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研究課題名(和文) Monitoring Endangered Species from Space - A First Application of ICARUS Technology for Long-Term High-Resolution Tracking of Cryptic Animals

研究課題名(英文) Monitoring Endangered Species from Space - A First Application of ICARUS Technology for Long-Term High-Resolution Tracking of Cryptic Animals

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研究成果の概要(和文)：本研究の成果としては、低エネルギーで宇宙ベースのICARUS観測システムを軽量で空パネル付きで、非常に小さい動物の追跡調査用のバイオロギングタグが可能となる技術として徹底的にアセスメントができた。本研究期間はICARUS観測システムの開発中の期間と重なり、システム起動が数回延期されたことよって、研究推進に遅れが生じた。こうした状況を上向かせ、本研究の担当者がICARUS側の開発チームと、低エネルギー電気通信の新技术のデザインに関して深く協力することができ、それが今後の実用的な追跡システムの起動に繋がる。

研究成果の学術的意義や社会的意義

We technically assessed ICARUS tags based on novel space tracking technology, with global potential to serve society to conserve small endangered animals that are hard to study. Also, we gathered ecological data on the Ryukyu flying fox (*Pteropus dasymallus*), a threatened Japanese fruit bat.

研究成果の概要(英文)：This project consisted in a practical assessment of ICARUS, which relies on low-energy, broadband communication with the low-orbiting International Space Station (ISS). ICARUS allowed for the development of very light (5 g), solar-powered biologging systems that can be equipped on small animals. We evaluated more particularly ICARUS-compatible prototype tags in this project.

As ICARUS was at that time still under development, the timespan of this project overlapped with the in-house testing of this technology and the absence of space link. Moreover, as ICARUS roll out was delayed on several occasions due to technical issues (e.g. EVA postponement due to ISS activities, coordination problems between the space agencies), our project's timeframe was postponed. The foregoing issues, however, led us to work in parallel to ICARUS on the design of new low-energy telecommunication technologies, which we are now turning into usable tracking systems jointly with our German partners.

研究分野：総合生物

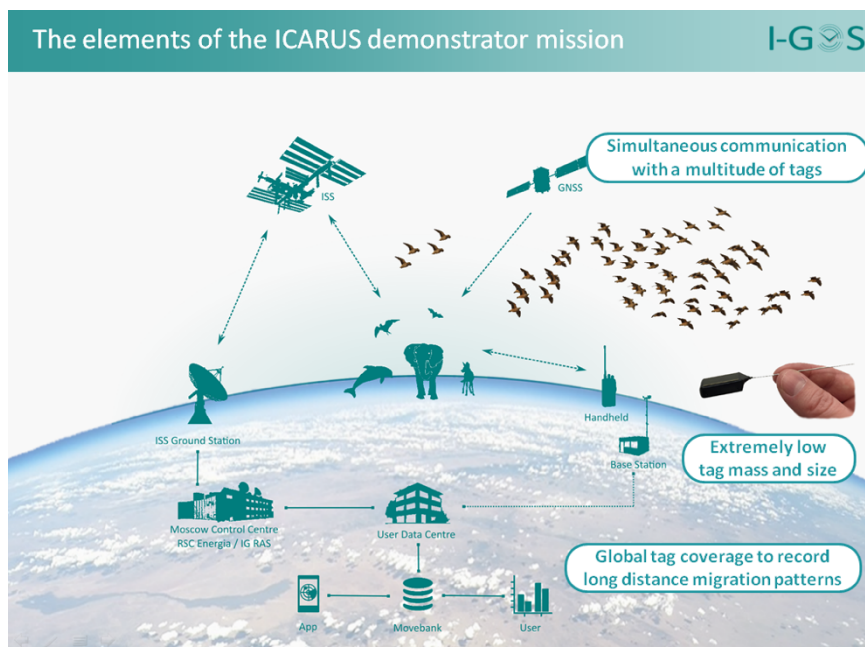
キーワード：バイオテレメトリー ISS wildlife tracking movement ecology bat flying fox Pteropus

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1. Background of the research (研究開始当初の背景)

General Background

The conservation of endangered animals requires understanding of their activity and movement patterns. However, elusive mobile animals (i.e. species that frequently move but are difficult to observe in the wild) represent a major challenge in this aspect. Indeed, positioning data are in such cases difficult to obtain, inaccurate, infrequent, discontinuous, and often cover only very short periods. Cryptic species of small size especially are even more challenging, and additionally cannot be ethically tracked using biologging solutions available to this date because of weight limitations.



