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本学は、次の者に博士（学術）の学位を授与したので、高知大学学位規則第１５条に基づき、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。

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高 知 大 学 学 報

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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。

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論文の内容の要旨

Costal marine waters and especially embayments throughout the world are under constant and increasing environmental stress, and therefore need constant monitoring for the proper coastal management. Ariake Bay is the Kyushu Island's largest bay and has the largest tidal flat area in Japan. Its inner part presents the highest tidal range from Japan, and the strong current caused high turbidity water by resuspended sediment particles. The bay is utilized for various activities as fisheries, clam extraction and "nori" (*Porphyra tenera*) culture. This bay is also known to present a number of endemic species, some of these are considered as continental relict species. However since the 1990s it have suffered decline on the fish and shellfish productions, and more recently red tides that damaged the seaweed production.

The aim of the present study is to investigate the spatial and temporal distribution patterns of copepods in Ariake Bay, because copepods are the main component of zooplankton as well as useful indicator organisms for environments. The thesis is divided into two main parts each presented in Chapters 2 and 3, respectively.

The goal of Chapter 2 entitled "Characteristics and regional classification of copepod community in Ariake Bay with note on comparison with three decades ago" is to determine the characteristics and regional classification of the copepod community in the whole Ariake Bay. To accomplish this goal, a plankton survey was carried out throughout　Ariake Bay in March 2009 (Fig. 1), with vertical tows

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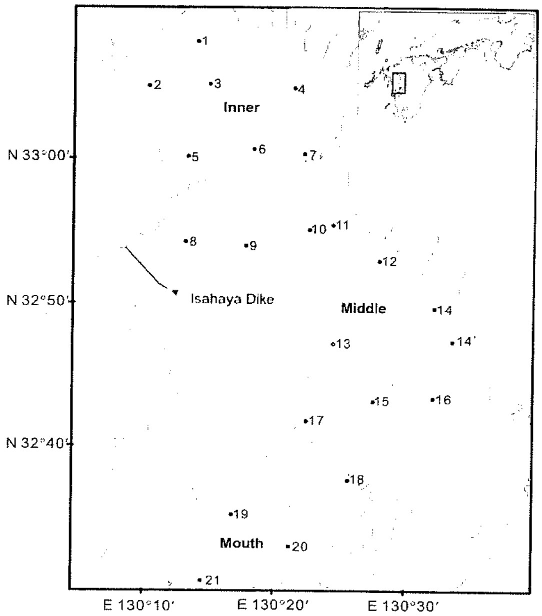
of a 0.1-mm mesh plankton net, along with measurement of temperature, salinity and transparency. The copepod community distributions obtained by the present survey and the past ones made during different season of October 2004 and 2005 by Monde (2006), were analyzed in relation to environmental conditions. Discussion is made on the comparison with other bays to clarify the characteristics of the copepod community in Ariake Bay, and also with the 1970s studies (Hirota 1974, 1977, 1979) to evaluate the long-term change. The results of analysis and discussion are as follows.

(1) The dominant copepods in Ariake Bay were *Oithona davisae* in January and March but *Microsetella norvegica* in October (Table 2.1).

(2) The population of *O. davisae* was concentrated in the inner and middle regions in January (Fig. 2.3e) and innermost region in March (Fig. 2.3i). In contrast, the subdominant species *M. norvegica* and *Paracalanus parvus* s.l. were distributed more abundantly in the middle and mouth regions than in the inner region in January (Fig. 2.3f-h).



(3) Cluster analysis revealed that the copepod communities from the three cruises were divided into two groups, which covered the warmer (October) and colder (January and March) seasons, respectively (Fig. 2.4).

(4) The copepod communities from each cruise were clustered into two groups covering generally the inner to eastern-middle region and the western-middle to mouth region, respectively (Fig. 2.5).

(5) The SIMPER analysis using PRIMER™ indicated that *O. davisae, M. norvegica* and/or *Acartia omorii* were the main contributors to the dissimilarities between the clustered groups.

