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研究課題名（和文）Establishing an open science platform of marine ecosystem by soundscape information retrieval

研究課題名（英文）Establishing an open science platform of marine ecosystem by soundscape information retrieval

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研究成果の概要（和文）：サウンドスケープは、海洋生態系の水中でのリモートセンシングに有用と考えられた。 本研究では、音声情報の自動分類により海洋生態系の生物多様性を評価を促進することを目的としている。長期録音データから、音声の可視化、音源分離 、イベント同定のための技術を開発した。本研究では、大陸棚、岩礁、河口、深海環境などから水中音データを収集した。開発した音声情報検索手法により、水中の音響環境の変化、生物多様性、人為的な干渉など、生態学的に注目される複数の音響事象を抽出できた。このプロジェクトでは、サウンドスケープを生態系モニタリングに利用したいと考えている研究者に向けて、今後も大量の音響データを提供していく。

研究成果の学術的意義や社会的意義
Listening to natural sounds allows us to remotely acquire data of biodiversity and investigate the changes in response to human development. The outcome can help managers and stakeholders to use soundscapes in the ecosystem assessment and improve the decision making of conservation management.

研究成果の概要（英文）：Soundscapes, which are composited by sounds of biological, environmental, and anthropogenic sources, have been considered as a remote sensing platform to monitor marine ecosystems. This project aims to facilitate the assessment of the spatial-temporal dynamics of marine ecosystems via soundscape information retrieval (SIR). During the project period, we developed techniques for audio visualization, source separation, and event identification. Long-duration recordings were collected from algal reefs, continental shelves, coral reefs, estuaries, and deep-sea environments. On the basis of SIR, single-channel audio can be transformed into multiple ecological dimensions, including the changes of acoustic environment, biodiversity, and anthropogenic interference. This project also enables the "Ocean Biodiversity Listening Project" and will further contribute a large amount of acoustic data for researchers who interest in using soundscape information for ecosystem monitoring.

研究分野：Ecoacoustics

キーワード：Soundscape　Information retrieval　Ecoacoustics　Machine learning　Deep sea　Underwater sound

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様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９、ＣＫ－１９（共通）

１．研究開始当初の背景

Visual-based information retrieval has been widely employed in modern society. It has also been applied in various ecological applications, such as satellite remote sensing and wildlife identification. However, the application of visual-based techniques in the ocean is restricted in short distances due to the limited visibility and accessibility. Monitoring of marine ecosystem dynamics remains challenging and represents a crucial issue for nations rely on marine resources.

Soundscapes, which are composited by biological, environmental, and anthropogenic sounds, have been considered as a remote sensing platform to monitor marine biodiversity and anthropogenic activities. Although soniferous animals, geophysical events, and human activities can be acoustically detected in long-duration underwater recordings, there are no sufficient annotated databases for researchers to recognize various biotic and abiotic sounds in the ocean. Therefore, the fundamental scientific question is how we can isolate and identify distinct sound sources from the marine soundscapes without the need for a large number of preexisting labels for model training.

２．研究の目的

Developing information retrieval techniques of marine soundscapes to evaluate the dynamics of marine ecosystems represents the core of this project. Our goal is to facilitate the assessment of the spatial-temporal dynamics of marine ecosystems via an international monitoring network of marine soundscapes. There are three primary tasks in this project:

(1) Developing open tools of soundscape information retrieval (SIR) to separate biotic and abiotic sounds from marine soundscapes.
(2) Evaluating the feasibility of soundscape monitoring in deep-sea environments.
(3) Establishing an open science platform of marine soundscapes.

３．研究の方法

(1) Soundscape information retrieval

SIR techniques, including source separation and event identification, generally require a large number of preexisting labels for supervised training. However, the preparation of annotated labels is expensive and time-consuming. It is also common for experienced marine acousticians to prepare only coarse labels determining the presence or absence of target signals. To reduce the dependency of preexisting labels, we integrated ecological knowledge in unsupervised learning models of source separation.

First, we separated continuous and transient acoustic signals from marine soundscapes by using different statistical measurements in a long-term spectrogram. Second, we implemented the periodicity constraint in a source separation model constructed by multiple layers of non-negative matrix factorization. This model was subsequently applied to separate biotic and abiotic sounds that displayed different occurrence patterns in diurnal, tidal, and seasonal cycles. Finally, we applied clustering to evaluate the acoustic diversity of biotic sounds (Fig. 1).

