ORIGINAL PAPER

Sexual dimorphism in the fish *Dormitator maculatus* (Teleosti: Eleotridae) from Alvarado Lagoon, Veracruz, Mexico

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Abstract

The shape of the urogenital papilla is used to visually determine the sexual dimorphism of *Dormitator maculatus*. However, it is occasionally not possible to determine this in practice. The objective of the present study was to propose and statistically validate other morphometric measures to fulfill this same purpose. The analysis was designed on the basis of a group of previously identified adults with urogenital papilla. It was found that the most useful morphometric measures are related to the size and weight of the species. The dorsal fins and the geometric structure of the head were also recommended as morphometric measures. The males are larger in size, they are robust with the fin 1DFL longer compared to the 2DFL fin and have a broad, elongated head. Females are smaller in size, slightly robust, with longer 2DFL fins compared to 1DFL fins, and have slender, not elongated heads. In the Alvarado lagoon, sexual differentiation in *D. maculatus* is important due to the selective exploitation of its gonads (mainly on females). For this reason, and to avoid errors in the identification of females for protection purposes, the results obtained are a viable alternative.

Keywords Urogenital papilla · Naca fish morphology · Distinction between sexes · Fat sleeper

Introduction

The "Naca" fish *Dormitator maculatus* (Bloch, 1972) is a demersal species that inhabits the coastal ecosystems of the Western Atlantic, from the USA to Brazil (Aiken et al. 2015). The species is important for fisheries because it is a food resource for other fish with high commercial value in the Gulf of Mexico (Rodríguez-Varela et al. 1992). The gonad of the females of *D. maculatus* is of commercial interest (Ayala-Pérez et al. 2015), because it is used to extract the gonad or roe, which regionally is considered a dish with a pleasant flavor in its different preparations (Ré-Regis and Estrada-García 1992). The greatest fishing activity for *D. maculatus* takes place inside the Alvarado lagoon in the rainy season, between September and October, coinciding with its reproductive season (Schmitter-Soto 1996). The rest of the year, *D. maculatus* remains semi-sunk in the mud and sheltered between the roots of mangroves or grasses (Schmitter-Soto 1996). In the coastal zone of the state of Campeche, Mexico, the species is reported to be at risk of extinction (Ayala-Pérez et al. 2015) and with decreasing catch volumes in the Alvarado lagoon, Veracruz (Dávila-Camacho 2020).

Pezold and Cage (2001) described sexual dimorphism of the urogenital papilla and reported that the papilla is rounded in females and tapered in males. The shape of urogenital papilla is currently the only key to determine the sex of this species without dissection. However, it is often difficult to distinguish in the field or laboratory and dissection is sometimes necessary to observe the gonads. Therefore, an alternative morphological key for sex determination is required.

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The objective of this study was to propose and statistically validate other morphometric measures for the determination of sex in adults of *D. maculatus*. The analysis was designed on the basis of a group of previously identified adults with the urogenital papilla. In the Alvarado lagoon, sexual determination of *D. maculatus* is important due to the selective exploitation of its gonads. This study can be applied toward the correct identification and protection of females, giving continuity to the fishery and as a viable alternative, in the development of culture technology.

Materials and methods

Field work

The present study was carried out at a sampling station strategically located at the mouth of Laguna Alvarado where the migration route of *D. maculatus* passes through (Fig. 1). During one of the reproductive seasons, in October 2017 (when the species is more accessible for fishing), approximately 0.5 ton was caught with a gillnet with a mesh size of 1.5 inches. Afterward, 52 live specimens without lacerations or external damage were selected. The specimens were transported to the Aquatic Resources Research Laboratory in the Tecnológico de Boca del Río, Veracruz., in a 25-L plastic container with drops of clove essence used as an anesthetic. The species was described taking into account the average weight and total length (Fischer et al. 1995; Schmitter-Soto 1996; Nelson 2006).

Morphometric character records

Males were distinguished from females by the copulatory organ called urogenital papill (Bacheler 2002; Pezold and Cage 2001). After differentiation between sexes, 52 specimens (24 males and 28 females) were measured for characters shown in Fig. 2. All fish were sexed and measured while alive and anesthetized. For recording the measures, an ichthyometer (Aquatic® biotechnology, Mod. iK2, 40 cm and 0.1 mm precision), an electronic digital scale (Core Adam CQT202, 200 g capacity and 0.001 g precision), and digital vernier (General®, Mod. H-7352, resolution 0.001 mm) were used. The morphometric characteristics of the species were identified with the taxonomic keys proposed by Cervigón et al. (1992), Fischer et al. (1995) and Schmitter-Soto (1996) and the morphometric measurements proposed by González-Martínez et al (2020). Subsequently, once recovered from anesthesia, the specimens were returned to the extraction site.

A preliminary statistic analysis on morphometric characters of male and females was implemented via the use of Statistica software version 7.0.

Dimorphism's analysis

A preliminary analysis on the numerical variation of each morphometric character was performed for males and females (Table 2). Thus, statistic normality at each morphometric characters was evaluated with the Shapiro–Wilk's test (Zar 1999) implemented using Statistica software version 7.0. In this case, the following hypotheses were established:

1. If for a morphometric character Ho: $\sigma 2 > \overline{X}$, then, the morphometric character has a normal distribution. This mean that in records of the morphometric character the numerical variation is present (records are not similar and repetitive). In order to accept Ho, a *P*-level > 0.05 is necessary.

