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New biological data on the rare, threatened shark *Carcharhinus leiodon* (Carcharhinidae) from the Persian Gulf and Arabian Sea

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Abstract. New biological data relevant to the conservation of the rare and threatened shark *Carcharhinus leiodon* are presented, based on specimens sampled in fish markets in Kuwait, the UAE and Yemen. The maximum size of this species is extended to 1648 mm total length (TL); females are mature by at least 1312 mm TL and demonstrate placental viviparity with litters of 4–6 embryos. In the north-western Persian Gulf there is evidence that parturition occurs in spring when embryos are ~350–515 mm TL, with at least some neonate individuals probably remaining in the area through the summer. Further records of *C. leiodon* from the western Arabian Sea indicate that adults are present in this region throughout the year. Landings of *C. leiodon* apparently caught in the eastern Persian Gulf may extend the highly fragmented known distribution of this species. Contrary to an earlier study, the first detailed examination of dissected adult *C. leiodon* jaws revealed that fine serrations are present on upper teeth, and characters are provided to separate the dentition and jaws of *C. leiodon* from congeners. The stomach of an adult *C. leiodon* contained bentho-demersal fish, and an individual with fin abnormalities is noted.

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Introduction

Published biological data on the rare and threatened smooth-tooth blacktip shark *Carcharhinus leiodon* (Garrick 1985) are currently limited to that collected from less than 30 individuals. These comprise the single holotype collected from Yemen's Arabian Sea coast in 1902 (Garrick 1985), the re-discovery of 25 individuals in Kuwait, some 3000 km away in the north-western Persian Gulf ('the Gulf') (Moore *et al.* 2011), and two individuals from southern Oman, near the type locality (Henderson and Reeve 2011). These records suggest *C. leiodon* has an unusual disjunct and restricted distribution of localised populations, as elasmobranch research in other Gulf states (Moore *et al.* 2012*a*, 2012*b*; Moore, unpublished data) and other areas of Oman's coast (Henderson *et al.* 2007) have not recorded *C. leiodon*.

Carcharhinus leiodon is currently classified by the IUCN *Red List of Threatened Species* as 'Vulnerable' (i.e. facing a high risk of extinction in the wild; IUCN 2012), and details of its life history were stated as being completely unknown by Compagno (2005). While the few specimens of *C. leiodon* recorded recently have provided information on the sizes between which males become mature (~900–1200 mm TL; Garrick 1985; Henderson and Reeve 2011; Moore *et al.* 2011), there is currently no existing data on female reproductive parameters, and further information is urgently required on aspects such as diet, distribution and habitat to inform conservation planning (Moore *et al.* 2011). Additionally, descriptions of the dentition of *C. leiodon*, a key character in the identification of many morphologically similar *Carcharhinus* species, are currently limited to data from juveniles (Garrick 1985; Moore *et al.* 2011) and *in-situ*, undissected jaws from a whole adult specimen (Moore *et al.* 2011). Based on an additional 47 specimens of this rare and very poorly known species, the current study presents important new data on size, female reproductive parameters, dentition (based on the first set of dissected adult jaws, in addition to those of a juvenile) and distribution, along with notes on diet and an abnormal specimen.

Methods

Table 1 presents the date and location of *C. leiodon* recorded by the authors during elasmobranch surveys of commercial landings at fish markets and harbours. Sampling in the United Arab