(2) Soundscape monitoring in deep-sea environments

This project collected underwater recordings generated by deep seafloor observatory. In addition, underwater sound recorders that can tolerate high-pressure environments were built and were empirically tested. After the pressure test, the sound recorders were integrated into various deep-sea exploration platforms of JAMSTEC, including remotely operated vehicles, human occupied vehicles, and free-fall observation systems. The underwater sounds were analyzed by using the developed techniques of SIR. On the basis of audio source separation, we investigated how different observation platforms may affect the quality of audio data.

(3) Open science platform of marine soundscapes

To promote the technical development of soundscape information retrieval and future applications of soundscape-based ecosystem monitoring, we published source codes in online repositories and made tutorials on Google Colab notebooks. In addition, this project collaborated with researchers in Japan, Taiwan, Hong Kong, and the Philippines. Based on a collaborative effort of soundscape monitoring, this project characterized soundscapes in different marine ecosystems, including coral reefs, algal reefs, seagrass habitats, continental shelves, and deep-sea environments. By sharing the outcomes on an open data archive, this project aims to enable governmental agencies, researchers, industries, and citizen scientists to evaluate the mutual interactions between marine biodiversity and anthropogenic development.

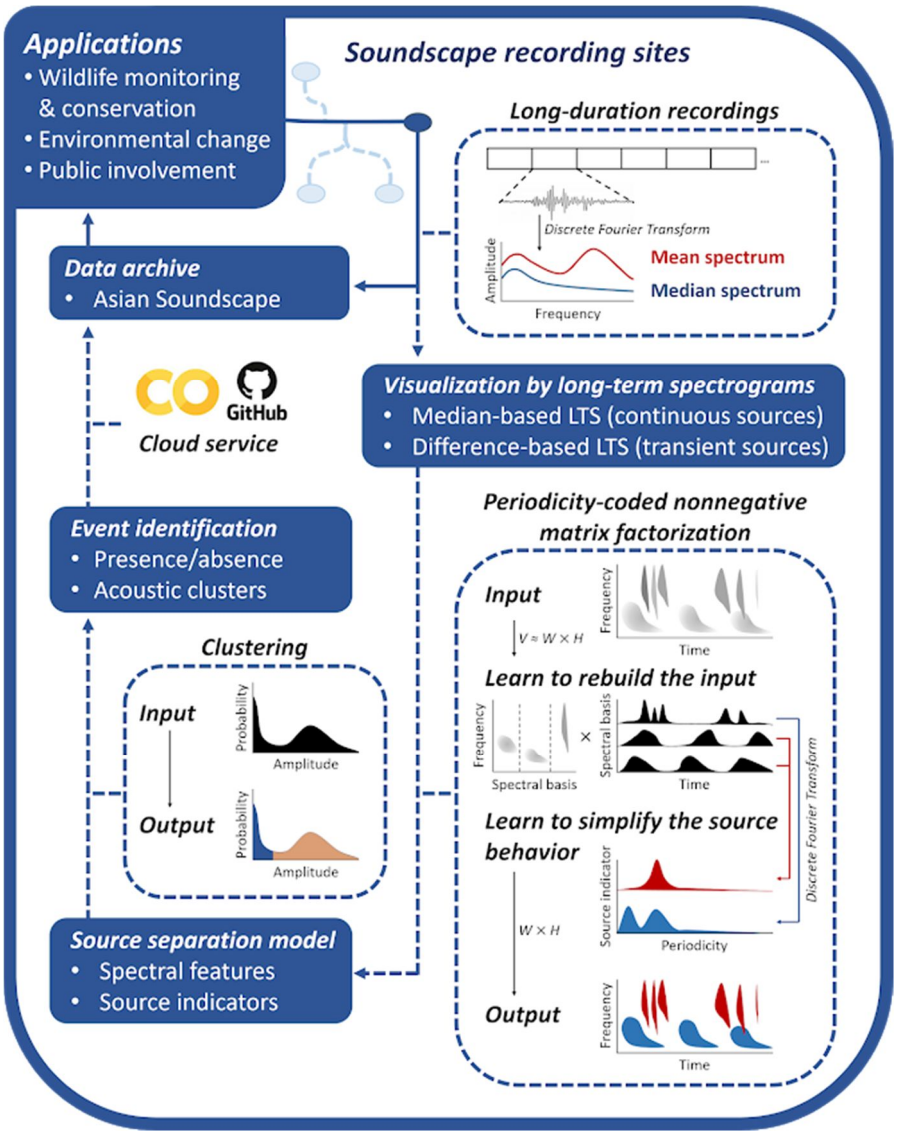

Figure 1. Techniques of soundscape information retrieval used in this study. The three analysis modules, including visualization of long-duration recordings, source separation, and clustering, were integrated in the Soundscape Viewer.

4．研究成果

(1) Acoustic diversity off northeastern Taiwan

We visualized the long-duration recordings (2.5 years) generated from the Marine Cable Hosted Observatory (277 m) by using a long-term spectral average (Fig. 2). A source separation model based on two layers of non-negative matrix factorization was constructed by assuming biotic and abiotic sounds display source-specific periodic patterns. The periodicity constraint allows the model to discriminate the source indicator of spectral features that are unsupervised learned from a long-term spectral average and to disentangle single-channel audio into independent sound sources.

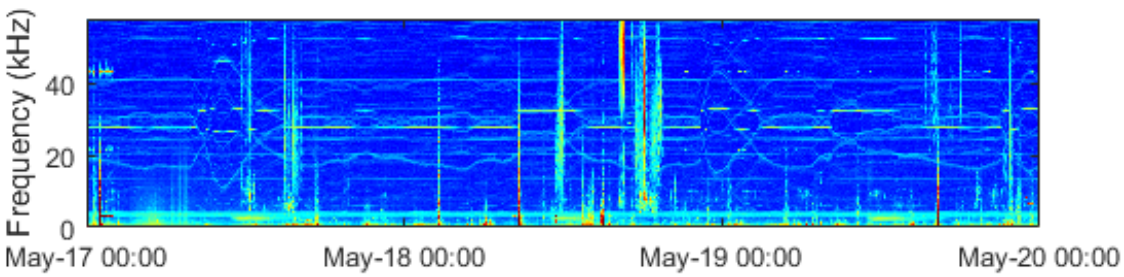