2. If for a morphometric character Ha: $\sigma 2 < \overline{X}$, then the morphometric character does not have a normal distribution. This mean that in records of the morphometric character the numerical variation is not present

Fig. 1 Geographical location of the Alvarado lagoon. The mark (★) represents the sampling site (18°46′07.75" N, 95°45′18.08" W)
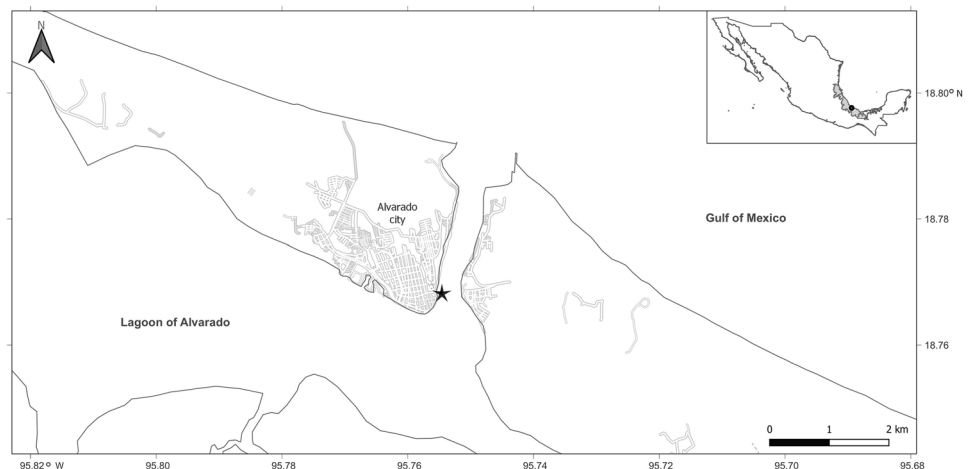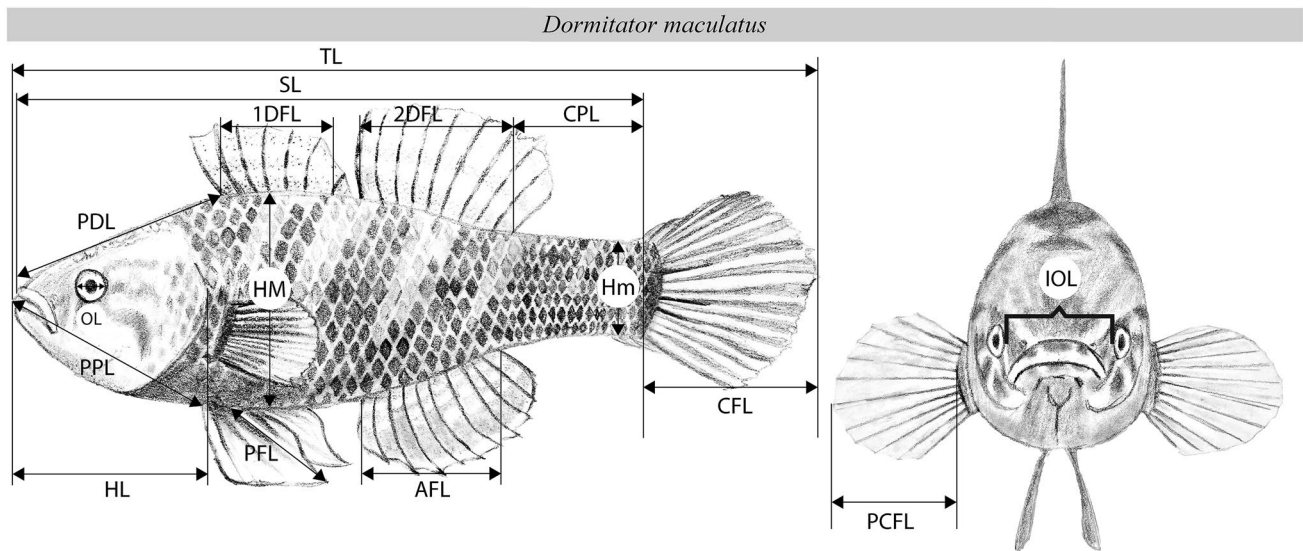
Fig. 2 Recorded morphometric measurements for *Dormitator maculatus*. First dorsal fin length (1DFL), second dorsal fin length (2DFL), caudal fin length (CFL), anal fin length (AFL), pelvic fin length (PFL), pectoral fin length (PCFL), caudal peduncle length (CPL), intra-orbital length (IOL), orbital length (OL), pre-pelvic length (PPL), pre-dorsal length (PDL), head length (HL), height maximum (HM), height minimum (Hm) and standard length (SL)

(records are similar and repetitive). To accept Ha, a *P*-level < 0.05 is necessary.

In the present study, the Ha hypothesis has higher probability to be accepted because caught adult specimens during the reproductive season were to very similar sizes. For this reason, from the beginning comparative analyses between morphometric characters of male and females were not necessary to perform because they were repetitive. About the recorded morphometric characters in the present study, it was concluded that with this information type the sexual dimorphism cannot be reliable to establish. Anticipating this situation, a classification neuronal model (Haykin 1994) was implemented to standardize all morphometric measurements within a probabilistic variation ranging between 0.00 and 1.00. The main objective of the mentioned analysis was to establish a specific probabilistic trend for an each morphometric characters of both sexes. Afterward, these estimated probabilistic trends were visually compared to establish the sexual dimorphism more reliable for this species. Structurally, a morphometric (SL) character was considered shorter in males or females when this morphometric character recorded a probabilistic descendent trend (from 1.00 to 0.00). The opposite case was considered when a morphometric (SL) character recorded a probabilistic ascendant trend (from 0.00 to 1.00).

The classification neuronal model was implemented using Statistica software version 7.0. In this case, the classification neuronal model was solved with an automatized routine where linear and nonlinear model combinations were established by the software, which afterward were optimized with the least squares method by a compiler dubbed "Intelligent Problem Solver (IPS)" (Haykin 1994). This option is a tool to create different alternatives to solve a problem, and one of these alternatives is marked by IPS as the better solution. This specific solution was chosen and interpreted in probabilistic terms. So, the use of particular references to explain implemented linear and nonlinear model combinations was not possible because these results were generated with a particular automatized process by the software. However, the use of linear and nonlinear models is completely justified to explain the length growth in different fish populations by Im et al. (2016) and Blasina et al. (2018).

