

Sexual dimorphism and mental barbel structure in the South Georgia plunderfish *Artedidraco mirus* (Perciformes: Notothenioidei: Artedidraconidae)

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Abstract A recent sample (28 specimens from South Georgia and 1 from Shag Rocks) of the plunderfish *Artedidraco mirus* collected in June 2004 during the ICEFISH Cruise yielded sufficient data to refute two long-held assumptions about this species: (1) it is endemic to South Georgia; (2) its mental barbel is sexually dimorphic (tapered in females and club-shaped with papillae in males). *A. mirus* exhibits three types of mental barbel: A: tapered without a terminal expansion; B: with a narrow terminal expansion composed of simple papillae; C: with a wide terminal expansion composed of convoluted or elaborately branched papillae. There is no correlation between barbel type and body size or sex. We also found sexual dimorphism in the relative height of the second dorsal fin (30% higher on average in males) and in the colour of the anal fin (black in males over 60 mm SL). The largest males possess a prominent ruffled urogenital papilla, also black in colour. Barbel histology resembles that of other artedidraconids (*Dolloidraco longedorsalis*, *Pogonophryne scotti*) studied in containing large nerve

trunks and blood vessels lateral to a pseudocartilaginous core and dermal papillae with an extensive network of nerves and blood vessels. The high degree of intraspecific variation in artedidraconid barbel structure warrants caution in using this structure as a diagnostic taxonomic character.

Introduction

Intraspecific variation in form is a vital yet perplexing aspect of research in systematic biology. Unmasking this variation assures proper identification but it is not an easy task (Mayr and Ashlock 1991, p. 55). Adequate sample sizes are necessary to address hypotheses about the nature of intraspecific variation—whether sexual, ontogenetic, allometric, or geographic. Thus adequate meristic data and an understanding of variation in other key morphological characters are necessary for accurate identifications and for the construction of workable taxonomic keys. However, large sample sizes may be difficult to obtain, especially for plunderfishes of the Antarctic nototheniid family Artedidraconidae, a distinctive group of sculpin-like fishes characterized by a mental barbel (Eakin 1990). Knowledge of barbel variability in this group is essential since barbel shape is frequently used as a character in taxonomic keys. Moreover, some species, *Pogonophryne scotti* and *Dolloidraco longedorsalis* for example, exhibit marked variability in the size and shape of the mental barbel (Eakin et al. 2001; Eastman and Eakin 2001). Barbel variability has also been noted in *Artedidraco glareobarbatus* (La Mesa and Vacchi 2005).

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The Artedidraconidae includes four genera (*Artedidraco*, *Dolloidraco*, *Histiodraco* and *Pogonophryne*) and 25 species (Eastman and Eakin 2000; Eastman 2005). Artedidraconids are an important element of

the benthic fauna on the Antarctic continental shelf and upper slope. For example, in the Weddell and Ross seas, they constitute 20–23% of the species diversity (Hubold 1992; Eastman and Hubold 1999). Our focus

