

論文の内容の要旨

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論文題目 Life history traits and population structure of the rockfish
Sebastes inermis around Miura Peninsula, central Japan
(三浦半島周辺海域におけるアカメバル *Sebastes inermis*
の生活史特性と資源構造)

Summary

The rockfishes (genus *Sebastes*) - important resource in recreational and commercial fisheries - comprise over 110 species worldwide distributed on both sides of the Northern Pacific Ocean. As many other species, rockfishes occupy different habitats during their development stages which can be used as an adaptive strategy: i.e. the ontogenic movement used to maximize settlement and avoid offshore dispersal. Catches of rockfishes in Japan decline as reported in species captured along coastal waters such as *Sebastes inermis*. Efficient restoration and protection strategies of these species require the identification of spawning grounds, juvenile nursery habitats as well as their population structure. The main objective of this thesis is to assess the life history traits, population structure and physiological condition of the rockfish *S. inermis* from different sites around Miura Peninsula, central Japan: two in the southwest coast, Aburatsubo Bay (Abt) and Sajima Bay (Saj) and one in the northeast coast inside Tokyo Bay (Tkb). Data of age and growth, physiological condition, reproductive traits, otolith microchemical composition and otolith shape were assessed to determine *S. inermis* ecological and biological features such as: larval and juvenile behaviour, settlement timings, quality of nursery areas, extension and shift of spawning season, the adult's health condition within the reproductive season and connectivity/separability of different sites with two different habitats: the inshore seagrass nursery areas and the adjacent nearshore/offshore deeper areas.

Age and growth

Age and growth structure of fish sampled from distinct sites around Miura Peninsula were investigated. Inshore areas in all sites were sampled in summer of 2010 and 2011 by set net and boat seine net, while nearshore/offshore areas were sampled from January 2011 to February 2012 by set net. Based on otolith microstructure, length frequency and age-at-length of *S. inermis* ($N = 1296$) were used to estimate the age and growth structure in the three sites. Growth function was fit to the observed length-at-age data (Cubic von Bertalanffy function; $L_{\infty} = 282.5$, $k = 0.31 \text{ year}^{-1}$, $t_0 = 0.71$) and the growth rate of fish in each site by gender was compared. Tkb had a higher mean age (4.6 years), while in Abt and Saj areas, younger fish were more frequent (3.4 and 2.9 respectively). Distinct growth patterns were identified shown by the different growth rates and maximum sizes found among sites. The geographic features (e.g. bottom composition, seagrass canopy), the depth profile, distance from shoreline from each sampling site and gear selectivity might be influencing the distinct age and growth structures found in *Sebastes inermis* in this study.

Early Life

Young-of-the-year (YOY) otolith microstructure was analysed to identify possible factors regulating larval extrusion, growth rates, and settlement patterns of *S. inermis* larvae and juvenile from Abt and Saj. In addition, physiological condition indexes (RNA:DNA ratio, total proteins, Fulton's K) were examined for habitat quality assessment. Four monthly extrusion groups were identified by daily age backcalculation. Growth rate during the planktonic period was positively correlated with the duration of this stage and with water temperature. Flexible settlement timings of each group suggested an adaptive strategy to variability in environmental condition: larvae experiencing unfavourable temperature settle earlier at smaller lengths and grow faster after settlement. Clear differences in variables related to planktonic and post-settlement stages between sites imply the utilization of different habitats during early life, and shows that offshore mixing of larvae might not be occurring. Saj had higher growth and nutritional indicators (RNA:DNA ratio, total proteins and Fulton's K), indicating a higher habitat quality and importance as nursery for *S. inermis* juveniles.

Reproductive traits

To assess population reproductive structure and adult physiological condition of *S. inermis*, presence and duration of different maturity stages and GSI variability were analysed to describe and compare the spawning season in each site. Fecundity and size/age at maturity were also examined to compare the reproductive traits among sites (including a southern population, Seto Inland Sea, off Shikoku Island coast – Set, as a geographic control) and within gender. Adults physiological condition during reproductive period was examined throughout the spawning season from 2011 to early 2012 using nutritional indicators such as, RNA:DNA ratio and total proteins, reproductive indicator (GSI), fecundity indicator (RF) and the morphological index Fulton's K. M:F ratio reduced strongly during the spawning peak. Shift in GSI and duration of maturity stages, indicated a spawning period from November to January with a peak

