

## 船舶観測による広域サンゴモニタリングと生死判別 Regional Coral Monitoring and Viability by Boat-based Observation

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地球規模の気候変動や熱帯地域の土地開発等により、世界規模で造礁サンゴの衰退が懸念されている。このため、サンゴ分布の現状をあきらかにするために、サンゴ生息海域における広範囲で高効率のサンゴモニタリング法が求められている。本研究では、潜水調査等ではカバーすることの難しい、100m以上の観測ラインのサンゴモニタリングを、小型船舶から高効率で実施することのできる、新しいモニタリング手法の開発を行った。この手法は、造礁サンゴに特有の蛍光たんぱく質の特性を利用したものであり、小型船舶から海底に向かって紫外線（UV）パルスレーザーを照射し、海底で生じる蛍光を、小型船舶上のゲートICCDカメラで撮影する、船舶搭載イメージング蛍光ライダー観測法である。パルスレーザーの射出時間は10ナノ秒以下と短く、ゲートICCDカメラの露光時間も100ナノ秒程度の短時間に抑えることができるため、日中でも太陽背景光の影響を抑制し、UVパルスレーザー励起によるサンゴの弱い蛍光イメージのみをとらえることが可能である。生きた造礁サンゴの多くは蛍光たんぱく質を有し、UV励起に対して青色から緑色の蛍光を示すのに対して、造礁サンゴが死ぬと蛍光たんぱく質が分解されるため、死んだサンゴ骨格、またはサンゴ骨格の表面に藻類が付着した状態となり、青色から緑色の蛍光を示さなくなる。このため、本観測法では、撮影画像中の対象物の形状を確認することで、サンゴの有無を判別することが可能であり、そのサンゴが蛍光を示しているかどうかを確認することで、サンゴの生死判別が可能である。このようなサンゴ観測を、DGPSによる船舶位置観測、SONARによる水深観測、ビデオ撮影による海底映像等と同時に記録することにより、小型船舶の航跡に沿って長距離の観測ラインを確保することが可能である。このサンゴ観測法により、沖縄県八重山郡竹富島周辺海域でグラスボートを用いて、サンゴの生死判別も含めて1km以上の観測ラインのサンゴ分布観測に成功した。

キーワード: サンゴ, 蛍光, モニタリング, レーザー, ライダー

Keywords: coral, fluorescence, monitoring, laser, lidar

## 化石サンゴから復元した北西太平洋における過去 6000 年間の台風履歴 Fossil corals record 6000 year history of typhoon activity in the Northwest Pacific

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Prediction of future typhoon activity is important for determining their role in ecological disturbance and economic loss. Recent increase in sea surface temperatures (SSTs) caused by anthropogenic impacts has led to an increase in intense typhoons. However, instrumental records of typhoon are too short and unreliable to reveal trends in the typhoon activity. Understanding long-term variability of past typhoons is important for assessing whether changes in the variability are induced ongoing increase in SSTs. Fossil tabular corals preserved in raised reef coast offer new indicator to understand the variability of past typhoon intense. This study presents a record of typhoon activity in the Northwest Pacific over the past 6000 years based on fossil tabular corals (*Acropora digitifera*) from Kikai Island in the Ryukyu Islands that are characterized by the variability of size related to typhoon intense. The record indicates that the frequency of typhoon has varied on millennial scales over this period; it weakened during the mid Holocene climatic optimum and it strengthened over the past 2000 years. The variability of typhoon intense was correlated with the strength of El Nino-Southern Oscillation (ENSO) during the past 6000 years. This data suggests that it is important to understand the variability of ENSO and locations of genesis of typhoon for prediction of the change in typhoon activity near future. Therefore, the information implies that recent increases in SSTs are probably not the important drivers of typhoon activity.

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キーワード: 台風, 化石サンゴ, 喜界島, ENSO  
Keywords: typhoon, fossil coral, Kikai Island, ENSO

## 海洋酸性化がサンゴ群集の多様性および生産性に及ぼす影響 Ocean acidification impacts on coral biodiversity and productivity

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### Introduction

Threatening of coral reefs by the climate change induced ocean acidification is now one of the biggest issues in the ocean ecosystem. Ocean acidification decreases the calcium carbonate saturation station, which result in the decrease of calcification rate of many calcifiers (Gattuso 1998, Kleypas 2004). Otherwise, the increase of seawater pCO<sub>2</sub> is predicted to increase the photosynthesis rate of phytoplankton and algae. Additionally, the seawater pH change will potentially affect the acid-base balance of marine organisms and impact their metabolic activity. In this study we focused on corals, and we experimentally evaluate the effects of ocean acidification on their physiology (calcification / photosynthesis / respiration). By integrating the future climate changing models and present results, we will discuss the potential impacts of ocean acidification on the coral biodiversity and productivity.

