Reproductive biology of the brown smoothhound shark
*Mustelus henlei*, in the northern Gulf of California, México

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Female brown smoothhound sharks *Mustelus henlei* were found to reproduce annually. A mature female carried both developing oocytes in the ovary and developing embryos in the uteri concurrently for c. 1 year. A great variability in the size of embryos was recorded each month, and the maximum embryo sizes were found from late January to mid-March. The largest oocytes in mature females were observed in mid-March. Gestation lasted c. 10 months. A linear relationship between maternal total length (*L*<sub>T</sub>) and the number of pups per litter (litter size one to 21) was estimated. Birth *L*<sub>T</sub> was reached in c. 280 mm. Females and males matured at 570–660 and 550–560 mm *L*<sub>T</sub>, respectively. Difference in the litter size among Californian coast (one to 10) and northern Gulf of California (one to 21) populations existed for this smoothhound shark.

Key words: *Mustelus henlei*; reproductive cycle; size at maturity.

**INTRODUCTION**

The brown smoothhound *Mustelus henlei* (Gill), a small triakid shark, is an abundant bottom-dwelling species of the eastern Pacific continental shelves, found from the intertidal region to at least 200 m depth (Compagno, 1984). It inhabits temperate and sub-tropical waters from northern California to the Gulf of California and Ecuador to Peru (Compagno, 1984) and is rarely reported south of the Gulf of California (Castro, 1996a).

The life history of the *M. henlei* is relatively well known in U.S.A. Californian waters. Several authors have provided information on its distribution and reproductive biology (Compagno, 1984; Castro, 1996a; Ebert, 2003), food habits (Russo, 1975; Talent, 1982; Haeseker & Cech, 1993), age and growth
(Yudin & Cailliet, 1990) and demography (Smith et al., 1998). The reproductive cycle, however, has not been documented for this species. Furthermore, the regional variability in the reproductive biology documented in some species of the genus Mustelus (Lenanton et al., 1990; Chiaramonte & Pettovello, 2000; Yamaguchi et al., 2000) suggest that reproductive variables should be estimated for the M. henlei throughout its range.

The objectives of the present study were to provide information of the reproductive biology for M. henlei in the northern Gulf of California, including the data to describe the reproductive cycle, comparisons of reproductive variables between northern Gulf of California and Californian waters, inferences on seasonal movements carried by mature females and to establish if there is a nursery ground in the study area for this species.

**MATERIALS AND METHODS**

A total of 658 M. henlei were obtained from three different sources during 2003 and 2004 in the northern Gulf of California: (1) 598 from two medium size trawlers (90 mm mesh-size in the net), (2) 46 from small boats (artisanal fleet) with bottom-set gillnets (100 mm mesh-size) and (3) 14 from small boats with bottom-set longlines (60 mm J hooks). Although M. henlei were caught between 30 and 266 m depth, c. 75% of them were caught in areas deeper than 80 m.

In the northernmost region of the northern Gulf of California is located the Biosphere Reserve of the Upper Gulf of California and Colorado River Delta (Fig. 1). The trawlers (fishing from 30 to 281 m depth) and small boats using bottom-set longlines (fishing from 74 to 102 m depth) fished out of the Biosphere Reserve (south of 31°N; Fig. 1), and the small boats using bottom-set gillnets (fishing from 6 to 55 m depth) fished at shallow waters in the Biosphere Reserve (north of 31°N; Fig. 1).

All specimens were measured and examined to quantify reproductive variables: 445 females 410–905 mm total length $L_T$ (mean $\pm$ S.D., 66 $\pm$ 11 mm), 212 males 355–710 mm $L_T$ (mean 60 $\pm$ 7 mm) and a rudimentary hermaphrodite 570 mm $L_T$. The $L_T$ was measured on a horizontal line between perpendiculars, from the tip of the nose to the tip of the tail, with the tail at its maximum extension (Castro, 1996b).

Claspers were measured from the cloacal apex to the tip of the claspers (claspers length, $L_C$). Males were considered mature if claspers: (1) exceeded the posterior edge of pelvic fins, (2) presented hardened internal structure and (3) could be rotated towards the anterior part without bending. Males were considered juvenile if they had relatively short and flexible claspers (Clark & von Schmidt, 1965).

