高知大学学位授与記録

本学は，次の者に博士（学術）の学位を授与したので，学位規則（昭和２８年文部省令第９号）第８条の規定に基づき，その論文の内容の要旨及び論文審査の結果の要旨を公表する。

目　　次

ふりがな	ｺﾗﾙ ｼﾞｮﾈﾙ ﾏﾝｹﾞﾝﾃ
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学位記番号	甲総黒博第 31 号
学位授与の要件	学位規則第 4 条第 1 項該当
学位授与年月日	令和元年 9 月 20 日
学位論文題目	Diversity, host specificity, and parasitic effect of the bopyrid isopods infesting brachyuran crabs in Western Japan （カニ類に寄生するエビヤドリムシ科等脚類の西日本における多様性と宿主特異性、および、宿主に与える影響）
発表誌名	(1) Corral, J. M., Henmi, Y., Shiozaki, Y. and Itani, G. (2019) Parasitic effects of the bopyrid *Megacepon goetici* (Crustacea: Isopoda) on the varunid crab *Gaetice depressus*. Diseases of Aquatic Organisms, 135: 71-75. (2) Corral, M. J., Henmi, Y. and Itani, G. (2019) Two new records of Bopyridae (Crustacea: Isopoda) infesting brachyuran crabs from Japan. Kuroshio Science. In press.
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論文の内容の要旨

Bopyrid isopod is a marine parasite known to infest decapods such as crabs and shrimps. It's life history is unique for having two crustaceans as intermediate and definitive host. The three stages in the life cycle of the bopyrid isopods includes epicaridium, microniscus and cryptoniscus. The mature female bopyrid releases epicaridium larvae that attach to copepods as their intermediate hosts. These larvae feed on the hemolymph of the host copepods and metamorphose into microniscus larvae. The microniscus larvae then leave the copepods and metamorphose into cryptoniscus larvae, which in turn attach to the definitive host. They occur in the branchial chamber of crabs or shrimps, however, there are some bopyrid that attaches to the abdomen of the host depending on the sub-family. Some bopyrid species in the high latitudes infest numerous hosts while species in the warmer seas are restricted to three or fewer host species. High diversity of bopyrids can be found in the warmer regions along the Indo-Malay-Philippines archipelago. There are 605 species of bopyrids (as of 2012) recorded and the number may have increased at present. In Japan, 15 species of bopyrid has been recorded infesting brachyuran crabs, however, reports are limited on taxonomic descriptions but ecological or host-parasite relationships are rarely investigated particularly on bopyrid infesting brachyuran crabs.

This study has elucidated parasitic effects of bopyrids infestation on four brachyuran crabs found in Western Japan, recorded new locality for two previously recorded bopyrids, and revealed the life history of a bopyrid. Brachyuran crabs include the varunid crab *Gaetice depressus* infested with bopyrid *Megacepon goetici* (Kii

Channel, Wakayama Prefecture), varunid crab *Hemigrapsus takanoi* infested with *Megacepon* sp. (Uranouchi Inlet, Kochi Prefecture), portunid crab *Charybdis bimaculata* infested with *Allokepon hendersoni* (Tosa Bay, Kochi Prefecture) and goneplacid crab *Carcinoplax longimanus* infested with *Gigantione tau* (Tosa Bay, Kochi Prefecture).

From the four brachyuran crabs, *G. depressus* (n = 1,694), *H. takanoi* (n = 607), *C. bimaculata* (n = 2,601), and *C. longimanus* (n = 310), parasitic rate of bopyrid infestation was 3.60%, 4.61%, 0.55%, and 18.1%, respectively. Prevalence was not different between male and female host crab for *G. depressus*, *H. takanoi*, and *C. longimanus* except for *C. bimaculata*. Parasitic effect on the weight of male host *G. depressus* infested with *M. goetici*, *H. takanoi* infested with *Megacepon* sp., *C. bimaculata* infested with *G. tau* and *C. longimanus* infested with *A. hendersoni* was detected. Similarly, the reduction of weight was also evident on the female host of these brachyuran crabs (except for *C. bimaculata* due to a small number of female samples). Effect on weight of male and female host crab caused by the bopyrid was not investigated from the previous reports on brachyuran crabs. However, the author has associated this on nutritional drain on the host. Nutritional drain can be attributed to the feeding activity of the bopyrid in the hemolymph of the host. The feeding activity of the bopyrid caused nutrient drain or imbalance on the host crab affecting its natural growth not to mention the associated depleting effect on titers of reproductive hormones that may affect host reproductive activity. This negative effect on the host weight was the first report for brachyuran crabs infested with bopyrid isopod.