Figure 2. Visualization of long-duration underwater recordings off northeastern Taiwan.

The results show that the deep-water soundscapes off northeastern Taiwan are composited by sounds of cetaceans, soniferous fish, and various abiotic sources. Despite the significant frequency overlap among sound sources and the interference of electrical noise,

our source separation model can still correctly identify 73.10% of fish chorus and 85.99% of cetacean vocalizations under 5% false positive rate. The separation results have facilitated the investigation of the phenology patterns of cetaceans and soniferous fish, as well as their temporal interactions. By performing clustering on the audio separation results, we could observe the compositional shift in six clusters of cetacean vocalizations and three clusters of fish chorus among diurnal and seasonal cycles.

(2) Using soundscapes to assess the deep-sea benthic environment

According to our review, we noticed that many deep-sea mining projects might significantly affect biodiversity hotspots, such as hydrothermal vents. Sounds of venting activities and animals that are associated with hydrothermal vents may be the important cues in the dispersal and habitat selection of deep-sea larvae. By decomposing soundscapes into sounds from biotic and abiotic sources, it is possible to evaluate the structure of the biological community and geophysical environment in response to a changing environment. The future implementation of soundscapes in the global ocean observing network will generate a comprehensive information on biodiversity dynamics and assist the assessment of anthropogenic disruption.

Until the end of this project, we successfully built two deep-sea sound recorders for a water depth of 2000 m and another two recorders for 6000 m. These recorders were deployed on the SHINKAI 6500, the KAIMEI ROV, baited camera systems, and the Edokko No.1. The underwater recordings collected by using the SHINKAI 6500 and the KAIMEI ROV were seriously corrupted due to the prominent gear noise. Baited camera systems and the Edokko No.1 are suitable platforms for soundscape monitoring if those systems do not equip an active acoustics system (Fig. 3). Based on the data collected, we discovered that the deep-sea soundscapes off Tohoku and in Sagami Bay were dominated by shipping noise. On the other hand, the soundscapes at Suiyo Seamount were dominated by low-frequency sounds that were possibly associated with venting activities.

