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Reprinted from the Alaska Fishery Research Bulletin
Vol. 12 No. 2, Winter 2007
The Alaska Fisheries Research Bulletin can be found on the World Wide Web at URL:
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Alaska Fishery Research Bulletin 12(2):264–269. 2007.

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ABSTRACT: The northern rockfish *Sebastes polyspinis* (Taranetz and Moiseev in Taranetz, 1933) is the second most important commercial rockfish species caught in the Gulf of Alaska. Current estimates of northern rockfish age and length at 50% maturity from the annual Gulf of Alaska stock assessment are based on macroscopic evaluations of a relatively small sample size collected in 1996. This study determined the maturity stage of female northern rockfish using histological techniques from 157 samples over a 2-year period. Estimated age at 50% maturity for female northern rockfish in the central Gulf of Alaska is 8 years and estimated length at 50% maturity is 310 mm. The maturity estimates presented in this study indicate that female northern rockfish mature at a younger age and smaller size than previously reported.

INTRODUCTION

The northern rockfish *Sebastes polyspinis* ranges in waters north of British Columbia, throughout the Gulf of Alaska (GOA), Aleutian Islands and into the eastern Bering Sea (Love et al. 2002). This species is the second most abundant rockfish species caught in the GOA and one of the most commercially important rockfish species caught in Alaskan waters (Clausen and Heifetz 2004). In 2002, the commercial trawl catch of all rockfish species was valued at $2.2 million in the GOA with northern rockfish catch second only to Pacific ocean perch *S. alutus*, (Hiatt et al. 2003). The unprocessed dollar amount of northern rockfish caught by all gear types in the GOA was estimated at $581,200 in 2004 by the North Pacific Fishery Management Council (2005).

Northern rockfish are one of the 4 rockfish species managed in the GOA continental slope rockfish assemblage along with rougheye rockfish *S. aleutianus*, Pacific ocean perch, and shortraker rockfish *S. borealis*. All 4 species are caught in commercial fisheries in the GOA. Each species is distributed along the continental slope at different depths and associated with different habitat types.

Northern rockfish are often caught in large schools over rough, hard bottom and steep slopes at depths of 75 to 125 m using bottom trawl gear adapted to the rugged substrate (Clausen and Heifetz 2004). Longline gear is primarily used to target the more singularly distributed rougheye and shortraker rockfish at depths of 300 to 400 m on steep slopes (Krieger and Ito 1999) although a large number of these 2 species are caught via a maximum retainable bycatch allowance in the pelagic trawl fishery targeting walleye pollock *Theragra chalcogramma*. Pacific ocean perch school in patchy aggregations at 10 to 30 m above hard substrate (Love et al. 2002) and are primarily caught using midwater trawls as well as bottom trawl gear. Current management of the commercial Pacific ocean perch and northern rockfish fishery in the GOA is governed by the GOA pilot rockfish rationalization program, an interim quota-based system.

Despite the abundance and commercial value of northern rockfish, detailed reproductive studies to determine maturity estimates for management models have not been conducted. Prior estimates of the age and length at 50% maturity were based on macroscopic visual observations of gonad maturity collected from a limited sample in the central GOA (Heifetz et al. 2003) and used in the 2004 annual GOA stock assessment for northern rockfish.

It is difficult to accurately evaluate the maturity stage of an ovary at the macroscopic level unless the female fish are examined when the individually hydrated eggs, i.e. fertilized oocytes, are easily recognized. Previous work investigating the reliability of macroscopic methods has revealed the potential for

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Acknowledgements: The author would like to sincerely thank the skipper and crew of the F/V *Hickory Wind*, and ADF&G Kodiak groundfish office for access to otherwise unobtainable samples, Dave Somerton for analysis support and manuscript guidance, and Mark Wilkins and Dan Nichol for manuscript revisions as well as two anonymous reviewers.

incorrect identification of oocyte development stages when compared to histological evaluation methods (McDermott 1994; Zimmermann 1997).

Reproduction in the *Sebastes* genus is described as viviparous, with the adult female providing some nutritional component to the developing larvae until parturition (Wourms 1991). Males may mature months before females, with insemination occurring up to 6 months prior to fertilization (Boehlert and Yoklavich 1984). Takahashi et al. (1991) described the presence of stored spermatozoa throughout the ovigerous lamellae of the ovaries of *Sebastes taczanowskii* as early as 5 months before fertilization of mature oocytes.