Bopyrid infestation caused negative effect on the secondary sexual character (chela) and abdomen width of male host crab. Reduction in the cheliped height was observed in male host of *H. takanoi*, *C. bimaculata*, and *C. longimanus* except for *G. depressus*. On the other hand, effect on abdomen width was evident on male hosts of *G. depressus*, *H. takanoi*, and *C. bimaculata* except for *C. longimanus*. Previous reports have indicated that negative effect on the secondary sexual character of male host was a result of the combination of nutrient drains, disruptions of the endocrine system, and secretion of gonad inhibiting hormones (GIH) by either the host or the parasite, though, physiological mechanism of these are not yet clear. The recent findings on the enlargement or feminization of male abdomen by bopyrid on pinnotherid crab (Yasuoka and Yusa 2017) brought us to investigate the effect on male abdomen on four studied crabs, however, enlargement of male abdomen was not observed.

Castration in female host was likely observed for *G. depressus* and *C. longimanus* due to the absence of parasitized ovigerous female (*H. takanoi* and *C. bimaculata* was not investigated due to a small number of parasitized female crabs). This negative effect on the reproductive capacity of female can be explained by the depleting titers of reproductive hormone and secretion gonad inhibiting hormones (GIH) by either parasite or the host. But as mentioned earlier, mechanism of these are still unclear.

The association of another parasitic castrator, the rhizocephalan barnacles, in *C. bimaculata* was also investigated on its parasitic effect and compared with the degree of parasitism with bopyrid isopod. Interestingly, the impact of infestation of either bopyrid and rhizocephalan on the host weight and secondary sexual character does not differ between them. However, both parasite have different impact on the abdomen of female host. Bopyrid reduces the size of female abdomen but the rhizocephalans caused an enlargement to the female abdomen. The author have concluded that the difference on the impact of infestation on the female abdomen may be because of the difference on their life history.

Collected number of parasites of *M. goetici* was sufficient enough to identify its life history stages. The following life history was identified for the female bopyrid of *M. goetici:* 1) cryptoniscus, attached to the female's

pleopods with elongated body, 2) undifferentiated larvae, attached to the tip between gill lamellae with prominent antennae and uropods with seta, 3) early juvenile female, found in between gill lamellae, with distinctive female features such as pleopods and uropod, 4) juvenile female, found on top of gill lamellae, segments of pleomeres are distinct, with oostegite partially but not completely closed, and 5) mature female, those with completely closed marsupium and with well-developed dorsal bosses. Breeding season of the parasite starts in spring season and ends in autumn. It was noticeable the declining ovigerous parasite from spring to autumn and eventually disappearance in the winter. It is hypothesize that cold temperature could halt the oviposition of egg. Settlement of bopyrid was also observed from spring to autumn. Difference on infestation was observed for the bopyrid *M. goetici* and *G. tau*. Early infestation was observed for *G. tau*. This was apparent due groupings of immature, juvenile and mature parasites in a succeeding order towards the larger sized crabs. This was also supported by the positive correlation between the size of the host and the parasite. A different case was observed for *M. goetici*. The wide distribution of immature parasite of *M. goetici* suggested that infestation was not limited on small crabs.

Finally, the present study have reported new locality of two studied bopyrid. *Allokepon hendersoni* added Tosa Bay in Japan as new locality which was previously collected in Bengal Bay and East China Sea. *Gigantione tau* added Tosa Bay and Wakasa Bay as locality which was also previously collected in East China Sea. The undescribed bopyrid of *H. takanoi* was also the first bopyrid parasite of *Hemigrapsus* crabs, that should be studied in detail in future.

Infestation of the bopyrids significantly affected the morphology and reproductive capacity of selected brachyuran crabs in Western Japan. However the low prevalence of parasites may not have significant effect on the population of brachyuran crabs, as a whole. However, studying parasitic effect on the crab population cannot be ignored because of the potential of affecting the host population, as observed in the extiction of shrimp population in the United States caused by infestation of an introduced bopyrid.