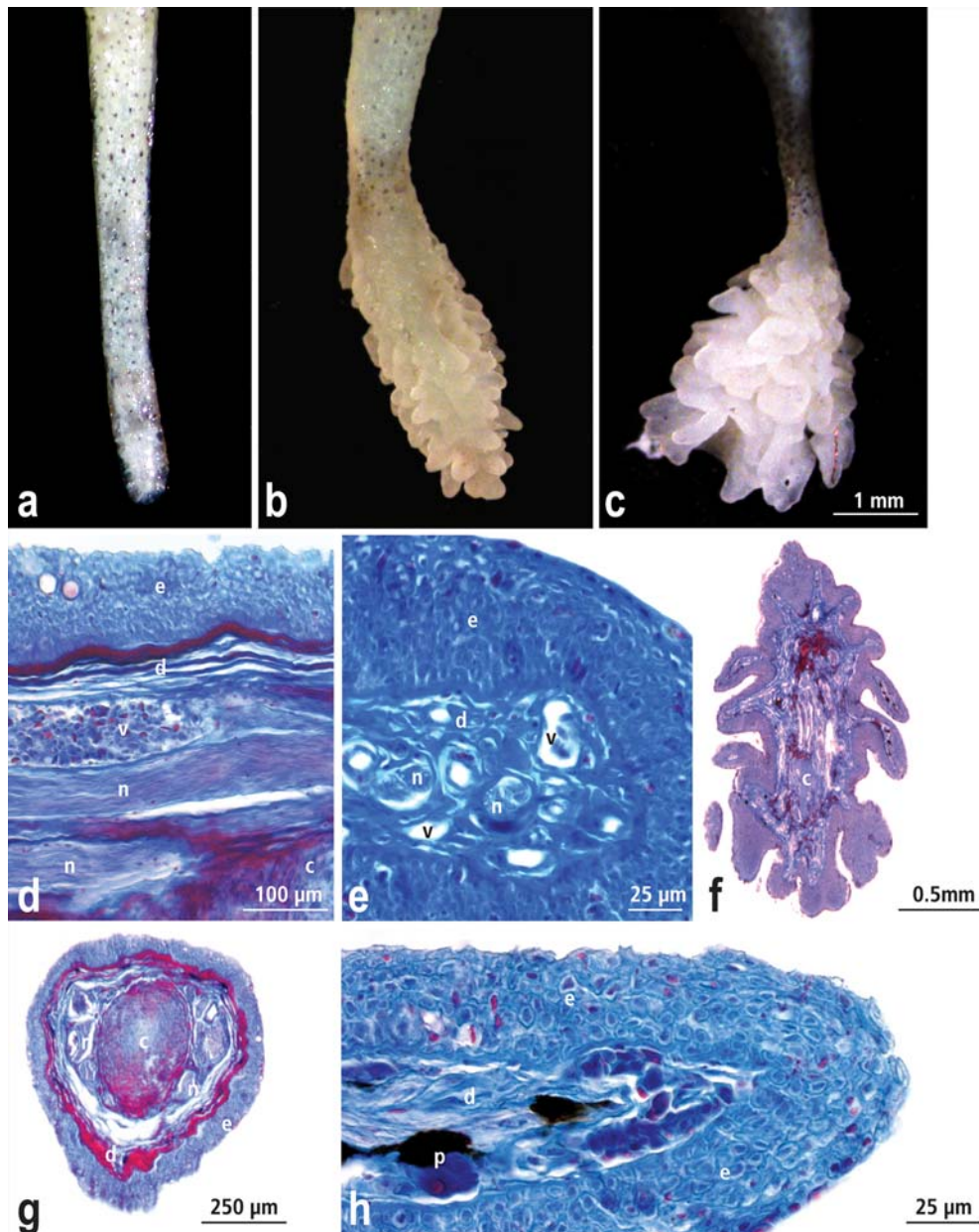


Fig 1 a–h Barbel variation and histology in *Artedidraco mirus*. **a** Type A barbel is slightly tapered and lacks a terminal expansion. **b** Type B barbel has a narrow terminal expansion and simple papillae. **c** Type C barbel has a wide terminal expansion and convoluted or elaborately branched papillae. **d** Longitudinal section of distal stalk of Type B barbel. Large nerve trunks and blood vessels are evident lateral to the core of barbel. Two mucous cells are visible in epidermis. **e** Longitudinal section of a papilla of Type C barbel showing epidermis with connective tissue of the dermis beneath. Blood vessels and nerves are evident within this dermal papilla. **f** Longitudinal

section of entire terminal expansion of Type C barbel showing the arrangement and branching of papillae and that dermis and connective tissue extend into papillae. **g** Cross section showing histological structure of stalk of Type C barbel. **h** High magnification of portion of a papilla of Type C barbel showing layering of cells in stratified squamous epithelium and absence of taste buds. Dark melanin pigment is present in dermis. **c** Core of barbel consisting of chondroid or pseudocartilage, **d** dermis, **e** epidermis, **n** nerve, **p** pigment (melanin), **v** blood vessel. Stain: **d–h** Gomori's trichrome. Magnifications: **a–c** $\times 11$, **d** $\times 110$, **e** $\times 275$, **f** $\times 22$, **g** $\times 44$, **h** $\times 370$

here is *Artedidraco mirus* Lönnberg, 1905. This species was originally described on the basis of four specimens from South Georgia and was thought to have a sexually dimorphic mental barbel, tapered in females (Fig. 1a) and club-shaped with papillae in males (Fig. 1b–c) (Lönnberg 1905). Subsequent workers accepted the veracity of this observation (Regan 1913; Norman 1938; Eakin 1990; Miller 1993). During recent collecting near South Georgia, we obtained a sufficient number of this species to refute this idea and to study aspects of barbel variability, sexual dimorphism and histology in *A. mirus*.

In this paper we (1) note a range extension of *A. mirus* to Shag Rocks; (2) present meristic data for *A. mirus*, doubling the existing database which stood at 26 specimens (Eakin 1981); (3) document variation in barbel morphology which is not sex related; (4) report on sexual dimorphism in the urogenital papilla and anal fin; and (5) examine barbel histology.