Table 1. Summary data for new records of *Carcharhinus leiodon*

No	Date	♂	♀	Range TL (mm)	Notes
Sharq fish market/quayside, Kuwait City, Kuwait (origin: NW Persian Gulf) (Sampler: ABMM)					
K1	23 Aug 2009	7	5	515–605	Immature; faint umbilical scars visible in some
K2	4–6 Apr 2011	3	2	646–852	Immature; no apparent umbilical scars
K3	6 Apr 2011	–	1	1420	Pregnant; 6 embryos
K3a		*2*	*3*	*440–450*	*Embryos of K3 (NB 1 embryo not sampled)*
K4	14 Apr 2011	–	1	1312	Pregnant; 4 embryos
K4a		*3*	*1*	*352–366*	*Embryos of K4*
Deira fish market, Dubai, UAE (landed into Oman; origin: Arabian Sea) (RWJ)					
U1	18 Feb 2011	–	5	1440–1648	Overland from Salalah (Oman)
U2	8 Apr 2011	–	1	1061	Overland from Salalah (Oman)
U3	30 Jul 2011	7	4	♂1441–1549 ♀1142–1582	Overland from Hitam & Dugum (Oman). All males mature
U4	29 Nov 2011	–	1	1500	Overland from Salalah (Oman)
U5	2 Jul 2012	–	1	1551	Overland from Masirah (Oman)
Deira fish market, Dubai, UAE (origin: UAE waters of the Persian Gulf) (RWJ)					
U6	23 Dec 2010	–	1	531	Umbilical scar visible
U7	24 Nov 2011	1	–	1372	Mature
Deira fish market, Dubai, UAE (origin: Persian Gulf/Gulf of Oman/Arabian Sea) (DA/WW)					
U8	17 Dec 2011	–	1	1110	
U9	8 Oct 2012	1	–	~1200	Mature; fin abnormalities
Mina Zayed fish market quayside, Abu Dhabi, UAE (origin: Persian Gulf) (RWJ)					
U10	27 Nov 2010	1	–	731	Immature; no apparent umbilical scars
Qusay'ir fish market, eastern Yemen (origin: Gulf of Aden/Arabian Sea) (DA)					
Y1	31 Mar 2013	1	2	♂1090 ♀780–850	Immature; no apparent umbilical scars
Al-Mukallah fish market, eastern Yemen (origin: Gulf of Aden/Arabian Sea) (DA)					
Y2	25 Mar 2013	1	–	790	Immature (umbilical scar not checked)

Emirates (UAE) was on a regular basis from October 2010-September 2012 (weekly in Dubai; twice a month for Abu Dhabi, Ras Al Khaimah and Sharjah), whereas sampling in Kuwait and Yemen was on a more opportunistic basis. In Kuwait, specimens landed into Sharq market are caught in local, inshore Kuwaiti waters of the north-western Gulf (Moore *et al.* 2011, 2012*a*). Sharks landed into the UAE ports sampled here are either transported overland from landings originating from the Arabian Sea waters of southern Oman, or are from local UAE waters of the Gulf (RWJ, unpubl. data). Specimens landed in eastern Yemen were thought to be caught locally (DA, unpubl. data). Specimens deposited in the CSIRO Australian National Fish Collection (ANFC) in Hobart are referred to by the prefix CSIRO, and those in the private collection of one of us (MH) are prefixed PMH. All measurements are as total length (TL), with the upper caudal fin lobe straightened along the body-axis. Specimens were identified based on the combination of diagnostic field characters of Moore *et al.* (2011), notably the presence of sharply demarcated black blotches on the apex of pelvic and anal fins in *C. leiodon* to discriminate it from the sympatric graceful shark *C. amblyrhynchoides*, which it most closely resembles. To support species identification, tissue samples of 19 Kuwait specimens were collected for genetic analysis (as per Moore *et al.* 2011) using the COI 'barcoding' gene and the ND2 gene. Stomachs were excised, opened, and had contents briefly examined, either on the quayside (for two adults) or following washing over a 1 mm sieve in the laboratory (for five juveniles). Terminology for dentition broadly follows that of Compagno (1988).

Results

Table 1 presents details of all new records of *C. leiodon* (K2, K3 and K4 were previously summarised in Moore *et al.* 2012*a*). The three male embryos of record K4a are deposited as CSIRO H 7297–01 to 03. Thirteen Kuwait individuals were successfully sequenced for ND2 (four failed to amplify and a further two did not provide full-length sequences), while seven Kuwait individuals were successfully barcoded for COI. For both of these genes, all individuals were found to have identical sequences to *C. leiodon* sampled from Kuwait in 2008 (R.D. Ward, CSIRO Marine and Atmospheric Research, Australia; and G.J.P. Naylor, Department of Biology, College of Charleston, USA; unpublished data).

Life history and diet

As indicated by the single smaller pregnant female from Kuwait (Table 1: K4), females are mature by at least 1312 mm TL. The two pregnant females (K3, K4) from Kuwait demonstrated placental viviparity with litter sizes of six and four, respectively, and all embryos (K3a, K4a) were fully developed and pigmented. The size of these embryos (352–450 mm TL) in April, combined with free-swimming individuals with faint umbilical scars of 515–605 mm TL from the same location in August (K1),