論文審査の結果の要旨

等脚目エビヤドリムシ科の甲殻類は、世界で600種余りが記載されており、エビ、カニなどの十脚目の甲殻類の鰓室や腹部に寄生する。エビヤドリムシ類は大型のメスと小型のオスの雌雄ペアで暮らしており、メスは宿主から吸血するために、宿主には成長不良や繁殖の抑制などの寄生的影響を与えることが知られている。しかし、そのほとんどは、エビ類や異尾類に寄生するエビヤドリムシ類で研究が行われているため、エビヤドリムシ類の生態の一般性を検証するには至っていない。そこで、学位論文提出者であるCorral氏は、カニ類に寄生するエビヤドリムシを用いて、宿主に与える影響を複数種で調査し、明らかに宿主に負の影響を与えることを確認した。また、カニ類に寄生するエビヤドリムシの生物多様性や生活史についても重要な知見を得ることができた。

論文は、研究の背景と目的を示した第1章と総合考察を行った第8章に加えて、異なる視点から研究された結果を詳述した6つの章に分けられる。本研究では、西日本各地で採集を行い、寄生者の生態を研究できるほどに宿主のカニ類を採集することができる対象として、4種のエビヤドリムシ類を定めた。その4種は、ヒライソガニ *Gaetice depressus* の鰓室に寄生する *Megacepon goetice*、タカノケフサイソガニ *Hemigrapsus takanoi* の鰓室に寄生する未記載種 *Megacepon* sp.、アカホシイシガニ *Charybdis bimaculata* の鰓室に寄生する *Allokepon hendersoni*、エンコウガニ *Carcinoplax longimanus* の鰓室に寄生する *Gigantione tau* である。第2章から第5章では、それぞれ、4種のエビヤドリムシ類が宿主に与える影響を論じた。第6章では、そのうちの1種の *M. goetice* の成長に伴う形態の変化と生活史特性について詳述した。第7章では、2種 *A. hendersoni* と *G. tau* を日本初記録として記述した。以下に、各章における発見について述べる。

第2章では、日本の潮間帯海岸において最も個体数の多いカニ類であるヒライソガニについて、和歌山の調査地でエビヤドリムシ類の *M. goetice* が3.6%の寄生率で寄生していること、宿主のコンディション（湿重量）と2次成長に関する形質、メスの繁殖に負の影響を与えることを明らかにした。普通種のヒライソガニですら、これまでその寄生者である *M. goetice* について全く注目されてこず、今後、カニ類の生態の研究をする際には、エビヤドリムシ類の影響を検討する必要があることを述べている。この章の内容は以下の参考論文となった。

Corral, J. M., Henmi, Y., Shiozaki, Y. and Itani, G. (2019) Parasitic effects of the bopyrid *Megacepon goetici* (Crustacea: Isopoda) on the varunid crab *Gaetice depressus*. Diseases of Aquatic Organisms, 135: 71-75.

第3章では、ヒライソガニと同様に日本の干潟域で個体数の多いカニ類であるタカノケフサイソガニについて、高知県の干潟でその寄生者である *Megacepon* sp. の影響を検討した。その結果、宿主のコンディション（湿重量）と2次成長に関する形質、メスの繁殖に負の影響を与えることを明らかにした。タカノケフサイソガニは、アジア産の個体がヨーロッパ等に移入しており、その原産地における寄生者の発見と生態の解明は、大きな意義がある。

第4章では、潮下帯に生息するフタホシイシガニに寄生する *A. hendersoni* と、カニ類の寄生者としてエビヤドリムシとともに著名なフクロムシ類の Sacculinidae sp. の寄生の影響を土佐湾の同一個体群で比較した。その結果、これまでの章と同様に *A. hendersoni* が宿主のコンディション（湿重量）と2次成長に関する形質、メスの繁殖に負の影響を与えることが確認できた。フクロムシも、エビヤドリムシと同様の影響を宿主に与えていたが、宿主のメスの腹部の発達への影響がエビヤドリムシとフクロムシで異なることを明らかにした。

第5章では、潮下帯に生息するエンコウガニに寄生する *G. tau* の調査を土佐湾にて行なった。カニ類に寄生するエビヤドリムシ類はそのほとんどの種がKeponinae亜科に属しているが、*Gigantione* 属のみ

が Pseudioninae 亜科に属している。系統の異なるエビヤドリムシ類の寄生生態を検討した結果、宿主に与える影響については、他の 3 種との違いは認められず、宿主のコンディション（湿重量）と 2 次成長に関する形質、メスの繁殖に負の影響を与えていた。しかし、宿主のサイズ別の寄生率に他の 3 種と異なる点があったことから、系統による生態の違いがある可能性が示唆された。