Materials and methods

Collection of specimens

We collected *A. mirus* during bottom trawling on the ICEFISH cruise (NBP 04-04) of the RVIB *Nathaniel B. Palmer*. We obtained one specimen at a station near Shag Rocks (53°45.9'S, 41°00.4'W) and 48 additional specimens during seven trawls at five stations near South Georgia. The stations at South Georgia ranged from 53°45.6'S, 38°14.1'W north of the island to 55°04.1'S, 35°12.2'W on the south. The vessel was on these stations from 5 to 12 June 2004. We used a 2-m Blake trawl and a 7.6-m otter trawl and towed at a speed of 2.5 knots for 0.5 h. Bottom depth at these stations was 98–231 m and sea surface temperature was 0.9–1.9°C. The single specimen from Shag Rocks, 210 km WNW of South Georgia, was a new locality record and was therefore deposited as USNM 385872 in the Smithsonian Institution, National Museum of Natural History.

Morphological and meristic analysis

We obtained morphological and meristic data for 35 specimens. We measured standard length (SL), total length (TL), head length (HL), mental barbel length (MBL), second dorsal fin height (SDFH), body depth (BD), eye diameter (ED), and interorbital width (IOW); we derived proportional values as percentage of SL or HL. We used needlepoint dial calipers to obtain morphological measurements (to the nearest 0.1 mm). Meristic counts included: dorsal (D, spines in

the first, and rays in the second), anal (A) and pectoral (P) fin rays and abdominal and caudal vertebrae from radiographs. We recorded the mental barbel shape and the incidence of the conspicuous ruffled urogenital papilla and black colour of the anal fin evident in some specimens. We were able to determine the sex of most of the specimens by inspection of the gonads under magnification.

Histological techniques

We preserved specimens by immersion in 10% formalin. Although the fish were preserved immediately after capture, the epidermis of some barbels had been abraded during capture. We removed one each of the Type B and Type C barbels and embedded these in paraffin according to standard procedures. We cut transverse and longitudinal sections at a thickness of 7 µm and stained them with hematoxylin and phloxine or Gomori's one step trichrome. We examined gonadal histology when necessary to ascertain the sex of small specimens. We also studied the histology of the ruffled urogenital papillae of two large males.

Statistical analysis

We utilized descriptive statistics in summarizing and comparing morphological data for males and females. We employed the non-parametric Mann–Whitney *U*-test in evaluating sexual dimorphism by comparing the median values of the different morphometric characters in male and female groups. For both males and females we used the least-squares method of regression analysis to test the relationship between SDFH and specimen size (SL). We then used a homogeneity of slopes test to compare regressions obtained for males and females, taking into account that the heterogeneity of regressions precludes an analysis covariance (ANCOVA) from being done (Underwood 1997). We used 2 × 3 contingency table to summarize and evaluate categorical data relating to barbel type and sex. We used the *P*-value provided by Fisher's exact probability test as a measure of association among these variables. In all cases the null hypothesis was that there was no association.

Results

Sexual dimorphism

Morphometric measurements and meristic counts are summarized in Table 1. Our sample consists of 28

Table 1 Morphometric and meristic data and sexually dimorphic features for 28 specimens of *Artedidraco mirus* with specimens arranged by increasing size within each sex