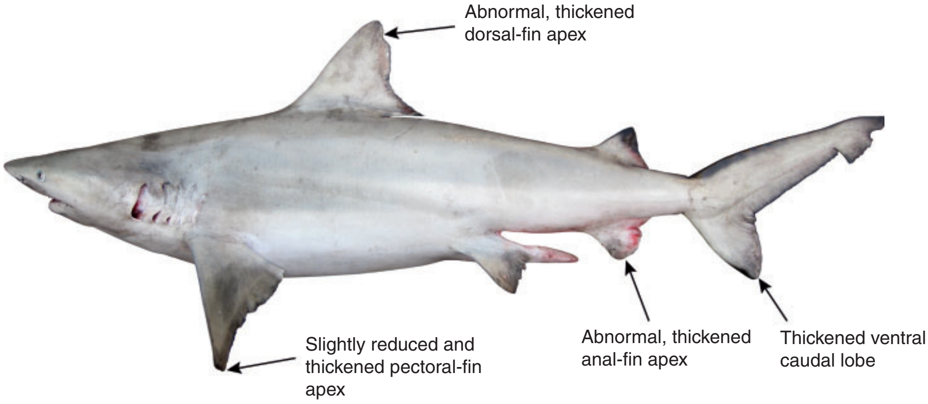

Fig. 1. Fin abnormalities in a mature male *Carcharhinus leiodon* of ca. 1200 mm TL, Deira fish market, Dubai, UAE, 8 October 2012.

provides some evidence that parturition in the north-western Gulf occurs in spring or summer when embryos are ~350 mm TL upwards. A single, probably free-swimming individual with an umbilical scar of 531 mm TL was also recorded in December, apparently caught in the eastern Gulf (U6).

The stomachs of seven individuals from Kuwait were examined (Table 1: K2, K3, K4), with most containing no prey items. One specimen, K3, contained one ~300 mm TL oriental sole *Euryglossa orientalis* (Soleidae), one ~150 mm TL mullet (Mugilidae), one ~150 mm catfish (Ariidae) head section, and one ~200 mm flathead (Platycephalidae) tail section. Two immature males (K2; 646 and 707 mm TL) contained small fish, i.e. one unidentified teleost in one individual and two unidentified teleosts and one mugilid in the other.

Abnormality

A single individual (U9) displayed some fin abnormalities, with the posterior apices of the first dorsal and pectoral fins irregular and somewhat thickened; the apex of the anal fin was reduced and thickened with an irregular posterior margin (Fig. 1).

Dentition description

Material examined: PMH-307–1, dried jaws: 746 mm TL female (Table 1: K2); PMH-307–2, dried jaws: 1420 mm TL female (Table 1, K4; Fig. 2).

Upper teeth with very narrow, erect cusps, only slightly oblique laterally and mildly notched distally in extreme posterior teeth. Cusps fairly short in adults, only moderately so in juveniles. Basal margins very wide in adults, exceeding the tooth height by roughly 25% in laterals; less so in juveniles. Distal and mesial margins strongly concave below basal margins. Cusp tips of adult specimens tapering rather abruptly to a short, slightly rounded apex and not forming a sharp, angular appearance; juveniles more angular. Cutting edge of juveniles completely smooth except for slight, irregular basal serrations, and in some specimens, very weak serrations occurring ~1/8 down the cusp length. Adults possess irregular, asymmetric serrations basally on both distal and mesial margins as well as fine serrations extending gradually down ~1/3 of the cusp length. Lower 2/3 of cusp and apex entirely smooth. Usually two small medial teeth present at symphysis. A single specimen (Garrick 1985) had three medials present.

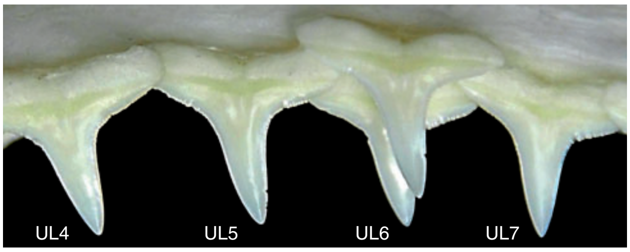

Fig. 2. Upper lateral tooth rows of a large adult female *Carcharhinus leiodon* of 1420 mm total length.

Lower teeth very similar in adult and juvenile specimens with narrow, erect cusps extending perpendicularly into very straight basal margins. Cusps perfectly straight from labial view with exception of the posterior rows in the series. Cusps of proportionate length and slightly recurved lingually. Basal margins also proportionate to genus and not noticeably wide. Cutting edge of cusps in both juvenile and adult specimens perfectly smooth-edged entirely without asymmetrical, irregular basal serrations. Usually two small symphysials bordering one medial at symphysis.