第 6 章では、季節毎に多くの個体を検討できた *M. goetice* について、宿主に着底した直後のクリプトニスクス幼生もふくめて各発達段階の出現状況を解析した。その結果、宿主の中型サイズの個体にもクリプトニスクス幼生や幼体が得られていることから、他のエビ類での研究例とは異なり、本種の着底は宿主の着底期に限らないことが明らかになった。

第 7 章では、*A. hendersoni* と *G. tauz* の形態を詳述し、この 2 種を日本初記録として記述した。これまで日本からは、12 属 15 種のエビヤドリムシ類がカニ類に寄生することが知られていたが、本研究の結果、12 属 17 種が分布することが明らかになった。この章の内容は以下の参考論文となった。

Corral, M. J., Henmi, Y. and Itani, G. (2019) Two new records of Bopyridae (Crustacea: Isopoda) infesting brachyuran crabs from Japan. Kuroshio Science. In press.

◆ 学位論文の評価

以上、カニ類の寄生者として、等脚目甲殻類のエビヤドリムシ類の影響を多角的に論じた Corral 氏の提出論文は、博士論文として申し分ない。黒潮圏科学の視点からみると、この甲殻類はアジア域で盛んに養殖されるワタリガニ類にも寄生しうるため、本論文で宿主に与える寄生の影響を評価し、種多様性と基礎生態について新たな知見を提供したことは、黒潮圏科学の理念に叶うものとなっている。

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学位授与の要件	学位規則第4条第1項該当
学位授与年月日	令和元年9月20日
学位論文題目	Habitat preference and low water temperature tolerance: key determinants in the successful colonization of tropical reef fishes in temperate waters under climate change （気候変動下での温帯域における熱帯性魚類の定着条件としての生息場所選好性と低水温耐性の重要性）
発表誌名	(1) Leriorato JC, Nakamura Y (2019) Unpredictable extreme cold events: a threat to range-shifting tropical reef fishes in temperate waters. Marine Biology 166: 110. https://doi.org/10.1007/s00227-019-3557-6
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論文の内容の要旨

Chapter 1: General Introduction

The persistent increase in ocean temperatures globally significantly affected the range distribution of most tropical marine organisms, causing range shifts on species sensitive to sea surface temperature (SST) increases—if not adapting—to avoid extinction (i.e., range contraction). However, most tropical reef fishes expanding ranges experienced conditions outside from their native range, e.g., different habitat structure, high thermal variability. Hence, this may require strategies and traits, e.g., ecological generalization, phenotypic plasticity, and physiological tolerance, to survive, adapt, and successfully colonize marginal novel environments.

Many of the tropical reef fishes were observed in temperate waters as a response to the favorable condition of the coral-tropicalized reef habitats, which have successfully expanded ranges consequent to the persistent ocean warming. However, the role of reef habitats in organizing the successful expansion of tropical marine organisms remains unresolved. In which, the lack of suitable habitat may potentially limit the range-expansion of tropical reef fishes with specific habitat requirements (i.e., habitat specialist), despite the persistent increase of winter temperatures and the consistent transport of poleward-flowing boundary currents.

The constant larval supply of tropical reef fishes to higher latitudes facilitated by poleward-flowing boundary currents serves as a prerequisite for their range expansion. However, the wider range of thermal variability and the low water temperatures in temperate waters during winter are known to physiologically limit the performance of most tropical reef fishes, impairing them to survive and become susceptible to potential predators. Hence, this potentially caused constraints on the successful poleward expansion of many

tropical reef fishes. Of which, winter remains the population bottleneck for most range-shifting tropical reef fishes. Yet, as the water temperature is predicted to increase amidst climate change, this may potentially favor the successful range expansion of tropical reef fishes, withstanding warmer winters.

This thesis tried to address the potential factors influencing the latitudinal distribution variability of range-shifting tropical reef fishes along the Kuroshio Current by assessing their distribution pattern in three climatic regions—tropical, subtropical, and temperate (Chapter 2), and further subjected representative congeneric species with varying occurrence in temperate-Kochi (southwestern Japan) to low water temperatures in a tank experiment (Chapter 3). Both the habitat availability, and suitability, and the low water temperatures appeared to have a significant impact on the assemblage structure of range-shifting tropical reef fishes in temperate waters, as revealed by the unprecedented occurrence of the extreme cold event in Kochi (Chapter 4). This thesis demonstrates that climatic changes not only alter the system functioning of marine ecosystems but also caused the contemporary range-shifts of many organisms. Of which, the key role of physiological climatic tolerance to winter water temperatures and ecological generalization (e.g., habitat generalist) are crucial factors in predicting a successful range-shifts. Thus, the extent as to which climate change may impact the marine ecosystems (e.g., fisheries and ecosystem services) is critical since ocean temperatures and frequencies of extreme events are predicted to increase amidst climate change, where impacts are inevitable and irrevocable (Chapter 5).