Obtained standardized probabilistic trends with classification neuronal model were used to construct a second data matrix that was used to implement the correspondence multivariate analysis (Hair et al. 1999). Based on this, a correspondence graphic was structured to spatially represent morphometric characters in relation to males and females. Taking into account spatial approximation between the morphometric characters in relation to sex types, it was considered that one or more morphometric characters can be used to differentiate between males and females. Thus, when higher is the approximation between a specific morphometric characteristic and a type of sex, this morphometric characteristic will be distinctive for a sex type. On the other hand, spatial separation between the morphometric characters with reference to sex types indicates that morphometric characters are not distinctive for a sex type.

The correspondence multivariate analysis was statistically evaluated with the Total Inertia index (TI = eigen-value from principal component 1 + eigen-value from principal component 2) (Hair et al. 1999). The aforementioned was specifically interpreted as follows:

1. If TI ~ 0.00, morphometric characters reached an important approximation in relation to male-to-sex information, and thus obtained results are reliable to explain the dimorphism between sexes.
2. If TI = 1.00 or > 1.00, morphometric characters did not reach an important approximation in relation to sex information, and thus obtained results are not reliable to explain the dimorphism between sexes.

The correspondence multivariate analysis was performed by Statistica software version 7.0

Results

Morphometric character records

Preliminary statistic analysis of morphometric characters is shown in Table 1.

Dimorphism's analysis

In the present study, the Shapiro–Wilks test corroborated that all morphometric characters of male and female specimens had similar and repetitive records (Table 2). For this reason, for these morphometric characters it was corroborated that they do not have a normal distribution. As was mentioned, this lack of statistic normality was generated because caught adult specimens during the reproductive season had very similar sizes. Due to the aforementioned, the classification neuronal model was implemented.

The best solution for the classification neuronal model was composed of three learning layers to process observed records of 1DFL, 2DFL, CFL, AFL, PFL, PCFL, CPL, IOL, OL, PPL, PDL, HL, HM, Hm, and SL (Table 2). The first learning layer has 15 neurons, the second learning layer is composed by 13 neurons, and the third learning layer has one neuron. Fifteen different linear models were used to activate the first learning layer [$a_i = (b \cdot X_i)\text{-}c$], where a is i activated neuron with estimated linear parameters b and c and X is the i morphometric character. For each a_i, fifteen synaptic signals were estimated using the following equation [$d_i = (\sum a_i \bullet W_i)\text{-}f_i$], where d is the i synaptic signal, W_i is the statistical weight of each a_i, and f is the estimated thresh each d_i. A hyperbolic model was used to activate the 13 neurons in the second learning layer [$g_i = e^{d_i} - e^{-d_i}/e^{d_i} + e^{-d_i}$],

Table 1 Morphometric measurement statistics for male and female

	Males (n = 24)				Females (n = 28)			
	± sd	cv	max	min	± sd	cv	max	min
1DFL	1.24 ± 0.27	0.21	2.0	0.8	1.25 ± 0.14	0.11	1.5	1.0
2DFL	1.41 ± 0.31	0.22	2.5	1.0	1.33 ± 0.16	0.12	1.6	1.2
CFL	1.78 ± 0.34	0.19	2.5	1.1	1.65 ± 0.32	0.19	2.5	1.3
AFL	1.20 ± 0.30	0.25	2.4	0.9	1.15 ± 0.17	0.15	1.4	0.9
PFL	1.47 ± 0.35	0.23	2.7	0.9	1.31 ± 0.15	0.11	1.7	1.1
PCFL	1.46 ± 0.32	0.21	2.6	1.0	1.39 ± 0.11	0.08	1.7	1.2
CPL	2.17 ± 0.48	0.22	3.6	1.3	1.95 ± 0.22	0.11	2.5	1.6
IOL	0.99 ± 0.24	0.25	1.7	0.6	0.86 ± 0.19	0.23	1.2	0.7
OL	0.38 ± 0.04	0.12	0.5	0.3	0.34 ± 0.05	0.14	0.4	0.3
PPL	1.25 ± 0.29	0.23	2.3	0.9	1.22 ± 0.14	0.12	1.5	1.1
PDL	1.41 ± 0.30	0.21	2.5	1.0	1.32 ± 0.16	0.12	1.6	1.1
HL	2.08 ± 0.47	0.22	3.8	1.2	1.83 ± 0.27	0.15	2.5	1.5
HM	2.13 ± 0.51	0.24	3.5	1.2	1.99 ± 0.26	0.13	2.7	1.6
Hm	0.95 ± 0.26	0.28	1.8	0.5	0.85 ± 0.15	0.18	1.2	0.7
SL	7.48 ± 2.00	0.21	12.5	4.8	6.79 ± 0.83	0.12	8.5	6.0
TL	9.11 ± 1.78	0.19	15.0	5.9	8.51 ± 1.04	0.12	11.0	7.3
W(g)	10.31 ± 4.23	0.41	20.0	3.5	9.53 ± 3.81	0.40	19.2	5.2

First dorsal fin length (1DFL), second dorsal fin length (2DFL), caudal fin length (CFL), anal fin length (AFL), pelvic fin length (PFL), pectoral fin length (PCFL), caudal peduncle length (CPL), intra-orbital length (IOL), orbital length (OL), pre-pelvic length (PPL), pre-dorsal length (PDL), head length (HL), height maximum (HM), height minimum (Hm), standard length (SL), total length (TL) and weight (W). All morphometric measures are in cm. Sample size (n), average standard deviation (sd), variation coefficient (cv), maximum record (max), and minimum record (min)

Table 2 Recorded morphometric measures of *Dormitator maculatus* (Bloch, 1972) during October 2017

