Artisanal fisheries and reproductive biology of the golden cownose ray, *Rhinoptera steindachneri* Evermann and Jenkins, 1891, in the northern Mexican Pacific

Joseph J. Bizzarro a,∗, Wade D. Smith a, J. Fernando Márquez-Farías b, Robert E. Hueter c

a Pacific Shark Research Center, Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, CA 95039, United States

b Instituto Nacional de la Pesca, Centro Regional de Investigación Pesquera de Mazatlán, Calzada Sábalos-Cerritos S/N, CP 82010, Mazatlán, Sinaloa, Mexico

c Center for Shark Research, Mote Marine Laboratory, 1600 Ken Thompson Pkwy., Sarasota, FL 34236, United States

Received 5 April 2006; received in revised form 16 September 2006; accepted 1 October 2006

Abstract

The golden cownose ray, *Rhinoptera steindachneri*, was one of the most abundant species landed in artisanal elasmobranch fisheries in the northern Gulf of California (Baja California and Sonora) and Bahía Almejas, Mexico during 1998–1999. In the northern Gulf of California, *R. steindachneri* was most frequently observed during summer months (11.4% of elasmobranch landings, catch per unit effort (CPUE) = 6.8 individuals/vessel trip) and was rare during winter (0.1%, CPUE = 0.1). In Bahía Almejas, its relative abundance was greater during August (5.2%) than June (0.3%), a trend also evident in CPUE (August = 1.2, June = 0.1). The mean size of *R. steindachneri* landed in the Gulf of California was 64.3 ± 12.8 (SD) cm disc width (DW). Median size at maturity for Gulf of California specimens was similar for females (70.2 cm DW) and males (69.9 cm DW). Fecundity was found to be one offspring per female, with parturition estimated to occur from late June–August. Size at birth was estimated at 38–45 cm DW after a gestation period of approximately 11–12 months. Greater maximum sizes (to 104 cm DW) and embryo sizes (to 43 cm DW) were observed in Bahía Almejas. The large size at maturity, low fecundity, and long gestation period determined for *R. steindachneri* indicate that this species could be particularly susceptible to overexploitation.

© 2006 Elsevier B.V. All rights reserved.

Keywords: Artisanal fisheries; Elasmobranch; Bahía Almejas; Gulf of California; Reproductive biology; *Rhinoptera steindachneri*

1. Introduction

Although more scientific and regulatory attention has been dedicated to sharks, batoids can also be extremely vulnerable to fishing pressure (Holden, 1973; Musick et al., 2000; Stevens et al., 2000; Dulvy and Reynolds, 2002; Frisk et al., 2002). For example, common skate (*Dipturus batis*) populations have been locally extirpated in the Irish Sea primarily as a result of incidental catch in groundfish fisheries (Brander, 1981). In the North Sea, fishing mortality has dramatically altered species composition of the local skate assemblage (Walker and Hislop, 1998; Dulvy et al., 2000). Declines of large myliobatiform rays also have been reported from the Bay of Biscay (Quero, 1998) and populations of *Dasypatis* spp. and *Aetobatus narinari* off Calicut, India were greatly reduced in the late 1970s because of increased fishing effort (Devadoss, 1984). Sawfishes (*Pristis* spp.) are among the most endangered of all elasmobranchs, because of habitat destruction, incidental catch, and directed fisheries (Thorson, 1982; Compagno and Cook, 1995; Simpenderfor, 2000). Detailed life history information for targeted batoid species is therefore essential for assessing fishery impacts and potential compensatory responses in order to develop sustainable management plans.

Previous assessments of Mexican elasmobranch (shark and batoid) fisheries indicated that sharks dominated landings and batoids contributed only a small portion (4.2% mass) to overall catches (Bonfil, 1994, 1997; Castillo-Géniz et al., 1998). Recent surveys of small-scale, or artisanal, fishing camps and landings data from the Gulf of California, however, revealed that batoids, especially rays, are important fishery targets throughout this region (Márquez-Farías, 2002). Additionally, rays have been commonly caught as bycatch by shrimp trawlers in the Gulf of California (Fitch and Schultz, 1978; Flores et al., 1995; Garcia-Caudillo et al., 2000), with mor-
tality from the shrimp fishery possibly exceeding that from directed elasmobranch fisheries (Márquez-Farías, 2002). Biological information on commercially exploited ray species in the Mexican Pacific Ocean is extremely limited and no quotas or seasonal closures have been established. Under these conditions, the depletion or collapse of exploited ray populations is a likely scenario.

