BRIEF COMMUNICATIONS

Age and size at sexual maturity of the smooth skate *Malacoraja senta* from the western Gulf of Maine

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Age and size at sexual maturity was determined for 185 male and 96 female smooth skates *Malacoraja senta* (ranging in size from 370 to 680 mm total length $L_T$), collected from the western Gulf of Maine. Maturity ogives for males, based on clasper length, testis mass and the proportion of mature spermatocysts in the testes, suggest that 50% maturity occurs between 9 and 10 years and 560 mm $L_T$. Maturity ogives for females, based on ovary mass, shell-gland mass and maximum follicle size, suggest that 50% maturity occurs at age 9 years and 540 mm $L_T$.

Key words: fishery management; life history; Rajidae; reproductive biology.

Directed fisheries have caused stock collapses in many shark species (Musick, 1999, 2004; Stevens *et al*., 2000). Recent skate stock assessments indicate that skates are also at risk. For example, Dulvy & Reynolds (2002) recently confirmed the disappearance of the common skate *Dipturus batis* (L.) from the Irish Sea, and reported that the long-nosed skate *Dipturus oxyrinchus* (L.) and the white skate *Rostroraja alba* (Lacèpède) were also absent from substantial parts of their ranges. In the north-western Atlantic Ocean, precipitous declines have occurred in the thorny *Amblyraja radiata* (Donovan) and smooth *Malacoraja senta* (Garman) skate stocks (NEFMC, 2003, 2005; NMFS, 2007).

*Malacoraja senta* is one of the smallest (66 cm total length, $L_T$; 1-2 kg total wet mass, $M_W$) species of skate endemic to the north-west Atlantic Ocean (McEachran, 2002). This species has a relatively broad geographic distribution, ranging from Newfoundland and the southern Gulf of St Lawrence in Canada to New Jersey in the U.S. (Robins & Ray, 1986; McEachran, 2002). Recently, the age and growth (Natanson *et al*., 2007) as well as the reproductive cycle (Sulikowski *et al*., 2007) of this species

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have been reported for specimens inhabiting the western Gulf of Maine. According to the results of Natanson et al. (2007), Sulikowski et al. (2007) and those of Wine-miller & Rose (1992) and Frisk et al. (2001), this species, like other elasmobranchs, displays characteristics that make them vulnerable to overexploitation.

The present study is the third in a series aimed at providing life-history data for the management of *M. senta* within the Gulf of Maine. The objectives were to determine size at sexual maturity by correlating the morphological and histological characteristics of developing reproductive tracts with body size. This method has provided a more precise determination of sexual maturity in other skate species than have morphological measurements alone (Sulikowski et al., 2005, 2006). Body size was then related to annular counts on vertebral centra to estimate age at sexual maturity.

For this study, *M. senta* were captured by otter trawl in an c. 2300 km² area centred at 42°50′ N; 70°15′ W in the coastal waters of the Gulf of Maine from October 2001 to October 2004. These locations varied from 30 to 40 km off the coast of New Hampshire, U.S.A. If weather permitted, fish were sampled at sea; otherwise, they were maintained alive on board the vessel until transport to the University of New Hampshire’s (UNH) Coastal Marine Laboratory (CML). Values of *L*ₜ (mm), disc width (*W*₅, mm) and *M*ₜ (kg) were recorded.

Dissection and processing of reproductive tracts for both male and female *M. senta* followed protocols previously described in Sulikowski et al. (2005, 2006, 2007). Detailed information pertaining to the ageing of this species is reported in Natanson et al. (2007). Males were identified as mature and reproductively capable of copulating when three criteria were met. This included elongated and calcified claspers with a clasper length (*L*ₐ, mm) to *L*ₜ ratio (*L*ₐ / *L*ₜ) ≥ 0.20, testes with a mass of (*M*ₐ) ≥ 5 g, and testes that containing ≥ 20% mature spermatocysts (Sulikowski et al., 2005, 2006, 2007). The relationships between *L*ₜ and mean *M*ₐ, and mean per cent mature spermatocysts were examined using 10 mm *L*ₜ size and 1 year age classes to assess the chronological reproductive development of males.

Females with reproductive tracts that contained ovarian follicles ≥ 14 mm in diameter and shell-glands weighing ≥ 5 g were identified as sexually mature (reproductively capable of egg encapsulation and oviposition). These morphological variables represented the minimum observed for *M. senta* females bearing egg cases in their uteri (Sulikowski et al., 2005, 2006, 2007). The relationships between *L*ₜ and mean ovary mass (*M*ₒ), mean shell-gland mass (*M*ₕ), and the presence of vitellogenic follicles were examined using 10 mm *L*ₜ size and 1 year age classes to assess the chronological reproductive development of females.