	1DFL	2DFL	CFL	AFL	PFL	PCFL	CPL	IOL	OL	PPL	PDL	HL	HM	Hm	SL
Male	1.25	1.33	1.33	1.18	1.25	1.28	1.48	1.14	0.70	1.25	1.31	1.46	1.48	1.10	7.90
Male	1.27	1.30	1.40	1.18	1.27	1.27	1.48	1.14	0.70	1.27	1.30	1.46	1.46	1.14	8.00
Male	1.27	1.33	1.43	1.20	1.30	1.30	1.51	1.17	0.73	1.30	1.33	1.51	1.52	1.17	7.50
Male	1.25	1.27	1.37	1.22	1.30	1.25	1.50	1.11	0.67	1.25	1.27	1.49	1.49	1.11	8.50
Male	1.25	1.27	1.37	1.22	1.30	1.25	1.50	1.15	0.67	1.25	1.27	1.49	1.49	1.11	8.50
Male	1.25	1.27	1.37	1.22	1.30	1.25	1.50	1.15	0.67	1.22	1.27	1.49	1.49	1.11	8.50
Male	1.15	1.20	1.23	1.15	1.23	1.23	1.46	1.15	0.76	1.15	1.20	1.43	1.43	1.11	7.00
Male	1.26	1.29	1.42	1.26	1.36	1.38	1.49	1.17	0.66	1.24	1.29	1.48	1.49	1.17	8.70
Male	1.22	1.26	1.32	1.18	1.22	1.29	1.44	1.14	0.74	1.22	1.26	1.42	1.44	1.10	7.20
Male	1.22	1.28	1.36	1.18	1.25	1.28	1.44	1.14	0.70	1.22	1.28	1.42	1.44	1.10	7.90
Male	1.20	1.27	1.46	1.20	1.30	1.33	1.48	1.20	0.76	1.23	1.27	1.46	1.54	1.20	7.00
Male	1.20	1.30	1.35	1.20	1.30	1.32	1.44	1.16	0.72	1.23	1.30	1.42	1.48	1.12	7.60
Male	1.20	1.30	1.30	1.28	1.33	1.32	1.46	1.13	0.60	1.26	1.30	1.45	1.45	1.16	12.50
Male	1.11	1.15	1.37	1.11	1.22	1.18	1.37	0.92	0.67	1.07	1.15	1.35	1.35	0.92	8.50
Male	1.10	1.14	1.32	1.10	1.20	1.17	1.36	1.02	0.62	1.06	1.14	1.34	1.38	1.02	9.50
Male	1.09	1.16	1.35	1.09	1.22	1.19	1.37	1.05	0.65	1.09	1.16	1.35	1.35	1.00	9.00
Male	1.11	1.15	1.25	1.11	1.18	1.22	1.39	1.02	0.67	1.11	1.15	1.35	1.30	0.97	8.50
Male	1.17	1.25	1.38	1.17	1.29	1.32	1.47	1.13	0.78	1.22	1.25	1.45	1.47	1.13	6.70
Male	1.20	1.27	1.39	1.23	1.30	1.33	1.46	1.15	0.76	1.20	1.27	1.43	1.46	1.11	7.00
Male	1.29	1.33	1.42	1.21	1.39	1.36	1.47	1.06	0.69	1.26	1.33	1.45	1.45	1.06	6.10
Male	1.30	1.38	1.60	1.30	1.41	1.38	1.48	1.15	0.78	1.30	1.38	1.51	1.45	1.08	5.00
Male	1.29	1.32	1.38	1.21	1.38	1.32	1.46	1.05	0.68	1.25	1.32	1.44	1.44	1.05	6.20
Male	1.22	1.32	1.40	1.27	1.27	1.32	1.43	1.10	0.80	1.27	1.32	1.40	1.40	1.02	4.80
Male	1.16	1.26	1.30	1.21	1.21	1.26	1.44	1.04	0.74	1.26	1.30	1.41	1.37	1.04	5.50
σ^2	0.004	0.004	0.005	0.003	0.004	0.003	0.002	0.004	0.003	0.005	0.004	0.003	0.003	0.004	2.626
$\overline{X}$	1.21	1.27	1.37	1.20	1.28	1.28	1.45	1.11	0.71	1.22	1.27	1.44	1.44	1.09	7.65
W	0.93	0.89	0.91	0.95	0.95	0.96	0.88	0.86	0.96	0.83	0.88	0.92	0.93	0.95	0.93
P	0.010	0.011	0.015	0.033	0.027	0.047	0.011	0.037	0.058	0.010	0.011	0.030	0.010	0.029	0.010
Female	1.24	1.30	1.40	1.24	1.30	1.30	1.44	1.14	0.70	1.24	1.30	1.42	1.48	1.10	8.00
Female	1.22	1.27	1.47	1.22	1.30	1.30	1.47	1.15	0.67	1.22	1.27	1.43	1.47	1.11	8.50
Female	1.30	1.30	1.46	1.27	1.30	1.33	1.48	1.15	0.76	1.27	1.30	1.46	1.43	1.11	7.00
Female	1.27	1.30	1.49	1.27	1.30	1.27	1.47	1.03	0.79	1.30	1.30	1.44	1.47	1.14	6.50
Female	1.30	1.30	1.46	1.27	1.33	1.33	1.48	1.20	0.76	1.27	1.30	1.50	1.43	1.11	7.00
Female	1.24	1.30	1.40	1.24	1.27	1.30	1.44	1.18	0.70	1.24	1.30	1.44	1.48	1.10	8.00
Female	1.30	1.33	1.46	1.30	1.33	1.30	1.48	1.15	0.76	1.30	1.33	1.46	1.50	1.11	7.00
Female	1.26	1.29	1.38	1.23	1.26	1.26	1.46	1.16	0.68	1.26	1.29	1.48	1.51	1.16	8.30
Female	1.30	1.33	1.46	1.30	1.30	1.30	1.48	1.15	0.76	1.30	1.33	1.46	1.46	1.15	7.00
Female	1.30	1.33	1.46	1.27	1.30	1.30	1.48	1.15	0.76	1.30	1.33	1.46	1.48	1.15	7.00
Female	1.22	1.25	1.22	1.18	1.22	1.22	1.41	1.11	0.67	1.22	1.25	1.39	1.41	1.11	8.50
Female	1.22	1.25	1.22	1.18	1.18	1.22	1.41	1.11	0.67	1.22	1.25	1.39	1.41	1.11	8.50
Female	1.23	1.27	1.36	1.27	1.30	1.33	1.47	1.14	0.79	1.23	1.27	1.44	1.51	1.14	6.50
Female	1.25	1.29	1.32	1.16	1.29	1.29	1.46	1.05	0.68	1.25	1.29	1.41	1.49	1.05	6.20
Female	1.28	1.28	1.35	1.20	1.28	1.35	1.46	1.05	0.68	1.24	1.28	1.40	1.46	1.05	6.30
Female	1.28	1.28	1.38	1.20	1.28	1.35	1.46	1.05	0.68	1.24	1.28	1.40	1.43	1.05	6.30
Female	1.24	1.28	1.31	1.20	1.28	1.31	1.46	1.05	0.68	1.24	1.28	1.40	1.40	1.05	6.30
Female	1.24	1.28	1.35	1.20	1.28	1.35	1.46	1.05	0.68	1.24	1.28	1.40	1.48	1.05	6.30
Female	1.28	1.28	1.38	1.20	1.28	1.35	1.46	1.05	0.68	1.24	1.28	1.40	1.40	1.05	6.30
Female	1.25	1.29	1.38	1.21	1.29	1.35	1.46	1.05	0.68	1.25	1.29	1.41	1.46	1.05	6.20
Female	1.28	1.28	1.38	1.20	1.28	1.35	1.46	1.05	0.68	1.24	1.28	1.40	1.46	1.05	6.30

