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Sexual Dimorphism in the Red Morwong, *Cheilodactylus fuscus*

Alexander Schroeder, Michael Lowry and Iain Suthers[A]

School of Biological Science, University of New South Wales, Sydney, NSW 2052, Australia.
[A] Author for reprint requests.

Abstract
The red morwong, *Cheilodactylus fuscus* Castelnau (Pisces:Cheilodactylidae), is a conspicuous fish on the rocky reefs of the eastern Australian coast. Visual determination of the sex of individuals in the field is necessary to remove sex bias in home-range and associated bioaccumulation studies. A sample of 61 fish (30–50 cm fork length) was collected from spear-fishing competitions in the Sydney area, and from each fish 16 morphometric measurements were taken. A multivariate analysis revealed that, in comparison with females, males are generally larger, with a significantly larger orbit-tubercle — or horn — situated in front of each eye, a smaller eye diameter and a smaller head length. A discriminant function analysis derived from these four features correctly identified 87% of an independent sample of 40 fish. Visual appraisal of fish on the basis of the proportional length of the horns misidentified <10% of fish >30 cm and <30% of fish 20–30 cm fork length. The orbit-tubercle in males is between 2% and 4% of the fork length and is composed of bone. According to this simplified visual technique, red morwong aggregations in the Sydney region have consistently biased sex ratios.

Introduction

The red morwong, *Cheilodactylus fuscus* Castelnau (Pisces:Cheilodactylidae), is a conspicuous fish on rocky reefs of eastern Australia from southern Queensland (Hervey Bay) to eastern Victoria (Mallacoota, Hutchins and Swainston 1986). *C. fuscus* is a benthic carnivore, reaching a total length of 60 cm and a maximum weight of 3.5 kg (Bell 1979). The species is used by local water authorities as an indicator of bioaccumulation in the marine environment, including that of organochlorines (Andrijanic 1992) and heavy metals (McLean *et al.* 1991). Bioaccumulation should depend in part on the home range, which is influenced by sex and reproductive condition (McCormick 1989*b*). Therefore, to determine home range, there is a clear need to reliably distinguish males from females in the field without destructive sampling.

Populations of reef fish can differ markedly in sex structure between different habitats (Holbrook and Schmitt 1984, 1992). Much of the local variation in spatial and temporal distribution can often be attributed to systematic trends involving the particular sex and size structure in a fish population (Helfman 1978; Leum and Choat 1980; Hoffman 1985; McCormick 1989*a*).

McCormick (1989*a*) found morphological differences between the sexes in a study on the banded morwong, *C. spectabilis*. Males of this species have larger pectoral fins, a larger snout angle and a longer midbody than do females. In particular, mature males had protuberances on the preorbital bone that developed fleshy nodules. These features permitted rapid sex identification of *C. spectabilis* in the field for fish >24 cm standard length, which is length at first maturity (McCormick 1989*b*).

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Since the sexes of *C. fuscus* are morphologically similar, the aim of this study was to conduct a morphometric analysis on male and female fish, in order to derive a simple visual technique to sex fish rapidly in the field. This technique was tested on independent samples and then used to describe the sex structure of some red morwong aggregations off the Sydney coast.

Materials and Methods

Measurements

Fish were collected at two spear-fishing competitions along the Sydney coast, conducted from Gunnamatta Bay in Port Hacking on 2 August 1992 (n = 34) and from Little Manly in Sydney Harbour on 11 September 1992 (n = 27). Sex was determined by inspection of the dissected gonads. The testis was a small, paired white organ, and the ovary was a distinctive bilobed globular organ (M. Lowry, unpublished histological data). An independent sample of 40 fish was speared either by ourselves at Quarantine Bay, Sydney Harbour (January 1993, n = 12), or at competitions in Gunnamatta Bay (December 1992, n = 18) and Jervis Bay (March 1993, n = 10) to test the original analysis.

To assess differences in size or shape between the sexes, 16 measurements were chosen (Fig. 1), similar to those used by McCormick (1989*a*). The length of the conspicuous horn in front of the eye (orbit-tubercle, OT), the truss length (TR) and the girth of the caudal peduncle (CP) were additionally recorded. A photograph (35-mm slide) of the lateral view was taken of each fish, which included a label and ruler for calculation of the original size. Two measurements from the head that did not appear in lateral view were directly measured from fresh fish: horn width (HW) and the width between orbits (OW). Fork length (FL) was chosen instead of standard length because the border between the tail and the caudal fin was not clearly discernible in the photographs. The measurements thus relied on visible border lines that represented features as seen in live fish, rather than features slightly deformed by callipers.