The oviducal glands width, the oocyte diameter and the uteri width were measured in females. The uteri were examined to determine if embryos or uterine eggs were present. Such data were used to assign the maturity stage category for each female (immature, gravid and non-gravid mature). Females were considered mature if they were gravid or when non-gravid if they had oviducal glands $\geq 11$ mm width, ripe oocytes $\geq 8.1$ mm diameter and uteri $\geq 12$ mm width. The smallest size for these reproductive organs was taken from well-defined non-gravid mature females that had one or two characteristics: (1) uteri enlarged, indicating recent parturition (postpartum females) and (2) in addition to ripe oocytes in the ovary, they contained uterine eggs (females in the process of ovulation).

To determine the reproductive cycle of females, a time series of oocyte diameter of mature females and the presence of uterine eggs and a time series of the size of embryos of gravid females were analysed. As proposed by Castro (1996b), to determine the litter size, aborting females or females that appeared to have aborted embryos were not considered, and if embryos could not be discerned, the total number of normal, viable uterine eggs was counted.
RESULTS

SIZE AT MATURITY

Males
One hundred and sixty-eight mature and 44 immature male *M. henlei* were examined. All specimens $\geq 550$ mm $L_T$ were mature, except the largest immature male $560$ mm $L_T$ and a rudimentary hermaphrodite specimen that measured $570$ mm $L_T$ (Fig. 2). As the smallest mature male was $550$ mm $L_T$ (calcified claspers $69$ mm), the size range at maturity would appear to be $550–560$ mm $L_T$.

Females
Two hundred and forty-six mature and 199 immature female *M. henlei* were examined. The largest immature female measured $660$ mm $L_T$, having oviducal glands $13$ mm width, oocytes $8$ mm diameter and uteri $12$ mm width. The smallest mature female was a gravid $570$ mm $L_T$, with oviducal glands $11.5$ mm width,
oocytes 2.5 mm diameter and uteri 28 mm width [Fig. 3 (a), (b), (c)]. This gravid female contained four embryos 64–70 mm $L_T$. Based on the size of the largest immature female and the smallest mature female results in a size range at maturity of 570–660 mm $L_T$.

Of 121 immature females $\geq 570$ mm $L_T$, 83 had well-developed reproductive organs: oviducal glands 10–20 mm width, oocytes 8–11 mm diameter and uteri 8–18 mm width. These 83 females occurred between late January and early September, although mainly in March ($n = 70$).

**OVARIAN CYCLE AND OVULATION**

The time series of oocyte diameter of mature females through the year [Fig. 4(a)] and the record of gravid females that recently ovulated (carrying uterine eggs), indicated that the ovarian cycle was annual and that ovulation occurs over a period of 3 months, from mid-March to mid-June. Most of females with oocytes close to the size at which ovulation is inferred to occur (postpartum mature females and near-term gravid females) were found in March [Fig. 4(a)]. Twenty-one postpartum mature females were examined in mid-March, two in late April and one in late August. In addition, mature females with ripe oocytes that also contained uterine eggs were examined in mid-March ($n = 2$) and mid-November ($n = 1$).

Thirty-three gravid females carrying uterine eggs and early embryos were registered in the Biosphere Reserve from late April to late June. These data suggest that some of these females ovulated probably in mid-June, thereby extending the ovulation period to this month.

**GESTATION PERIOD**

Averaging from the middle of the period when gravid females contained all their embryos $\leq 60$ mm $L_T$ (between April and June), to the middle of the period when females contained the largest embryos (in February and March),
results in a gestation of c. 10 months [Fig. 4(b)]. The great variability of the size of embryos registered each month [Fig. 4(b)] suggests that the birth season lasts several months, probably from late January to approximately late April, lasting a similar length of time to ovulation (c. 3 months).
BIRTH LENGTH

Based on the size of the largest embryos examined, it was estimated that the size at birth is c. 280 mm \( L_T \). The smallest free-swimming \( M. \) henlei examined measured 355 mm \( L_T \). This specimen caught in mid-November had a healed umbilical scar.

LITTER SIZE

The litter size ranged from one to 21 (mean ± s.d., 10 ± 5). Data were obtained from 219 gravid females 570–905 mm \( L_T \). As the \( L_T \) of the gravid females increased, the litter size also increased (Fig. 5).