Table 2 (continued)

	1DFL	2DFL	CFL	AFL	PFL	PCFL	CPL	IOL	OL	PPL	PDL	HL	HM	Hm	SL
Female	1.29	1.29	1.41	1.21	1.29	1.32	1.46	1.05	0.68	1.25	1.29	1.44	1.49	1.11	6.20
Female	1.29	1.29	1.32	1.21	1.29	1.29	1.46	1.05	0.68	1.25	1.29	1.41	1.51	1.05	6.20
Female	1.28	1.28	1.38	1.20	1.28	1.31	1.46	1.05	0.68	1.24	1.28	1.40	1.50	1.05	6.30
Female	1.30	1.30	1.36	1.27	1.30	1.33	1.47	1.03	0.66	1.23	1.30	1.44	1.49	1.14	6.50
Female	1.21	1.29	1.41	1.21	1.29	1.32	1.46	1.05	0.68	1.25	1.25	1.41	1.46	1.05	6.20
Female	1.25	1.29	1.32	1.21	1.29	1.35	1.44	1.05	0.68	1.25	1.29	1.41	1.44	1.05	6.20
Female	1.22	1.30	1.34	1.22	1.26	1.34	1.43	1.07	0.70	1.26	1.30	1.40	1.50	1.12	6.00
σ^2	0.001	0.000	0.005	0.001	0.001	0.001	0.000	0.003	0.002	0.001	0.000	0.001	0.001	0.002	0.695
$\overline{X}$	1.26	1.29	1.38	1.23	1.28	1.31	1.46	1.09	0.70	1.25	1.29	1.43	1.46	1.09	6.84
W	0.20	0.18	0.14	0.19	0.28	0.17	0.34	0.31	0.35	0.23	0.18	0.19	0.17	0.26	0.25
P	0.019	0.021	0.020	0.025	0.012	0.010	0.015	0.050	0.045	0.025	0.028	0.025	0.010	0.028	0.030

First dorsal fin length (1DFL), second dorsal fin length (2DFL), caudal fin length (CFL), anal fin length (AFL), pelvic fin length (PFL), pectoral fin length (PCFL), caudal peduncle length (CPL), intra-orbital length (IOL), orbital length (OL), pre-pelvic length (PPL), pre-dorsal length (PDL), head length (HL), height maximum (HM), height minimum (Hm), and standard length (SL). Shapiro–Wilk's test (W). For each morphometric measure, W recorded a significance statistic $(P) > 0.05$. All morphometric measures are in cm

where g is the i activated neuron $(-1, +1)$. For each gi, thirteen synaptic signals were estimated using the following equation $[hi = (\sum gi \cdot Wi)-k]$, where h is the i synaptic signal, Wi is the statistical weight of each gi, and k is the estimated thresh for h_i. Afterward, a logistic model was used to activate the last neuron in the third learning layer $[li = 1/(1-e^{-hi})]$, where l is the activated neuron $(0, +1)$. With the latter equation, the probabilistic tendencies of each morphometric character were estimated for males and females.

Standardize probabilistic values are listed in Table 3, and their trends are shown in Fig. 3. The results of probabilistic trends indicated that, in comparison with females, males recorded shorter the following morphometric characters: 2DFL, PFL, PDL, AFL, and CPL. On the other hand, males recorded longer the following morphometric characters: PCFL, 1DFL, HM, Hm, PPL, IOL, SL, OL, CFL, and HL (Fig. 3). In comparison with males, females recorded shorter the following morphometric characters: PCFL, 1DFL, HM, Hm, PPL, IOL, SL, OL HL and CFL (Fig. 3). On the other hand, females recorded longer the following morphometric characters: 2DFL, PFL, PDL, AFL, and CPL.