| Fish ID | TL | SL | Sex | HL | MBL | Mental barbel type | SDFH | BD | ED | IOW | D | A | P | Vertebrae (A + C = T) | Ruffled urogenital papilla | Black anal fin papilla |
|------------|-------|------|-----|------|-----|--------------------|------|------|-----|-----|--------|----|----|-----------------------|----------------------------|------------------------|
| 45/BT24/16 | 45.0 | 35.7 | F | 12.9 | 3.8 | B | 6.8 | 6.3 | 3.6 | 1.4 | III+24 | 16 | 17 | | | |
| 35/BT15/9 | 55.4 | 47.0 | F | 15.4 | 4.6 | C | 7.5 | 10.2 | 4.3 | 2.6 | III+24 | 16 | 16 | 13+21=34 | | |
| 45/BT25/9 | 62.2 | 49.2 | F | 16.9 | 4.0 | A | | 10.0 | 4.2 | 2.3 | III+23 | 16 | 16 | | | |
| 35/BT15/6 | 67.7 | 55.7 | F | 19.6 | 5.6 | B | 9.5 | 9.9 | 4.9 | 3.0 | III+24 | 17 | 16 | 13+22=35 | | |
| 45/BT24/14 | 68.1 | 55.0 | F | 20.1 | 6.5 | B | 8.4 | 10.9 | 5.1 | 2.7 | III+23 | 17 | 17 | | | |
| 35/BT15/4 | 69.0 | 57.1 | F | 20.3 | 5.5 | B | 9.0 | 15.0 | 4.6 | 3.5 | III+24 | 18 | 15 | 13+22=35 | | |
| 45/BT24/10 | 69.5 | 54.7 | F | 19.9 | 5.4 | A | 10.0 | | 5.0 | 2.6 | III+24 | 16 | 16 | | | |
| 35/BT15/7 | 69.9 | 59.3 | F | 21.1 | 5.7 | A | 8.5 | 11.2 | 5.8 | 3.5 | III+23 | 16 | 16 | 13+21=34 | | |
| 45/BT24/4 | 70.1 | 55.5 | F | 20.0 | 5.1 | B | 8.8 | 11.7 | 5.3 | 3.2 | III+23 | 16 | 14 | | | |
| 45/BT24/9 | 74.5 | 60.6 | F | 23.4 | 6.7 | C | 11.3 | 11.7 | 6.3 | 2.5 | III+22 | 17 | 15 | | | |
| 35/OT34/1 | 76.9 | 62.2 | F | 21.4 | 7.1 | B | 12.1 | | 6.3 | 2.3 | III+24 | 16 | 17 | 13+22=35 | | |
| 45/BT24/1 | 82.4 | 69.8 | F | 24.1 | 6.0 | A | 12.0 | 14.5 | 6.5 | 3.1 | III+25 | 17 | 16 | | | |
| 35/BT15/1 | 96.1 | 79.4 | F | 29.4 | 5.9 | A | 12.2 | 19.6 | 7.8 | 3.9 | III+24 | 16 | 16 | 13+22=35 | | |
| 45/BT22/1 | 97.5 | 78.5 | F | 30.3 | 6.8 | A | 14.8 | 17.9 | 7.6 | 2.9 | III+24 | 17 | 16 | | | |
| 35/BT15/8 | 53.0 | 44.5 | M | 14.6 | 4.3 | A | 7.3 | 8.8 | 4.0 | 2.4 | III+24 | 17 | 16 | 13+22=35 | | |
| 40/BT21/1 | 53.3 | 42.4 | M | 16.6 | 4.5 | A | 7.4 | 8.5 | 4.4 | 1.6 | III+22 | 16 | 16 | | | |
| 45/BT24/13 | 53.6 | 43.2 | M | 15.1 | 3.9 | A | 7.6 | 8.2 | 4.3 | 2.8 | III+23 | 17 | 16 | | | |
| 35/BT15/10 | 53.8 | 41.8 | M | 14.7 | 4.4 | B | 6.7 | 8.5 | 4.1 | 1.6 | III+24 | 17 | 17 | 13+22=35 | | |
| 45/BT24/6 | 64.0 | 52.5 | M | 18.5 | 4.9 | A | 8.8 | 10.6 | 5.4 | 2.8 | III+24 | 17 | 14 | | Present | |
| 35/BT15/5 | 67.4 | 54.1 | M | 19.1 | 4.7 | A | 9.8 | 11.4 | 5.5 | 3.0 | III+24 | 18 | 16 | 13+22=35 | Present | Present |
| 45/BT24/2 | 76.0 | 62.5 | M | 24.2 | 5.4 | A | 15.5 | 14.3 | 5.6 | 2.8 | III+22 | 17 | 16 | | Present | Present |
| 45/BT24/7 | 77.0 | 63.4 | M | 23.0 | 5.0 | A | 14.1 | 14.2 | 5.5 | 3.4 | III+24 | 17 | 15 | | Present | Present |
| 45/BT24/11 | 81.2 | 66.6 | M | 24.6 | 6.0 | A | 18.0 | 14.0 | 7.2 | 3.9 | III+25 | 18 | 16 | | Present | Present |
| 45/BT24/8 | 83.5 | 69.4 | M | 24.8 | 5.9 | A | 18.2 | 15.3 | 7.7 | 3.2 | III+23 | 18 | 15 | | Present | Present |
| 45/BT24/3 | 88.5 | 73.0 | M | 27.1 | 5.8 | A | 17.7 | 16.1 | 7.8 | 3.5 | III+22 | 15 | 16 | | Present | Present |
| 35/BT15/2 | 91.1 | 76.4 | M | 29.6 | 7.4 | B | 18.3 | | 7.7 | 4.1 | III+23 | 17 | 15 | 13+21=34 | Present | Present |
| 45/BT24/5 | 93.6 | 76.0 | M | 28.1 | 7.6 | A | 18.3 | 18.0 | 8.5 | 3.7 | III+24 | 17 | 15 | | Present | Present |
| 35/BT15/3 | 104.7 | 87.0 | M | 33.7 | 8.9 | C | 15.1 | 20.5 | 8.5 | 5.3 | III+24 | 17 | 16 | 13+22=35 | Present | Present |

individuals after the exclusion of the seven specimens too small to be accurately sexed. Females and males are similar in size with males exhibiting slightly higher mean values for SL, TL and HL (Table 2). We detect no significant differences between the sexes in the

mean values of other morphological parameters, with the exception of the second dorsal fin height that is on average 30% higher in males (Table 2). When expressed as percentage of SL, only the second dorsal fin height/standard length ratio differs significantly