The golden cownose ray, *Rhinoptera steindachneri* (Rhinopteridae), has been reported from the central Pacific coast of the Baja California Peninsula, Mexico (Castro-Aguirre and Espinosa-Perez, 1996) to Peru (Chirichigno, 1974), including the Gulf of California (McEachran and Notarbartolo-di-Sciara, 1995) and Galapagos Islands (Grove and Lavenberg, 1997). This stingray is commercially landed in artisanal elasmobranch fisheries in the Gulf of California (Notarbartolo-di-Sciara, 1987; Márquez-Farías, 2002) and Bahía Almejas, on the Pacific coast of Baja California Sur (Villavicencio-Garayzar, 1995; Fig. 1). However, because batoid landings have only been recorded in Mexico since 1986 and species-specific data are not collected (Márquez-Farías, 2002), the activities and production of these fisheries are not well known. Despite the widespread occurrence of *R. steindachneri* in the eastern Pacific Ocean and its exploitation in Mexican artisanal fisheries, life history data are also extremely limited for this species. The objectives of this study were to describe artisanal fishery characteristics and assess critical reproductive and maturity parameters necessary to formulate effective management strategies for *R. steindachneri* populations in the Gulf of California and Bahía Almejas.

2. Materials and methods

2.1. Data collection: Gulf of California

Seasonal surveys of fishing camps located in the Mexican states bordering the Gulf of California were conducted during 1998–1999 (Fig. 1), as part of a larger project to characterize the regional artisanal elasmobranch fishery. Data from Baja California, Sonora, and Sinaloa were derived from this data set and used for analyses, with supplemental reproductive information collected in Sonora during 2000. Seasons were defined as follows: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Winter surveys were limited to Sonora and Sinaloa during 1999. Time spent at each camp varied from one to several days and was generally proportional to the amount of elasmobranch fishing effort and landings occurring during the survey. Fishing effort, fishery targets, gear use, and landings were recorded at each site. Principal elasmobranch fishing camps were revisited to allow for seasonal comparison of fishing.
effort and species composition. In addition to statewide surveys, long-term monitoring projects were established in 1999 at Bahía Kino (28°49.11’N, 111°56.35’W) and El Choyudo (28°19.12’N, 111°27.18’W), Sonora. Elasmobranch landings and effort were consistently greater at these camps than others, and much of the data used for this analysis was derived from these locations.

At each camp, artisanal fishing vessels (“pangas”), typically 6.7–7.6 m long, open-hulled fiberglass boats with outboard motors of 55–115 hp, were sampled to determine fishery targets, elasmobranch species composition, fishing location, and gear type. *R. steindachneri* landings were enumerated, sexed, measured, and weighed opportunistically. Disc width (DW; linear distance across the widest portion of the disc) and body length (BL; linear distance from the tip of the snout to the distal edge of the longer pelvic fin) were measured to the nearest centimeter. Weight (WT) was recorded to the nearest 0.1 kg with a spring scale. All size references refer to DW unless otherwise noted.

Inner clasper length was measured from the posterior edge of the cloaca to the tip of the longer clasper. Reproductive status was assessed for both males and females and specimens were classified as either mature or immature. Males with fully calcified claspers that could be easily rotated were considered mature (Pratt, 1979; Smith and Merriner, 1986). Female maturity was determined by macroscopic inspection of the ovaries and uterus (Martin and Cailliet, 1988; Snelson et al., 1988). Mature females had vitellogenic follicles >10 mm diameter and/or embryos in uteri. Number, sex and disc width of embryos were recorded.

### 2.2. Data collection: Bahía Almejas

In Bahía Almejas, landings were sampled during June–August 1998, June and August 1999, and June 2000. All specimens were derived from Puerto Viejo (24°28.34’N, 111°37.12’W), a small artisanal camp that targeted rays during the late spring and summer months. The entire elasmobranch catch of each vessel was identified and enumerated. Landed *R. steindachneri* specimens were processed as previously described. Gravid females and mature males with seminal fluid were noted, but male and female maturity was not routinely assessed and clasper measurements were not taken at this location.