The objectives of this study are to describe the timing of maturation of female northern rockfish and estimate the age and length at 50% maturity. Estimates of maturity from this study, based on histological analysis of the samples collected near Kodiak and in the central GOA, could improve estimates for future northern rockfish stock assessments.

METHODS

Samples for this maturity study were collected opportunistically from 1) port sampling of commercial jig and trawl fisheries around Kodiak Island, 2) hook and line and bottom trawl sampling from chartered vessels around Kodiak Island and 3) bottom trawl sampling near Kodiak Island on the GOA groundfish trawl survey conducted by the National Marine Fisheries Service, Alaska Fisheries Science Center (AFSC), in 2001. Due to the timing of the commercial rockfish fishery, samples were available for collection in the months of February, July, and November of 2000, and February, April, May, and June of 2001. Exact locations were not available for many of the samples collected due to the confidential nature of the catch reporting system.

Standard biological samples were collected from each individual female including fork length, total body weight, both otoliths and ovaries. Otoliths were aged by the AFSC's Age and Growth Program using standard break and burn procedures (Chilton and Beamish 1982). Ovarian tissue samples were taken from the middle of the right ovary, or the left ovary if the right was damaged, and fixed in a 10% neutral buffered formalin solution. Previous studies examining the maturity stages of ovaries at the histological level from 4 different rockfish species have determined no differences in oocyte development between the left and right ovary (Shaw 1999). Tissue samples were embedded in paraffin, thin-sectioned to 7 µm using a rotary microtome, mounted on slides and stained using standard hematoxylin and eosin methodology (Sheehan and Hrapchak 1980). All histological preparations for this study were conducted by the author at the Kodiak Fisheries Research Center.

A compound microscope and ocular micrometer were used to measure the diameter of the oocytes. The diameter of the fifth largest oocyte on a randomly selected transect along the histological cross section of the gonad was used as criteria for evaluating the most advanced nonatretic oocyte and to determine the stage of the ovary (West 1990). These ovary stages were evaluated based on 7 maturity stages and corresponding oocyte development adapted by the author from maturity stage development for *S. flavidus* by Bowers (1992), *S. crameri* by Nichol and Pikitch (1994) and descriptions by Shaw (1999) of oocyte development for 4 other *Sebastes* species (Table 1). Presence of vitellogenesis as the most advanced oocyte stage in an ovary sample as well as oocytes developed to the migratory nucleus stage were used as a criteria for evaluating the ovary as mature.

Data Analysis

Age and length at 50% maturity was determined by fitting a logistic function to the maturity data as a function of age or length with generalized linear modeling using S-plus[1] statistical software then evaluating the fitted model at a maturity proportion of 0.50 (S-plus 6.2.; Insightful Corp., Seattle, Washington). The variance of age and length at 50% maturity and 95% confidence intervals were estimated using percentile bootstrapping methods (Efron and Tibshirani 1993).

RESULTS

Ovaries, otoliths, and fork lengths were collected from 158 females to estimate age and length at 50% maturity. Otoliths collected from one female were unreadable, resulting in 157 samples in the age and length at 50% maturity analysis. The ages of northern rockfish collected ranged from 3 to 34 years and lengths ranged from 140 to 440 mm. The age at 50% maturity was estimated to be 8 years (95% CI = 7.6–8.6) and the length at 50% maturity was estimated to be 310.4 mm (95% CI = 304.1–317.3; Figure 1, Table 2).

Oocytes developed to the vitellogenesis stage were present in all months sampled (Figure 2). Fertilized ova through eyed embryo stage (oocyte Stages 4 and 5) were observed in the April through June samples. Only 1% of the ovaries collected (n=1) in April had

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1. Maturity criteria for staging gonads of female northern rockfish based on macroscopic and microscopic observations. Adapted from Bowers (1992), Nichol and Pikitch (1994) and Shaw (1999).