Table 2 Morphometric and meristic comparison of females and males of *Artedidraco mirus*

| Character | Females ^a | Males ^a | Mann–Whitney <i>U</i> -test |
|---|----------------------|--------------------|-----------------------------|
| Standard length (SL, 0.1 mm) | 58.6 (11.7) | 60.9 (14.7) | NS |
| Total length (TL, 0.1 mm) | 71.7 (13.9) | 74.3 (17.1) | NS |
| Head length (HL, 0.1 mm) | 21.1 (4.7) | 22.4 (6.1) | NS |
| Mental barbel length (MBL, 0.1 mm) | 5.6 (1.0) | 5.6 (1.5) | NS |
| Second dorsal fin height (SDFH, 0.1 mm) | 10.1 (2.3) | 13.1 (4.8) | NS |
| HL as % SL | 35.8 (1.6) | 36.6 (1.8) | NS |
| MBL as % SL | 9.7 (1.3) | 9.3 (0.9) | NS |
| SDFH as % SL | 15.8 (4.8) | 20.9 (4.1) | * |
| Body depth as % SL | 17.9 (8.0) | 19.9 (5.9) | NS |
| Eye diameter as % HL | 26.3 (1.7) | 27.6 (2.3) | NS |
| Interorbital width as % HL | 13.6 (2.5) | 14.1 (2.4) | NS |
| Dorsal spines (D1) | 3 | 3 | |
| Dorsal rays (D2) | 22–25 | 22–25 | |
| Anal rays | 16–18 | 15–18 | |
| Pectoral rays | 14–17 | 14–17 | |
| Vertebrae | 13+21–22 = 34–35 | 13+21–22=34–35 | |

^aReported values are mean (SD)

**P* < 0.005

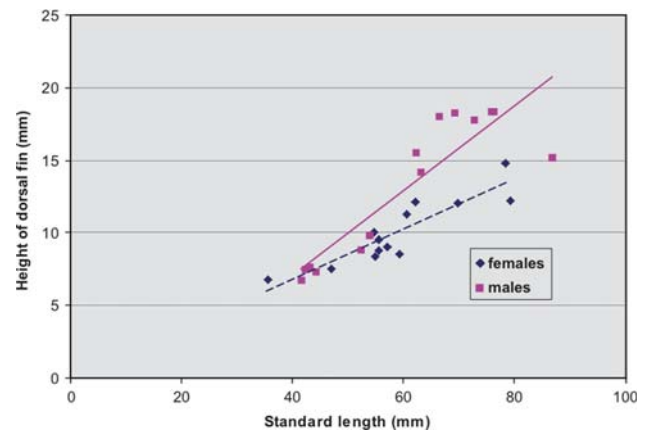
Table 3 Contingency table of sex by barbel type for 28 specimens of *Artedidraco mirus*

| | Barbel type | | | Totals (%) |
|------------|-------------|--------|--------|------------|
| | A | B | C | |
| Males | 11 | 2 | 1 | 14 (50) |
| Females | 6 | 6 | 2 | 14 (50) |
| Totals (%) | 17 (61) | 8 (28) | 3 (11) | 28 (100) |

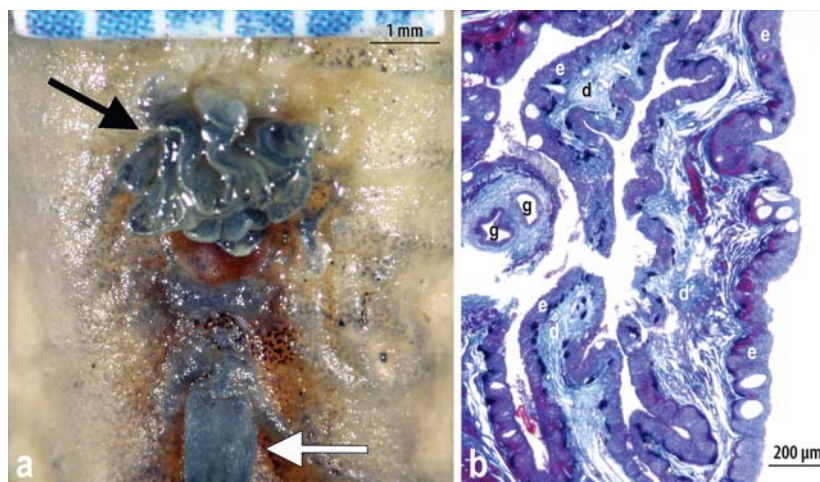
P-value from Fisher's exact probability test, $P \leq 0.162$, NS