### 2.3. Data analyses

Yearly elasmobranch landings were combined by season for the northern Gulf of California (Baja California and Sonora) and by month (June and August) for Bahía Almejas. Only landings from vessels targeting elasmobranchs were used. Relative abundance and catch per unit effort (CPUE), defined as number of individuals/vessel trip, were determined for *R. steindachneri* from landings in both locations. Relative abundance and CPUE of sharks and batoids were also computed from northern Gulf of California landings. Because landings data from Sinaloa were not recorded during 1998 and inconsistently recorded among seasons during 1999, they were not included in these analyses.

All specimens measured from Baja California, Sonora, and Sinaloa were used to determine size composition and sex ratio of landings and for morphometric comparisons. Male and female size compositions were tested for normality (visual inspection, probability plots) and equal variances (F-tests). Potential differences in mean size were then evaluated using parametric or nonparametric statistics, as appropriate. Sex ratios were tested using $\chi^2$-analysis with Yates correction for continuity (Zar, 1996). The relationships of BL and WT to DW were calculated using linear and power regressions in SigmaPlot (Version 8.0, SPSS Inc., Chicago, IL). Sex-specific differences between these relationships were tested using analysis of covariance (ANCOVA).

Size at maturity was estimated for *R. steindachneri* based on the reproductive status assigned to specimens from Sonora. The proportion of mature rays within 1 cm DW size classes was analyzed for females and males separately. Binomial maturity data (0 = immature; 1 = mature) were fit to the logistic model $Y = [1 + e^{-(a+bx)}]^{-1}$ following Mollet et al. (2000); where $Y$ is the proportion of mature individuals and $x$ is DW (cm). Median DW at maturity was calculated from the resulting model as $-a/b$. The model was fitted using least squares nonlinear regression in SigmaPlot (Version 8.0, SPSS Inc., Chicago, IL).

### 3. Results

#### 3.1. Fisheries characterization

In the northern Gulf of California, fishing operations were conducted daily and gear was typically soaked for 12–24 h. Data were collected at 25 of 36 artisanal fishing camps documented in Baja California ($n = 12$, $N = 17$) and Sonora ($n = 13$, $N = 19$). Among 2110 vessels sampled, the following gear types were used: bottomset gillnets (91.5%), surface gillnets (6.0%), surface longlines (1.8%), and bottomset longlines (0.7%). Vessels using bottomset gear were encountered almost exclusively during winter (98.3%) and spring (99.5%), but also comprised the great majority of sampled vessels during summer (81.9%) and autumn (91.9%).

Of 161,151 elasmobranchs identified from artisanal fishing camp landings in Baja California ($n = 4418$) and Sonora ($n = 156,733$), the great majority were batoids, especially ray species (Table 1). This group was particularly dominant in summer landings and was also landed in considerably greater abundance than sharks during spring. CPUE of batoids was slightly higher during summer than during spring, whereas catch rates of sharks were considerably greater during spring than summer. The winter elasmobranch fishery consisted primarily of sharks, which were also dominant among autumn landings (Table 1). During winter months, CPUE of sharks was the highest recorded for either group in any season and batoid catch rates were almost an order of magnitude less than those recorded among other seasons. CPUE of sharks and batoids was most similar during autumn, when both groups were caught at relatively high rates.

*R. steindachneri* was most abundant in summer landings, when it constituted 11.4% of the total elasmobranch catch and was also commonly landed during spring (6.0%) and autumn.
Sphyrna zygaena and Gymnura marmorata. Other co-occurring species landed during this time were Rhinobatos productus in Baja California and Dasyatis dipterura.

Total 161,151

<table>
<thead>
<tr>
<th></th>
<th>Landings</th>
<th>Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>5997</td>
<td>59</td>
</tr>
<tr>
<td>Spring</td>
<td>78,497</td>
<td>1008</td>
</tr>
<tr>
<td>Summer</td>
<td>35,631</td>
<td>602</td>
</tr>
<tr>
<td>Autumn</td>
<td>41,026</td>
<td>441</td>
</tr>
<tr>
<td>Total</td>
<td>161,151</td>
<td>2110</td>
</tr>
</tbody>
</table>

Autumn species composition that operated off the southern coast during late winter and early spring months. Fishing occurred daily in the Bahía Almejas summer ray fishery and bottomset gillnets, typically soaked for 24 h, were used exclusively. R. steindachneri was the fifth most abundant of 22 elasmobranch species landed (2.8%, n = 113) among 137 sampled vessels. It was more abundant in August (5.2%, n = 107) than in June landings (0.3%, n = 6), a trend also evident in CPUE (August = 1.2; June = 0.1).