### Methods

Three branching coral species from the family Acroporidae (*Acropora digitifera*, *A. tenuis* and *Montipora digitata*), and one encrusting coral species from the family Siderastreidae (*Psammacora contigua*) were collected from the patchy reefs in Okinawa island. All these species are highly common in the indo-pacific coral reefs. Several nubbins or mass of corals were taken from different colonies (5~10) and cultured for about one month under 3 different seawater pCO<sub>2</sub> conditions (380 ~2,300 ppm). These CO<sub>2</sub> conditions were selected according to the IPCC2007 models. All cultures were conducted under natural light conditions and flow through system. The seawater chemistry (pH, total alkalinity, salinity, temperature) was measured every day. Buoyant wet-weight was measure every week, and the physiology (calcification / photosynthesis / respiration) was measured at the end of culture using total alkalinity (TA) and total inorganic carbon (DIC) measurement technique.

### Results and discussion

The sensitivity of corals to the ocean acidification was highly diverse among species. While *Montipora digitata* showed the highest decrease on calcification rate, *Psammacora contigua* show less sensitivity and *A. digitifera* was completely insensitive to high CO<sub>2</sub>. Additionally, light and dark calcification rate were differently affected between species, and we suggest that dark calcification is possibly one of the keys that dominate the sensitivity of corals to the ocean acidification.

Photosynthesis rate of most corals was not affected by ocean acidification. Otherwise, the respiration rate of both *A. tenuis* and *P. contigua* increase with seawater pCO<sub>2</sub> rise. Since the metabolic activity of corals highly influence the seawater carbonate chemistry, these physiological impact induced by the ocean acidification is suggested to feed back on the reef water carbonate chemistry and may change the coral reef carbon cycle. Additionally, the species-specific response of corals to the ocean acidification is suggested to change the coral community structure and may result in the decrease of coral reef biodiversity.

キーワード: 酸性化, サンゴ, 石灰化, サンゴ礁, 気候変動

## 海洋酸性化によるサンゴ礁棲有孔虫殻の安定同位体比の変化

### The stable isotope composition of reef-dwelling foraminifers subjected to varied pCO<sub>2</sub> seawater

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Ocean acidification in response to rising atmospheric pCO<sub>2</sub> is generally expected to reduce rates of calcification by reef calcifying organisms, with potentially severe implications for coral reef ecosystems. Various studies have revealed potentially dramatic responses in a variety of calcareous organisms to the range of pCO<sub>2</sub> values projected to occur over this century. In our previous culture experiment with reef-dwelling foraminifers, *Amphisorus kudakajimensis* and *Calcarina gaudichaudii* at five different pCO<sub>2</sub> conditions seawater for four weeks, net calcification of *A. kudakajimensis* was reduced under higher pCO<sub>2</sub>, whereas calcification of *C. gaudichaudii* generally increased with increased pCO<sub>2</sub>. The contrasting responses are possibly due to differences in calcification mechanisms, but the factors affecting these calcification mechanisms are poorly understood. In this study, to get better understanding of the effect of ocean acidification on foraminiferal calcification, we cultured three reef-dwelling foraminifers: *Amphisorus hemprichii*, belong to imperforate species, *Baculogypsina sphaerulata* and *C. gaudichaudii*, belong to perforate species, using same experiment systems in the seawater of five different pCO<sub>2</sub> conditions for twelve weeks and we address the response of carbon and oxygen isotope compositions of the carbonate shells of foraminifers. Oxygen isotope value of cultured foraminiferal tests under five varied pCO<sub>2</sub> seawater indicated no significant correlation to pCO<sub>2</sub> values. The oxygen isotope values stay constant within narrower range from carbonate ion concentration. On the other hand, carbon isotope of foraminiferal tests indicated heavy trend with rising pCO<sub>2</sub> in all species. Alteration of carbonate chemistry result from ocean acidification may be effect strongly on carbon isotope composition relate to metabolic system. In perforate species, carbon isotopes are close to DIC value with increasing CO<sub>2</sub>. It is possible that decreasing of metabolic CO<sub>2</sub> supply for the shell construction. In perforate species, both of oxygen and carbon isotope was lower than that in imperforate. For oxygen isotope variation possibility among species would be caused by their Mg-content concentration in calcite shells. The distinct difference in the level of carbon isotope values between pure calcite and perforate foraminifera might be influenced by the degree of dependency on metabolic CO<sub>2</sub> used for shell construction. While ~7% of the carbon used for calcification would be derived from respiratory for the perforate species, the imperforate species would use most carbon derived from bicarbonate ion of seawater directly because carbon isotope of shell is almost same to that of pure calcite. This study suggested that oxygen and carbon isotope of foraminiferal test have the potential to reveal difference in calcification mechanism of two species.