Chapter 2: Latitudinal distribution pattern of tropical reef fishes across three latitudinal climatic regions along the Kuroshio Current

Range-shifts in tropical marine organisms, including reef fishes, are more pronounced in western boundary regions. However, latitudinal distribution patterns of tropical reef fishes along the Kuroshio Current are poorly known, and despite evidences showing their range-shifts, many of tropical reef fish species are still found non-occurring in temperate waters. Since latitudinal population and environmental gradients are important predictors in understanding vagrancy of tropical reef fishes in temperate waters, this chapter aimed to determine the latitudinal distribution pattern of tropical reef fishes in the three climatic regions—tropical, subtropical, and temperate—along the Kuroshio Current.

This chapter selected three separate locations representing the three climatic regions along the Kuroshio Current, i.e., Philippines for tropical, Okinawa for subtropical, and Kochi for temperate. Fish assemblage structures were assessed in all the reef habitats within the respective regions in two different seasons (cool/winter and hot/summer) by underwater visual census, using SCUBA. Among the habitats identified in each region, coral habitats significantly harbored higher species richness and abundance, including the coral-tropicalized habitats in temperate-Kochi. Each climatic region had different fish assemblage structure, and dominant species, wherein Kochi appeared to have the least species richness and abundance, despite the noticeable occurrence of tropical reef fishes in the area. Also, the notable non-occurrence of some tropical reef fishes in temperate-Kochi may indicate that not all tropical reef fishes have successfully colonized temperate waters. Whereas, the clear seasonal pattern in higher latitudes—subtropical and temperate—and the significant declines on the abundance of some species in Kochi during winter, may indicate that winter water temperature is still a population bottleneck for most vagrant tropical reef fishes. The presence of coral habitats may have considerably facilitated the colonization of most tropical reef fishes in temperate waters. However, the latitudinal distribution pattern and the varying occurrence of some congeneric

species in temperate-Kochi may be due to their difference in tolerance to low water temperatures. In this chapter, species with year-round occurrences (with possible reproduction in temperate waters) were referred as adapted species while species showing low abundance to complete absence—during and after winter—and with no adult population in temperate-Kochi were tagged as non-adapted species.

Chapter 3: Physiological and behavioral responses of tropical reef fishes to low water temperature: differences between temperate water adapted and non-adapted species

Many of the tropical fishes transported to higher latitudes exhibited high mortality rate during winter. However, the recent significant ocean warming may allow some of these tropical vagrant species to tolerate winter conditions in temperate waters. Despite the mounting evidence of tropical fishes expanding ranges to temperate regions globally, little is known how these species adapt to local conditions (e.g., winter), and how closely-related species differ in physiological tolerances to low temperatures. Since winter mortality *in situ* is difficult to quantify, this chapter aimed to demonstrate the temperature-specific physiological performances and behavioral responses of congeneric adapted and non-adapted tropical fishes to low temperatures in a tank experiment.

This chapter subjected congeneric adapted and non-adapted species from two fish families, Pomacentridae and Chaetodontidae. Each of which has different latitudinal distribution pattern and occurrence in temperate waters of Kochi, central Tosa Bay (see Chapter 2). Results have shown that low water temperatures affected both the adapted and non-adapted species resulting in declines on their feeding rate as the temperature approached 15°C (lowest winter temperature in Tosa Bay). However, non-adapted species had significantly higher mortality rates than their congeneric adapted species. Most of which also have resulted in a marginally higher temperature ranges on behavioral responses, e.g., minimum acclimation temperature, feeding cessation, and critical thermal minimum, compared with their congeneric adapted species. This indicates that adapted species may physiologically tolerate winter water temperatures than non-adapted species, thereby potentially allowing them to survive and colonize higher latitudes. Such trait is important and a known pre-requisite for successful colonization. Winter temperatures are predicted to increase amidst persistent ocean warming, thereby potentially allowing not only the adapted but may favorably allow non-adapted species to thrive and colonize temperate waters.