3.2. Size composition and morphometrics

No differences were noted in the mean size of female (64.4 ± 14.0 (SD) cm, n = 505) and male (64.2 ± 11.8 cm, n = 585) R. steindachneri captured in the Gulf of California (Mann–Whitney, U = 148302.000, P = 0.909). Specimens ranged from 39 to 98 cm (Fig. 2), with only females occupying size classes >89 cm. Size composition of the overall catch was bimodal, with the majority of specimens ranging from 46–51 or 58–81 cm. The sex ratio (1.16:1), differed significantly from the expected 1:1 (χ^2 = 5.73, P = 0.018).

Although far fewer individuals were sampled from Bahía Almejas (n = 28), the largest specimens observed in this study were recorded there. Individuals averaged 69.3 ± 19.4 cm, and ranged from 44 to 104 cm. Females of 104 and 102 cm and a 96 cm male were observed at this site. Weight data were not available for the largest individual, but the 102 cm female was 18.0 kg and the heaviest weighed individual, a 100 cm female, was 19.5 kg.

Sex-specific differences in morphometric relationships of Gulf of California specimens were observed between WT and DW (ANCOVA, F = 20.001, P < 0.001), but not between BL and DW (ANCOVA, F = 0.831, P = 0.362). The relationship between BL and DW (Fig. 3a) was represented by the following linear equation:

\[ WT = 0.72 BL + 8.93 \]

Fig. 2. Size composition of Rhinoptera steindachneri (sexes combined) landed in Gulf of California artisanal elasmobranch fisheries during 1998 and 1999.
equation: $\text{BL}(\text{cm}) = 0.746 \text{DW} - 5.423$ ($r^2 = 0.953$). The power relationships between WT and DW (Fig. 3b) that provided the best fits were, for females: $\text{WT}(\text{kg}) = 2.806 \times 10^{-5} \text{DW}^{2.886}$, $r^2 = 0.916$; males: $\text{WT}(\text{kg}) = 5.515 \times 10^{-5} \text{DW}^{2.710}$, $r^2 = 0.880$.

3.3. Reproductive biology

Size at maturity was similar between female and male *R. steindachneri*. Among females from Sonora ($n = 245$), the smallest mature specimen was 66 cm and the largest immature individual was 76 cm. The smallest gravid specimen measured 68 cm. Among males ($n = 333$), a steady increase in the proportion of clasper length to DW was evident between approximately 60–70 cm, indicating the onset of male sexual maturity (Fig. 4). The smallest mature male was 65 cm and largest immature male was 72 cm. Median size at maturity was estimated at 70.2 cm for females and 69.9 cm for males (Fig. 5a and b). The proportion of mature females increased more gradually and with greater variability as compared to males. The smaller gravid female ($n = 2$) and smallest male with seminal fluid ($n = 5$) observed from Bahía Almejas were 100 and 70 cm, respectively.

Fecundity was found to be one offspring per female for all gravid specimens examined (Sonora: $n = 147$; Bahía Almejas: $n = 2$). In Sonora, the smallest free-swimming specimen was 39 cm and the largest embryo was 40 cm. The largest embryo recorded from Bahía Almejas was a 43 cm specimen taken from the largest individual (104 cm) observed during this study. In this region, the smallest immature specimen measured 44 cm. Gravid females were recorded in Sonora during all seasons, with the greatest proportion observed during spring (60.5%, $n = 89$) and smallest during summer (1.4%, $n = 2$). The mean disc width of embryos increased from April (26.3 cm, range = 165–333 mm) to May (30.4 cm, range = 245–350 mm), to June (38.8, range = 375–400 mm) in sampling conducted during 1999 and 2000 (Fig. 6). In June, embryos averaged 44.3% of their mother’s disc width. No embryos were observed during
this research indicated that for Sonora and additional data from Baja California, results of Sinaloa, a functional understanding of fishery aspects from this region. In mortality for this species and should be monitored more closely. The mer portunid crab fishery may represent a significant source of seasons (winter–summer). Its capture for use as bait in a summer landings) at Puerto Viejo during the course of this study. Garayzar (1995) previously reported that an early-term embryo, however, was noted in Bahía Almejas during August 1998.