Maturity Stage	Macroscopic description	Histological description	Oocyte stages
1. Immature	Thin and thready ovaries, pink or light red in color; oocytes are not visible	Oogonial nests and unyolked oocytes, oocyte diameter is between 40 and 160 μm	Oogonia organized into nests with some oocytes at early perinucleus and late perinucleus development
2. Maturing or Intermediate	Ovaries cream to light yellow in color with thin ovarian wall; oocytes visible	Initial yolk accumulation in oocytes with yolk globules very small, oocyte diameter 160 to 270 μm	Late perinucleus and stage I thru II yolk accumulation in oocytes, oogonia nests and early perinucleus stage oocytes are also present
3.Vitellogenesis	Individual eggs are visible, bright yellow in color; ovarian wall thickening and darkly pigmented	Yolk globules and oil vesicles present, oocyte diameter 270 to 600 μm	Tertiary yolk stage and initial oil vacuoles coalescing in oocytes
4. Fertilized	Large translucent eggs with pink to yellow tint, ovaries enlarged to accommodate large hydrated eggs	Embryo diameter is 600 to as large as 1,000 μm	Stage VIII migratory nucleus through early embryonic development
5. Eyed larvae	Ovary enlarged with eyed larvae, ovarian wall thin and transparent, easily torn or broken open	Embryos with dark pigmented eyes	Eyed larvae
6. Post-parturition	Ovary flaccid and dark red in color, some eyed larvae are visible	Postovulatory follicles and atretic oocytes, residual larvae are present	Evidence of parturition based on postovulatory follicles, atretic oocytes and residual embryos

developed to the post-parturition stage while the rest of the post-parturition stage ovaries were observed in the May and June samples. Samples collected in April had the highest number of advanced ovary development with 40% of the samples (n=43) having oocytes at Stage 4 or higher. Samples taken in July and November only had oocytes developed to the vitellogenesis stage, indicating a protracted period of yolk accumulation (Figure 2). Parturition can occur as early as April although the majority of the April samples were developed to the fertilized ova stage followed by May and June as the months with eyed larvae and postovulatory follicles as post-spawn evidence.

DISCUSSION

Maturity parameters used in the stock assessment model for female northern rockfish in the GOA are 13 years for age at 50% maturity and 361 mm for length at 50% maturity (Heifetz et al. 2003). These values reported in the 2004 Stock Assessment and Fisheries Evaluation document are based on macroscopic classification of a sample of 77 females collected off Kodiak Island in April of 1996 (D. M. Clausen, Auke Bay Laboratory, AFSC, personal communication). Female northern rockfish caught off the coast of northern British Columbia, Canada were reported to mature at 5 to 7 years of age and 190 to 220 mm (Love et al. 2002), values similar to the 50% maturity estimates reported in this study. The maturity estimates currently used in the stock assessment are larger and older than the values reported for northern rockfish in Canada and the results of this study. This difference could be due to a smaller sample size or the limited seasonal component of the 1996 sample. It seems more likely that the difference is a result of the 1996 estimates being based on visual examination of the ovaries compared to the histological examination used in this study to assess the maturity stage of the oocytes, as was found by McDermott (1994) and Zimmermann (1997).

Evaluating the maturity stage of ovaries at a macroscopic level has been a desirable component of fieldwork when collecting biological fisheries data. However, caution should be used when evaluating the maturity stage of female rockfish at a macroscopic level in months when ovaries are in the early stages of seasonal development. Nichol and Pikitch (1994) histologically observed "immature cycling" of Stage 2 oocytes never developing beyond an early stage of vitellogenesis in darkblotched rockfish *S. crameri* with resorbtion of these oocytes prior to total yolk accumulation and potential fertilization.

It is clear, based on information in this study, that unless the final stages of maturity are present (Stages

