
Gonadal development in a giant threatened reef fish, the humphead wrasse *Cheilinus undulatus*, and its relationship to international trade

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An opportunity arose to obtain humphead wrasse *Cheilinus undulatus* specimens between 2006 and 2009 from Indonesia, the major source and exporting country of this species, making study on its early gonad development possible for the first time. Protogynous hermaphroditism, previously proposed for this species, was confirmed in this study. Based on histological examination of 178 specimens, mainly <500 mm total length (*L*<sub>T</sub>) and ranging from 208 to 1290 mm *L*<sub>T</sub> (119·1 g to 43·0 kg whole body mass), the minimum body sizes for female and male sexual maturation were determined to be 650 and 845 mm *L*<sub>T</sub>, respectively. Primary male development through juvenile sexual differentiation was not detected. A unique blind pouch, with a possible sperm storage function and associated with the testis, was reported for the first time in the Labridae. In Hong Kong retail markets, the global trading centre for this valuable species, live *C. undulatus* on sale for food were dominated by body sizes <500 mm *L*<sub>T</sub> between 1995 and 2009, reflecting an international trade largely focused on juveniles. In consideration of these findings, and given the threatened status of this species, management for *C. undulatus* capture and trade nationally and internationally are discussed with recommendations for ensuring sufficient spawning biomass in exploited populations and for sustainable trade.

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Key words: CITES Appendix II; hermaphroditism; juvenile fishery; Labridae; live reef food fish trade; management.

INTRODUCTION

The humphead, or Napoleon, wrasse *Cheilinus undulatus* Rüppell is the largest living member of the family Labridae with a reliable record for maximum body size of c. 1500 mm total length (*L*<sub>T</sub>) and reported to exceed 2000 mm *L*<sub>T</sub> (Sadovy *et al*., 2003a; Choat *et al*., 2006). Protogynous hermaphroditism was proposed for *C. undulatus* through histological examination, with males derived from adult females through sex change (through a transitional phase to functionally secondary

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males) and a suggestion of diandry due to the presence of two males smaller than the smallest mature female (520 mm $L_T$) sampled (Sadovy et al., 2003a). A study on age and size distributions of females and males likewise suggested protogyny for the species (Choat et al., 2006). Insufficient availability of small specimens, particularly <500 mm $L_T$, however, has precluded a more detailed assessment of early gonadal development of C. undulatus and further assessment of its sexual pattern, i.e. diandry or monandry.

Because of the biological characteristics of long life (exceeding three decades) and because it is naturally uncommon and has a particularly high retail live value, C. undulatus is susceptible to overexploitation in unregulated fisheries (Sadovy et al., 2003a). In 2004, C. undulatus was listed on the International Union for Conservation of Nature (IUCN) Red List as ‘Endangered’ and on Appendix II of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Hong Kong is the hub of the international live reef food-fish trade (LRFFT) and the major global importer of C. undulatus; the species has the highest price among all fishes in the trade and is imported both for local consumption as well as for transshipment to mainland China (Sadovy et al., 2003a, b). The major export countries of C. undulatus are Indonesia, Malaysia and the Philippines according to import records in Hong Kong (Sadovy et al., 2003a, b). The total estimated annual import volume of C. undulatus into Hong Kong based on government figures by all transportation modes (including air, non-Hong Kong and Hong Kong-licensed vessels) was c. 9 to 189 t between 1997 and 2008 with a peak volume in 1997 and declining to <10 t in both 2007 and 2008 (Sadovy et al., 2003a, b; AFCD, 1997–2008) (Fig. 1). These are believed to be substantial underestimates because much of the trade is evidently unmonitored and illegal as indicated by personal communications.

Fig. 1. Estimated total annual imports (tonnes) of Cheilinus undulatus into Hong Kong by all modes of transport (air and HK-licensed and non-HK-licensed vessels) between 1997 and 2008. Data from the Agriculture, Fisheries and Conservation Department (AFCD) of Hong Kong through a monthly questionnaire submitted voluntarily by traders who use Hong Kong-licensed vessels for live marine-fish imports (■) and from the Census and Statistic Department (CSD) of Hong Kong through the trade declaration forms and by air and non-Hong Kong-licensed vessels for live marine-fish imports (□).
from traders, biologists and government officials and based on regular confiscations of imports in Hong Kong. The species is also sold chilled in many countries but likewise is scarce in local markets.

