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論 文 審 査 委 員	主　　査　准教授　高橋　晃周 教授　福地　光男 教授　小達　恒夫 准教授　佐藤　克文　東京大学 准教授　依田　憲　名古屋大学

論文内容の要旨

Organisms in polar and temperate regions live in a seasonal environment where they experience regular changes in resources and/or weather conditions. Exploring how organisms respond to seasonality in environment, and what kind of environmental characteristics influence their distributions is fundamental for understanding their habitat requirements as well as adaptations in behaviour, physiology and morphology to the environment. Recent advances in tracking technologies enable us to examine the foraging movements of a variety of seabird species during the breeding season, and to identify inter-specific and sexual segregations as well as individual consistency in foraging area. In contrast, seabird distributions outside the breeding season are much less documented due to the technical and practical difficulties. Therefore, understanding of how individual seabirds respond to seasonal changes in the marine environment during the non-breeding period, and if such the response differs between sexes, among colonies, or within individuals has been elusive. The aims of this study were to examine the seasonal movement patterns of a pelagic seabird, the streaked shearwater (*Calonectris leucomelas*), during the non-breeding period (including post-breeding, migration, wintering, and pre-laying periods) in relation to (1) seasonal changes in the marine environment, (2) sex-related, inter- and intra-colony, and inter-annual differences, and (3) individual consistency over successive years.

The study was conducted at three breeding colonies, Sangan Island (39°18'N, 141°58'E, Iwate, Japan) and Mikura Island (33°52′N, 139°14′E, Izu Islands, Japan) located in the Pacific Ocean, and Awa Island (38°27'N, 139°13'E, Niigata, Japan) located in the Sea of Japan, from August 2006 to October 2010. I recorded the seasonal movement patterns of streaked shearwaters during their non-breeding period using leg-mounted global location sensors. I obtained data of 223 tracks, including 47 birds that tracked over two successive years.

Streaked shearwaters migrated to four wintering areas in November-February during the non-breeding period: most to the seas off northern New Guinea (73.1% of migrations), and others to the Arafura Sea (17.0%) and South China Sea (9.0%), and two birds to the seas off northwestern Australia (0.9%). Furthermore, streaked shearwaters from Sangan Island predominantly migrated to the seas off northern New Guinea over four non-breeding seasons. Therefore, the seas off northern New Guinea represent the key wintering area for streaked shearwaters from the study colonies. The surface concentration of chlorophyll a was low in the seas off northern New Guinea, in contrast to previous studies showing a close relationship between primary productivity and the occurrence of marine top predators. The western equatorial Pacific is generally characterized as an oligotrophic region with deep mixed and isothermal layers, but also shows a deep chlorophyll maximum at subsurface depth. Thus, biomass, including zooplankton and mesopelagic fish, is relatively high in the epipelagic layer despite low chlorophyll a concentration at the sea surface. Streaked shearwaters showed diurnal changes in their activity in the tropical oceans, as they flew for longer periods and landed on the water more frequently around dawn and dusk. This pattern of activity is similar to that of subsurface predators, such as tuna, and to that of tropical seabirds that are known to feed with subsurface predators. It possibly indicates the feeding association of streaked shearwaters with sub-surface predators in wintering areas. The seas off northern New Guinea have one of the largest fisheries for several tuna species in the Pacific Ocean. Feeding association with subsurface predators, such as tuna, is an important foraging

strategy for tropical seabirds, because subsurface predators drive prey fish nearer to the surface where the seabirds can reach them.

Although most shearwaters migrated to the seas off northern New Guinea, there were sex-related, inter- and intra-colony differences in the proportion of individuals that migrated to four different wintering areas. Males were more likely to migrate to the South China Sea (11.8% in males *vs.* 5.2% in females), while females were more likely to migrate to the Arafura Sea (9.5% in males *vs.* 29.2% in females). Among birds, including males and females, migrants to the Arafura Sea started the southward migration relatively earlier, and migrants to the South China Sea started the migration later than those that migrated to the seas off northern New Guinea. Between the sexes, females started the southward migration earlier than males. Among the colonies, shearwaters from Awa Island were less likely to migrate to the seas off northern New Guinea, compared to the other breeding colonies. There were two different migration routes in shearwaters from Awa Island: Pacific Ocean route and Sea of Japan route. Fewer birds that traveled along the Sea of Japan migrated to northern New Guinea (33.3% of 18 birds) than did those that traveled in the Pacific Ocean (61.3% of 31 birds). Migratory routes along the Sea of Japan were closer to the South China Sea and Arafura Sea, compared to those in the Pacific Ocean. Therefore, the South China Sea and Arafura Sea were more accessible to migrants that traveled along the Sea of Japan from Awa Island.

In this study, I found remarkable individual consistency not only in wintering areas, but also for the timing of southward migration. Individuals that were tracked for two successive years migrated to the same wintering areas at a similar timing to the previous year. This may suggest that streaked shearwaters possess individual-specific migratory schedules that are possibly under the control of endogenous time programmes.