in December in Saj and Tkb. Fish from Set spawned one month later than fish from Miura Peninsula. The distinct timing of maturation of young and older females and the decrease of length and age throughout the spawning period in both sites showed that older and bigger females spawn earlier than younger and smaller females. Macroscopic analysis of maturity stages and positive relationship between total length and relative fecundity confirmed the higher reproductive potential of bigger females. The age and length at 50% maturity estimated was 3.4 years and 177 mm for females and 3.2 years and 171 mm for males. Reproductive structure of *S. inermis* along Miura coast showed variability and the estimation for Tkb and Saj indicated that Tkb individuals mature earlier than Saj ones. Female's physiological condition increased within a spawning season achieving almost a simultaneous peak with *GSI* and Saj was considered the site where adult rockfish presented higher fitness confirmed by the higher biochemical and morphometric condition indicators. Saj also had the better reproductive performance (higher fecundity) when compared with the other sites due to the higher number of bigger females found in this site. Comparative analysis by gender showed distinct reproductive traits both in females and in males within site.

Otolith elemental and shape signatures

Otolith microchemistry was investigated and specific signatures of YOY, sub adults and adults were determined to define the population structure for *S. inermis* around Miura Peninsula with possible interaction between inshore and offshore habitats in each study site. It was also aimed to analyze otolith signatures in both coasts of Miura Peninsula to examine a possible influence of the environmental factors characteristic of an estuarine area -Tokyo Bay. Elemental composition (Sodium-Na; Estroncium-Sr; Barium-Ba; Manganese-Mn; Magnesium-Mg; Iron-Fe and Calcium-Ca) of otoliths of each size group (YOY, sub adults and adults) was analysed using inductively coupled plasma, atomic emission spectroscopy (ICP-AES). Differences among sites and size groups' signatures were detected by CDA with 74% and 85% of classification success respectively. Abt and Tkb were highly separated and Ba:Ca, Mn:Ca and Sr:Ca ratios were the main determinant which might be related with estuarine and nearshore water environments. Signatures of fish occurring in inshore habitat (YOY and sub adults) were separated among sites as well as fish found offshore (adults), with classifications of 75% and 97% of success respectively. Na:Ca and Sr:Ca were the determinant to separate adult signatures. The putative breeding populations were assessed by examining any proximity of inshore/offshore signatures in each site. There was a geographic separation of *S. inermis* signatures around Miura Peninsula and the similarity of signatures within all size groups in each site support a possible connectivity of habitats within small geographical range. The analysis of otolith elemental composition showed the relative importance of the distinct inshore nursery areas in supporting the respective adult population offshore.

Univariate shape indicators (e.g. aspect ratio, circularity) and Fourier elliptical descriptors were determined for each otolith and used to define the specific shape tag in each size group in the study site. Sexual differences in otolith shape tag were found for adults and

univariate descriptors were the main determinant for such differences. Sites were well differentiated (77%) within small geographical range. The southwest coast sites - Saj and Abt - were separated from the one in the northeast coast - Tkb. Sub adult's otoliths – with broader shape - were more similar to adults rather than YOY. Differences in otolith shape amongst site showed distinct features corresponding to possible distinct *S. inermis* groups in Miura Peninsula and size group shape similarity found in each site might indicate inshore/offshore connectivity.

Conclusions

Age and growth data, reproductive traits patterns, physiological indicators and otolith signatures enabled to identify differences in *S. inermis* groups that inhabit Miura Peninsula coast waters and to define the population structure of this species in this area. Site in the southwest coast (Saj) seems to assure better spawning and nursery conditions for the rockfish *S. inermis* when compared with that in the northeast coast (Tkb), under the influence of Tokyo Bay (e.g. environmental, anthropogenic and geographic). Fish from both sides of Miura Peninsula were also differentiated based on otolith elemental and shape signatures indicating a possible division of this *S. inermis* population in: two closer groups from southwest coast (Saj and Abt) and one separated group in northeast coast (Tkb).

The discrimination of site and size-specific elemental and shape signatures and life traits was successful within a small geographic range. It is suggested that, habitat connectivity within each site enables the ontogenic movement of larvae from nearshore to inshore settlement areas – shown by distinct early life traits – and enables the permanence of sub adults and adults in nearshore/offshore habitat – shown by the significant differentiation of elemental signatures in both groups among different sites. It is believed that the information of the population structure together with the information of habitat and site connectivity is a good indicator of a sustainable *S. inermis* population in waters around Miura Peninsula.

This study increases the knowledge of the ecology and reproductive biology of this valuable resource and provides information regarding some possible sites for spawning and subsequent recruitment of this marine fish around Miura Peninsula. Such data is increasingly important given several pressures affecting rockfish populations: i.e. habitat loss, decline in endemic aquatic fauna or fishery overexploitation effects. Further studies in larger spatio temporal scale should be conducted to investigate deeper *S. inermis* population in Japan.