Study on gonadal development is particularly challenging in the case of *C. undulatus* because of its low natural availability, low catchability and high price. Donations of confiscated *C. undulatus* captured in, or exported illegally from, Indonesia to the University of Hong Kong (HKU) provided a unique opportunity to examine sexual development of the species, especially among smaller specimens. Examination of small size classes prior to first sexual maturation is particularly important for determining the type of protogyny in teleosts (Sadovy de Mitcheson & Liu, 2008).

An understanding of body sizes of *C. undulatus* marketed in the LRFFT reflects market preference and availability in the fishery and is important to document for management planning. The aims of this study were: (1) to describe gonadal development from the juvenile to adult phases of *C. undulatus* to specifically determine the type of protogyny and the size of sexual maturation, (2) to examine the body sizes of *C. undulatus* imported into and on retail sale in Hong Kong and in relation to sexual maturation, and (3) to consider the possible management implications of (1) and (2) for *C. undulatus*.

**MATERIALS AND METHODS**

**SPECIMEN COLLECTION AND MEASUREMENT**

One hundred and seventy-eight specimens of *C. undulatus* from Indonesian waters were confiscated by the Indonesian and Hong Kong authorities and donated to HKU between 2006 and 2009. All specimens were captured or traded illegally following the CITES listing; 58 were caught in Selayar waters (7° S; 121° E) without the necessary permits for capture, and the rest entered Hong Kong by air with exact capture locations in Indonesia unknown but also without CITES import permits. All specimens were preserved in –20°C freezers for >6 months prior to measurement and dissection. The month of capture was not known nor whether the fish had been kept in captivity for grow out prior to export.

Specimens were measured in the laboratory for *L*<sub>T</sub> (to the nearest 1 mm), standard length (*L*<sub>S</sub>, to the nearest 1 mm), whole body mass (*M*, to the nearest 0·1 g) and whole gonad mass (*M*<sub>G</sub>, to the nearest 0·1 g). The gonado-somatic index (*I*<sub>G</sub>) was calculated only in mature females and males from *I*<sub>G</sub> = 100 *M*<sub>G</sub>/(*M* – *M*<sub>G</sub>). Otoliths were initially removed from specimens, but growth lines were not evident and they were not considered readable for ageing.

**HISTOLOGY**

Gonads and associated tissues were cut into several pieces of c. 10 mm in length each, fixed in Dietrich’s fixative and stored at room temperature for at least 14 days. In preparation for histology, the tissues were dehydrated in ascending grades of alcohol from 75 to 95%, embedded in paraffin wax and sectioned transversely at 6–7 μm thickness. The sections were stained with haematoxylin and eosin and mounted on slides. Depending on gonad size, the tissues were sectioned for their entire length or at short regular intervals throughout their length and the resulting sections examined under light microscopy.

**SEXUAL DEFINITION**

All gonads of *C. undulatus* had an ovarian structure with a lumen and numerous lamellae, irrespective of sex. Each gonad was assigned to one of six developmental phases based on the
degree of egg and sperm cell development, the appearance of sperm sinuses and the presence of sperm in sperm sinuses; sexual maturation stages were defined as immature, mature inactive and mature active (Grier, 1981; Selman & Wallace, 1989; Liu & Sadovy, 2004) (Table I). Adult females were classified as mature inactive or mature active with vitellogenic stage oocytes or later stages (hydrated oocytes, atretic vitellogenic oocytes or postovulatory follicles). Adult males were either mature inactive or mature active with sperm sinuses and with or without sperm. Sexual transition was identified by the concomitant appearance of degenerating vitellogenic stage oocytes (often in the form of late stage, large, atretic vitellogenic oocytes) and proliferating spermatogenic cysts (Sadovy & Shapiro, 1987; Sadovy et al., 2003a; Sadovy de Mitcheson & Liu, 2008).

