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研究課題名(英文) Phylogeography and species delimitations of IndoPacific deep corals.

## 研究代表者

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研究成果の概要(和文)：本研究では、熱帯域に位置するコーラルトライアングル(CT)と沖縄海域の深場(水深30m以深)に生息するサンゴの多様性を比較し、その関係性を明らかにした。そのため沖縄、フィリピン、インドネシアの深場におけるサンゴの分布およびいくつかの種の遺伝的多様性を調べた。その結果、3海域で深場サンゴの群集構造にはわずかな違いがあることが示された。一方、いくつかの種では遺伝的多様性には類似性が確認された。本研究の成果はCT海域におけるサンゴの種の系統地理学的研究を発展させるための基礎情報となることが期待される。さらに今回の調査では、従来CT海域に分布の記録がなかったサンゴ種の生息が確認された。

## 研究成果の学術的意義や社会的意義

This project showed that MCEs in Japan and the CT are connected. It acted as starting point for studies on MCEs in Indonesia, established an international core of MCE researchers in the wider CT region and opened opportunities for students from the CT to be trained to MCE research in Japan.

研究成果の概要(英文)：This project aimed to explore the biodiversity in the upper mesophotic coral ecosystems (MCEs) in the Coral Triangle (CT) and set bases of the understanding of the relationships between MCEs in the Coral Triangle and Okinawa. For this I compared mesophotic coral diversity using field and molecular data in Japan, the Philippines and Indonesia. The results obtained showed slight differences in mesophotic communities in the three different regions, although similarities were visible at the species level through genetic data. Due to the size and diversity of habitats in the CT, this study is not exhaustive but it provides a perfect baseline to develop further phylogeographic studies in the CT. In addition of revealing phylogeographic connections between southern Japan and the CT, this study also confirmed the presence of some mesophotic corals outside of their known distribution range.

研究分野：Biodiversity

キーワード：Scleractinia

様式 C-19、F-19-1、Z-19、CK-19 (共通)

## 1. 研究開始当初の背景

Mesophotic coral ecosystems (MCEs) are the parts of coral reefs found below 30 m depth. Due to their remote nature, MCEs have been largely ignored in past research. Recent technological development gave access to these poorly known ecosystems<sup>1</sup>. Yet, mesophotic studies are still limited by problems to identify coral species due to their plastic morphology adapting to low light environments.

MCEs can play an essential role in the preservation of shallow coral species in a context of increasing global warming<sup>2</sup>. In Okinawa, I found the first evidence of the role of MCEs as refuge for shallow coral species. Indeed, the coral *Seriatopora hystrix*, a species locally extinct from a shallow reef after severe bleaching events, survived in a deep refuge near its original shallow location (Sinniger et al. 2013). In 2016, massive bleaching caused by ocean warming affected Okinawan reefs. And it highlights the necessity to understand how shallow and deep corals are related and how mesophotic corals in Japan are related to neighboring regions such as the Coral Triangle (CT).

One major bottleneck of MCE research concerns the problems to identify coral species and the complex and confusing phylogenetic relationships between and within morphospecies. Moreover, most studies are based on localised MCEs and little is known on the biogeography of the mesophotic corals and connectivity between different MCEs. For example *Acropora tenella*, an endangered mesophotic coral, shows similar DNA among Okinawan samples; however, DNA sequences are very different from those obtained in Australia. The amount of genetic differentiation is equivalent to completely different species and lead to unresolved phylogenies. In the coral *S. hystrix*, or the emblematic coral genus *Leptoseris*, contradicting information is obtained when comparing mitochondrial and nuclear genetic markers both within Okinawan specimens and within Australian samples. Such results might indicate recent introgressive hybridization. Therefore in order to clarify these complex situations, it is necessary to expand the research to neighboring regions.

Currently no scientific knowledge is available on CT mesophotic corals. Preliminary observations show that MCEs in Okinawa and Philippines look similar in terms of coral biodiversity and communities.

**References:** <sup>1</sup> Kahng et al. 2014. *Curr. Opin. Envir. Sust.* 7, 72–81; <sup>2</sup> Bongaerts et al. 2010. *Coral Reefs* 29, 309–327

## 2. 研究の目的

This project aimed to establish a network of mesophotic researchers in Indonesia, the Philippines and Japan to identify coral biodiversity of upper MCEs in the Coral Triangle (CT) and clarify the phylogenetic relationships and community patterns between the CT and both Japan and Australia by comparing the results with data already obtained from these locations. This aim will be reached by testing the following hypothesis.