4. Discussion

Results of these surveys confirm that R. steindachneri is a common component of artisanal elasmobranch fisheries in the northern Gulf of California and Bahía Almejas. Villavicencio-Garayzar (1995) previously reported that R. steindachneri was the sixth most abundant ray species (3.9%) landed at Puerto Viejo, Bahía Almejas, where it was caught between July and October. R. steindachneri remained a minor seasonal component of ray landings (fifth most abundant elasmobranch, 2.8% of summer landings) at Puerto Viejo during the course of this study. Márquez-Farías (2002) provided the first detailed information on operations and activities specific to the Gulf of California artisanal ray fishery and demonstrated the importance of Sonora as the primary source of batoid production along Mexico’s Pacific coast. Based on data collected in Sonora during 1998–1999, R. steindachneri landings were found to be the third greatest among batoids (Márquez-Farías, 2002). Using a more expansive data set for Sonora and additional data from Baja California, results of this research indicated that R. steindachneri was the fourth most abundant batoid in landings from the northern Gulf of California. It is evident that R. steindachneri may comprise a substantial portion of the northern Gulf of California elasmobranch catch during warm water periods (March–November).

Fishery information from the southern Gulf of California (Baja California Sur and Sinaloa) is extremely limited for R. steindachneri, both historically and from this study, precluding a functional understanding of fishery aspects from this region. In Sinaloa, R. steindachneri was documented among all surveyed seasons (winter–summer). Its capture for use as bait in a summer portunid crab fishery may represent a significant source of mortality for this species and should be monitored more closely.

Notarbartolo-di-Sciara (1987) documented the incidental capture of R. steindachneri in a southwestern Gulf of California mobulid fishery during summer months. R. steindachneri also was observed in landings from the Gulf coast of Baja California Sur during this study, but insufficient information was available from this region for evaluation.

Artisanal landings of R. steindachneri were derived almost exclusively from bottomset gillnets. Although this stingray is known to occur in surface waters of nearshore regions (McEachran and Notarbartolo-di-Sciara, 1995; Grove and Lavenberg, 1997), most surface longline and gillnet sets were located in offshore waters, targeting large pelagic sharks. Additionally, bottomset longline gear was usually baited with fish or squid, food items that are not typically consumed by R. steindachneri (McEachran and Notarbartolo-di-Sciara, 1995; Grove and Lavenberg, 1997; pers. obs.). Because of its relatively large size, tail spine, and schooling behavior, R. steindachneri and its congeners appear to be especially susceptible, however, to capture in bottomset gillnets. During this study, catches of 100–300 individuals/trip were observed from northern Gulf of California vessels using bottomset gillnets. In addition, catches of 250–7000 R. javanica have been reported from bottomset gillnets and shore seine in the Gulf of Mannar, India (James, 1962). The capture of R. steindachneri predominantly by this gear type is therefore consistent with previous findings.

R. steindachneri landings in the northern Gulf of California peaked during summer months, as did CPUE. During winter, this species was rarely landed. Based on catch records, interviews with fishermen, and previous information (Villavicencio-Garayzar, 1995), a similar pattern is evident in Bahía Almejas. R. steindachneri, like other rhinopterid rays, is believed to undergo extensive migrations in the eastern North Pacific (Schwartz, 1990; McEachran and Notarbartolo-di-Sciara, 1995) moving northward in early spring and southward in autumn, primarily in response to differences in water temperature (Smith and Merriner, 1987; Blaylock, 1993). These migrations to and from the northern extent of its range are the probable cause of seasonal differences in landings and CPUE. R. steindachneri CPUE in the northern Gulf of California increases with increasing water temperatures in spring, peaks during the period of warmest water temperatures in summer, drops as water temperatures cool in autumn and is lowest during the coldest (winter) water period (Soto-Mardones et al., 1999).