(6) The BIOENV analysis indicated that in October and January transparency was the most highly correlated environmental parameter with the copepod community (Fig. 2.6).

(7) Comparing with similar sized, eutrophic Tokyo and Osaka Bays, Ariake Bay differs from Tokyo Bay in the dominance *M. norvegica*, which is less abundant in Tokyo Bay, and from Osaka Bay in high

abundance of *O. davisae* even in winter.

(8) he present results of the dominant copepod distributions and those of clustering analysis were similar to those analyzed on the data three decades ago, suggesting that the copepod community in Ariake Bay has not notably changed during the last three decades regardless of the environmental degradation for recent decades.

(9) Cluster analysis revealed that the copepod communities from the three cruises were divided into two groups, which covered the warmer (October) and colder (January and March) seasons, respectively.

(10) The copepod communities from each cruise were clustered into two groups covering generally the inner to eastern-middle region and the western-middle to mouth region, respectively (Fig. 2.5).

(11) The SIMPER analysis using PRIMER™ indicated that *O. davisae, M. norvegica* and/or *Acartia omorii* were the main contributors to the dissimilarities between the clustered groups.

(12) The BIOENV analysis indicated that in October and January transparency was the most highly correlated environmental parameter with the copepod community (Fig. 2.6).

(13) Comparing with similar sized, eutrophic Tokyo and Osaka Bays, Ariake Bay differs from Tokyo Bay in the dominance *M. norvegica*, which is less abundant in Tokyo Bay, and from Osaka Bay in high abundance of *O. davisae* even in winter.

(14) The present results of the dominant copepod distributions and those of clustering analysis were similar to those analyzed on the data three decades ago (Figs. 2.7 and 2.8), suggesting that the copepod community in Ariake Bay has not notably changed during the last three decades regardless of the environmental degradation for recent decades.

(15) Cluster analysis revealed that the copepod communities from the three cruises were divided into two groups, which covered the warmer (October) and colder (January and March) seasons, respectively (Fig. 2.4).

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(20)The present results of the dominant copepod distributions and those of clustering analysis were similar to those analyzed on the data three decades ago (Figs. 2.7 and 2.8), suggesting that the copepod community in Ariake Bay has not notably changed during the last three decades regardless of the environmental degradation for recent decades.

The goal of Chapter 3 entitled "Seasonal and interannual changes of copepod community in the innermost part of Ariake Bay from 2002 to 2010" is to know the temporal (seasonal and interannual) characteristics of copepod community in the inner part, which is characterized by turbid water and serves as the Japan's biggest nori farming ground. For this purpose, monthly net-plankton samples, which were taken from eight stations in the inner part from March 2005 to March 2010 by the Saga Prefectural Ariake Fisheries Research and Development Center, were examined, and the eight-year data on copepod community since 2002, including Monde's (2003 and 2006) three-year data from March 2002 to February 2005, were analyzed in relation to environmental parameters. Analysis for seasonal and interannual variations of copepods in Ariake Bay is made for the first time by the present study. The results of the analysis and discussion are as follows.

(1) *Oithona davisae* was the almost exclusively dominant throughout the year with the mean density (242.2 ind. L^{-1}) in all samples comprising 81.4% of total copepods (Table 3.1). The other abundant copepods were *Parvocalanus crassirostris* (6.0%), *Microsetella norvegica* (5.6%), *Paracalanus parvus* s.l. (2.3%) and *Acartia omorii* (2.2%).

(2) *Oithona davisae* was very abundant from June to August, generally with the highest abundance in July (Fig. 3.17), and its monthly mean density was often beyond 1000 ind. L^{-1}.

(3) Seasonal high abundances of the subdominant copepods were seen from July to September for *Parvo. crassirostris* (Fig. 3.18), from August to September for *M. norvegica* (Fig. 3.19), and *Acartia omorii* from March to May (Fig. 3.21). *Para. parvus* s.l. did not show remarkable seasonal variation but the most abundant in May (Fig. 3.20).