To evaluate the accuracy of the photographic method, 14 fish of the first sample of 61 were measured fresh. These measurements were compared with those taken with a ruler from projected slide images by correlation analysis.

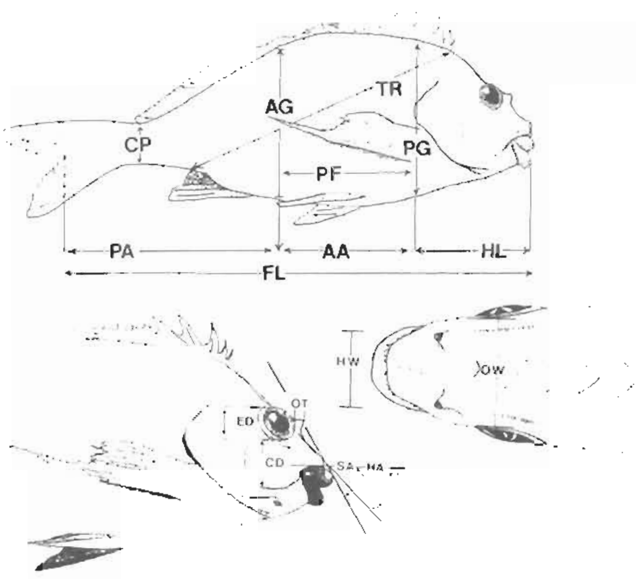


Fig. 1. *Cheilodactylus fuscus*. Lateral view of body (top), and dorsal and lateral views of head, showing the 16 morphological measurements: FL, fork length; HL, head length; AA, anterior anal length, calculated as FL – (HL + PA); PA, posterior anal length; PG, pectoral girth; AG, anal girth; CP, caudal peduncle; PF, pectoral fin length; TR, truss; OT, orbit-tubercle length or 'horn length'; ED, eye diameter; CD, cheek depth; SA, snout angle; HA, head angle; OW, width between orbits; HW, horn width.

Analysis

Morphometric characters are measurements of absolute size as well as shape. The analysis initially considered all the raw measurements in a discriminant function analysis. These preliminary analyses showed that size in general — specifically FL — was a powerful discriminating variable, and also that some morphometric characters had no discriminating power. To remove the effect of size, measurements of each variable were transformed into residuals from a univariate regression on FL. This method allows the complete removal of size effects with minimal adverse effects on the discriminant function analysis (Reist 1985).

To simplify the shape analysis, characters were excluded that were not significantly different between the sexes in an analysis of covariance (ANCOVA) with respect to FL or that had a canonical correlation coefficient of less than 0.2, which indicates a small influence of the character in the discriminant function. After the set of variables was reduced according to these criteria, a further reduction of the number of variables identified the most efficient discriminant function.

Results

Evaluation of Fresh v. Slide Measurements

Correlation coefficients between measurements from fresh fish and those from slides (n = 14), for each of the 14 morphometric characters recorded from the slide, were between 0.8–0.96, and slide measurements were 1–5% larger. Exceptions were the snout and head angles (r = 0.26 and –0.2 respectively), which were more difficult to measure on fresh fish than on a slide. Eye-associated measurements were smaller in the slide, and they were more variable (ED, r = 0.68) on fresh fish because the soft tissue about the eye was easily deformed by the callipers. Because they were easy to acquire, slide measurements were used as the reference measures for living fish.

Size

Males were significantly larger in the original sample (Kolmogorov–Smirnov test, P = 0.003), with a mean fork length of 41.4 cm (± 0.6 s.e.) compared with 37.8 cm (± 0.7 s.e.) for females (Fig. 2). A discriminant function derived from the entire set of morphometric characters, using the raw data, resulted in 100% correct reclassification (n = 61), although this analysis mostly relied on size.

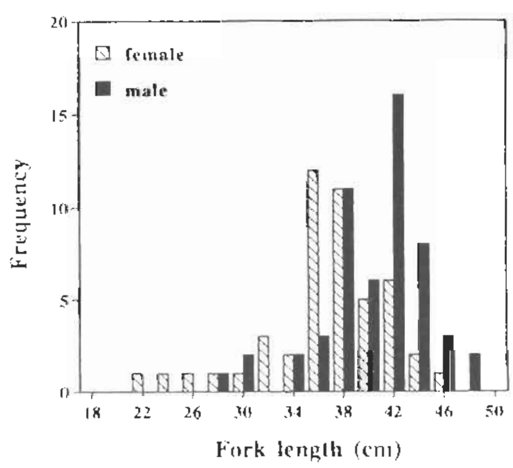


Fig. 2. Frequency distribution of fork length (FL) for all fish sampled, showing males (n = 54, mean FL 41.4 ± 0.6 cm) and females (n = 47, mean FL 37.8 ± 0.7 cm).