R. steindachneri is also likely more abundant, at least during summer months, in the northern Gulf of California than in Bahía Almejas. Although observed spatial differences in CPUE could be an artifact of differential sampling or fishing effort, gear type (bottomset gillnets) was consistent between regions and the discrepancy in catch rate (northern Gulf of California = 8.3, Bahía Almejas = 0.8) was considerable. Bahía de Sebastian Vizcaíno, at the border of Baja California and Baja California Sur, represents the northernmost occurrence for R. steindachneri outside the Gulf of California and is within 500 km of Bahía Almejas (Castro-Aguirre and Espinosa-Perez, 1996). Cooler waters evident in the Pacific influence the northern distribution of this species and likely confine it to coastal bays and estuaries that maintain higher temperatures during summer.
months (Alvarez-Borrego et al., 1975; Lluch-Belda et al., 2000). The limited heterogeneous nature of suitable habitat along the Pacific and possible high energetic costs associated with traversing the mouth of the Gulf of California, a deep water region of basins and rift zones (Rusnak et al., 1964; Dauphin and Ness, 1991), may restrict immigration to Bahía Almejas.

Batoid landings and CPUE were considerably higher than those of sharks among vessels sampled in the northern Gulf of California. As was evident for R. steindachneri, batoids were especially dominant during summer months, when frequency and CPUE were highest. These findings are contrary to those of Bonfil (1994), who stated that batoids were a minor component of the Mexican elasmobranch fishery, contributing only 4.2% by mass to landings. Although most prior Mexican artisanal elasmobranch fishery studies have focused on sharks (e.g., Applegate et al., 1993; Villavicencio-Garayzar, 1996; Castillo-Géniz et al., 1998), a mobulid fishery south of La Paz has been well documented (Notarbartolo-di-Sciara, 1987, 1988) and recently, Márquez-Farías (2002, 2005) reported on the significance of ray landings from Sonora and, to a lesser extent, the Baja California Peninsula. This apparent contradiction between the recent and past importance of batoid landings in the northern Gulf of California suggests that the available catch records have under-reported historic ray landings, that a significant expansion of the directed fishery for rays has occurred (possibly prompted by a reduction in landings of sharks and traditionally fished teleost species), or that a combination of these factors is responsible for the difference in reported catch compositions.

Although R. steindachneri landings in the Gulf of California represented almost the entire potential size range of this species, neonates and juveniles (<50 cm) were disproportionately taken. Immature specimens were also more common than adults among landings in Bahía Almejas. It is possible that the predominance of small individuals in landings is a consequence of gear selectivity, but the large mesh sizes typically used by fishermen should have selected for large, not small, individuals (Kirkwood and Walker, 1986; Márquez-Farías, 2005). Rhinoptera species are known to aggregate in similar size classes and juveniles generally occupy sheltered, nearshore waters, making them especially vulnerable to bottomset gillnet fisheries (Smith and Merriner, 1987). Although the population of the northern Gulf of California does not seem to exhibit a truncated size distribution, size composition of future landings should be monitored to determine the prolonged effects of exploitation.

Our results expand the size range previously reported for R. steindachneri in both Bahía Almejas and the Gulf of California. The second largest female (104 cm) and largest male (96 cm) R. steindachneri recorded during this study were landed at Puerto Viejo, Bahía Almejas. A 105 cm female and 91.5 cm male, also landed at Puerto Viejo, represent the maximum size and largest male previously reported for this species (Villavicencio-Garayzar, 1995). The sizes of these specimens are comparable to the largest sizes recorded for Rhinoptera bonasus (females, 107.0 cm and males, 98.1 cm; Smith and Merriner, 1987). Outside Bahía Almejas, the largest documented R. steindachneri was a 78.1 cm male from the La Paz region, Baja California Sur (Notarbartolo-di-Sciara, 1987). Grove and Lavenberg (1997) reported that R. steindachneri reached sizes of “about 0.9 m”, at the Galapagos Islands though no specimens were measured. Based on Gulf of California survey results, 184 individuals were >78 cm and 10 were >90 cm. The sizes documented here are considerably larger than those generally reported and serve to underscore the historic lack of attention paid to this species.

Size differences were noted between populations of R. steindachneri from Bahía Almejas and those from the Gulf of California. In both regions, females reached slightly larger sizes than males. However, maximum sizes were considerably larger in Bahía Almejas. These results are especially striking because gear type and mesh sizes were similar between regions, both regions have been subjected to prolonged fishing pressure (Ramirez-Rodriguez, 1987; Musick et al., 2000; Sala et al., 2004), and sample size of measured specimens was much greater in the northern Gulf of California.