BODY SIZES ON RETAIL SALE IN HONG KONG

The four major retail markets in Hong Kong (Lei Yue Mun, Sai Kung, Sham Shiu Po and Tsun Mun) for the LRFFT, including C. undulatus, were visited two to four times each year between 1995 and 2009 at different times, including major celebrations when seafood sales are particularly high. Since fishes are typically sold within a short time (a week) of arriving, there was no double counting. All shops in these retail markets were visited during each trip, and all live C. undulatus observed on sale in tanks were estimated for $L_T$ (to the nearest 50 mm) by holding a tape against them outside the tank.

RESULTS

BODY SIZES ON RETAIL SALE IN HONG KONG

Two thousand three hundred and ten live C. undulatus were measured ($L_T$) between 1995 and 2009 (Fig. 6). Body size distributions showed that the international trade sector was dominated by juveniles and small adults; fish $< 650$ mm $L_T$ contributed to 89.4% of the total number measured and $< 500$ mm $L_T$ to 76.2%.

GONADAL MORPHOLOGY AND BIOLOGICAL VARIABLES

Gonads of all C. undulatus specimens lie in the posterior dorsal part of the body cavity and consist of a pair of elongate lobes separated anteriorly but united posteriorly before reaching the urogenital opening (Fig. 2). Two unique gonadal features were found in C. undulatus previously unreported in other labrids. First, in all gonads, paired kidney heads were located at the point where the two gonad lobes united posteriorly [Fig. 2(a)]. Second, a single blind pouch (male accessory structure) was present in the testes [Fig. 2(b)]. It did not occur in any of the ovaries from immature to mature females, indicating secondary development. The male accessory structure was located in the posterior portion of the testes where the two gonad lobes united and opened to the common duct.

One hundred and seventy-eight C. undulatus specimens processed histologically ranged in body sizes from 208 to 1290 mm $L_T$ and from 119·1 to 43·0 kg $M$. The relationship between $L_T$ and $M$ was presented: $M = 1 \times 10^{-5} L_T^{3·0554}$ ($n = 178, r^2 = 0·9745, P < 0·05$). The relationship between $L_S$ and $L_T$ was presented: $L_T = 0·9514 + 1·2261 L_S$ ($n = 178, r^2 = 0·9972, P < 0·05$).

SEXUAL MATURATION

Numbers of females and males and their sexual maturation stages with body size classes were summarized (Table II). Of the 178 specimens, 145 were immature
<table>
<thead>
<tr>
<th>Sexual maturation stage</th>
<th>L</th>
<th>LA</th>
<th>O1</th>
<th>O2</th>
<th>O3</th>
<th>AO</th>
<th>SC</th>
<th>SS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature female</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>Gonads consisted of only O1 and did not exhibit any signs of previous female function such as AO. There were no signs of SC</td>
</tr>
<tr>
<td>Mature inactive female</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>−</td>
<td>Gonads consisted of O1; O2 may or may not occur. AO were prominent. There were no signs of SC</td>
</tr>
<tr>
<td>Mature active female</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>Gonads consisted of O1, O2 and O3, indicating female maturation. AO were found not prominent. There were no signs of SC</td>
</tr>
<tr>
<td>Sexual transition</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>Gonads consisted of O1 and AO. SC proliferated along the germinal epithelia of lamellae. SS may not form</td>
</tr>
<tr>
<td>Mature inactive male</td>
<td>+</td>
<td>+</td>
<td>+/−</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Gonads consisted of different stages of SC except sperm. SS ran within the gonadal wall and were empty with occasionally sperm residual. AO were found but not prominent. O1 may or may not occur</td>
</tr>
<tr>
<td>Mature active male</td>
<td>+</td>
<td>+</td>
<td>+/−</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>Gonads were dominated by sperm. SS converged into some chambers within the wall of the common duct and were full of sperm. AO were found but not prominent. O1 may or may not occur</td>
</tr>
</tbody>
</table>