Chapter 4: Unpredictable extreme cold events: a threat to range-shifting tropical reef fishes in temperate waters

Tosa Bay, southwestern Japan is one of the global hotspots of tropicalization, where habitat-forming tropical corals have become established as a result of ocean warming. The poleward establishment of corals may have been facilitating the successful colonization of tropical reef fishes in the temperate waters. However, climate change has also caused an increasing occurrence of extreme weather events, e.g., extreme cold events. Such cold events are known to have adverse consequences on corals greater than the effects of elevated temperatures. However, no published information demonstrated how such cold events affect range-shifting tropical reef fishes in temperate waters.

This chapter semiannually assessed (in winter and summer) the tropical reef fish assemblage structure in Tosa Bay for two years (2017-2018), fortuitously covering the unprecedented extreme cold event that occurred in the bay during the winter of 2018. The event caused an extremely low sea surface temperature (SST) during the

winter resulting in a rapid coral bleaching and the subsequent mortality of more than 90% coral during summer. Both the extremely low SST and the massive coral loss resulted in significant declines on the species richness and abundance of tropical reef fishes in the area. In which, the extreme winter affected both the breeding and the non-breeding population while the massive coral loss substantially impacted the coral-associated species, primarily the corallivore fishes. This chapter is the first to elaborate the potential impact of the extreme cold event on the persistent establishment of tropical reef fishes in temperate waters, thus highlighting its potential threat on the stability of temperate waters as a refuge for range-shifting species amidst increasing ocean warming.

Chapter 5: General Discussion

Climate change has caused adverse consequences to the earth's ecological system structure and functioning. Of which, many marine organisms (e.g., corals and reef fishes) are the most affected as they are more vulnerable to rapid changes in ocean temperatures, thus, resulted in their contemporary range-shifts.

Establishments of marine protected areas (MPAs) may have provided conservation to commercially exploited species and contributing to reef resilience as well as benefits to fisheries through leakage of 'surplus' adults (spillover) and larvae (larval replenishment). Of which, effects of climate change and the climate-mediated contemporary range-shifts might be of less concern when it comes to fisheries management since most of the reef fishes are the small-sized non-commercially targeted species where impacts may not directly affect large-bodied commercially important species. However, these MPAs offer limited protection from the impacts of extrinsic disturbances, e.g., climate change. Wherein, commercial fisheries may still be susceptible to additional impacts from the contemporary range-shifts of reef fishes as they constitute part of its trophic niche. Nevertheless, as climate change causes significant changes to the coral reef ecosystem, this could have implications on fisheries given that corals serve as a source of food and refuge to many marine organisms. This may subjectively affect the biomass of all trophic levels in the marine ecosystem (including the targeted fisheries) and may likely increase the risk of fisheries collapses and may affect the services it provided. Hence, understanding how organisms (e.g., reef fishes) respond to contemporary climatic changes may help facilitate in effectively managing the impacts of climate change and develop sustainable planning and management strategies.

論文審査の結果の要旨

1980 年代以降に顕著になってきた地球規模の温暖化に伴って、世界各地で熱帯域の生物の分布域が温帯域に拡大している。このような現象は海域でもみられ、特に熱帯域から極方向に流れる暖流付近の沿岸域から多く報告されている。熱帯域から温帯域に海流によって輸送された熱帯性生物が、冬季海水温の上昇によって越冬・定着できるようになったというのが上記現象を引き起こす基本的なメカニズムと考えられている。

黒潮の影響を強く受ける土佐湾でも、熱帯・亜熱帯域を分布の中心とする海藻やサンゴの種が 1990 年代以降に出現・定着していることが報告されている。魚類については過去のデータがないために経年比較をすることができないものの、沿岸域に造礁サンゴ群落（以下、サンゴ場とよぶ）が発達してきていることから、サンゴ場を主生息場所とする熱帯性の魚種にとって住みやすい環境になってきていることが指摘されている。

土佐湾に出現する熱帯性魚類をみると、沖縄でみられるような魚種がすべているわけではない。どのようなタイプの魚種が土佐湾に多いのか、あるいは少ないのか、またどのような理由でその差が生まれるのか、という点を明らかにすることは、温暖化に伴ってどのような生理生態的特性を持った魚種がいち早く温帯域に定着するのか、という問いを解く鍵となる。