Differences in reproductive morphological and histological variables among age groups were tested with ANOVA followed by a Tukey’s post hoc test. The proportion of mature spermatocysts was transformed to arcsin values to make the data conform to the assumption of normal distribution. Statistical significance was accepted at *P* < 0.05. Pearson correlation (*r*) analyses were performed to test whether morphological measurements were correlated. The *L*ₜ and age (A) at which smooth skates reached 50% sexual maturity (*L*ₜ₀ and *A*ₜ₀) were estimated by fitting maturity ogives to *L*ₜ (at 10 mm intervals) and A (1 year intervals) by sex using probit analyses (Sulikowski et al., 2005, 2006, 2007).

Sexual maturity was determined for 185 males ranging in size from 340 to 680 mm *L*ₜ. Relative *L*ₐ, *M*ₐ and per cent mature spermatocysts increased with *L*ₜ until the
onset of sexual maturity (Table I). For relative $L_C$, significant differences were found from ages 6 and 7 (c. 438–482 mm $L_T$) and 9 and 10 years (c. 540–570 mm $L_T$). In contrast, significant differences in $M_t$ and per cent mature spermatocysts were found from ages 8 to 9 (c. 513–540 mm $L_T$) and 9 to 10 years, respectively. All variables remained relatively constant after the age of 10 years (>570 mm $L_T$), except for the per cent mature spermatocysts, which remained constant after age 12 years. In addition, simultaneous changes in these measured variables were strongly correlated with each other (mean ± s.e. $r$ value = 0.82 ± 0.02) over the course of sexual maturation.

Maturity ogives suggested that $LT_{50}$ and $A_{50}$ occurs at 560 mm [Fig. 1(a)] and 9.5 years [Fig. 1(b)]. These data are in overall agreement with the measured reproductive variables, which suggested that maturity occurs at 565 mm $L_T$ and c. 10 years. Thus, maturity in males occurs at c. 87% of their maximum observed $L_T$ and 63% of their maximum observed age. The smallest mature male was 550 mm $L_T$ and 8 years, and the largest immature male was 575 mm $L_T$ and 10 years.

In females, sexual maturity was determined from 96 fish ranging in size from 370 to 630 mm $L_T$. Values of $M_w$, $M_o$ and average follicle size increased until an abrupt increase at sexual maturation. A significant increase in $M_{sg}$ was observed as females matured from ages 8 to 9 years (c. 531–545 mm $L_T$). As fish matured, the number of small vitellogenic follicles significantly increased from ages 7 to 8 years (c. 498–531 mm $L_T$) and from 8 to 9 years (c. 531–545 mm $L_T$) (Table II). As females continued to mature, follicle size gradually increased until age 12 years (c. 568 mm $L_T$). Thereafter the average size of the largest follicle remained relatively constant (Table II). Although no significant differences were detected, there was a trend of increasing $M_o$ up to age 10 years (Table II). Analogous to males, synchronous changes in the measured variables were strongly correlated with each other (mean ± s.e. $r$ = 0.80 ± 0.05) over the course of maturation.
Maturity ogives for females predicted that $L_{T50}$ and $A_{50}$ occur at 540 mm [Fig. 1(a)] and 9 years [Fig. 1(b)]. These estimates are corroborated by the maturity estimates derived from the use of shell-gland and follicle size data, which suggest 50% maturity at 545 mm $L_T$ and c. 9 years of age. Thus, female maturity occurs at c. 87% of their maximum observed $L_T$ and 64% of their maximum observed age. Using the measured reproductive variables, the smallest mature female was 500 mm $L_T$ and aged 8 years, while the largest immature female measured 560 mm $L_T$ and aged 10 years.