AO, atretic vitellogenic oocyte; L, lumen; LA, lamellae; O1, primary-growth stage oocyte; O2, cortical-alveolus stage oocyte; O3, vitellogenic stage oocyte; SC, spermatogenic cyst; SS, sperm sinus. +, present; −, absent; *, without sperm or sperm residual in sperm sinuses; **, with sperm filled fully in sperm sinuses.
females and 15 were mature inactive or active females [Fig. 3(a)–(f)]. The $I_G$ in immature females and mature inactive females ranged from <0·10 to 1·12% and from 0·60 to 1·89% in mature active females. Seventeen were mature active or inactive males with $I_G$ not exceeding 0·15% [Fig. 4(a)–(d)]. The minimum sizes for mature female and male were 650 and 845 mm $L_T$, respectively. No sexually transitional specimens were found. Among the 178 C. undulatus specimens, 81·5% were <650 mm $L_T$ (the minimum size of female sexual maturation according to this study) and 77·5% were <500 mm $L_T$ (i.e. less than the minimum size of female sexual maturation in Sadovy et al., 2003a) (Table II).

In all specimens, the gonad and kidneys were in close contact [Fig. 3(a), (b)], and the male accessory structure was surrounded by connective tissue in the outer epithelium [Fig. 5(a)–(c)]. Within the wall, there were chamber-like structures filled with sperm. The inner epithelium has folds protruding into the duct connected to the common duct with sperm sinuses within the wall [Fig. 4(d)].

**DISCUSSION**

Protogynous hermaphroditism is confirmed for C. undulatus based on evidence of sexual transition, indicating sex change from functional females to males (Sadovy et al., 2003a), in combination with histological examination of the juvenile phase (this study) and age and size distributions of females and males (Choat et al., 2006). The presence of two small males (295 and 480 mm $L_T$, i.e. smaller than or similar to the size of female sexual maturation) in an earlier study led to a suggestion of
Table II. Numbers of *Cheilinus undulatus* specimens from Indonesia in 50 mm total length ($L_T$) classes by sexual maturation stage ($n = 178$) (see Table I for gonad histological criteria)

<table>
<thead>
<tr>
<th>$L_T$ classes (mm)</th>
<th>Immature female</th>
<th>Mature inactive female</th>
<th>Mature active female</th>
<th>Mature inactive male</th>
<th>Mature active male</th>
</tr>
</thead>
<tbody>
<tr>
<td>200–249</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250–299</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>300–349</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350–399</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400–449</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450–499</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500–549</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>550–599</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600–649</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>650–699</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>700–749</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>750–799</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>800–849</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>850–899</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>900–949</td>
<td>2</td>
<td>1</td>
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<td></td>
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<tr>
<td>950–999</td>
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<tr>
<td>1000–1049</td>
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<td>1</td>
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<td></td>
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<tr>
<td>1050–1099</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100–1149</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1150–1199</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>1200–1249</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1250–1299</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Subtotal</td>
<td>146</td>
<td>4</td>
<td>11</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Minimum $L_T$</td>
<td>208</td>
<td>690</td>
<td>650</td>
<td>845</td>
<td>850</td>
</tr>
<tr>
<td>Maximum $L_T$</td>
<td>765</td>
<td>930</td>
<td>885</td>
<td>1198</td>
<td>1290</td>
</tr>
</tbody>
</table>

This study, made possible through the fortuitous availability of small specimens particularly, provided an opportunity to further examine the type of protogyny and better understand early sexual development.