The creation of the Gulf of California and emergence of the Baja California Peninsula as a barrier to marine dispersal has resulted in disjunct distributions for several fish species and the speciation of Gulf of California endemics (Astrid et al., 2000; Huang and Bernardi, 2001). Genetic differences between populations from the Gulf of California and Pacific coast of the Baja California Peninsula have been reported for Rhinobatos productus and for several teleost species (Bernardi et al., 2003; Sandoval-Castillo et al., 2004). Intraspecific variation among life history traits in fishes from these regions also has been reported (Villavicencio-Garayzar, 1993; Hovey and Allen, 2000). Geographic variation in life history traits has been observed between cownose ray (R. bonasus) populations from the Gulf of Mexico and Chesapeake Bay, with populations from the former region attaining maturity at a smaller size and age and potentially reaching smaller maximum sizes (Neer and Thompson, 2005). It is possible that populations of R. steindachneri from Bahía Almejas and the northern Gulf of California have a limited amount of genetic interchange and may exhibit different age, growth, and other life history characteristics. The degree of connectivity and potential for variation in life history traits between R. steindachneri populations has major implications for management of this species in the Mexican Pacific Ocean and requires further investigation.

Size at maturity has not previously been assessed for R. steindachneri, but anecdotal information is available for comparison. In the southwestern Gulf of California, Notarbartolo-di-Sciara (1987) reported a 73 cm immature male and mature males of 75.3 and 78.1 cm. These findings are consistent with those determined for males (smallest mature = 65 cm, largest immature = 72 cm) in the northern Gulf of California from this study. In Bahía Almejas, Villavicencio-Garayzar (1995) noted the smallest mature and largest immature females at 87 and 75 cm and the smallest mature male at 81 cm among limited samples. A 70 cm male with seminal fluid was observed during this study, representing the smallest mature male specimen from Bahía Almejas to date. More research is needed to determine size at maturity for R. steindachneri in this region.

Size at maturity for R. steindachneri in the Sonora was found to be similar for females and males. This finding is in contrast to the common observation that male myliobatiform rays, and elas-
moobranchs in general, mature at smaller sizes (e.g., Branstetter, 1987; Martin and Cailliet, 1988; Snelson et al., 1988; Jensen et al., 2002), but analogous to estimates reported for other rhinopterid populations. First maturity of female *R. bonasus* from Chesapeake Bay were reported at disc widths approximately 5 cm greater than those of males (84.5 cm, females; 80.0 cm, males; Smith and Merriner, 1986). Female and male *R. bonasus* from the northern Gulf of Mexico reached 50% maturity at similar (65.3 cm, females; 64.3 cm, males; Neer and Thompson, 2005). Female and male *R. steindachneri* from Sonora matured at sizes comparable (70.2 cm, females; 69.9 cm, males), but intermediate, between congeneric populations of *R. bonasus*. Low sample size precluded the calculation of median size at maturity for Bahía Almejas specimens. However, based on observed differences in size composition, it is likely that individuals from Bahía Almejas mature at larger sizes than Sonoran specimens.

The fecundity of *R. steindachneri* (one pup per litter) is extremely low, even among elasmobranchs (Pratt and Casey, 1990). This condition, however, is typical for rhinopterids (Setna and Sarangdhar, 1949; Smith and Merriner, 1986) and mobulids (Notarbortolo-di-Sciara, 1988; Homma et al., 1999); considered to be the most derived batoid families (Compagno, 1999; McEachran and Aschliman, 2004). All stingrays (Myliobatiformes) are viviparous, with a single functional ovary and embryonic nutrition supplied by uterine histotroph (Wourms, 1977; Hamlett and Koob, 1999). *R. steindachneri* represents an extreme example of the general myliobatiform reproductive strategy (i.e., to produce few large offspring with a high survival rate). The dominance of juveniles in landings from the Gulf of California and Bahía Almejas could confound this strategy by removing immature individuals from the population before they can reproduce.

Although increased fecundity with increasing maternal size has been frequently reported among sharks (e.g., Pratt, 1979; Loefer and Sedberry, 2002), this tendency was not observed for *R. steindachneri*. Larger females appeared to carry larger embryos throughout the year, although temporal differences in data collection and low sample sizes precluded statistical analysis. It is likely that larger female *R. steindachneri* may give birth to larger offspring. This characteristic has been suggested for several other myliobatiform rays, including *D. imbricatus* (DeVadoss, 1978) and *D. sephen* (Raje, 2003). The relationship between maternal size and fecundity or offspring size among myliobatiform rays requires additional investigation to clarify these trends and their potential implications on life history and population dynamics.

