

氏 名 高 橋 邦 夫

学位（専攻分野） 博士(理学)

学 位 記 番 号 総研大甲第762号

学位授与の日付 平成16年3月24日

学位授与の要件 数物科学研究科 極域科学専攻

学位規則第4条第1項該当

学 位 論 文 題 目 Life cycle strategy of herbivorous copepod  
*Calanoides acutus* (Crustacea, Calanoida) in  
the Antarctic Ocean

論 文 審 査 委 員	主 査	教授	内藤 靖彦
		教授	小達 恒夫
		教授	福地 光男
		教授	寺崎 誠 (東京大学)
		助教授	谷村 篤 (三重大学)
		博士	Graham W.Hosie (オーストラリア南極局)

## 論文内容の要旨

The dominant Antarctic herbivorous copepod *Calanoides acutus* accumulates large quantities of lipids as an energy reserve during the productive season, and migrates to deeper waters to enter a state of diapause during winter month. Lipid storage is a major adaptation to the extreme seasonality of phytoplankton growth in the polar regions. Therefore, storage lipid is an important factor affecting their biological activity. However, there have only been sporadic studies on copepod lipid storage and life cycles in Antarctic waters. Taking the opportunity of multi-ship observations in the Indian sector of the Antarctic Ocean, the objectives in the present study were to examine both the preserved samples by a net sampling, and physiological characteristics of *C. acutus* over the whole summer, and to develop hypotheses of the species life cycle strategy. This is the first time that such time serial observations over the whole summer, combined with a comprehensive approach to the species life cycle from both preserved samples and physiological characteristics have been conducted.

Copepods were collected on RSV Aurora Australis in November 2001, Hakuho Maru in January 2002 and RV Tangaroa in February 2002 along a transect on 140°E between 61 and 66.25°S using a twin NORPAC standard net. Closed 2-l jars served as cod ends to avoid damage to the specimens.

Until recently it had been accepted that the life span of *Calanoides acutus* was one-year, and the overwintering stages are predominantly copepodite V (CV) stage. They molt to adulthood and mature at depth, and fertilized females ascend to the surface waters for spawning. However, from the observation of this study, CV stages were dominant in the surface in November ranging from 10 to 40% of the total population. In previous studies, the development rate of *C. acutus* was reported to be around 15 to 30 days per copepodite stage. Therefore, CV stages at the surface in November had not developed from eggs in that spring, but had overwintered, and had not been able to mature at depth prior to ascending to the surface. Therefore, they belong to a second-year group.

In addition, from the results of the dry weight and lipid weight, the dry weight of *Calanoides acutus* CV in January was double that of those of November, while the lipid weight did not change dramatically (34 and 40%). Thus, CV stages after overwintering had preferred to store lipid as energy reserves, and maintained high lipid contents during summer months, with surplus energy probably used for growth. There was also high variation in the amount of lipid storage between individuals in February. The existence of CV stages in February that had developed from eggs in that spring was reasonable based on the previous reports of development rate of *C. acutus* (15 to 30 days/copepodite stage). It is difficult to consider that CV stages with high lipid contents in November and January had used storage lipid at the surface prior to previous the winter. Therefore, they are probably new generation developed from eggs in the current spring.

In this way, as a result of evaluation from both preserved samples and physiological characteristics, *Calanoides acutus* could probably have a life cycle of more than two years. A

first-year group of lipid-poor individuals developed from eggs in the current spring co-existed in autumn with a second-year group, lipid-rich individuals with high lipid contents, evident in November, that had already overwintered once as a CV stage.

The phytoplankton bloom at the sea-ice edge is often discussed as a factor affecting distribution, growth and reproduction of copepods inhabiting seasonal ice zone. The spatial variability of stage composition in November was also observed in this study associated with ice-edge retreat. Spring reproduction of *Calanoides acutus* in the seasonal ice zone coupled with primary production associated with the ice-edge, allowed suitable growth from eggs to early copepodite stage. In this study, only CV stage and adult female were found at the southern (continent) part of the transect in November, and young CI to CIII stages that had developed from eggs in that spring, were found towards the north. Therefore, the spawning period was late in the southern end, due to the time lag of the retreating ice-edge and phytoplankton bloom development in this study site. The results of stage composition in January confirmed that the timing of the life cycle of *C. acutus* was late in the southern region due to the time lag in spawning.