For the correspondence multivariate analysis, the TI at 0.41 was estimated (Fig. 4). Obtained results indicated that specific morphometric characters reached an important spatial approximation in relation to sex information. Then, the following morphometric characters were validated to explain the dimorphism in the *D. maculatus*:

1. The morphometric characters that should characterize females better were 2DFL, IOL and OL.
2. The morphometric characters that should characterize males better were 1DFL, SL and HL. With the SL morphometric measure, it was evidenced that males are larger than females. This result was consistent

with that listed in Table 1 because for males, weight averages were recorded in 10.31 ± 4.23 g and the total length in 9.11 ± 1.78 cm. For females, weight averages were recorded in 9.5 ± 3.81 g and the total length in 8.51 ± 1.04 cm. With these results, it was confirmed that, persistently, males are larger in size compared to females (Fig. 4).

3. The PDL, AFL, CFL, HM, PCFL, PPL, Hm, and PFL morphometric characters were not helpful in differentiating males from females. For these cases, it was concluded that these morphometric characters are reliable similar between males and females.

Figure 4 shows the analysis of the trend probability values of the neural network and shows the spatial approximation between the morphometric characters in relation to sex types means that one or more morphometric characters can be used to differentiate between males and females. Principal components PC1 and PC2 (Total Inertia index = eigenvalue from PC1 + eigenvalue from PC2) (Hair et al. 1999).

Discussion

When identification problems are recurrent to analyze sexual dimorphism based on a single morphological structure (as is the case of the genital papilla in *D. maculatus*), other morphological measures should be available and statistically validated. However, the drawback that arises when proposing other alternative morphological measurements is the little difference in length that exists between different morphological measurements (Table 1) and additionally, the little variation in their records when specimens with approximately the same dominant are analyzed.

Table 3 Standardized morphometric characters of *Dormitator maculatus* (Bloch, 1972)

	1DFL	2DFL	CFL	AFL	PFL	PCFL	CPL	IOL	OL	PPL	PDL	HL	HM	Hm	SL
Male	0.20	1.00	0.06	0.99	1.00	0.01	0.90	0.04	0.11	0.02	0.99	0.26	0.01	0.56	0.01
Male	0.22	1.00	0.07	0.98	1.00	0.02	0.89	0.04	0.12	0.02	0.99	0.26	0.01	0.55	0.01
Male	0.25	1.00	0.08	0.98	1.00	0.02	0.87	0.05	0.13	0.02	0.98	0.26	0.02	0.54	0.01
Male	0.28	1.00	0.08	0.97	1.00	0.03	0.85	0.06	0.14	0.03	0.97	0.26	0.02	0.53	0.02
Male	0.31	1.00	0.09	0.96	1.00	0.04	0.82	0.07	0.15	0.04	0.96	0.27	0.03	0.51	0.02
Male	0.34	1.00	0.10	0.94	0.99	0.06	0.80	0.08	0.16	0.05	0.95	0.27	0.04	0.50	0.02
Male	0.38	0.99	0.11	0.92	0.99	0.08	0.77	0.09	0.17	0.06	0.93	0.28	0.05	0.49	0.03
Male	0.42	0.99	0.12	0.89	0.98	0.12	0.74	0.10	0.18	0.07	0.90	0.28	0.07	0.48	0.04
Male	0.46	0.98	0.13	0.85	0.96	0.18	0.70	0.12	0.20	0.09	0.86	0.29	0.09	0.47	0.04
Male	0.50	0.97	0.15	0.79	0.92	0.26	0.67	0.14	0.22	0.12	0.81	0.30	0.12	0.45	0.06
Male	0.54	0.95	0.17	0.72	0.85	0.36	0.63	0.17	0.23	0.15	0.75	0.31	0.16	0.44	0.07
Male	0.58	0.92	0.19	0.63	0.74	0.48	0.59	0.19	0.25	0.19	0.68	0.31	0.22	0.43	0.09
Male	0.62	0.87	0.21	0.54	0.58	0.61	0.55	0.22	0.27	0.24	0.59	0.33	0.28	0.42	0.11
Male	0.66	0.78	0.23	0.43	0.40	0.72	0.51	0.26	0.30	0.29	0.51	0.34	0.35	0.41	0.14
Male	0.69	0.66	0.26	0.34	0.25	0.80	0.47	0.30	0.32	0.36	0.42	0.35	0.44	0.40	0.18
Male	0.73	0.52	0.29	0.25	0.14	0.87	0.43	0.34	0.35	0.43	0.34	0.36	0.52	0.39	0.22
Male	0.76	0.37	0.32	0.18	0.08	0.91	0.39	0.38	0.37	0.50	0.26	0.38	0.61	0.38	0.28
Male	0.79	0.25	0.36	0.13	0.04	0.94	0.35	0.43	0.40	0.57	0.20	0.39	0.69	0.37	0.34
Male	0.82	0.15	0.40	0.09	0.02	0.96	0.32	0.48	0.43	0.64	0.15	0.41	0.76	0.36	0.40
Male	0.84	0.09	0.44	0.07	0.01	0.97	0.29	0.53	0.46	0.70	0.11	0.42	0.81	0.36	0.47
Male	0.86	0.06	0.48	0.05	0.01	0.98	0.26	0.58	0.50	0.76	0.09	0.44	0.86	0.35	0.54
Male	0.88	0.03	0.52	0.04	0.00	0.98	0.23	0.63	0.53	0.81	0.06	0.46	0.89	0.34	0.61
Male	0.90	0.02	0.56	0.03	0.00	0.99	0.20	0.68	0.56	0.85	0.05	0.47	0.92	0.33	0.67
Male	0.91	0.01	0.60	0.02	0.00	0.99	0.18	0.72	0.60	0.88	0.04	0.49	0.94	0.33	0.73
Female	0.78	0.00	0.93	0.02	0.00	0.98	0.11	0.96	0.88	0.98	0.01	0.74	0.99	0.45	0.99
Female	0.75	0.00	0.92	0.02	0.00	0.98	0.13	0.95	0.87	0.98	0.02	0.74	0.98	0.46	0.99
Female	0.72	0.00	0.92	0.03	0.00	0.97	0.15	0.94	0.86	0.97	0.03	0.74	0.98	0.47	0.98
Female	0.69	0.00	0.91	0.04	0.00	0.96	0.18	0.93	0.85	0.96	0.04	0.73	0.97	0.49	0.98
Female	0.66	0.00	0.90	0.06	0.01	0.94	0.20	0.92	0.84	0.95	0.05	0.73	0.96	0.50	0.98
Female	0.62	0.01	0.89	0.08	0.01	0.92	0.23	0.91	0.83	0.94	0.07	0.72	0.95	0.51	0.97
Female	0.58	0.01	0.88	0.11	0.02	0.88	0.26	0.90	0.82	0.93	0.10	0.72	0.93	0.52	0.96
Female	0.54	0.02	0.87	0.15	0.04	0.82	0.30	0.88	0.80	0.91	0.14	0.71	0.91	0.53	0.96
Female	0.50	0.03	0.85	0.21	0.08	0.74	0.33	0.86	0.78	0.88	0.19	0.70	0.88	0.55	0.94
Female	0.46	0.05	0.83	0.28	0.15	0.64	0.37	0.83	0.77	0.85	0.25	0.69	0.84	0.56	0.93
Female	0.42	0.08	0.81	0.37	0.26	0.52	0.41	0.81	0.75	0.81	0.32	0.69	0.78	0.57	0.91
Female	0.38	0.13	0.79	0.46	0.42	0.39	0.45	0.78	0.73	0.76	0.41	0.67	0.72	0.58	0.89
Female	0.34	0.22	0.77	0.57	0.60	0.28	0.49	0.74	0.70	0.71	0.49	0.66	0.65	0.59	0.86
Female	0.31	0.34	0.74	0.66	0.75	0.20	0.53	0.70	0.68	0.64	0.58	0.65	0.56	0.60	0.82
Female	0.27	0.48	0.71	0.75	0.86	0.13	0.57	0.66	0.65	0.57	0.66	0.64	0.48	0.61	0.78
Female	0.24	0.63	0.68	0.82	0.92	0.09	0.61	0.62	0.63	0.50	0.74	0.62	0.39	0.62	0.72
Female	0.21	0.75	0.64	0.87	0.96	0.06	0.65	0.57	0.60	0.43	0.80	0.61	0.31	0.63	0.66
Female	0.18	0.85	0.60	0.91	0.98	0.04	0.68	0.52	0.57	0.36	0.85	0.59	0.24	0.64	0.60
Female	0.16	0.91	0.56	0.93	0.99	0.03	0.71	0.47	0.54	0.30	0.89	0.58	0.19	0.64	0.53
Female	0.14	0.94	0.52	0.95	0.99	0.02	0.74	0.42	0.50	0.24	0.91	0.56	0.14	0.65	0.46
Female	0.12	0.97	0.48	0.96	1.00	0.02	0.77	0.37	0.47	0.19	0.94	0.54	0.11	0.66	0.39
Female	0.10	0.98	0.44	0.97	1.00	0.01	0.80	0.32	0.44	0.15	0.95	0.53	0.08	0.67	0.33
Female	0.09	0.99	0.40	0.98	1.00	0.01	0.82	0.28	0.40	0.12	0.96	0.51	0.06	0.67	0.27
Female	0.08	0.99	0.36	0.99	1.00	0.01	0.84	0.24	0.37	0.10	0.97	0.49	0.04	0.68	0.22