In this study, all *C. undulatus* testes had a secondarily derived morphology, with a lumen and lamellar configuration, and all specimens $<650$ mm $L_T$ ($n = 145$), i.e. smaller than the size of female sexual maturation, had an ovarian structure with no sign of spermatogenic cysts. This suggests that *C. undulatus* is a monandric protogynous hermaphrodite. In terms of function, it appears that a few small males may develop directly from the juvenile phase (Sadovy et al., 2003a). In certain labrids, males likewise have secondary testes irrespective of whether or not they are gonochoristic or sequential hermaphrodites (Hoffman, 1980; Kobayashi & Suzuki, 1990; Coulson et al., 2009), highlighting the need for detailed examination of gonadal development, especially of juveniles, to assess functional sexual pattern in this family (Shapiro & Rasotto, 1993; Sadovy de Mitcheson & Liu, 2008). Moreover, two large mature females of *C. undulatus* with body sizes of 905 and 930 mm $L_T$ were found possible diandry (Sadovy et al., 2003a). The low sample size of small specimens in the 2003 study, particularly $<500$ mm $L_T$, however, precluded a comprehensive assessment of early sexual development. This study, made possible through the fortuitous availability of small specimens particularly, provided an opportunity to further examine the type of protogyny and better understand early sexual development.
Fig. 3. Female *Cheilinus undulatus*. Immature females of (a) 208 mm total length ($L_T$) and (b) 365 mm $L_T$ with gonad lobes associated with kidney. Mature inactive females of (c) 690 mm $L_T$ and (d) 905 mm $L_T$ showing presence of atretic vitellogenic oocyte (AO) in the intralamellae. Mature active females of (e) 725 mm $L_T$ and (f) 800 mm $L_T$ showing presence of AO in the intralamellae. BV, blood vessel; GW, gonadal wall; L, lumen; LA, lamellae; O1, primary-growth stage oocyte; O2, cortical-alveolus stage oocyte; O3, vitellogenic stage oocyte. Bars = 100 μm.

supporting the suggestion, based on ageing data, that some females never undergo adult sex change (Choat *et al.*, 2006). These various findings reflect the considerable sexual plasticity exhibited by the Labridae.

No specimens were undergoing sexual transition in this study, possibly due to the small sample size of large fish, while the earlier study on the same species identified two sexually transitional individuals at 670 and 750 mm $L_T$, respectively (Sadovy *et al.*, 2003a). Moreover, in this study of Indonesian-sourced specimens, minimum sizes of mature female and male were 650 and 845 mm $L_T$, respectively, while from the Great Barrier Reef, Australia, the smallest male was 700 mm $L_T$ (Choat *et al.*, 2006). Based on the three studies, it is suggested that adult sex change for *C. undulatus* probably occurs at c. 650–800 mm $L_T$. © 2010 The Authors

The apparent differences in estimated minimum size of female sexual maturation among the different studies and locations merit comment to enable a recommendation on female maturation size for *C. undulatus*. In Indonesia and Papua New Guinea (PNG), minimum sizes were 650 and 520 mm $L_T$, respectively, based on measured samples and gonad histology and applying the same criteria of sexual maturation (Sadovy *et al.*, 2003a; this study). Minimum size for females to spawn in captivity was reported at c. 500 mm $L_T$ at grow-out facilities in Indonesia. In Palau, Micronesia, and Layang Layang, Malaysia, the minimum sizes of female sexual maturation were estimated visually at c. 350–450 mm $L_T$, based on observations of female spawning underwater (TRACC, 2004; Colin, 2010). Specimens from Indonesia and PNG included few specimens of the size range of 450–550 mm $L_T$, most were either much larger (PNG; Sadovy *et al.*, 2003a) or smaller (Indonesia, this study). While more information is needed to determine minimum size of female sexual maturation more precisely by assessing more fish in the range of 450–550 mm $L_T$, based on available information, it is suggested that the typical size of female sexual maturation for *C. undulatus* be considered, for practical purposes, to occur at c. 400–500 mm $L_T$.

Various male gonad accessory structures are described in several teleost perciform families, such as Labridae, Gobiidae and Blennioidei (*e.g.* Blenniidae) (Fishelson,
Fig. 5. Male accessory structure in *Cheilinus undulatus*. (a) The wall with chamber-like structure. (b), (c) Sperm in chambers. AS, accessory structure; SP, sperm. Bars = 100 μm.

1991; Rasotto, 1995; Rasotto & Shapiro, 1998; Richtarski & Patzner, 2000; this study); the phylogenetic pattern in their appearance merits further investigation. The possible functions of male accessory structures in Gobiidae and Blennioidei include the nutrition and storage of sperm and production of seminal fluid. Intraspecific variations in male accessory structure development are suggested to be associated with male mating systems and sperm competition (Rasotto, 1995). In labrids, male accessory structures have been described with a suggested role in controlling gamete release. In the protogynous wrasse, *Thalassoma bifasciatum* (Bloch), for example, testes associated with the sphincter and ligament muscular structures were considered to play a role in sperm release with ligament muscles possibly associated with the number of sperm released in males (Rasotto & Shapiro, 1998).