Copepods in the southern end of the transect, experienced a short growth period due to the time lag of the retreat of sea-ice. They had a relatively high lipid weight, high weight of wax ester, high proportion of long-chain fatty acids (20 and 22), a lipid-dominated metabolism and a low efficiency of lipid storage. On the other hand, relatively low lipid weight, low weight of wax ester, high proportion of short-chain fatty acids (16 and 18), a protein-dominated metabolism and a high efficiency of lipid storage were observed in CV stage at the northern end with a long growth period. These results suggested that *Calanoides acutus* CV stage in southern regions had completed preparation to overwinter as first-year CV stages compared to those of the northern regions. The proportion of the second-year CV stage in the south in February was higher than in the proportions north. Thus, in the southern end, individuals with insufficient time to grow to lipid-rich CV stage in their first summer could probably adopt the two year life cycle strategy and overwinter. In other words, sea-ice is one of the controlling factors affecting the growth period, and determining the life span of *Calanoides acutus*.

## 論文の審査結果の要旨

博士論文の審査申請のあった高橋邦夫君の論文は、南極海でもっとも普通に、また、量的にも多く出現するカイアシ類の1種である *Calanoides acutus* の生活史戦略を扱ったものである。これまでの断片的な観測から、春に卵からハッチアウトした後、真夏に植物プランクトンを摂食しながら成長し、植物プランクトンが少なくなる冬に備えて、エネルギー源として体内に脂質を貯蔵して深層で越冬し、翌年春に交尾した後、成体のメスが表層に浮上し産卵するといわれてきた。しかしながら、季節海氷域の低緯度側は比較的早く海氷がなくなり再び海氷に覆われるまで長い時間がある。また海氷に覆われない南極海では太陽高度が増すと植物プランクトンの生産が可能になるのに対し、高緯度側では海氷がなくなってから再び海氷に覆われるまで時間が短い、すなわち植物プランクトンの生産期間が短いことから、過去の断片的な知見に基づく本種的生活史には、高緯度側と低緯度側で異なるはずだという仮説を立てた。申請者は2001/2002年シーズン11月から2月にかけて、「オーロラオーストラリス」、「白鳳丸」、「タンガロア」に乗船し、時系列的に連続した試料採集および現場飼育実験を行ない、本種の生長、発育段階の進行による貯蔵脂質の時系列変化に焦点をあてた研究を行なった。

本種的生活史は一年と言われていたが、本研究で固定試料による分布特性と、時系列的な貯蔵脂質変動の双方から検討した結果、少なくとも2年以上のサイクルを有する個体が存在することを明らかにした。さらに、越冬前の秋期になるとこの春生まれ、脂質貯蔵が十分ではない新世代と、一度越冬を経験した豊富に脂質を貯蔵する2年目の個体が共存していることを明らかにした。このような脂質貯蔵の異なる個体の出現には空間的な差がみられ、季節海氷の存在により成長期間が比較的短い高緯度側の観測点ほど2年以上を費やす個体の出現率が高いことを示した。さらに現場代謝実験の結果から、高緯度側の個体群は、既に脂質を利用した代謝を行なっていることから、低緯度側の海域に比べてより越冬状態に近い生理状態であることを明らかにした。このことは、海氷の存在により、植物プランクトンを利用して成長する時間が短い海域の本種は冬期を生き延び、確実な再生産を行なうため、2年以上の時間を費やし、ゆっくり成長する生活史戦略をとっていると考察している。また、低緯度側で越冬状態に達していない個体が出現することから、低緯度側では産卵期間が長いものと考察している。

以上のように、同一海域において、ひと夏の全時期をカバーした時系列観測を行ない、さらにはネット採集による固定試料および生理的情報の双方から生活史に包括的なアプローチをする試みは初めてであり、得られた結果やその解釈も学位論文として価値がある。得られた結果はほとんどが新しい知見であり、解析方法を含め、論旨の展開など適切であり、この分野の研究の新しい展開に重要な貢献をすると認められる。本審査委員会では、高橋邦夫君の申請した論文は、学位（理学）に相当すると全員一致で判定した。