The impacts of ocean warming and acidification on the behavior and muscular system of marine animals

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海洋温暖化と酸性化が海産動物の行動と筋肉系に与える影響

第1章 General introduction

There are two major sources of ocean acidification; anthropogenic CO$_2$ and carbon capture and storage project (CCS). About 30% of anthropogenic CO$_2$ dissolves into the ocean and reacts with seawater causing decreasing seawater pH. The pH of ocean surface water has decreased 0.1 unit since the beginning of the industrial era. The IPCC had predicted that anthropogenic CO$_2$ will increase about 1000 and 1900 ppm by 2100 and 2300 respectively. The CCS was introduced for mitigating global climate change. The CCS can reduce CO$_2$ emissions by containing and injecting CO$_2$ into geological reservoirs via pipelines. Accidental leakage of stored CO$_2$ leakage through the seabed, which would impact benthic ecosystems around a leakage site, has been one of the major concerns about the CCS technology. In addition, global climate change also drives sea surface temperature increase. The IPCC predicted that sea surface could increase to 4°C by 2100. Numerous papers have revealed that ocean warming and acidification has shown negative impacts on calcification and physiological of marine organisms. Presently, we have little knowledge about how elevated temperature and CO$_2$ can affect the behavior and muscular system of marine animals, particularly in the important commercial marine animals. This study aimed to examine both the separated and combined effects of elevated CO$_2$ and temperature on behavior and muscle functions of Japanese anchovy, sea urchins and tiger prawn under the prediction of IPCC and Carbon capture and storage leakage.

第2章 Escape responses of the Japanese anchovy *Engraulis japonicus* under elevated temperature and CO2 conditions

An increasing number of papers have been published on the effects of ocean acidification and warming on fishes over the last several years. However, there is little information on how these environmental changes affect the swimming behavior of fish. This study examined the escape response under elevated CO$_2$ concentration and temperature of the Japanese anchovy *Engraulis japonicus*. Following acclimation to four conditions (CO$_2$ 400/1000 μatm, temperature 15/19°C) for one month, the fish were tested for escape response through kinematic analysis of startle reactions to a mechanical stimulus. The response was recorded with a high speed video camera of 500 frames per second. The result showed turning rate was significantly higher at 19°C than at 15°C. Neither CO$_2$ nor temperature affected the kinematic parameters analyzed (the escape trajectory, swimming velocity, acceleration, escape direction, or frequency of single and double bends), with the exception of the turning rate that was significantly higher at 19°C than at 15°C. However, we must clarify how future oceanic environmental changes affect escape responses of schooling fish and prey-predator interactions under more rigorous experimental conditions, to elaborate our prediction capacity for the trajectory of anchovy populations and thereby assess possible implications for anchovy fisheries.
第3章 The effect of elevated CO\textsubscript{2} on movement muscular system of sea urchins

It has been reported that sea urchins are highly vulnerable species to ocean acidification. Muscles are important organs for feeding and attaching substratum of sea urchins. At the present time, we have no information on how ocean acidification affects the muscular system of sea urchins. This study examined the feed intake, muscle function and protein profiles of the sea urchin (*Pseudocentrotus depressus*) under CO\textsubscript{2} concentration at 400 (control), 2000 and 10000 μatm. Feed intake had significantly become lower in CO\textsubscript{2} concentration 10000 μatm, while 2000 μatm did not affect feed intake. Histological observation revealed that cross-sectional area of retractor muscle fibers of the masticatory apparatus was smaller in 2000 and 10000 μatm than in the control. Muscle contraction force of tube feet was significantly reduced in 2000 and 10000 μatm compared to the control condition, while protractor and retractor muscle were no significant effect by CO\textsubscript{2}. Two-dimensional gel electrophoresis showed that eight spots changed in protein volume: six up-regulated, and two down-regulated. Using matrix-assisted laser desorption/ionization-quadrupole ion trap-time of flight mass spectrometry, three up-regulated spots (tubulin beta chain, tropomyosin fragment, and actin N-terminal fragment) and two down-regulated spots (actin C-terminal fragment and myosin light chain) were identified. The results suggest that elevated CO\textsubscript{2} could impair the tube feet muscle of sea urchins due to alteration of proteome composition, mainly associated with post-translational processing/proteolysis of muscle-related proteins. This finding might give a clue to understand the mechanism(s) of functional impairment of sea urchin muscles by elevated CO\textsubscript{2}.

第4章 The effects of ocean warming and acidification on early life stage of tiger prawn

The effect of ocean acidification and warming due to the elevated CO\textsubscript{2} conditions in the atmosphere on crustaceans is unclear. Early life stage is more vulnerable than the adult stage to environmentally changed conditions. The fertilized eggs of tiger prawn were exposed to four different temperature levels (28°C (control), 30°C, 32°C and 34°C) and four different sea water pH (8.1 (control), 7.6, 7.0 and 6.0). This study examined the hatching rate, survival rate, swimming performance and muscle histological. The results showed that the hatching rate significantly decreased in higher sea water pH, while the temperature had significantly reduced hatching rate at 32°C and 34°C when compared with the control. The survival rate of tiger prawn larvae were all reduced due to lower pH and increase temperature in comparison to the control group. The study on histology did not show different in both temperature and seawater pH treatments. The observation of swimming speed at post larval 15 have done only for temperature experiment. The result showed that swimming speed at temperature 30°C is higher than 28°C and 34°C.

第5章 General discussion

The results of this study suggested that each species has a different response to temperature and CO\textsubscript{2}. Fish seem to be more robust in future environmental conditions than the other two species. The results of my study showed that neither temperature nor CO\textsubscript{2} affected the escape response of Japanese anchovy. These results are different in comparison to the studies in coral reef fishes. It is not clear whether these differences in escape response between the species are due to the differences in life stages of test fish, test temperature or acclimation period or the neuromechanical nature of the kinematic behavior inherent to each species. In sea urchin, the result showed contraction force of tube feet decreased in high CO\textsubscript{2} groups. The lowered contraction force of the tube feet may partly be attributable to the effect of pH/CO\textsubscript{2} per se. However, it is also possible that the contractive machinery itself may have been disrupted as revealed by the proteomic analysis. For tiger prawn, current information only shows that seawater pH affected the early life stage of tiger prawn, while the optimum temperature of hatching and survival is 30°C and seawater pH is 7.6. However, further research needs to be conducted to continue to gain knowledge to ensure that the effects of temperature and CO\textsubscript{2} on behavior and/or muscle functions of these animals is understood.