本学位論文では、熱帯性魚類の黒潮流域圏における緯度分布と各生息場所における分布様式を野外観察によって調べた上で、土佐湾に多く出現する種とそうでない種の低水温耐性の違いを水槽実験によって明らかにすることで、サンゴの有無や冬季の低水温耐性というものが多くの熱帯性魚類が温帯域に定着する上で重要であることを具体的に示した。研究成果の一部は既に国際誌に論文として掲載されている。

Leriorato JC, Nakamura Y (2019) Unpredictable extreme cold events: a threat to range-shifting tropical reef fishes in temperate waters. Marine Biology 166: 110. https://doi.org/10.1007/s00227-019-3557-6

本学位論文は５つの章で構成されている。第１章の総合序論と第５章の総合考察を除く第２章から４章が研究成果となっている。上記論文は第４章の研究成果である。各章の概要はそれぞれ次の通りとなっている。

第１章の総合序論では、温暖化に伴う熱帯性生物の極域への分布拡大に関する近年の研究を紹介するとともに、温帯域における造礁サンゴの定着とサンゴ場の発達が冬季の水温の上昇とともに熱帯性魚類の温帯域での定着の重要な条件となるという仮説を立てることで、第２章以降の研究内容への導入部分の役割を果たしている。

第２章では、黒潮流域圏における熱帯性魚類の緯度間での分布について調べた結果を示している。温帯域の高知、亜熱帯域の沖縄本島、熱帯域のフィリピン・ミンダナオ島においてそれぞれ２か所調査地を設定し、各調査地に存在するすべての生息場所に出現する魚類（ここでは、スズメダイ科、チョウチョウウオ科、ブダイ科、ニザダイ科）の種数と個体数を高知と沖縄本島では冬季と夏季に、ミンダナオ島では雨季と乾季に潜水観察によるベルトトランセクト法を用いてそれぞれ調べた。その結果、どの調査地でもこれら魚類の大部分の種は、サンゴ場を中心に出現すること、また、季節間の種数と個体数の差が高知で特に大きかったことから、温帯域に熱帯性魚類が定着できる重要な条件として、サンゴ場の存在と、冬季の低水温に対する耐性を挙げている。

第３章では、熱帯性魚類の低水温に対する耐性について調べた結果を示している。土佐湾で越冬や産卵が確認されている種（以下、温帯適応種）とそうでない種（温帯非適応種）をスズメダイ科とチョウチョウウオ科の同じ属の中からそれぞれ１種選び（スズメダイ科２属、チョウチョウウオ科１属）、土佐湾沿岸の晩夏の水温（25℃）から冬季の最低水温（15℃）に至るまでの温帯適応種と温帯非適応種との間における摂食行動や死亡率などの違いを水槽実験で調べた。その結果、温帯非適応種は温帯適応種と比べて低水温時における死亡率が高く、また、水温低下に伴う摂食行動や成長率なども顕著に低下した。以上の結果から、温帯域に定着する条件として冬季の低水温に対する耐性が重要であることを明らかにした。

第４章では、2018 年初頭に起きた西日本の記録的な大寒波によって生じた土佐湾の造礁サンゴ群集の大規模な死滅現象に着目し、造礁サンゴの死滅前後の夏季の魚類群集の構造を比較することで、生サンゴの有無が温帯域における熱帯性魚類の出現に与えた影響について記している。生サンゴの被度が９割から１割に減少したことで、そこに出現する熱帯性魚類（スズメダイ科、チョウチョウウオ科、ブダイ科、ニザダイ科）の種数と個体数は８割ほど減少し、特にサンゴ食魚類はほぼ姿を消した。これらの結果から、生サンゴの存在が多くの熱帯性魚類の加入や定着に重要であること生サンゴの大量死滅現象を通して確認している。

第５章の総合考察では、本研究で得られた成果から温帯域における魚類群集構造の将来的な変化について考察するとともに、気候変動下でのサンゴ場における魚類の保全・管理策に対する方向性について考えを述べている。

◆　学位論文の評価

気候変動に伴う沿岸生物群集の変化は、沿岸域の生物資源を利用する社会にも影響を与える。このような変化に対処するには、生態系の変化とそのメカニズムを明らかにし、そこから立てられる予測を基にした対策を講じる必要がある。本研究で得られた知見は、学術的な重要性だけでなく、上記課題にも応用できるなど共生社会の実現を目指す黒潮圏科学の理念にも合う点で評価できる。