Ontogenic heterodonty present within upper teeth of this species (see Garrick 1985 for illustration of juvenile form). Monognathic heterodonty very graduated but evident in both jaws with erect cusps anterolaterally and oblique, faintly notched posteriors. Dignathic heterodonty strongly evident; upper and lower jaws somewhat diverse with cusps of upper teeth much thicker in appearance and lowers with thin, lingually recurved cusps. Dental meristics 16-(2-3)-16/14-15-(3)-14-15, based on the two specimens examined and two from the literature (Garrick 1985; Moore *et al.* 2011).

Discussion

Life history and diet

The *C. leiodon* size range of 515–1648 mm TL presented in the present study considerably extends the lower and upper limits previously reported (673–1236 mm TL; Moore *et al.* 2011). The new data presented here confirm that females of this species are mature by at least 1312 mm TL, demonstrate placental viviparity (like nearly all carcharhinids, excepting *Galeocerdo cuvier*), and give birth to litters of 4–6 embryos at a size between ~350–530 mm TL. Litter size and size at birth of *C. leiodon* reported here is similar to that of many *Carcharhinus* species (Compagno *et al.* 2005). Together, data suggest that *C. leiodon* is a medium-sized *Carcharhinus*, with a maximum total length similar to that of inshore Indo-Pacific species such as blacktip reef shark *C. melanopterus* and spottail shark *C. sorrah.*

Year-round sampling is required to refine estimates of the timing of parturition, but our preliminary data provide evidence that it occurs in at least spring or early summer in the north-western Gulf. However, the single 531 mm TL individual recorded in December in the eastern Gulf could indicate that this period of parturition is extended, or varies geographically.

Assuming a birth size of ~350–500 mm TL, the presence of larger juveniles (646–852 mm TL) in Kuwait in April is of interest. As the morphologically and genetically similar Australian blacktip shark *C. tilstoni* has rapid growth of 17 cm in the first year of life (Davenport and Stevens 1988), these larger juveniles could be one or more years old and indicate some level of residency locally, but this requires confirmation.

Further stomach content data are needed to determine habit and habitat preferences accurately, but the presence of benthodemersal fish (i.e. catfish, flathead, and sole; also see catfish noted in Moore *et al.* 2011) in the single adult sampled here indicate feeding on or near the seabed at least some of the time.

Distribution

The year-round distribution of young and adult *C. leiodon* requires elucidation to inform conservation planning, although caution is required in interpreting patchy published survey efforts. Based on the current study and other reports, the well established known range of *C. leiodon* is still restricted to a highly disjunct distribution comprising the north-western Persian Gulf (Kuwait) and the western Arabian Sea (landings into central/southern Oman, and eastern Yemen). However based on two individuals we also present tentative preliminary evidence that *C. leiodon* occurs in the eastern Persian Gulf. Together with a further individual recorded in Muttrah fish market, Muscat, Oman (1310 mm TL female, 28 August 2011; A. Henderson and A. Reeve, unpubl. data) whose capture location was unknown, we acknowledge that further specimens of known provenance are required to confirm the distribution of this species outside of the two known core areas of occurrence.

For *C. leiodon* in the north-western Gulf (Kuwait), we provide the first evidence for presence of apparently near-term pregnant females in spring (April), and the presence of neonates within the first few months of life in summer (August). This adds to previous April records of immature individuals and mature males (Moore *et al.* 2011). While no survey data are available for the summer period between April–August it is reasonable to assume young *C. leiodon* are present around Kuwait at this time. However, distribution of all *C. leiodon* life stages, particularly through the autumn and winter, is still largely unknown and year-round presence in Kuwaiti waters

Table 2. Features for separating jaws and dentition of *C. leiodon* and *C. amblyrhynchoides*