The ICARUS initiative

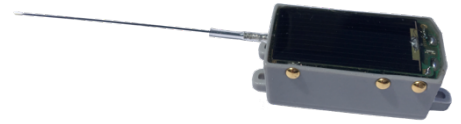
To address these challenges, the International Cooperation for Animal Research using Space (ICARUS) was founded in 2002 by researchers at the Max Planck Institute in collaboration with the European Space Agency (ESA) and Roscosmos, and now includes many other agencies and partners. It aims at creating a lightweight tracking solution that can be equipped on small animals. The gain in weight is made possible by energy saving through short-distance communication with the International Space Station (ISS), which is located in low orbit over the Earth. This technology was recently equipped on the ISS (with some large delay, see section 4A) and is planned to be fully operational from 2021.

2. Purpose of research (研究の目的)

In 2017, we secured a collaboration agreement with Max Planck Institute for Ornithology, namely with Prof. Martin Wikelski, the head of the ICARUS initiative, and Dr Walter Naumann, the CEO of I-GOS GmbH, the company implementing the ICARUS system, to perform early testing and experiments using this new technology. Our initial goal was mainly twofold. First, assess the operational capacity and performance of the tracking tags as well as the telecommunication system. Second, collect some first batch of comparative test dataset from challenging target species, in the present case solitary island fruit bats of the genus *Pteropus*, which represent a typical case of endangered and highly challenging species to track.

3. Method of study (研究の方法)

ICARUS trackers (see figure on the right) were to be developed and provide positioning data, as well as measurements from an array of sensors (e.g. accelerometers, magnetometers, barometric pressure) to allow for the study of animal behavior and flight dynamics. We initially aimed to put prototype tags under technical test (in lab settings and in realistic outdoor conditions), evaluate tag attachment methods to ensure animal safety requirements, and assess the overall operational value of the system in realistic contexts.



4. Implementation, Challenges and Research achievements (研究成果)

A. Delay in ICARUS deployment in space and impact on the Kaken Hi project



This Kaken Hi project was initially planned to start shortly (i.e. 6 months) before the finalization of ICARUS tracking tag prototypes and less than one year before deployment of the entire system in space. Nevertheless, the schedule of the ICARUS initiative itself was significantly delayed, as final space deployment was shifted by over two years. Several consecutive problems with the ICARUS initiative were responsible for this very large delay, among others rescheduling of ISS activities leading to significant delay in the EVA focused on antenna installation (see pictures), immediate failure of the onboard computer of the receiving module, which had to be brought back to Earth, repaired and launched back into space in December 2019, etc. Unforeseeable issues are common in high-technology projects typical of the space industry. We had therefore planned some safety buffers (>1 year time between the announced ICARUS operation start and the end of the Kaken Hi grant) in our schedule of this project. Yet, the extent and extreme duration of the difficulties encountered by space deployments and operation start were unusual and unexpected even by ICARUS project leaders. In total, the cumulative delay amounted to almost two years. As a consequence, the related Kaken Hi project was significantly impacted in terms of schedule, duration and exhaustiveness of the tasks envisaged, esp. as regards the testing of the data transmission technology.

B. Preliminary assessment of ICARUS, a pioneer space tracking technology

The ICARUS tracking technology relies on an original spatial telecommunication system (incl. totally new RF transmission protocol) and interaction with the International Space Station, on which interferences with other equipment cannot easily be ruled out without trials. Due to the challenges and novelty of this approach, a strong need to evaluate its effective characteristics (i.e. reliability, transmission rate, accuracy) would have to be addressed. Moreover, the effect of particular constraints due to the deployment on bats (e.g, attachment method, nocturnal behavior leading to uncertainty about solar-charging efficiency) would have to be revealed during this project and serve as reference for future studies. With the assistance of the I-GOS team, we evaluated the characteristics of the system and provided feedback useful for tag design improvements.

