & Lorrain, A. Healthy seabirds, healthy reefs ? Seabird poop, corals food. World Seabird Twitter Conference 7. 4-6 Mai 2021. Virtual Meeting.

Thibault, M., et al. Healthy seabirds, healthy reefs ? Enrichment patterns in coral ecosystems by guano-derived nutrients. World Seabird Conference 3. 4-8 Octobre 2021. Virtual Meeting.


Students: *1 Post-doctorat (M. Thibault, 2019/2021), 3 masters (N. Choisnard, L. Toussaint, A. Mercier), 1 PhD starting in September 2022.*