Feature	*C. leiodon*	*C. amblyrhynchoides*
Uppers		
Base of laterals	Wide (> tooth height by ~25%)	Closer to tooth height (> tooth height by ~12–14%)
Serrations	Finely serrated in adults. Heavier basally, graduating down ~1/3 cusp length. Bottom 2/3 of cusp and apex entirely smooth. Cusps in juveniles entirely smooth	Upper teeth more coarsely serrated. Heavier basally, heavy to fine serrations extending along entire cusp length to just before apex in both adult and juvenile
Cusps/tips/apex	Very narrow cusps, tips tapering abruptly to a slightly rounded apex	Broader cusps, tips tapering gradually to a very pointed apex
Cusps	Mostly erect in anterolaterals	Erect in anteriors but usually oblique laterally
Concavity/shape	Deeply concave distally and mesially just below the basal area forming a perpendicular 'T' shape; not conical	Slightly concave distally and mesially (more so distally); conical in shape
Root surface	Not noticeably concave	Noticeably concave
Root lobes	Not projecting upward	Projecting upward
Lowers		
Serrations (adults and juveniles)	None	Fine, along entire cusp to just prior of apex
Meckel's cartilage (MC)		
Posterior edge	Round, without indentation just below mandibular joint	Shallow indentation just below mandibular joint
Anterior section	Slightly narrow, very gradually expanding to posterior plates	Heavier, abruptly expanding into posterior plates
Other		
Tooth count (average)	Slightly higher 16 (2–3) 16/14–15 (3) 14–15	Slightly lower 15 (1–3) 15/14–15 (1–3) 14–15
Ontogenetic heterodonty	Present, with adults having shorter, narrower cusps in upper jaw with slight serrations. Juveniles with heavier, more triangular cusps in upper jaw with completely smooth edges	Absent
Orbital process of palatoquadrate	Larger in size; expanded with somewhat proportionately flatter distal surface	Smaller; round and not expanded distally

cannot be assumed. The discharge of the Tigris-Euphrates system influences salinity in waters of northern Kuwait, and fish surveys here indicate a decline in diversity and abundance of other elasmobranch species in winter months (J. Bishop, unpubl. data).

In the western Arabian Sea, adult-sized individuals have been recorded year-round (Table 1, U1-U5; Henderson and Reeve 2011); juveniles have also been caught in March (Table 1, Y1–2) and October (Henderson and Reeve 2011). It should be noted that the new Yemeni records from Qusay'ir presented here remove any uncertainty voiced by Garrick (1985) regarding Qishn (Yemen) as the type locality of *C. leiodon*, as these two locations are only ~150 km apart.

Abnormality

It should be noted that the abnormal specimen reported here does not demonstrate the distinct black fin tips that are diagnostic characters for *C. leiodon* since these regions of the fins have been reduced by the apparent abnormality. The overall external morphology and the presence of the characteristic distinct black band on the upper margin of the caudal fin agree well with the description in Moore *et al.* (2011). The identity of this specimen was also confirmed by sequencing of the ND2 gene (as used in Moore *et al.* 2011), which revealed its NADH2 sequence clustered with other previously collected *C. leiodon* samples (G. Naylor, unpubl. data).

The cause of the abnormality in this *C. leiodon* is unknown. Heupel *et al.* (1999) could not determine a cause for skeletal deformities observed in several shark species, although these authors encouraged further reporting of such instances. Although a range of factors could potentially have contributed to the abnormality in *C. leiodon*, two are of particular interest. First, a high prevalence of spinal deformity was reported for another species of rare carcharhinid shark (*Glyphis garricki*) with a highly restricted known distribution; Thorburn and Morgan (2004) suggested this could be indicative of inbreeding within a small population. As the available data suggest *C. leiodon* is not common, inbreeding could be a cause but further investigation would be required to add any weight to this scenario. Second, pollution could be involved as a factor. For example, polycyclic aromatic hydrocarbons (PAHs) in fish can result in impacts such as lesions (Gelsleichter and Walker 2010), and PAH levels in sharks from Kuwaiti waters have been reported as being of concern (Al Hassan *et al.* 2000).

Dentition and identification

Carcharhinus leiodon closely resembles the sympatric *C. amblyrhynchoides* (Moore *et al.* 2011). These authors provided several characters to separate the two species, including a lack of serrations on *C. leiodon* teeth compared to *C. amblyrhynchoides*. However, this was based on examination of jaws intact in a whole specimen, where it can be problematic to examine teeth in detail. The present work (based on dissected jaws) provides an important update to Moore *et al.* (2011), as it confirms that fine serrations are in fact present on the upper teeth of adult specimens of *C. leiodon*. This feature, along with several other features that can be used to separate dentition and jaws of *C. leiodon* from *C. amblyrhynchoides*, are presented in Table 2.

While the data presented here are important additions to that known about this unique species, further work on habitat utilisation, population size, and age and growth is urgently required to determine extinction risk accurately. Considering the largely unregulated shark fisheries in the region (e.g. Moore *et al.* 2012*a*), the difficulty of *C. leiodon* identification from congeners by non-specialists, and apparently highly localised populations, any realistic conservation measures might be restricted to spatial or gear closures. However, for any such initiative to be successful, detailed knowledge of the spatial and temporal distribution of *C. leiodon* is required.

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