Hypothesis: Mesophotic corals in the CT are genetically related to Japanese mesophotic corals.

## 3. 研究の方法

In this project, the data were obtained through photoquadrats as described in Sinniger et al. 2019 and analyses of collected specimens. Photoquadrats were obtained from shallow to upper mesophotic depths, in Okinawa, the Philippines and Indonesia. Coral samples were morphologically examined using both traditional taxonomic approaches and whenever possible using scanning electron microscopy (SEM) to reveal the skeletal microstructure features. For DNA analyses a combination of mitochondrial and

nuclear markers were analysed with markers adapted for each scleractinian family. The coral samples were processed directly in their country of origin. Skeleton of the coral samples are kept in their countries of origin to serve as reference vouchers for future mesophotic studies.

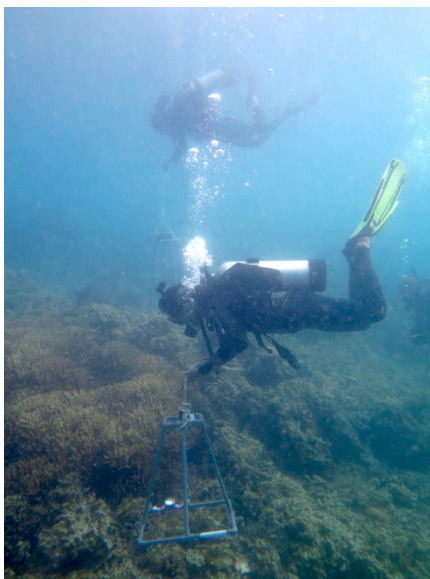
#### 4. 研究成果

The first year of this project was mainly focused on the Indonesian part of the Coral Triangle and the formalization of the collaboration agreements. During this first year of the project, an international workshop was organized in Makassar, Sulawesi, Indonesia with collaborators from the University of the Ryukyus (Japan), the Hasanuddin University (Indonesia), the Institut Perenthian Bogor (Indonesia) and from the Marine Science Institute (Philippines).



**Speakers at the 1st Workshop to develop collaborative mesophotic research in the Coral Triangle.**

Beside from collaborators from Japan, Indonesia and the Philippines, numerous local researchers and students attended this workshop. It allowed attracting the attention to the needs for MCE research in the Coral Triangle and developing the core of an international collaboration network



**Indonesian collaborators training to take photoquadrats for mesophotic research.**

on MCEs in the region. Following this workshop, a field survey was conducted in the Spermonde Archipelago with both Indonesian and Japanese collaborators. This field survey helped to train local researchers to MCE research as well as allowed to find the first mesophotic coral communities in the region (Sinniger et al. in prep).

Later this year, additional photoquadrats were obtained from another site in Indonesia and samples of several species of importance for mesophotic research (*Seriatopora*, *Stylophora*, *Leptoseris*, *Pachyseris*, etc.) were collected by Indonesian collaborators for DNA comparison with data from Japan. In parallel, the results on the genetic

comparisons between deep and shallow *Seriatopora* in Southern Japan were published in the international, peer-reviewed journal *Frontiers in Marine Science*

(Sinniger et al. 2017). These results show that all the genotypes of *Seriatopora* found in shallow water were also found mesophotic, thus in Southern Japan MCEs can act as a repository of biodiversity for at least some shallow corals. This study establishes a baseline to compare how Japanese corals are related to those in the Coral Triangle and how the patterns of shallow and deep corals in the CT are comparing with the patterns observed in Japan.

The second year of this project was mainly focused on the analyses of the Indonesian samples as well as obtaining data from the Philippines. Field work was organized in the Philippines with

collaborators from the University of the Philippines. Abundant and high quality photoquadrat data could be obtained from several sites within two regions in the Philippines (north and central Philippines) as well as numerous samples for morphological and genetic analyses. The morphological vouchers remained in the Philippines providing a reference collection for future studies on mesophotic corals in the region. All the molecular analyses were also performed directly at the University of the Philippines, strengthening the collaboration with the collaborators from the Philippines. Both quadrat and genetic data showed that MCEs in the Philippines are different from those in Japan, yet several striking similarities occur, especially at the species level as shown through the genetic analyses (Sinniger et al. in prep.).