C. Collection of ecological data on endangered species



The final purpose of the ICARUS system is to enable high-resolution long-term data collection on movements and locomotion of endangered species in order to allow for their conservation. To support a preliminary evaluation study of the system, we decided to integrate it into a biological conservation project focusing on flying foxes (i.e. bats of the *Pteropus* genus) that aims to understand where/when/why some cryptic species (i.e. the Japanese *P. dasymallus* and French/Neo-Caledonian *P. vetulus*) move. During these tests, we could infer precious information about foraging and roosting habits, seasonal and inter-annual variations in activity (currently under publication). In the frame of this Kaken Hi grant, we undertook data collection for a technological comparative study in which we deployed GPS tracking units on a dozen Ryukyu flying foxes (*P. dasymallus*) on Ishigaki Island, Japan (see photographs). This work would provide valuable comparative information to assess the performance of ICARUS (see tracking data beside). Making the most of the captured individuals, we also used this opportunity to collect genetic material from them (in the form of wing biopsies and hair samples). This side-project led to the writing of two manuscripts, one of which already published (see Taki et al. 2020a, Taki et al., 2020b). We also collected information on bat-farmer conflicts, which contributed to other of our studies (see Florens and Vincenot, 2019; Chaerntantanakul, Shibata and Vincenot, 2019). The larger deployment to further test this technology on *P. vetulus* in New Caledonia, which was scheduled for March 2020, had to be canceled due to travel restrictions resulting from the COVID-

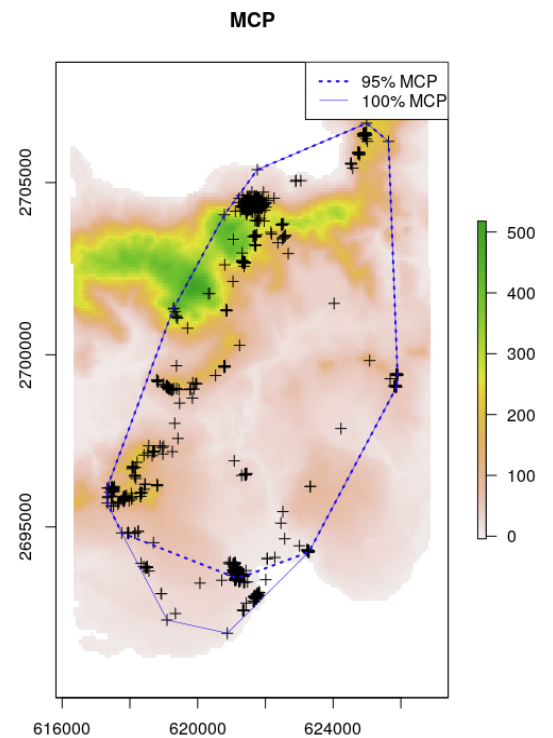
19 pandemics. Yet, Prof. Fabrice Brescia (IAC, France) and our team already planned to resume this work as soon as travel bans are lifted (unfortunately still impossible at the time of this report writing).

D. Contribution to project dissemination and new tag development

This Kaken Hi project was also successful at disseminating the ICARUS project technology and goals. We have become a focal point for the ICARUS initiative in Asia-Pacific and have overseen and coordinated the interests of various research groups throughout the region. Furthermore, collaboration has become tighter with some members with time. Based on constraints identified in the ICARUS tag development, joint work has evolved into a new full-fledged collaboration to design and test tags based on technologies even more finely tailored to the tracking requirements that we have to meet in the case of studies on human-wildlife conflicts in the case of small, cryptic species. Joint development on this research front is also currently being undertaken.

Acknowledgements and Photo Credits

We thank colleagues at Max Planck Institute (MPI) for Ornithology for talks regarding the ICARUS initiative, and more particularly Dr Walter Naumann and Ms Elli Yohannes (formerly I-GOS GmbH) for continuous interactions and very fruitful discussions. The first four figures presented in this report are also courtesy of I-GOS GmbH.



5. 主な発表論文等

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〔図書〕 計0件

〔産業財産権〕

〔その他〕

Island Bat Research Group (IBRG)
www.batresearch.net

6. 研究組織

	氏名 (ローマ字氏名) (研究者番号)	所属研究機関・部局・職 (機関番号)	備考
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7. 科研費を使用して開催した国際研究集会

〔国際研究集会〕 計0件

8. 本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関
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