キーワード: 安定同位体比, サンゴ礁棲有孔虫, 海洋酸性化

Keywords: stable isotope, reef-dwelling foraminifera, ocean acidification

## 地球温暖化に伴う水温上昇および海洋酸性化が日本近海のサンゴ分布に及ぼす影響 ~ CO<sub>2</sub> 排出シナリオの違いから ~

### Projected shift of coral habitats around Japan under different future CO<sub>2</sub> emission scenarios

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We estimate the effects of both global warming and ocean acidification on potential habitats for corals around Japan under different future CO<sub>2</sub> emission scenarios (SRES A2 and B1), based on published estimates and newly developed datasets on sea surface temperatures (SSTs) and aragonite saturation states (OMEGA<sub>arag</sub>). The difference in the future coral habitats caused by higher SSTs and lower OMEGA<sub>arag</sub> between the two scenarios was significant, suggesting possible conserve coral habitats under the A2 and B1 scenarios, respectively. We conclude that both reducing CO<sub>2</sub> emissions and setting up conservation plans to reduce direct anthropogenic effects would be required to save corals in the future.

キーワード: サンゴ, 地球温暖化, 海洋酸性化, 気候モデル, CO<sub>2</sub> 排出シナリオ

Keywords: Coral, Global warming, Ocean acidification, Climate model, CO<sub>2</sub> emission scenario

## 温帯のサンゴ礁・サンゴ群集と最近の変化

## Temperate coral reefs and coral communities and their recent changes

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南北に長い日本では、南から北へとサンゴ礁地形やサンゴ群集の緯度勾配に沿った変化が観察される。これまで、サンゴ礁の北限は長崎県壱岐と考えられてきたが、ボーリングと年代測定により北限が対馬であることが確認された (Yamano et al., 2012)。このサンゴ礁はククメイシ科のサンゴで形成されており、沖縄など熱帯・亜熱帯で見られるミドリイシ科主体のサンゴ礁とは形成種が全く異なっている。最近、このサンゴ礁の近傍で、暖温帯性のエンタクミドリイシの定着が確認された。日本沿岸においては、1930年代から現在にかけての数時期にサンゴの調査が行われており、その結果をデータベース化することにより、エンタクミドリイシのみならず、熱帯・亜熱帯性のスギノキミドリイシ、クシハダミドリイシ、シコロサンゴが分布北上しており、北上速度は最大で 14km/年であることが明らかとなった (Yamano et al., 2011)。日本近海では最近 100 年間に水温が 1~1.6 度程度上昇しており、その水温上昇がサンゴ分布北上の原因と考えられる。サンゴは藻類と競合関係にあり、サンゴの北上や増加は沿岸海洋生態系を変えてしまう可能性がある。

キーワード: サンゴ, 北上, 地球温暖化

Keywords: coral, poleward expansion, global warming



## Biodiversity of upper mesophotic coral community in Okinawa. Biodiversity of upper mesophotic coral community in Okinawa.

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Mesophotic coral ecosystems (MCEs) are usually found at depth ranging from 30 to over 100 m depth. Mesophotic coral communities are often composed of both eurybathic tolerant species and species adapted to specific condition of the mesophotic zone. The taxonomic composition of such communities is still poorly known, yet important to conduct accurate paleoenvironmental interpretations of fossil reef deposits, especially in studies aiming to reconstruct past sea-level changes. Moreover, from a biological perspective, the Deep Reef Refugia Hypothesis (DRRH) states that mesophotic coral ecosystems, due to their more stable environmental conditions, may act as refugia for shallow water species to survive extreme climatic events and re-colonise shallower reefs in the future.