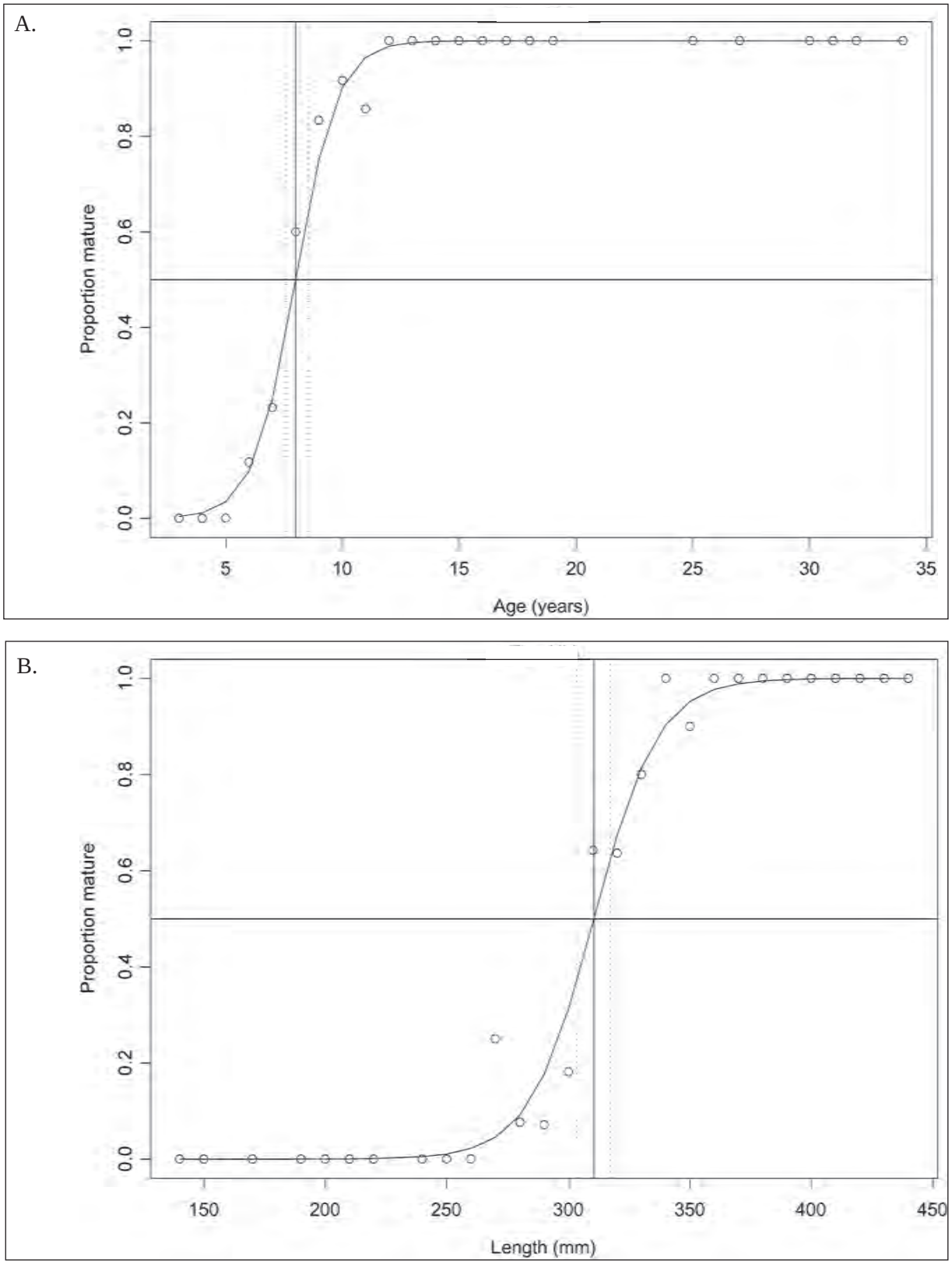

Figure 1. Age (A) and length (B) at 50% maturity for female northern rockfish caught in the central Gulf of Alaska (n=157). Vertical dashed lines denote 95% CI for $A_{0.5}$ and $L_{0.5}$.

Table 2. Maturity parameters for female northern rockfish in the central Gulf of Alaska and their variances estimated by fitting a logistic function to the maturity data as a function of age or length with generalized linear modeling.

	Value	Variances
$L_{0.5}$	310 mm	10.874
a	-23.39	18.206
b	0.075	0.0002
$A_{0.5}$	8	0.070
a	-8.858	4.275
b	1.108	0.079

4, 5, or 6 as described in Table 1), it can be difficult to accurately assess the maturity of an ovary at the gross visual level without histological evidence. Westrheim (1975) found that the presence of rockfish gonads at the intermediate, maturing stage throughout the year provided the possibility of underestimating the true size and age at maturity for both males and females. He suggested only evaluating size and age at maturity in the field during "parturition season", the peak stage of ovary development when eyed larvae are visible.

The results of this study found oocytes developed to the vitellogenic stage in all months sampled, November through July, with maturity Stages 4, 5 and 6 only present in the months of April through June. The white-edged rockfish *S. taczanowskii*, a western Pacific Ocean species caught along the shores of northern Japan, showed a prolonged duration of vitellogenesis over a 6-month period (September through March) compared to less than 2 months of vitellogenesis in *S. inermis,* a rockfish species found in the southern waters of Japan (Takemura et al. 1987). The 8-month period of vitellogenesis in northern rockfish caught in the GOA at lat 56°N to 58°N is consistent with that of *S. marinus* caught in the southern waters of Newfoundland, between lat 47°N and 48°N, which also showed prolonged periods of vitellogenesis beginning in February and continuing through May (Ni and Templeman 1985).