Shape

Reduction of the morphometric character set was as follows:

(i) Characters with no significant difference between males and females in the ANCOVA with respect to FL (P > 0.25), for either slope or intercept, were excluded; these were TR (truss length), CD (cheek depth) and HW (horn width). The P-values for OW (width between the orbits), SA (snout angle), PG (pectoral girth), AA (anterior anal length) and PA (posterior anal length) were marginally significant (0.16 > P > 0.05) and were initially retained.

(ii) From a preliminary discriminant function analysis, OW, SA, PG and AA had a canonical correlation coefficient of less than 0.2 and were therefore excluded (the same applies to HW, CD and TR, which were already excluded above).
(iii) Because AG (anal girth) and CP (caudal peduncle girth) were highly correlated ($r = 0.71$), as expected from inspection of Fig. 1, AG was excluded as being the more difficult to measure from a photograph.

Along with FL, seven variables were left to calculate the discriminant function: OT (orbit-tubercle length), ED (eye diameter), HL (head length), HA (head angle), PF (pectoral fin length), PA (posterior anal length), and CP (caudal peduncle).

Discriminant Function Analysis

The discriminant function based on shape, from all transformed variables (residuals), resulted in 13.3% misidentified fish. The reduced set of seven transformed variables produced 18.3% misidentified fish (Pillai's trace = 0.53, d.f. = 7,52, $P < 0.001$; Table 1*a*; $n = 60$ with one fish lacking HA). A reduction to only three transformed variables (OT, ED and HL) yielded the best results, with 16.4% misidentified fish. Combining these three transformed (shape) variables with the untransformed FL (size) to derive the final discriminant function produced 91.8% correctly identified sexes when applied to the original data set (Pillai's trace = 0.73, d.f. = 4,56, $P < 0.001$; Table 1*b*).

Application of this discriminant function to the additional test sample of 40 fish resulted in 87.5 % correct identification of the sexes (Table 1*c*).

The orbit-tubercle length (OT, 'horn length') seemed to be the most important character, with males >30 cm FL often having horns 2–5 mm longer than those of other fish (Fig. 3*a*).

The other two characters that proved to be useful for the discrimination were eye diameter (ED, Fig. 3*b*) and head length (HL, Fig. 3*c*), which tended to be bigger in females.

Visual assessment of size and head features before dissection (Fig. 4), especially the horn length, yielded nearly 90% correct sex determination (Table 1*d*).

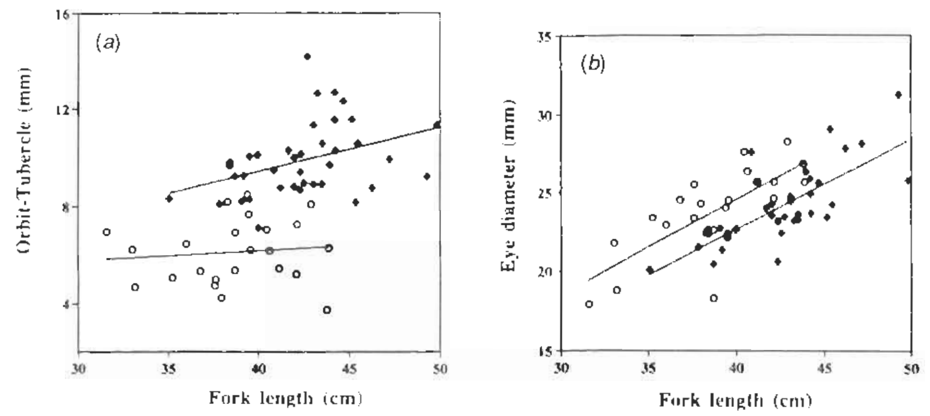
Table 1. Actual sex (rows) of red morwong (*C. fuscus*) v. predicted sex (columns)