between males and females; the mean value for males is 20.9% SL and that for females is 15.8% SL (Table 2). The relationship between SDFH and SL are significant for both males ($y = 0.2924x - 4.7556$, $R^2 = 0.7953$, $F_{1,12} = 46.6$, $P < 0.001$) and females ($y = 0.1715x - 0.0939$, $R^2 = 0.7947$, $F_{1,11} = 42.6$, $P < 0.001$) (Fig. 3). The homogeneity of slopes test reveals a significant difference in slopes between males and females ($F_{1,23} = 4.73$, $P < 0.05$). Since one large male has a low relative dorsal fin height that is similar to that of the females, relative dorsal fin height is not an infallible guide to sex. As is the case with most of the morphological features, meristic characters show no differences between the sexes (Table 2). When specimens are grouped by sex and barbel type in a contingency table (Table 3), Fisher's exact probability test indicates no significant differences in the association of barbel type with sex. Thus the barbel in *A. mirus* is individually variable.

The ten largest males (TL ≥ 64.0 mm) in our sample exhibit a prominent urogenital papilla which has a ruffled form and black colour (Fig. 2a). The urogenital

**Fig 3** Regression lines of heights of second dorsal fin in adult males and females of *Artedidraco mirus*

papilla in teleosts is the site of the anal opening as well as the usually separate genital and urinary openings (Harder 1975). In addition all these specimens, except for the smallest, have a black anal fin (Table 1; Fig. 2a). These characters are not present in the smaller males or in any of the females (Table 1). Histology indicates that the ruffles of the urogenital papilla are composed of both the dermis and epidermis of the scaleless skin and that melanin pigment is located in the dermis (Fig. 2b). There are no multicellular glands or specialized secretory areas in the epidermis. The stratified squamous epithelium does contain mucous cells (Fig. 2b), but in no greater concentrations than in other notothenioids with scaleless skin (Eastman and Hikida 1991).

**Fig 2** Urogenital papilla and anal fin of *Artedidraco mirus*. **a** Close up view of urogenital area of 88.5 mm TL male showing ruffled urogenital papilla (black arrow) and the black anal fin (white arrow). **b** Histological cross section of urogenital papilla of a 104.7 mm TL male showing disposition of epidermis and

dermis. Dark melanin pigment in dermis is unlabeled as are clear mucous cells in epidermis. *d* Dermis, *e* epidermis, *g* lumina of paired genital ducts. Stain: Gomori's trichrome. Magnifications: **a** $\times 9$, **b** $\times 35$

We note three different mental barbel types (Fig. 1) in both sexes. The most common type in both males and females is the slightly tapered barbel without a terminal expansion (Type A, Fig. 1a, Table 3). Conversely, the two club-shaped barbel types, with numerous papillae (Type B and C, Fig. 1b, c) are less frequently represented in our sample. None of the three types is related to size of the specimen (Table 1) nor, as indicated by the analysis in Table 3, is barbel type a sexually dimorphic feature in *A. mirus*.

Barbel histology

Since the histology of the unexpanded barbel in *D. longedorsalis* is well documented (Eastman and Eakin 2001), we emphasize the structure of the *A. mirus* Type B and C barbels with narrow and wide terminal expansions. The basic histology of the two types is the same, with differences centring on the length and elaborateness of the papillae of the terminal expansion. The skin of the barbel consists of stratified squamous epithelium underlain by a collagenous dermis and a hypodermis of loose connective tissue (Fig. 1d–f, h). The epidermis and more darkly stained dermis are well differentiated by Gomori's trichrome (Fig. 1d, g). The epithelium contains mucous cells and varies in thickness from 50–65 μm on the stalk (Fig. 1d, g) to 50–100 μm on the terminal expansion (Fig. 1e, f, h). The epithelium is not notably thicker in the Type C barbel. As is the case with all other artedidraconids studied to date, there are no taste buds in the epidermis. The stalk of the barbel has a chondroid or pseudocartilaginous core surrounded by perichondrium (Fig. 1d, g). This core extends from the tip of the lower jaw to one-third to one-half way through the terminal expansion (Fig. 1f). In the stalk, large nerves and blood vessels are present lateral to the core (Fig. 1d, g). The nerves account for 20–29% of the diameter of the stalk. In the terminal expansion, branches of the nerves and vessels are found in the connective tissue of the dermal papillae beneath the epidermis (Fig. 1e, f, h). The extensive network of nerves and blood vessels is especially evident in longitudinal sections of papillae (Fig. 1e).