Recent global environmental changes affected seriously shallow coral reefs around Okinawa. The combination of major bleaching events and several typhoons lead to changes in coral communities with some species apparently extinct from several locations. Around Sesoko Island in the northern part of Okinawa, several corals species disappeared since 1999 and were not recorded since then (van Woesik et al. 2011). *Seriatopora hystrix* was one of those species.

During the recent survey of a mesophotic coral ecosystem located between Sesoko Island and Motobu Peninsula, high coral diversity and dense communities were found between 35 and 55 m depth including abundant populations of *S. hystrix* between 39 and 47 m. In order to estimate the coral biodiversity as well as the relationships between shallow and mesophotic corals, several genetic markers, both nuclear and mitochondrial, were sequenced for the samples collected. Symbiotic dinoflagellates were also identified. Here we will present the results of the molecular analyses showing the important coral diversity in this location. Our results also show intraspecific diversity within the population of *S. hystrix*. The genotypes of those deep populations correspond to genotypes previously observed from shallower reefs as well as to new genotypes. Such results suggest an absence of vertical structuring in Okinawan *S. hystrix* populations and support the (DRRH). In the future, and if shallow environmental conditions become suitable again for this species, deep populations of *S. hystrix* might be of critical importance for the re-colonisation of shallow coral reefs.

Reference: van Woesik R, Sakai K, Ganase A, Loya Y (2011) Revisiting the winners and the losers a decade after coral bleaching. *Mar Ecol Prog Ser* 434: 67-76

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キーワード: Mesophotic, Deep Reef Refugia Hypothesis, Seriatopora

Keywords: Mesophotic, Deep Reef Refugia Hypothesis, Seriatopora

## サンゴ礁の炭素循環研究への溶存無機炭素安定同位体比の応用

### Use of the isotope ratio of dissolved inorganic carbon for investigating the carbon cycle of coral reef ecosystems

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石垣島のサンゴ礁域において、溶存無機炭素 (DIC) の炭素安定同位体比 ( $^{13}\text{C}_{\text{DIC}}$ ) を測定し、その時空間変動を解析した。夏季 (9月) と冬季 (1月) に複数の異なる生物群集上で短期間 (6 - 24 時間) のモニタリングを実施した。全期間では  $^{13}\text{C}_{\text{DIC}}$  は -0.2 ‰ から +3.2 ‰ の間を変動した。 $^{13}\text{C}_{\text{DIC}}$  の時間変化は夏季と冬季とで異なっており、夏季の方がはるかに大きな時間変化を示した。昼間では光合成と石灰化による DIC の消費のため DIC の濃度とアルカリ度が減少すると同時に、 $^{13}\text{C}_{\text{DIC}}$  は上昇した。夜間には逆の時間変化が観察された。 $^{13}\text{C}_{\text{DIC}}$  を DIC の濃度に対してプロットした場合、時間変化に伴う勾配はサンゴ群集でも海草藻場でもほぼ同様であった。対照的に、 $^{13}\text{C}_{\text{DIC}}$  をアルカリ度に対してプロットすると、その勾配は枝サンゴ群集の場合よりも海草藻場やアオサンゴ群集の場合の方がやや大きくなった。これは両群集間での炭素同位体分別の違いを反映している可能性がある。DIC の濃度 (またはアルカリ度) が等しい場合どうして比較すると、海草藻場における  $^{13}\text{C}_{\text{DIC}}$  はサンゴ群集におけるそれに比べて必ず低くなっていた。これは、岸に近い海草藻場においては地下水由来の  $^{13}\text{C}_{\text{DIC}}$  の低い DIC の影響があるためと考えられる。群集間での同位体分別係数の違いを適切に補正できるならば、DIC 濃度・アルカリ度・ $^{13}\text{C}_{\text{DIC}}$  の3つの変数の測定結果を適当な数値モデルに当て嵌めることにより、サンゴ礁生態系における光合成量、石灰化量、呼吸量、地下水等による外部からの DIC 供給量を同時かつ定量的に評価することが可能になる。

キーワード: サンゴ, 海草, 炭素同位体比, 溶存無機炭素, 同位体分別, 地下水

Keywords: coral, seagrass, carbon isotope, DIC, isotope fractionation, groundwater