(a) The discriminant function based on seven transformed characters (residuals) from the original data set (18.3% of fish misidentified by shape alone); *(b)* the discriminant function based on three transformed characters (HL, OT, ED) plus FL from the original data set (8.2% of fish misidentified by size and shape); *(c)* the additional test data set using the discriminant function derived from the original data set in *(b)*, involving the three transformed characters (HL, OT, ED) plus FL (12.5% of fish misidentified); and *(d)* the test data set and some fish from the original data set that were visually assessed before dissection, on the basis of relative size and orbit-tubercle length (10.3% of fish misidentified). Percentages in parentheses are the proportions of each sex wrongly classified

	Predicted male	Predicted female	Total
(a) Actual male	32	5 (14%)	37
Actual female	6 (26%)	17	23
(b) Actual male	34	4 (7%)	38
Actual female	1 (4%)	22	23
(c) Actual male	11	5 (31%)	16
Actual female	0 (0%)	24	24
(d) Actual male	23	6 (21%)	29
Actual female	1 (3%)	38	39

Size, Seasonality and Feld Identification of Sex

Red morwong exhibit gonad maturation at sizes >30 cm FL during winter (Lowry, unpublished data). Research collections of red morwong taken at North Head, Sydney Harbour, in 1992–93, show that visual determination of sex before dissection is at least 90%



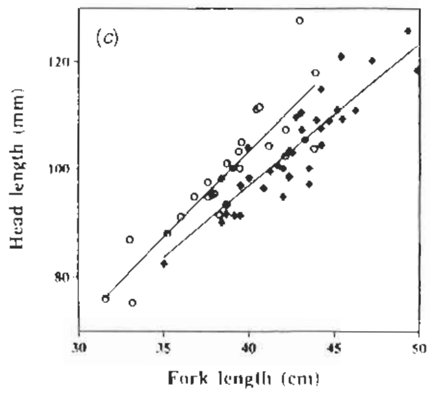


Fig. 3. (*a*) Line of best fit for orbit-tubercle length (OT, 'horn length') on fork length (FL) for males (+, [OT] = 0.18[FL] + 2.34, r^2 = 0.14) and females (o, [OT] = 0.04[FL] + 4.62, r^2 = 0.10). (*b*) Regression of eye diameter (ED) on fork length (FL) for males (+, [ED] = 0.58[FL] – 0.49, r^2 = 0.56) and females (o, [ED] = 0.61[FL] + 0.23, r^2 = 0.53). (*c*) Regression of head length (HL) on fork length (FL) for males (+, [HL] = 2.67[FL] – 10.10, r^2 = 0.79) and females (o, [HL] = 3.21[FL] – 25.26, r^2 = 0.79).

successful throughout the year for fish >30 cm FL (93% in winter/spring, n = 15; 90% in summer/autumn, n = 42) but less successful for fish 20–30 cm FL (87% in winter/spring, n = 24; 72% in summer/autumn, n = 39). The sex of fish <20 cm FL cannot be determined from macroscopic examination of gonads.

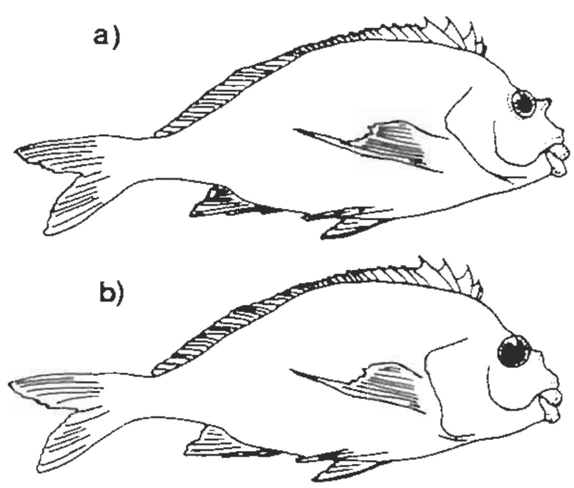


Fig. 4. Sketch of (*a*) typical male (greater horn length, smaller eye diameter and head length) and (*b*) typical female (smaller horn length, greater eye diameter and head length).

There was no apparent seasonality in the relative size of the orbit-tubercle or in our success in visual sex determination. The orbit-tubercle horn is composed entirely of bone, covered by a thin, red-brown epidermis.

Application of the visual technique underwater revealed that sex ratios were consistently biased at two sites — towards females in Sydney Harbour and towards males on the Sydney open coast (Table 2).