Discussion

Sexual dimorphism

Our specimens show some characteristics that tend to distinguish adult males from females. The most obvious of these is the approximately 30% higher second

dorsal fin of males. The dorsal fin is relatively higher in most males over 60 mm SL (Fig. 3). However, one large male had a dorsal fin height similar to that of the females. Sexual dimorphism in dorsal fin height occurs in a number of notothenioid species. Among channichthyids, *Champscephalus gunnari*, *Chaenocephalus aceratus*, some species of *Chionodraco* and *Chaenodraco wilsoni* males have a higher first dorsal fin than females (Olsen 1955; DeWitt and Hureau 1979; Iwami and Abe 1981; Gerasimchuck 1989; Iwami and Kock 1990). Males of the nototheniid species *Patagonotothen sima* exhibit a higher second dorsal fin than females (Gosztonyi and Lopez-Arbarello 2000). Among artedidraconids, males with a higher second dorsal fin are reported in species of *Pogonophryne* (Andriashev 1967; Eakin 1990). The significance of this kind of sexual dimorphism in notothenioids is largely unknown, but it could be indicative of territorial behaviour. The higher dorsal fin in males could be a means to lure females and also a visual signal of dominance in competition with other males (Andersson 1994). The black anal fin noted in most of the larger *A. mirus* males may be interpreted as another character related to territoriality. Black anal fins may constitute an important visual signal both to attract females and to compete with other males, as documented in blennioid fishes (Zander 1975). Similar to many species of wrasses, blennies and other temperate marine fish families, this dimorphic colour pattern could be a transitory characteristic of males during the reproductive season (Helfman et al. 1997). Our sample of *A. mirus* was collected during their reproductive period (Lönnerberg 1905; Kock and Kellermann 1991; North 2001), lending credence to this hypothesis.

Our examination of a variety of artedidraconids indicates that modest ruffling is the typical morphology for the urogenital papillae in this family. However, the enlarged, conspicuous black urogenital papilla seen in *A. mirus* males has not previously been noted in any notothenioid. Although anal fin glands of male blennioids may produce secretions which attract females during the reproductive period (Zander 1975), the skin of the ruffled urogenital papilla of *A. mirus* is typical skin unspecialized for secretion. It is, for example, unlike the columnar epithelium in the anal fin gland of the blennioid *Scartella cristata* (Neat et al. 2003) and thus we have no reason for hypothesizing that the ruffled urogenital papilla in *A. mirus* serves a similar secretory function.

Based on our finding of sexually dimorphic characters, we postulate that *A. mirus* probably exhibits territorial behaviour similar to that described for the

plunderfish *Harpagifer antarcticus* (Daniels 1978; Burren 1988) and the nototheniids *Patagonotothen tessellata* and *P. sima* (Rae and Calvo 1995; Gosztanyi and Lopez-Arbarello 2000). The attraction of females to spawning sites may be facilitated by visual signals (dark anal fin and flag-like dorsal fin) of males.

Caution is necessary when employing the barbel in identifying artedidraconids

Every artedidraconid species that has been studied in adequate number shows substantial morphological variation in the length, shape, and degree of development of the terminal expansion of the barbel. In addition to *A. mirus*, this includes *P. scotti* (Eakin et al. 2001) and *D. longedorsalis* (Eastman and Eakin 2001). A recent collection of *A. glareobarbatus* has revealed additional barbel variation in the papillae of the terminal expansion (La Mesa and Vacchi 2005). Thus it cannot be assumed the barbels are invariant diagnostic characters until their relative degree of stability or relative degree of variability has been established.