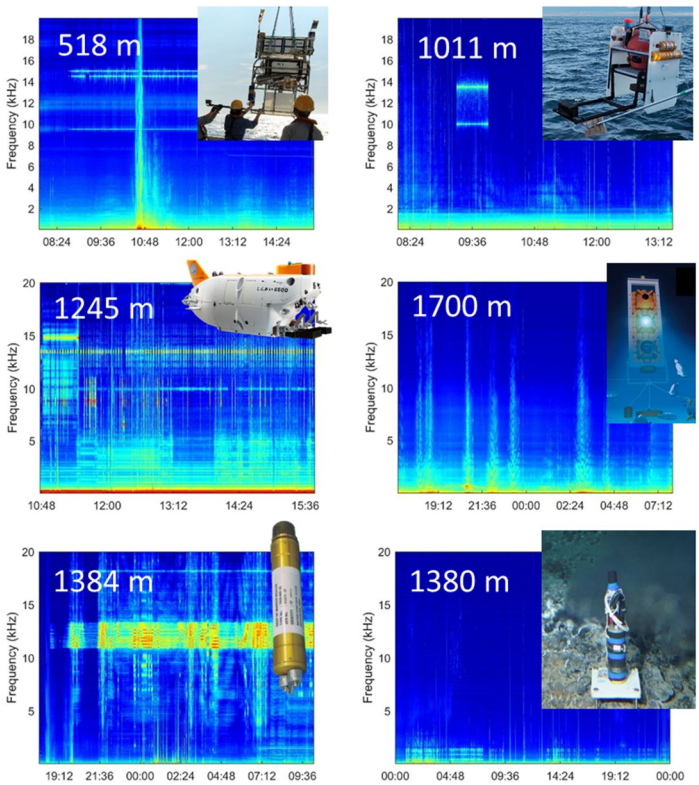

Figure 3. Underwater sounds collected by using different deep-sea observation platforms. The number indicates the water depth of the audio recorder.

(3) Characterization of ecosystem-specific soundscapes

Through the international collaboration, we have collected underwater recordings from five locations: (1) algal reefs at Taoyuan, Taiwan (assisted by Dr. Kuo-Chang Wen, Tunghai University); (2) Chunggang River Estuary, Miaoli, Taiwan (assisted by Dr. Chiou-Ju Yao, National Museum of Natural Science); (3) Pearl River Estuary, China (assisted by Dr. Leszek Karczmarski, Cetacea Research Institute); (4) coral reefs off Sesoko Island, Okinawa

(assisted by Dr. Tomonari Akamatsu, Ocean Policy Research Institute, Sasakawa Peace Foundation); and (5) coral reefs off Cebu, Philippines (assisted by Dr. Florence Evacitas, University of the Philippines Cebu).

Our results reveal that the soundscapes of algal reefs were profoundly affected by tides due to the very shallow and wavy environment. During high tide, snapping shrimp sounds dominated the soundscape. In estuarine environments, fish chorus, snapping shrimp sounds, and dolphin vocalizations represent the dominant biological sound sources. The coral reef soundscapes were dominated by sounds of snapping shrimps and fish chorus. Furthermore, the shallow water reefs and mesophotic reefs display different acoustic diversities. Expect the algal reef ecosystem, all the other recording sites were frequently interfered by shipping activities during the daytime.

On the basis of international collaboration, we identified the soundscape characteristics of different marine ecosystems. The analysis result will be published in open-access repositories. After this project, we will collaborate with the Working Group of Acoustic Measurement of Ocean Biodiversity Hotspot of the International Quiet Ocean Experiment to promote the soundscape-based biodiversity monitoring. The applied techniques of SIR will also be implemented in the Asian Soundscape, which is an open science platform supported by the Trans-Eurasia Information Network.

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掲載論文のDOI（デジタルオブジェクト識別子） 10.1002/rse2.141	査読の有無 有
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〔産業財産権〕

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６．研究組織

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