The seasonal timing of the ovary collections for this maturity study was a crucial component towards histologically evaluating the most advanced oocytes within the developing ovaries especially in the months of April and May. Future studies focusing on the reproductive maturity of rockfish would benefit from collecting samples throughout the year.

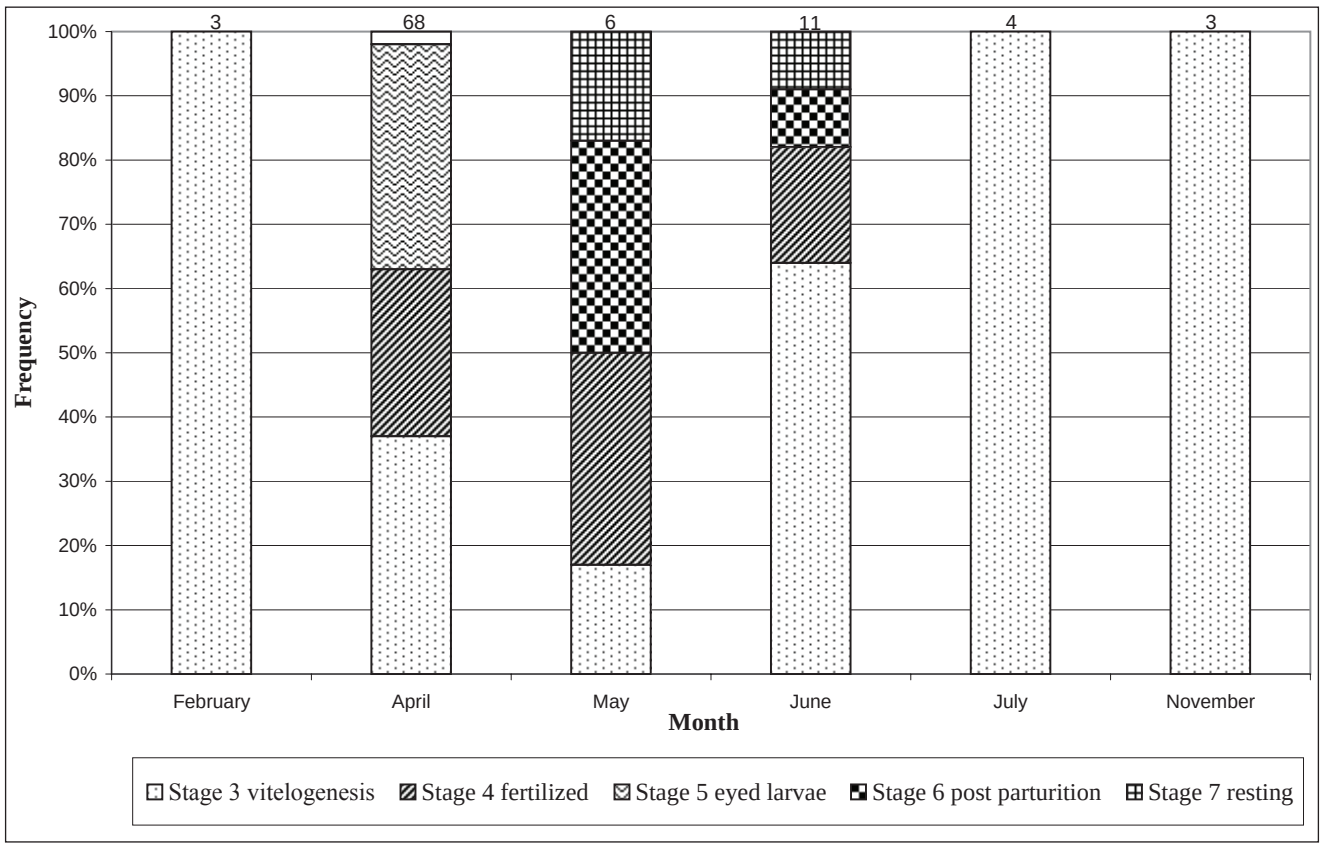

Figure 2. Percent frequency of the most advanced oocyte stage present in female northern rockfish for each month sampled. Sample sizes are shown above each bar.

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