(4) Interannual variability of the copepod density was analyzed using the mean density of each fiscal-year. The highest mean density was observed in 2007 for *Oithona davisae*, *Parvo. crassirostris* and *Para. parvus* s.l., but in 2009 for *M. norvegica* and 2008 for *A. omorii* (Figs. 3.23 and 3.24).

(5) Clustering analysis using the monthly mean data revealed that the copepod community was divided into three seasonal communities, viz. colder, early-warmer and late-warmer season communities (Figs. 3.25 and 3.26). The month when the colder season community was replaced by the early-warmer season community became earlier in the year since 2003.

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(6) Pearson's correlation coefficients between the copepod density and environmental parameters were examined. *Oithona davisae* and *Parvo. crassirostris* exhibited significant positive relationship with temperature, nutrients (DIN, NO) and chlorophyll-*a*. Comparing with this, *A. omorii* showed the reversal relationship with these parameters.

(7) No notable significant relationship was detected between interannual variations of copepods and parameters.

(8) However, significant correlations of the annual *O. davisae* density were found negatively with diatom red tides during the summer and positively with the density of chaetognaths. This suggests harmful effects of diatom blooms and supportive effects of chaetognaths by reducing competitive copepods.

(9) The annual mean density of *O. davisae* was seemingly correlated positively with both winter and summer temperature. This suggests that temperature during not only summer but also winter, when *O. davisae* maintains the population for the next season, may be an important factor affecting their population density in summer.

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有明海は日本最大の泥干潟を有し，その湾奥部は強い潮流によって底泥が撹拌され，きわめて濁度の高い水域となっている。湾奥部を中心としたノリ養殖は全国一であり，また，固有種や大陸遺存種が生息していることでもよく知られ，水産的にも学問的にも貴重な湾である。しかし，1990 年代から魚貝類の生産が減少し，最近ではノリ養殖に被害を及ぼす赤潮が起こっている。とくにノリは有明海最大の水産物であるが，植物プランクトンの増加によって栄養塩欠乏が起こり，その結果，ノリが白化して商品価値が落ち，甚大な被害が発生している．そのため，植物プランクトンのブルーム（大増殖）がなぜ起こるかという問題を解明するために，栄養塩や濁度をはじめとしてさまざまな海洋環境の調査が行われているが，植物プランクトンの摂食者である動物プランクトンの調査は 1980 年以降ほとんどされていない．動物プランクトンの摂食圧は植物プランクトンの現存量を決める大きな要因の一つであり，動物プランクトンの種組成，現存量，分布に関する研究は植物プランクトンの増減の要因を解明する上で不可欠である．

本研究の目的は，そうした有明海の最近の問題を背景に，数量的に動物プランクトンのほとんどを占めるカイアシ類について，その空間的，時間的分布様式を調べ，過去に行われた研究データと合わせて解析を行い，有明海のカイアシ類相の特徴を明らかにしたものである．また，約 30 年前に有明海で行われた動物プランクトン調査の研究結果と比較し，現在のカイアシ類相がどのように変わったかを考察している．博士課程における主要な研究成果は学位論文の 2 章と 3 章で述べられており，それぞれ具体的に行った研究方法や結果，考察は次の通りである．

2 章では，2009 年 3 月に有明海湾内 22 点において目合 0.1 mm のプランクトンネットを用いて底からの鉛直曳きを行い，幼体を含めたカイアシ類全種の同定と計数結果から，分布様式を明らかにしている．また，過去に門出（2006）によって 2004 年 10 月と 2005 年 1 月に行われた調査結果のデータを合わせて解析し，カイアシ類相の分布について一般的傾向を明らかにしている．まず，湾内の平均密度としは *Oithona davisae* という内湾種が優占し，最湾奥部で多くなる結果になった．ただし，2004 年 10 月では *Microsetella norvegica* が最優占し，過去の調査を含めた全データのクラスター解析では，暖水期（10 月）と冷水期（1，3 月）のデータに大きく 2 分され，カイアシ類相は地理的違いより季節的違いが大きいことを示した．3 回の調査ごとの分析では，群集は湾奥部側と湾口部側に 2 分され，湾中央部は西側水域が湾口側群集になり，東側水域が湾奥側群集になる傾向があった．また，その分布は水温や塩分より濁度と相関することを示した．