After returning to the seas around the breeding colony in March (the pre-laying period), streaked shearwaters changed their foraging areas in relation to seasonal changes in sea surface temperatures of the North-western Pacific. Females moved their foraging areas northwards from April to July, but not being apparent for males. This was probably because females followed changes in the distribution of their prey, such as Japanese anchovy, that are known to conduct a seasonal northward migration in relation to the increase in sea surface temperature from spring to summer. In contrast to females, males mainly foraged in the areas around the breeding colony from April to June. During this period, males returned to the colony more frequently than females, probably to defend their nests from prospectors. Thus, sexual differences in breeding role may limit foraging ranges, leading to the different seasonal movement patterns between the sexes.

The results from the present study showed that streaked shearwaters have a unique seasonal movement pattern compared to other shearwater species, as they forage in a temperate region during the breeding season and winter in tropical oceans during the non-breeding season. Pelagic seabirds often occupy similar latitudinal areas year-round either by conducting a trans-equatorial migration or remaining in areas around the colony, because general characteristics of the marine environment differ between temperate/polar and tropical oceans, and may require different foraging tactics. Streaked shearwaters forage mainly at the sea surface and are considered as an excellent glider in terms of their morphological characteristics. These behavioural and morphological characteristics appear to be adaptive to the tropical marine environment, and may enable this species to occupy both temperate and tropical marine environments.

博士論文の審査結果の要旨

出願のあった論文は、日本近海に生息する主要な飛翔性海鳥類の一種、オオミズナギドリの非繁殖期における季節的な移動パターンとそれに影響する生態的要因を明らかにすることを目的としている。一般に、極域から温帯の海洋環境は顕著な季節変化を示す。機動性の高い飛翔性海鳥類がどのように移動して海洋環境の季節変化に対応しているかという問題は、海鳥類の海洋環境への行動的適応に関する主要な研究課題である。しかし、技術的な困難からこれまでの研究は繁殖期間中の 1-2 ヶ月程度に限られ、生活史の大半を占める非繁殖期間中の知見は限定されていた。本研究は、ジオロケータという近年開発された小型の動物装着型記録計を用いて技術的制約を克服し、非繁殖期におけるオオミズナギドリの季節的な移動パターンを総合的に明らかにしたものである。

本研究は、まず、繁殖後の渡り・越冬時期（10 月-4 月）のオオミズナギドリの季節的な移動パターンについて報告している。日本近海の 3 箇所の繁殖地（岩手県三貫島、東京都御蔵島、新潟県粟島）で 4 年間にわたって合計 176 個体から行動データが取得され、越冬海域、渡りの経路・時期の繁殖地間、年間、雌雄間、個体間の違いが総合的に検討された。その結果、オオミズナギドリが 10 月-12 月にかけて越冬海域への渡りを行い、3 月-4 月に繁殖地周辺海域に戻る季節移動パターンをもつこと、熱帯海域を中心に 4 箇所の越冬海域があるものの、全体の約 7 割の個体がパプアニューギニア北方海域に集中して越冬することなどが初めて明らかにされた。パプアニューギニア北方海域は衛星リモートセンシングデータで見る限り生物一次生産の高い海域ではないが、オオミズナギドリの海表面での採餌に影響を与えうるカツオの現存量が高いこと、中層での小型魚類のバイオマスが高いことなどが、この海域が主要な越冬海域となった理由であると考察された。また他種におけるこれまでの研究との比較から、温帯域で繁殖を行い熱帯域で越冬するというオオミズナギドリの季節移動は、ミズナギドリ目の中でも特徴的なパターンであると結論づけられた。

本研究は、次に、繁殖前の時期(4 月-7 月)のオオミズナギドリの季節的な移動パターンについて報告している。黒潮・親潮混合域および黒潮域に位置する三貫島と御蔵島の 2 箇所の繁殖地で、いずれも主要な採餌海域が全体として季節的に北上する傾向があることが示された。一方、繁殖地間で採餌海域は異なり、三貫島では東北地方の太平洋側沿岸にそって、御蔵島では黒潮続流域にそって採餌海域が北上・拡大していることが示された。また採餌海域の季節変化のパターンは雌において雄よりも顕著に見られ、雄は繁殖地周辺海域にとどまる傾向があることが示された。衛星リモートセンシングデータによる環境解析から、黒潮域および黒潮・親潮混合域では海水温が季節的に顕著に上昇すること、その一方で採餌海域の約 50%以上が特定の表面水温帯（14-17℃、20-22℃）に位置することが明らかにされた。季節的に水温が変化する中でオオミズナギドリがこの温度帯の海域を選好したと考えられた。以上の結果から、本研究は、黒潮・親潮混合域の季節的な海水温の上昇が餌生物である小型魚類の分布変化を通じてオオミズナギドリの採餌海域の季節変化に影響を与えていると結論づけた。また、その変化パターンの繁殖地間および雄雌間の違いから、繁殖地からの採餌海域までの距離や繁殖地での雌雄の行動の違いが、繁殖前期のオオミズナギドリの季節的な移動パターンに影響することが示唆された。

以上の結果は、オオミズナギドリの移動パターンを多数個体について10ヶ月以上の長期にわたり追跡することで初めて明らかになった成果である。季節的に変化する海洋環境に対応した海洋高次捕食動物の生活史戦略や環境応答についての重要な知見を示しており、同様に大きな季節変化を経験する極域動物の研究にも貢献するものである。したがって、審査委員会では、提出された論文が学位論文に値するものと、全員一致で判定した。