REPRODUCTIVE CYCLE

Female \( M. \) henlei reproduced annually. The ovarian cycle and gestation are concurrent; the oocytes and embryos are developed at the same time, the oocytes
reaching the largest diameter and the embryos the maximum $L_T$ in March [Fig. 4(a), (b)]. Therefore, soon after parturition, females mate and ovulate.

**SEASONAL MOVEMENTS AND NURSERY GROUND**

With the available data, it could not be determined whether mature female *M. henlei* carried out seasonal movements in the northern Gulf of California. Also, neonates were not registered in the present study, and near-term gravid females or postpartum mature females were not caught in the Biosphere Reserve (the northernmost and shallow region). Near-term gravid females were registered in areas deeper than 80 m, and most gravid females containing uterine eggs and early embryos were caught in the Biosphere Reserve from April to June.

**RUDIMENTARY HERMAPHRODITISM**

A rudimentary hermaphrodite *M. henlei* of 570 mm $L_T$ caught in late January was examined. This specimen had oviducal glands 10 mm width, oocytes 8-5 mm diameter, uteri 8 mm width, and small and uncalcified claspers 35 mm $L_C$. Males with similar length (570 mm $L_T$) had calcified claspers 70–85 mm (Fig. 2).

**DISCUSSION**

The lack of information on species composition in Mexican official catch statistics, even for the most important species in the catch, generates the necessity for the estimation of life-history variables for the assessment of shark populations in Mexican waters.

Before this study, nothing was known of *M. henlei* life-history variables in the Gulf of California, and the reproductive cycle is not documented in previous studies from the Californian coast (Table I). In each species of this genus
that an estimation of the reproductive cycle has been made has resulted in it being annual (Conrath & Musick, 2002) as in the *M. henlei* from the northern Gulf of California. Apparently, female and male *M. henlei* from the Californian coast begin maturing at a smaller $L_T$ in comparison to the northern Gulf of California (Table I). A strong difference in reproductive variables among northern Gulf of California and Californian populations exists for the litter size only (Table I). The litter size in the northern Gulf of California was of one to 21 and in Californian waters has been reported of one to 10 (Compagno, 1984; Talent, 1985; Ebert, 2003). The litter size of *M. henlei* increase according to the maternal $L_T$ as has also been documented for them in Californian waters (Ebert, 2003) and for other species of *Mustelus* (Conrath & Musick, 2002; Mohamed, 2002).

In other species of *Mustelus*, differences in some reproductive variables among populations have also been documented (Lenanton et al., 1990; Chiaramonte & Pettovello, 2000; Yamaguchi et al., 2000). Lenanton et al. (1990) state that differences in the reproductive biology of gummy shark *Mustelus antarcticus* Günther populations could be explained by limited uniform mixing of individuals over the geographical range of the species and to the fact that they are environmentally mediated differences that are specific to certain regions. On the other hand, Chiaramonte & Pettovello (2000) hypothesized that fishing pressure could force a density-dependent response of stocks of the narrownose smoothhound shark *Mustelus schmitti* Springer (e.g. changing $L_T$ at maturity), and Yamaguchi et al. (2000) state that differences for the starspotted smoothhound shark *Mustelus manazo* Bleeker could be attributed to food supply and water temperature.

Difference in litter size among populations has also been documented for *M. manazo*. According to Yamaguchi et al. (2000), litter size showed a trend from north to south, in which the northern population had the smallest litter size. This pattern is seen also in the *M. henlei* because the litter size is smaller

**Table I. Comparison of reproductive variables among northern Gulf of California and Californian *Mustelus henlei* populations**