以上の結果から，有明海のカイアシ類相の特徴は，東京湾や大阪湾と比較した場合，*Oithona davisae* と *Microsetella norvegica* がともに優占することであり，また，湾中央部の東西で湾内のカイアシ類相が 2 分できる傾向は，1970 年代に行われた動物プランクトン調査のデータを同じ方法で解析した場合も同じであり，かつ優占種も変わらないことから，有明海のカイアシ類相は 30 年前と顕著には変わっていないと結論している．

3 章では，佐賀県有明水産振興センターが湾奥部で新月の日に行っている『浅海定線調査』のプランクトンサンプルのうち 2005 年 3 月から 2010 年 3 月までの 11 定点の約 700 本のサンプルを分析した．同じく，浅海定線調査のサンプルを分析した門出 (2003，2006) のデータを合わせて 8 年分のデータを解析し，カイアシ類相の季節変化と経年変化をまとめている．その結果， *Oithona davisae* が年間を

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通して圧倒的に優占し，その年間平均密度は全カイアシ類の 81.4%を占め，次いで *Parvocalanus crassirostris*, *Microsetella norvegica*, *Paracalanus parvus* s. l., *Acartia omorii* が多いことが示された．最優占種である *O. davisae* は 6 月から 8 月まで非常に高密度になり，8 年間の平均密度では 7 月に最大に達し，単年度の月平均値ではしばしば 1000 ind. L^{-1} を越え，他の海域からは報告がないきわめて高い密度であることが明らかにされた．また，2 章の全湾調査で 2004 年 10 月に最優占種となった *M. norvegica* は湾奥部でも多く，季節的には 8～9 月に多くなり，1 定点での最高密度は 1400 ind. L^{-1} に達している．これも，本種の密度として他に例がなく，有明海湾奥部の生産性の高さを示す結果であるといえる．各年各月の平均データを用いたクラスター解析では，カイアシ類群集は冷水期，暖水期前半，暖水期後半の 3 つの群集に別れ，冷水期群が暖水期群に入れ替わる月は 2003 年以降年々早くなる傾向を明らかにしている．有明海カイアシ類群集の鍵種といえる *O. davisae* の経年変動では，2007 年に最も密度が高くなり，その経年変動と様々な環境要因との相関を調べた結果，珪藻赤潮の規模と有意な負の相関があるという興味深い発見をしている．その相関の理由として，*O. davisae* の摂食圧と近年明らかになってきた珪藻食による繁殖阻害作用をあげている．また，肉食性動物プランクトンであるヤムシ類との有意な正相関を発見し，*O. davisae* と競合する他のカイアシ類に対するヤムシ類のサイズ選択捕食の可能性を指摘した．これらの考察は推測の域はでないものの，興味深い今後の研究テーマとなることであろう．

有明海は，黒潮流域圏の中でも生物生産性の高い有数の湾であることが知られており，また，泥粒子による高濁度な環境は東南アジアや中国大陸沿岸の環境に似ていると言われ，それが日本では有明海にしか分布しない大陸共通種（大陸遺存種）が多くいる理由であると考えられている．有明海のカイアシ類相の水域分布や，季節的・経年的変化を明らかにした本研究の成果は，赤潮等の最近の有明海の問題解明の一助となるだけでなく，将来の黒潮流域圏沿岸の動物プランクトン研究にとっても重要な参考研究となることが期待される．以上のことから，本論文は黒潮圏科学専攻にとって相応しい論文であると評価できる．