**Materials and Methods**

Skate samples were collected from 2002 to 2005 by the National Marine Fisheries Service Southwest Fisheries Science Center (NMFS -SWFSC) during fishery-independent trawl and longline surveys of central California (36º 40.44’ N, 122º 57’ W to 36º 59.76’ N, 122º 11.86’ W) (Figure 1). Specimens were sexed, assigned a maturity status following Ebert (2005), and measured for total length (TL) and total weight (TW). Additional biological measurements included gonad weight for both sexes, inner clasper length (mm) for males and oviducal gland width (mm) and largest ova diameter (mm) for females.

Maturity was determined by examination of gonads and in males, the degree of clasper rigidity. In addition, inner clasper length and oviducal gland width were plotted against TL for males and females respectively to help assess maturity. An abrupt change in slope indicates maturation. Three reproductive classifications were determined for each sex: juvenile, subadult and adult. Males were considered adult when the clasper terminal cartilages were well calcified, the claspers extended beyond the pelvic fin tips and the epididymis was highly coiled. Males were considered subadult when the claspers extended beyond the pelvic fin tips, but the terminal cartilages were not fully calcified and the epididymis was partially coiled. Males were considered juvenile when the claspers did not extend beyond the pelvic fin tips and the epididymis had little to no coiling. Females were considered adult when large circular oocytes were present, the oviducal gland was well-differentiated and the uterus was thick. Subadults females were identified by smaller ovaries without mature oocytes and only some differentiation of the oviducal gland from the uterus. Females were considered juvenile when there was no differentiation of the ovaries or the oviducal gland from the uterus (Ebert 2005).

Size at maturity was determined for each species using maturity ogives. Binomial maturity data (0 = immature; 1 = mature) was binned into 2 cm TL size classes and fitted to a logistic regression using SigmaPlot graphical software (SPSS Inc., version 8.0, Chicago, IL):

where Y is the maturity status and x is the TL in cm. An estimate of median TL at 50% maturity was calculated as *–a/b*.

To assess potential seasonality of reproduction a gonadosomatic index (GSI) was plotted by month and oceanographic season for male and female adults only. GSI is calculated as:



where TW is total weight (g) and GW is the gonad weight (g). Oceanographic seasons in central California were described by Skogsberg (1936), Skogsberg and Phelps (1946) and Bolin and Abbott (1963) as the Upwelling Season (UPS) (March-July), the Oceanic Season (OCS) (August-November) and the Davidson Current Season (DCS) (December-February). The UPS is distinguished by the upwelling of cold, nutrient-rich water along the coast that moves offshore due to southerly winds. The OCS follows the UPS and is exemplified by a weakening of southerly winds and upwelling while the California current moves closer to shore. The DCS is the continued weakening of the California current and the beginning of an inshore northward current that has little to no thermocline and a warm upper water column. Differences in GSI by month or oceanographic season were tested by one-way ANOVA or if assumptions were violated, a non-parametric Kruskal-Wallis test (Zar 1999).

A second method that compares ova size among months was used to assess seasonality of ovulation in females (Conrath 2004; Ebert et al. 2007; Ebert et al. 2009). In females all mature oocytes were counted and the largest ovum was measured to the nearest mm. An oocyte was considered mature when it exceeded 10 mm in diameter. The largest ovum diameter of each adult female was averaged and plotted by month and oceanographic season. Differences in average maximum ovum diameter by month or oceanographic season were tested using a one-way ANOVA or if assumptions were violated, a non-parametric Kruskal-Wallis test (Zar 1999).

**Results**

*Beringraja binoculata*

A total of 110 females ranging from 17.6 to 169.1 cm TL were sampled (Figure 2). Female *B. binoculata* attained greater lengths than males. The relationship between oviducal gland width and TL increases in slope between 100 and 120 cm indicating the onset of maturity (Figure 3). Oviducal gland width of mature females ranged from 7.0 to 13.0 cm with minimal overlap of maturity groups. The smallest mature individual measured 117.6 cm TL and the largest immature individual measured 127.0 cm TL. Total length at 50% maturity was estimated at 126.6 cm (Figure 4). First maturity and 50% maturity were estimated at 69.5% and 74.9%, respectively, of the maximum female TL observed in this study. There were no significant seasonal differences of gonadosomatic index by month (p = 0.284) or by oceanographic season (p = 0.657). There also were no significant seasonal differences of average maximum ovum diameter by month (p = 0.221). There were insufficient samples to test for differences by oceanographic season. Two gravid females were collected during this study one in October and one in November.

A total of 130 males ranging from 18.2 to 131.0 cm TL were sampled (Figure 2). An increase in slope of the relationship between inner clasper length and TL was observed at 90 cm TL indicating the onset of maturity (Figure 3). Inner clasper length of mature males ranged from 29.0 cm to 40.4 cm with one unusually small mature male present. The smallest mature individual measured 56.8 cm TL and the largest immature individual measured 115.6 cm TL. Total length at 50% maturity was estimated at 100.5 cm TL (Figure 4). First maturity and 50% maturity were estimated at 43.4% and 76.7%, respectively, of the maximum male TL observed in this study. There were no significant seasonal differences of gonadosomatic index by month (p = 0.627) or by oceanographic season (p = 0.532).

*Beringraja rhina*

A total of 129 females ranging from 24.0 to 109.0 cm TL were sampled (Figure 8). There is no discernable slope change in the relationship between oviducal gland width and TL that would indicate the onset of maturity (Figure 9). Oviducal gland width of mature females ranged from 3.9 to 7.1 cm with a large amount of overlap between maturity groups. The smallest mature individual measured 69.2 cm TL and the largest immature individual measured 109.0 cm TL, which was the largest specimen sampled in this study. Total length at 50% maturity was estimated at 96.0 cm (Figure 10). First and 50% maturity were estimated at 63.5% and 88.1% respectively of the maximum female TL observed in this study. There were no significant seasonal differences of gonadosomatic index by month (p = 0.297) or by oceanographic season (p = 0.297). There also were no significant seasonal differences of average maximum ovum diameter by month (p = 0.530) or oceanographic season (p = 0.521). No gravid females were encountered during this study.

A total of 147 males ranging from 19.8 to 94.2 cm TL were sampled (Figure 8). An increase in slope in the relationship between inner clasper length and TL was observed around 80.0 cm TL indicating the onset of maturity (Figure 9). Inner clasper length of mature males ranged from 18.9 to 27.2 cm with little overlap among maturity groups. The smallest mature individual measured 64.4 cm and the largest immature individual measured 94.2 cm TL, which was the largest male sampled. Total length at 50% maturity was estimated at 78.1 cm (Figure 10). First maturity and 50% maturity were estimated at 68.4% and 82.9%, respectively, of the maximum male TL observed in this study. There were no significant seasonal differences of gonadosomatic index by month (p = 0.097) or by oceanographic season (p = 0.494).

A.



B.



Figure 3. Relationships for *B. binoculata* between (a) oviducal gland width and TL, and (b) inner clasper length and TL.



Figure 4. Estimated median size at maturity for *B. binoculata* using maturity ogives with total lengths in 2 cm bins. Open circles are females and filled circles are males.

A.

A.



B.



Figure 9. Relationships for *B. rhina* between (a) oviducal gland width and TL, and (b) inner clasper length and TL.



Figure 10. Estimated median size at maturity for *B. rhina* using maturity ogives with total lengths in 2 cm bins. Open circles are females and filled circles are males.