<table>
<thead>
<tr>
<th>Reproductive variable</th>
<th>Gulf of California</th>
<th>California</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reproductive cycle</td>
<td>Annual</td>
<td>?</td>
</tr>
<tr>
<td>Gestation period</td>
<td>10 months</td>
<td>10–11 months*</td>
</tr>
<tr>
<td>Ovulation period</td>
<td>M March to M June</td>
<td>?</td>
</tr>
<tr>
<td>Parturition period</td>
<td>L January to L April</td>
<td>?</td>
</tr>
<tr>
<td>Birth $L_T$</td>
<td>280 mm</td>
<td>190–300 mm †‡*</td>
</tr>
<tr>
<td>Litter size</td>
<td>1–21</td>
<td>1–10†§*</td>
</tr>
<tr>
<td>Maternal $L_T$ v. litter size</td>
<td>Yes</td>
<td>Yes*</td>
</tr>
<tr>
<td>$L_T$ at maturity: females</td>
<td>570–660 mm</td>
<td>520–660 mm †</td>
</tr>
<tr>
<td>$L_T$ at maturity: males</td>
<td>550–560 mm</td>
<td>510–630 mm †</td>
</tr>
</tbody>
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$L$, late; $L_T$, total length; M, middle.

*Ebert (2003).
†Compagno (1984).
‡Castro (1996a).
§Talent (1985).
in Californian waters than in the northern Gulf of California. This difference could be attributed to water temperature as suggested by Yamaguchi et al. (2000) for the M. manazo.

The location of a nursery area for the M. henlei in the northern Gulf of California remains unknown. The available data suggest that absence of neonate M. henlei in the northern Gulf of California was not related to the selectivity of fishing gears. Trawls were used mainly in waters deeper than 80 m, where it is probable that neonates were not distributed because it is well known that nursery grounds are located in shallow and relatively enclosed regions (Castro, 1993). If neonates were distributed there, however, they could have been caught because trawls had a narrow mesh-size of 90 mm. The artisanal fleet captured in the shallow area (north of 31° N; Fig. 1) neonates of the pacific sharpnose shark Rhizoprionodon longurio (Jordan & Gilbert), 300–350 mm L_T, in length similar to neonate M. henlei (c. 280 mm L_T), which could have been taken if were distributed in the same area.

In addition, near-term gravid females were not registered in the Biosphere Reserve. On the contrary, in this area, 33 gravid females carrying uterine eggs and early embryos were examined from April to June. It is possible that some of these females moved to this area due to parturition and stay there after ovulation occurs. So, if some near-term gravid females moved from deep to shallow waters due to parturition, they and postpartum mature females could have appeared in catches from March to June in the Biosphere Reserve (north of 31° N), however, they were not caught there. In fact, all near-term gravid and postpartum mature females were caught in deep waters (80–265 m), instead of shallow waters.

Also, in other species of Mustelus, such as the spotted estuary smoothhound shark Mustelus lenticulatus Phillipps, gravid females in the early stages of pregnancy are also found to occupy shallow waters, and near-term gravid females and postpartum mature females tended to be located in deep waters (King, 1984). The author states that for this species the ovulation and embryonic development up to 150 mm takes place inshore, whereas late embryonic development and parturition probably occur on the continental shelf and slope off Golden Bay, New Zealand. Additionally, for M. schmitti the absence of near-term gravid females in shallow areas during the parturition period has also been documented (Van der Molen & Caille, 2001). The authors suggest that parturition for this mustellid occurs in relatively deep waters.

Although near-term gravid female M. henlei were distributed in deep waters (>80 m) in the northern Gulf of California, it cannot be concluded that parturition takes place there, because according to Castro (1993) a near-term gravid female may readily migrate from one habitat to another many kilometres away to give birth. For example, it has been documented that near-term gravid females of the M. manazo carried out seasonal movements from deep to shallow coastal waters due to parturition and feeding (Yamaguchi et al., 2000).

Hermaphrodites are rare in elasmobranches (Pratt, 1979), and the case of rudimentary hermaphroditism in M. henlei presented here are probably the first documented in the genus Mustelus. In the literature reports on hermaphroditism exist for blue shark Prionace glauca (L.) (Pratt, 1979) and the blacktip shark Carcharhinus limbatus (Müller & Henle) (Castro, 1996b).
The available data suggest that the population of the *M. henlei* in the northern Gulf of California could be highly productive and therefore not cause of concern because of its relatively large litter size and its annual cycle of reproduction. In addition, according to Yudin & Cailliet (1990), the *M. henlei* is a short-lived species (maximum age 13 years), that reaches maturity earlier (2–3 years) than other species of sharks, resulting in a higher capability of recovering from fishing pressure (Smith *et al.*, 1998).

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References