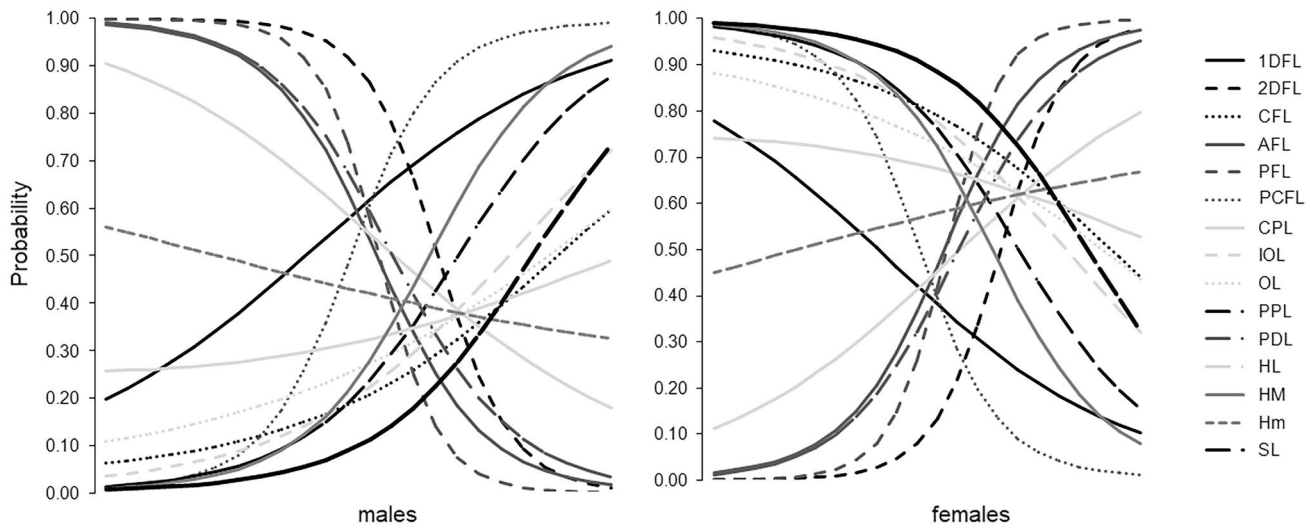Standardize probability values range between 0.00 and 1.00