## 気候変動が温帯性サンゴの成長に及ぼす影響の飼育実験による検討

### Climate change influences on coral growth tested by a culture experiment of temperate species

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近年, 地球温暖化に伴う海水温の上昇により, 日本周辺で急速に北へ分布拡大するサンゴ(以下, 北上種サンゴ)が確認されている。しかし, 温暖化と同時に, 大気中 CO<sub>2</sub> 濃度の上昇に伴う海洋酸性化(海水の炭酸塩飽和度( )が低下する現象)が海水温の低い高緯度側から進行しており, 北上種サンゴや日本周辺の温帯北限域に生息するサンゴの成長を妨げる可能性が懸念されている。特に方解石に比べて海水に溶解しやすいあられ石(アラゴナイト)骨格を持つサンゴにとっての低下は, 石灰化に直接的に影響することが危惧されているものの, 北上種サンゴを含め, 日本周辺に生息する温帯性サンゴを対象にした近未来の環境変動に対する骨格成長の影響評価は行われていない。そこで本研究では, 厳密に環境を制御した飼育実験によって, 地球温暖化および海洋酸性化が, 本州沿岸の高緯度に分布する温帯性サンゴ類(ミドリイシ属)の成長に及ぼす影響について検討した。

飼育実験は5段階の温度区(13, 17, 21, 25, 29 )に対して2つの実験, 「調整・水温実験」と「非調整・水温実験」を行った。「調整・水温実験」は, 全温度区の二酸化炭素分圧を一定になるよう調整することで, 値を高温区から, 3.1 から 1.8 の範囲に設定した。これに対して「非調整・水温実験」では, 各温度区に二酸化炭素を添加しないことで 値を大きく変化させず, 結果として 値を 2.4 から 2.1 の範囲で比較的一定に保った。両実験とも飼育期間は6週間実施し, 実験期間中の光量や流量は一定の環境下で行った。サンゴ成長への温度・変化の影響評価は, (1) 生残率, (2) 水中重量法による骨格成長量, (3) 白化率の計測に基づいた。また, 骨格から生物組織を剥離した後, 走査型電子顕微鏡によりサンゴ骨格の微細構造を観察した。

温帯性サンゴの飼育実験の結果から, 「調整・水温実験」と「非調整・水温実験」の全サンゴ種において13 の温度条件下では白化後, 斃死することが明らかになり, 冬の低水温が日本周辺の温帯性サンゴの分布域の決定要因の一つになっていることが示唆された。一方, 両実験に共通した北上種の一つであるエンタクミドリイシの結果を詳細に比較検討した結果, 温度だけではなく海洋酸性化による炭酸塩の低下もまた, サンゴの成長量に負の影響を与えることが明らかになった。

キーワード: サンゴ, 地球温暖化, 海洋酸性化

Keywords: coral, global warming, ocean acidification

## サンゴ礁海域の環境・生態系変動の記録媒体としての潮上帯堆積物コアの有用性の検討

### Supratidal beach sediment cores as recorders of long-term environmental and ecological changes in coral-reef ecosystems

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Coral reef ecosystems have been degraded worldwide. Modeling and culturing studies have been conducted to predict future outcomes of coral reef ecosystems. However, few studies conducted long-term (10-100 years scale) environmental changes and associated ecological changes in coral reef ecosystems, data on which would provide insight into long-term effects of global environmental changes and anthropogenic impacts on coral reef ecosystems. Here we focused on supratidal sediment cores as potential recorders of long-term (10-100 year scale) environmental and ecological changes in coral reef ecosystems. Approximately two-meter sediment cores were taken from supratidal zones of Sesoko Beach (Sesoko Island, Okinawa) and Yakomo Beach (Okinoerabu Island, Kagoshima). Sedimentary structure, grain size composition, bioclastic composition, and radiocarbon ages of bioclasts (coral/mollusk/foraminifer) were examined. Based on sedimentary features and grain-size variations, cores were divided into three parts (lower, middle and upper units), each of which indicates intertidal, storm, and aeolian deposits, respectively. Radiocarbon ages of coral fragments suggest that the two-meter cores were deposited in recent times (after 1950 yr AD). Bioclastic compositions indicate no ecological changes since the deposition of these cores. The shell morphology and weight of *Baculogypsina* (symbiont-bearing hyaline foraminifers) indicate that the modern tests grew larger and heavier than fossil tests (ca. 1300 yr AD), which are possibly due to biological consequences of ocean acidification and global warming.