Based on the largest embryos and smallest free-swimming individuals recorded, size at birth was estimated to occur between 38 and 45 cm for *R. steindachneri*. Although the largest embryo documented in this study measured 43 cm, Villavicencio-Garayzar (1995) reported a 44 cm embryo from a 95 cm female and neonates of 41–45 cm in landings from Bahía Almejas. No embryos larger than 40 cm were documented in the Gulf of California and it is possible that parturition occurs at smaller sizes there. Size at birth for *R. steindachneri* appears to be similar but more variable than for *R. bonasus*, for which the smallest free-swimming individual and largest embryo were 32.3 and 44.0 cm, respectively (Smith and Merriner, 1986).

The reproductive cycle of this species likely consists of an 11–12-month gestation period. Mean size of embryos sampled in Sonora indicated slow and steady growth throughout the autumn and winter months with growth rates increasing during April and maximum sizes observed during June. Information from this study and prior research in Bahía Almejas (Villavicencio-Garayzar, 1995) indicate parturition from late June–August and males with seminal fluid present during July and August. It is likely that parturition, mating, and fertilization occur during a relatively short interval between late June and early August in Bahía Almejas and probably also in the Gulf of California. Reproduction is likely to be annual for *R. steindachneri*, but expanded sampling and more detailed assessments of female reproductive tracts is necessary to detect any potential resting periods.

The reproductive pattern observed for *R. steindachneri* from the northern Mexican Pacific corresponds well to that described for *R. bonasus* from Chesapeake Bay and the northern Gulf of Mexico. Smith and Merriner (1986) reported parturition during late June and early July following a possible 11–12-month gestation period. Female ovulation was found to occur immediately following parturition and early stage embryos were observed in late summer months. Neer and Thompson (2005) also reported an 11–12-month gestation period for *R. bonasus*.

### 5. Conclusions

Although Mexican elasmobranch fisheries are among the largest in the world, species-specific catch information is extremely limited (Bonfil, 1994; Stevens et al., 2000). Our surveys of artisanal elasmobranch fisheries indicate that batoids are a primary component of landings throughout the Gulf of California and from Bahía Almejas. *R. steindachneri* constitutes a substantial portion of the artisanal catch in these region, especially during summer months, and may be commonly taken as bycatch by shrimp trawlers. Currently, no quotas, seasonal closures, or gear restrictions are established for these mixed species elasmobranch fisheries and bycatch is unregulated in shrimp trawler fisheries. The conservative reproductive strategy exhibited by *R. steindachneri*, in which a single pup is produced annually (or longer) after maturity is reached at a relatively large size, suggests that this species is of low productivity and highly susceptible to overexploitation. Furthermore, the common schooling behavior of these highly mobile nearshore rays makes them extremely vulnerable to gillnet gear typically used in artisanal elasmobranch fisheries. The combined lack of potential resiliency to population reduction, peak in landings during the pupping and breeding season, and susceptibility to commonly employed fishing gears create conditions by which rapid depletion or collapse of *R. steindachneri* populations in the northern Mexican Pacific is likely to occur without precautionary management. The biological and fisheries information detailed in this study demonstrates the urgent need for directed life history studies and fisheries management of Mexican elasmobranchs.
Acknowledgements

We thank Leonardo Castillo, John Tyminski, Altacgracia Landa, Phillip Sanchez, Julie Neer, and Erin Jones for field and technical assistance. Thanks also to Gregor Cailliet, David Ebert, Stori Oates, and two anonymous reviewers for advice and assistance with this manuscript. This study was the by-product of two broader projects directed at assessing the biology and fishery characteristics of exploited elasmobranchs in the Gulf of California and Bahía Magdalena lagoon complex. Funding for these projects was provided, in part, by the David and Lucile Packard Foundation, Homeland Foundation, Jili Foundation, California Sea Grant College System, PADI Project AWARE, World Wildlife Fund, Christensen Fund, Moss Landing Marine Laboratories, Mote Marine Laboratory, Instituto Nacional de la Pesca, and National Oceanic and Atmospheric Administration/National Marine Fisheries Service (to the National Shark Research Consortium).

References