Based on the results of this study, male and female $M. senta$ appear to reach maturity at about the same relative percentage of their observed maximum size (between 88 and 87%, respectively) and age (63 and 64%, respectively), suggesting that the
TABLE II. Morphological measurements and reproductive variables (mean ± S.E.) for the female Malacoraja senta

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>n</th>
<th>$L_T$ (mm)</th>
<th>$M_W$ (kg)</th>
<th>$M_O$ (g)</th>
<th>$M_{sg}$ (g)</th>
<th>Largest follicle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>375 ± 0</td>
<td>0.17 ± 0.00 &lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>9-60 ± 3.04</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>443 ± 1</td>
<td>0.36 ± 0.01</td>
<td>0.97 ± 0.01</td>
<td>0.60 ± 0.01</td>
<td>&lt;1</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>498 ± 1</td>
<td>0.64 ± 0.08</td>
<td>1.30 ± 0.10</td>
<td>0.81 ± 0.09</td>
<td>&lt;1</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>531 ± 0</td>
<td>0.63 ± 0.03</td>
<td>4.30 ± 1.13</td>
<td>3.10 ± 0.66</td>
<td>12-90 ± 1.33</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>545 ± 0</td>
<td>0.68 ± 0.04</td>
<td>5.90 ± 0.73</td>
<td>5.30 ± 0.51</td>
<td>9-60 ± 3.04</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>557 ± 1</td>
<td>0.70 ± 0.04</td>
<td>7.10 ± 0.72</td>
<td>5.10 ± 0.34</td>
<td>14-60 ± 1.18</td>
</tr>
<tr>
<td>11</td>
<td>17</td>
<td>565 ± 0</td>
<td>0.76 ± 0.04</td>
<td>7.20 ± 0.53</td>
<td>5.70 ± 0.40</td>
<td>15-90 ± 0.79</td>
</tr>
<tr>
<td>12</td>
<td>11</td>
<td>568 ± 1</td>
<td>0.83 ± 0.05</td>
<td>8.00 ± 0.56</td>
<td>6.60 ± 0.39</td>
<td>16-10 ± 0.65</td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>573 ± 0</td>
<td>0.85 ± 0.07</td>
<td>7.20 ± 0.32</td>
<td>5.60 ± 0.33</td>
<td>15-40 ± 0.56</td>
</tr>
<tr>
<td>14</td>
<td>8</td>
<td>599 ± 1</td>
<td>0.99 ± 0.03</td>
<td>9.40 ± 0.57</td>
<td>6.70 ± 0.35</td>
<td>17-10 ± 0.46</td>
</tr>
</tbody>
</table>

For each column, arrowed brackets represent significant differences ($P < 0.05$; ANOVA followed by a Tukey’s post hoc test) between fish in consecutive age groups. $n$, sample size; $L_T$, total length; $M_W$, total wet mass; $M_O$, ovary mass; $M_{sg}$, shell-gland mass.

The majority of growth occurs prior to the onset of maturity and then slows considerably. This observation is consistent with maturity and growth patterns exhibited by other skate species, with maturity occurring at 80–90% of their maximum $L_T$ and 60–70% of their maximum ages (Dulvy et al., 2000; Ebert, 2005, Sulikowski et al., 2007; Oddone & Amorim, 2008).

In male elasmobranchs, sexual maturity is most often marked by an abrupt increase in $L_C$ and calcification (Francis et al., 2001; Oddone et al., 2007). This was consistent with the present results; however, external morphological features indicated earlier maturity than the internal tissues. This type of morphological delay has also been observed in the winter skate Leucoraja ocellata (Mitchill) (Sulikowski et al., 2005) and the roundel skate Raja texana Chandler (Sulikowski et al., 2007). Differences between morphological and histological maturity were c. 1 year and 30 mm $L_T$ for the L. ocellata and 2 years and 75 mm for R. texana. A lag period in functional maturity has also been documented in the bonnethead shark Sphyraena tiburo (L.) (Gelsleichter et al., 2005). In this shark species, claspers grow continuously in length during puberty, but do not reach functional maturity until a short period before mating activity commences. The cause of these lags may be a result of differential physiological constraints on the rate of internal and external organ development. The present results provide further evidence for the use of multiple variables for sexual maturity assessment, particularly in male elasmobranchs.

For female elasmobranchs, an abrupt increase in $M_O$ and follicle size typically marks the onset of sexual maturity (Conrath et al., 2002; Sulikowski et al., 2005; Ebert et al., 2008). This trend was also observed in $M. senta$ as marked increases in follicle size (26%), $M_{sg}$ (41%) and $M_O$ (27%) were observed as this species matured from ages 8 to 9 years, or the age prior to 50% maturity. Although these changes were not statistically significant, they were strongly correlated, signalling a biologically significant shift towards sexual maturity occurred within this age group (Sulikowski et al., 2005; 2006).
In summary, the life-history variables from Sulikowski et al. (2007) and Natanson et al. (2007), along with the data from the current study, indicate that the *M. senta* is a late maturing and long-lived species and is therefore vulnerable to overexploitation (Stevens et al., 2000; Frisk et al., 2001; Musick, 2004).

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