Aside from the data from the Philippines, during FY2018, the samples from Indonesia were processed in Indonesia jointly with collaborators from the Institut Perenthian Bogor. The data obtained appear to corroborate the results obtained from the Philippines and will provide a sound baseline for expanding this research further.

This project also resulted in my invitation to participate to a mesophotic coral survey in Kimbe Bay in Papua New Guinea (PNG) where I could confirm that *Leptoseris amitoriensis*, a species described from Japan expands its distribution until Kimbe Bay (Sinniger, Bridge and Baird 2019).

During the FY2018, the results from this project were presented at several international conferences. It was first presented at the World Conference on Marine Biodiversity in Montreal, Canada. This presentation was important to attract the attention of the global marine biodiversity community to the thematic related to mesophotic coral ecosystem and inform this community on the richness of the mesophotic biodiversity in Japan compared to other region known for their coral diversity (such as the CT). The fieldwork in the Philippine was organized to allow me to present my results at the Asia-Pacific Coral Reef Symposium in Cebu, Philippines. With an audience more specialized in coral reefs, this conference was important to address the lack of knowledge in South East Asia and the efforts of this project to solve this issue. Finally, my mesophotic work led me to be invited speaker at the Gordon Conference on mesophotic coral reef ecosystems in USA. This conference specifically targeting mesophotic researchers allowed to get specialist feedbacks on the results obtained and to develop further the theories between the quadrat analyses.

A chapter on the Ryukyu Islands (Sinniger et al., 2019) was published in the book “Mesophotic Coral Ecosystems” (Loya et al., eds). This book chapter summarise the state of the knowledge of MCE in Japan and incorporate some of the data obtained through the project reported here.

The first mesophotic workshop in the Coral Triangle was also reported in the newsletter of the International Society for Coral Reefs in September 2018.

## 5. 主な発表論文等

[雑誌論文] (計 3 件)

- ① [Sinniger Frederic](#), Bridge Tom, Baird Andrew (2019) First record of *Leptoseris amitoriensis* Veron 1990 in Kimbe Bay, PNG. SCESAP Bulletin 5: 6. (査読なし)
- ② [Sinniger Frederic](#) (2018) Workshop to Develop Collaborative Mesophotic Research in the Coral Triangle. Reef Encounters 33(1): 68-69. (査読なし)
- ③ [Sinniger Frederic](#), Prasetia Rian, Yorifuji Makiko, Bongaerts Pim, Harii Saki (2017) *Seriatopora* diversity preserved in upper mesophotic ecosystems in Southern Japan. Frontiers in Marine Science 4,

〔学会発表〕 (計 4 件)

- ① Corals Across Depths: Status of the DRRH in the highly diverse Japanese MCEs  
Sinniger F., M. Pichon, P. Muir, R. Praselia, H. Rouzé, S. Harii  
Gordon Research Conference on Mesophotic Coral Reef Ecosystems, USA, June 2018 Invited lecture
- ② Overlapping coral diversity between shallow and mesophotic ecosystems: Perspectives on the Deep Reef Refugia Hypothesis in the North-West Pacific  
Sinniger F., M. Pichon, P. Muir, R. Praselia, H. Rouzé, S. Harii  
4th World Conference on Marine Biodiversity, Canada, May 2018
- ③ High mesophotic coral biodiversity in Okinawa: implications for the DRRH  
Sinniger F., M. Pichon, P. Muir, R. Praselia, H. Rouzé, S. Harii  
Asia-Pacific Coral Reef Symposium, Philippines, May 2018
- ④ Is Okinawa a hotspot of mesophotic coral diversity in the World?  
Sinniger F., M. Pichon, R. Praselia, H. Rouzé, S. Harii  
20th Japanese Coral Reef Society annual meeting, Japan, Dec 2017

〔図書〕 (計 1 件)

- ① Sinniger Frederic, Harii Saki, Humblet Marc, Nakamura Shohei, Ohba Hideo, Praselia Rian (2019) Ryukyu Islands, Japan. In: Loya Yossi, Puglise Kimberly, Bridge Tom (eds) *Mesophotic coral ecosystems*. Springer, New York, pp. 231-247 (査読有り)

## 6. 研究組織

### (1)研究分担者

研究分担者氏名：なし

ローマ字氏名：

所属研究機関名：

部局名：

職名：

研究者番号 (8 桁)：

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