Gonad morphology of *C. undulatus* in this study revealed a previously undescribed single blind pouch associated with testes in males. This male accessory structure did not occur in any ovarian stages, indicating its secondary development. The chamber-like structure within the wall of the accessory structure contained sperm, indicating a possible sperm storage function in *C. undulatus* males. The species spawns between several and all months of the year and a male can spawn in pairs.
Fig. 6. Total length ($L_T$) distribution for live *Cheilinus undulatus* on sale in all major Hong Kong retail markets between 1995 and 2009 ($n = 2310$). The minimum sizes of female sexual maturation were indicated based on gonad histology and same criteria for female sexual maturation (650 mm $L_T$, this study; 520 mm $L_T$, Sadovy *et al.*, 2003).

Body size distribution of *C. undulatus* on sale in Hong Kong major retail markets showed a strong skewed pattern, with most fish juveniles <$500$ mm $L_T$. According to Hong Kong government data, the major exporting country for the species over the last decade or so is Indonesia, followed by Malaysia and the Philippines with most fish recorded from Malaysia coming from the southern Philippines even though export of live fish from the Philippines is illegal. Given that a high proportion of *C. undulatus* entering Hong Kong come from Indonesia and that c. 77.5% of the confiscated fish in this study from Indonesia are <$500$ mm $L_T$ with 68.5% <$400$ mm $L_T$, it is clear that a significant proportion of captures and exports from Indonesia are of immature juveniles. This finding is important because the country has the national regulation that *C. undulatus* <1 kg (c. 420 mm $L_T$) should not be exported.

Subsequent to the CITES listing for *C. undulatus* in 2004, Indonesia and Malaysia set annual trade quotas of 8000 and 26 600 individuals since 2005 and between 2007 and 2009, respectively, with a zero quota introduced in Malaysia in 2010. The non-detriment findings (NDF) of CITES (i.e. the sustainable management plan for export) were developed and introduced into Indonesia and Malaysia in 2007 and 2008, respectively, partially supported by a fishery model (Sadovy *et al.*, 2007).

Due to concerns for *C. undulatus*, a number of source countries that do not have significant international trade for this species, regulations are in place. In Palau and PNG, the minimum size for capture is c. 650 mm $L_T$ (c. 3.9 kg $M$) (Sadovy *et al.*, 2003a). The species has been fully protected in West Australia and Queensland since
1998 and 2003, respectively (Pogonoski et al., 2002; Sadovy et al., 2003a). Export of *C. undulatus* has been prohibited from Maldives, New Caledonia, Niue, Palau and Philippines (e.g. Palawan) for about ten years (Sadovy et al., 2003a), and Fiji and Palau prohibited capture in 2004; PNG no longer allows the species to be exported.

For a species susceptible to fishing pressure due to its biological characteristics and international trade such as *C. undulatus*, minimum size regulations and quota setting may not be sufficient to ensure its sustainable use. Based on results of this and other studies, threatened status of this species (www.IUCNredlist.org), illegal capture in source countries and illegal imports into Hong Kong from Indonesia and enforcement of the national regulation in Indonesia regarding minimum body size for export are needed, and the international trade in the species requires considerably tighter enforcement. The air-only export for this species is now required for *C. undulatus*, reinforced by additional measures in Hong Kong, the major importer, with more comprehensive inspection of air exports, and the recent CITES decision to tighten enforcement of sea shipments should assist in enforcement. Additional actions could include marine protected areas to protect spawning biomass, especially for preserving large males, which are now considered rare wherever the species is heavily exploited. Size regulation for *C. undulatus* should take into account both the size of sexual maturation of females and the size of sexual transition (between 650 and 800 mm *L_Τ*) (Sadovy et al., 2003a; Choat et al., 2006; this study) as well as incorporating spawning areas into marine protected areas to ensure sufficient spawning biomass for population persistence.

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References


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