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References

- Andersson M (1994) Sexual selection. Monograph in behavior and ecology. Princeton University Press, Princeton
- Andriashev AP (1967) Review of the plunderfishes of the genus *Pogonophryne* Regan (Harpagiferidae) with descriptions of five new species from the East Antarctic and South Orkney Islands. Biol Results Sov Antarct Exped (1955–1958) 3:389–412
- Burren P (1988) Reproductive biology of *Harpagifer* sp. at Signy Island, South Orkney Islands. MSc Thesis, University College of North Wales
- Daniels RA (1978) Nesting behaviour of *Harpagifer bispinis* in Arthur Harbour, Antarctic Peninsula. J Fish Biol 12:465–474
- DeWitt HH, Hureau JC (1979) Fishes collected during “Hero” Cruise 72-2 in the Palmer Archipelago, Antarctica, with the description of two new genera and three new species. Bull Mus Natl Hist Nat Paris 1:775–820
- Eakin RR (1981) Osteology and relationships of the fishes of the Antarctic family Harpagiferidae (Pisces, Notothenioidei). In: Kornicker LS (ed) Antarctic research series, vol 31, Biology of the Antarctic Seas IX. American Geophysical Union, Washington, pp 81–147
- Eakin RR (1990) Artedidraconidae. In: Gon O, Heemstra PC (eds) Fishes of the Southern Ocean. JLB Smith Institute of Ichthyology, Grahamstown, pp 332–356
- Eakin RR, Eastman JT, Jones CD (2001) Mental barbel variation in *Pogonophryne scotti* Regan (Pisces: Perciformes: Artedidraconidae). Antarct Sci 13:363–370
- Eastman JT (2005) The nature of the diversity of Antarctic fishes. Polar Biol 28:93–107
- Eastman JT, Eakin RR (2000) An updated species list for notothenioid fish (Perciformes: Notothenioidei), with comments on Antarctic species. Arch Fish Mar Res 48:11–20
- Eastman JT, Eakin RR (2001) Mental barbel and meristic variation in the Antarctic notothenioid fish *Dolloidraco longedorsalis* (Perciformes: Artedidraconidae) from the Ross Sea. Polar Biol 24:729–734
- Eastman JT, Hikida RS (1991) Skin structure and vascularization in the Antarctic notothenioid fish *Gymmodraco acuticeps*. J Morphol 208:347–365
- Eastman JT, Hubold G (1999) The fish fauna of the Ross Sea, Antarctica. Antarct Sci 11:293–304
- Gerasimchuk VV (1989) On the sexual dimorphism of white-blood fishes *Chaenodraco wilsoni* and *Chionodraco hamatus* (Channichthyidae: Perciformes). Zool Zhur 68:142–146
- Gosztanyi AE, Lopez-Arbarello A (2000) Sexual dimorphism in *Patagonotothen sima* (Richardson, 1844). Antarct Sci 12:427–428
- Harder W (1975) Anatomy of fishes. E. Schweizerbart’sche Verlagsbuchhandlung, Stuttgart
- Helfman GS, Collette BB, Facey DE (1997) The diversity of fishes. Blackwell, Malden
- Hubold G (1992) Zur Ökologie der Fische im Weddellmeer. Ber Polarforsch 103:1–157
- Iwami T, Abe T (1981) The collection of fishes trawled in the Ross Sea. Antarct Rec Natl Inst Polar Res Tokyo 71:130–141
- Iwami T, Kock K-H (1990) Channichthyidae. In: Gon O, Heemstra PC (eds) Fishes of the Southern Ocean. JLB Institute of Ichthyology, Grahamstown, pp 381–399
- Kock K-H, Kellermann A (1991) Reproduction in Antarctic notothenioid fish. Antarct Sci 3:125–150
- La Mesa M, Vacchi M (2005) On the second record of the Antarctic plunderfish *Artedidraco glareobarbatus* (Artedidraconidae) from the Ross Sea. Polar Biol 29:40–43
- Lönnerberg E (1905) The fishes of the Swedish South Polar Expedition. Wissensch Ergeb Schwed Südpolar-Exped 1901–1903 5:1–72
- Mayr E, Ashlock PD (1991) Principles of systematic zoology, 2nd edn. McGraw-Hill, New York
- Miller RG (1993) History and atlas of the fishes of the Antarctic Ocean. Foresta Institute for Ocean and Mountain Studies, Carson City
- Neat FC, Locatello L, Rasotto MB (2003) Reproductive morphology in relation to alternative male reproduction tactics in *Scartella cristata*. J Fish Biol 62:1381–1391
- Norman JR (1938) Coast fishes. Part III. The Antarctic zone. Discovery Rep 18:1–104
- North AW (2001) Early life history strategies of notothenioids at South Georgia. J Fish Biol 58:496–505

- Olsen S (1955) A contribution to the systematics and biology of chaenichthyid fishes from South Georgia. *Nytt Mag Zool* 3:79–93
- Rae GA, Calvo J (1995) Fecundity and reproductive habits in *Patagonotothen tessellata* (Richardson, 1845) from the Beagle Channel, Argentina. *Antarct Sci* 7:235–240
- Regan CT (1913) The Antarctic fishes of the Scottish National Antarctic Expedition. *Trans R Soc Edin* 49:229–292
- Underwood AJ (1997) *Experiments in ecology: their logical design and interpretation using analysis of variance*. Cambridge University Press, Cambridge
- Zander CD (1975) Secondary sex characteristics of blennioid fishes (Perciformes). *Pubbl Staz Zool Napoli* 39(Suppl):717–727