Table 2. Sex structure of two red morwong aggregations in the Sydney region, based on visual assessment during SCUBA dives

The unknown category frequently referred to fish <30 cm FL

Locality	Date	Total fish	Female (%)	Male (%)	Unknown (%)
Middle Head, Sydney Harbour					
	9.ix.93	80	88	6	6
	26.ix.93	40	24	63	13
	21.x.93	20	80	20	0
	26.x.93	60	83	17	0
	3.i.94	70	86	14	0
	5.i.94	80	75	25	0
	21.i.94	50	80	20	0
	30.i.94	40	83	17	0
	15.ii.94	70	43	57	0
	25.ii.94	20	55	30	15
Shark Point, Clovelly					
	21.ix.93	24	17	83	0
	28.x.93	8	12	88	0
	16.xi.93	14	22	78	0
	9.xii.93	12	17	83	0
	24.xii.93	15	7	93	0
	19.i.94	15	7	93	0
	8.ii.94	25	20	55	25

Discussion

Nearly 90% of red morwong >30 cm FL (and at least 70% of those 20–30 cm FL) can be correctly classified as males or females by simply noting the size of the fish and the relative head, eye and orbit-tubercle sizes (Fig. 4). Fish incorrectly classified were generally small males. Large females do occur (Fig. 2) but are easily discriminated by the relative horn size. In fact, the ratio of horn length to fork length (OT:FL) correctly classified 87% of the original sample, with males having a ratio between 2.0% and 4.0% and females between 0.8% and 1.95%.

Using the simplified visual technique, we found that two aggregations around Sydney had biased sex ratios that fluctuated over time and that happened to be predominantly female at the harbour site and predominantly male at the oceanic site (Table 2). Aggregations of between 15 and 100 fish are common, and as this species appears to be generally undisturbed by divers, the distinctive horns are easily identifiable from 3–5 m away.

Size

Heterogeneity in size (FL) among samples can occur for a variety of reasons. Uneven collection of specimens in time or space, or selective collection by spear-fishing for larger fish, will obviously influence the size distribution of the sample. Biologically based differences in size resulting from different growth rates or life spans could be a valuable means of sex discrimination, but because size variation must be regarded as at least partly artificial, it is best to separately investigate the contributions of size and shape on any classification (Reist 1985).

The data obtained from the fish collected for this study show that males tended to be larger than females (Fig. 2). Sampling bias due to differences in behaviour of males and females cannot be excluded, but the samples should adequately represent dimorphism in the larger size group.

Shape

Of the important characters found for banded morwong, *C. spectabilis*, by McCormick (1989*a*) — snout angle (SA), midbody length (AA) and pectoral fin length (PF) — none proved to be useful for *C. fuscus* in the present study. However, McCormick (1989*a*) noted that SA was associated with preorbital protuberances (as in the orbit-tubercle characteristic), and the present study also found PF to be a weakly discriminatory variable.

C. spectabilis develops fleshy nodules or papillae on the preorbital protuberances in breeding males (McCormick 1989*a*). No such seasonal changes were observed in *C. fuscus*, and the bony orbit-tubercle did not appear to vary proportionally between live and dead specimens.

The removal of size from characters that were used to describe shape decreased the efficiency of the classification by the discriminant function. Use of the transformed characters (residuals) often led to large males being taken for females and small females being taken for males. This was because horn length is not as linearly related to FL (Fig. 3*a*) as are eye diameter (Fig. 3*b*) or head length (Fig. 3*c*). The slopes of the regression lines of ED and HL on FL are also much steeper than that of OT on FL.

After the size influence was removed from characters to determine useful means for the differentiation of sex-related shape, the transformed characters were recombined with FL to form the final discriminant function. With the inclusion of size, the number of misidentifications was halved. Males were still taken for females, which was due to the fact that some of the small males <35 cm FL do not have a significant horn. This was also the reason why visual predissection assessment failed in a number of cases. This small horn might be an indicator of delayed maturity or a natural variation. In addition, some fish collected at spear-fishing competitions showed damaged horns or horns of different lengths. The importance of this feature and its small size leads to a greater relative error.

Conclusions

Male red morwong tend to be larger than females, with conspicuous, bony orbit-tubercles that exceed 2% of the fork length. Field identification of sex is useful because large male cheilodactylids also tend to have a larger home range than do females (Leum and Choat 1980; McCormick 1989*b*). Recent studies on bioaccumulation in the red morwong show higher concentrations of organochlorines in *C. fuscus* near the former Malabar coastal outfall off southern Sydney (Andrijanic 1992). Therefore, identification of sex in the field permits determination of sex-based home ranges, which could influence contaminant concentrations if, for example, males move out of the coastal outfall area. Many studies of fish assemblages on rocky reefs should achieve greater precision if counting or sampling can be stratified by sex.

Acknowledgments

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