Fig. 3 Standardize probabilistic trends for morphometric measure in males and females of *D. maculatus*. In this figure, a morphometric character is shorter in males or females when its probabilistic trend is descendent (from 1.00 to 0.00). The opposite case was considered when a morphometric character shows a probabilistic ascendant trend (from 0.00 to 1.00)
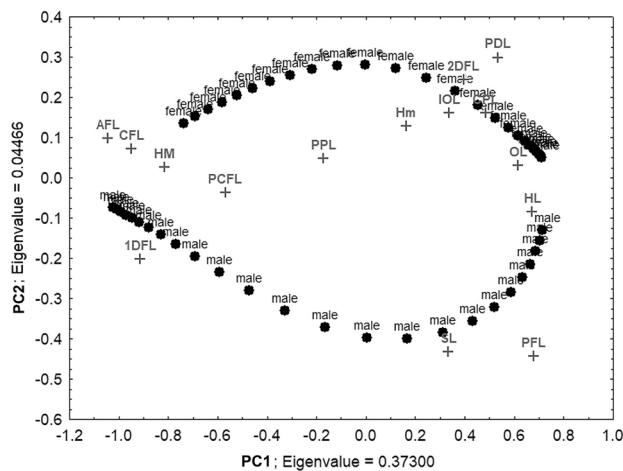

Fig. 4 The correspondence graphic shows by spatial approximation the morphometric measurements that characterized better male from females of *D. maculatus*

According to Armbruster (2012), the standardization of morphological records is essential to highlight the details in the information. In the present study, standardization was performed based on MNC probability trends and details, such as the difference between lengths for different morphological measurements obtained. Additionally, specific measures were recommended to identify males from females of *D. maculatus*, provided that the urogenital papilla method cannot be implemented. On the contrary, the morphometric measurements that were partially useful should not be used in future studies.

The morphological measurements that were considered in the present work were based in part on the reference points for the fish geometry recommended by Strauss and Bookstein (1982) and Hubbs and Lagler (1964), and others were added to complement the analysis of sexual dimorphism (Fischer et al. 1995). For this case, it was taken into account that the morphometric measurements were consistent up to the family level, since the details by species were analyzed separately.

Based on the probabilistic trend of the SL (Fig. 3) and additionally with the direct measurement of the TL, it was corroborated persistently for *D. maculatus*, that males are larger in size compared to females (Fig. 4). On the other hand, with the total weight records it was concluded that males are persistently more robust compared to females (Table 1). These same trends were documented for *Dormitator latifrons* (Richardson 1844) by González-Martínez et al. (2020). The species presented sexual dimorphism, and the main distinctive features were greater height and weight in males than in females. As an additional data point, the authors recorded that there was no significant difference in the morphometric measurements of the fins. This information is not consistent with the present work, because the aforementioned authors did not make the comparison with probability trends. In the present analysis, it was observed that probabilistically the 1DFL fin is longer in males and the 2DFL fin is longer in females (Fig. 3).

Another sexual dimorphism in males is HL, which, being longer, is consistently related to increases in TL and SL. In males, the head geometry was persistently very elongated and wider (IOL), compared to females (Figs. 3, 4). According to the TL, SL, and W(g) measurements, it is observed

that males are longer and heavier than females, which has been reported by Franco-López et al. (2021) and Dávila-Camacho and Galaviz-Villa (2021) for *D. maculatus*. This sexual dimorphism has been documented by Gonzalez-Martínez et al. (2020) for *Dormitator latifrons*, and by Segura-Guevara et al. (2011) for *Gobiomorus dormitor*, both species of the Eleotridae family.

Consistent with the present work, Gonzalez-Martínez et al. (2020) report that HL is longer in males *Dormitator latifrons.* Franco-López et al. (2021) reported the OL size is not significantly different between males and females of *D. maculatus*. In the present study, the OL size in males and females of *D. maculatus* was probabilistically and directly correlated with the morphometric measurements HL and IOL (Fig. 3). Thus, the head of *D. maculatus* grows proportionally in HL, IOL and OL. On the other hand, the PDL and PPL morphometric measurements maintained a concordance with the geometric growth of the head, but when registering variation in the correlation effects with the LH, they were not recommended to be used for the analysis of sexual dimorphism.

The probabilistic trends of PFL-PCFL (Fig. 3) establish that both morphometric measurements are not significantly different between males and females of *D. maculatus* (Fig. 4). For this reason, they were not recommended for use in the analysis of sexual dimorphism. 2DFL and CPL morphometric measurements are distinctive of the Eleotridae family (Fischer et al. 1995). At the species level, the above was confirmed for the 2DFL fin. However, it was found CPL has a direct correlation with the 2DFL fin (R = 0.99 $P < 0.05$). In accordance with Fig. 2, these two morphometric measurements are adjacent (the same with CPL and AFL), which explains the result of the direct correlation and its high approximation in Fig. 4. Unlike that indicated by the aforementioned authors, it is advisable to extend the 2DFL fin measurement to include CPL. For this reason, CPL is not recommended in the analysis of sexual dimorphism.

For the CFL and AFL morphometric measures, no discussion material was found, but like PDL, PPL, AFL, CFL, CPL, PCFL, PFL, HM, and Hm, they were not recommended in the determination of sexual dimorphism. On the other hand, it was concluded that HM probabilistically does not vary between males and females (F = 0.70, $F_{0.05} = 4.04$, $P = 0.40$). However, according to Fig. 4, in HM females tend to be of lower amplitude.

Conclusions

1. Alternative morphometric measures were identified for the determination of sexual dimorphism in *D. maculatus*. The most useful morphometric measurements were related to the size and weight of the species. The dorsal fins and the geometric structure of the head were also recommended.

2. Males are larger in size, robust with a longer 1DFL fin compared to 2DFL fin, and have a broad, elongated head.

3. Females are smaller in size, not very robust with a longer 2DFL fin compared to 1DFL fin, and have a slender, not elongated head.

Declarations

Conflict of interest The authors declare that no conflicts of interest exist.

Ethics approval/declarations All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

Consent to participate Not applicable.

Consent for publication Not applicable.

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