Fish Species Identification Using the Rhombic Squamation Pattern

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The shape of fish scales is, to a considerable degree, species-specific, making it possible to identify species using only one fish scale per specimen. However, to our knowledge, the shape of the rhombic lamination pattern has not been considered to identify species. This study used landmarks and geometric morphometric approaches to address two questions: (1) whether the rhombic lamination pattern of fish scales along the longitudinal axis varies within species and sex and (2) how many fish scales of the rhombic squamation pattern should be considered to obtain an adequate identification. These questions were assessed with a MANCOVA and a cross-validated quadratic discriminant analysis (DA) using the rhombus of one, three, and six scales, and 6, 14, and 26 landmarks, respectively, in order to discriminate between two co-generic species, *Mugil cephalus* and *Mugil curema*. Proportions of the total shape variance explained by the total length and the centroid size were 2.3, 11.8, and 10.5% and 4.2, 5.1, and 5.4% for one, three, and six scales, respectively. Thus, analyses were performed on the shape and the form (shape plus size). The MANCOVA and DA analyses were found to be effective in detecting differences in scale pattern shape between species (except in the case of three scales; \( p = 0.079 \) for the shape and \( p = 0.065 \) for the form), whereas no differences were recorded between size and sex in all cases. Findings indicate that a good identification of species is possible, with no significant differences when using shape or form. The DA provided values of 75.8, 75.0, and 73.4% based on the shape, and of 72.7, 75.8, and 75.0% based on the form, for 1, 3 and 6 scales, respectively. Thus, it is possible to obtain a rapid and reliable identification of species using the rhombus of one scale only without considering the size. This is a useful finding in practical terms since scaling requires data on length. The finding of a suitable discrimination using only the rhombus of one scale raises the possibility of using an ocular adaptor on a camera or mobile phone, allowing many individuals to be easily screened without having to collect scales.

Keywords: geometric morphometrics, landmarks, teleost fish, elasmoid scales, fish mullet, *Mugil cephalus*, *Mugil curema*

INTRODUCTION

Scales of most teleost fish are of the elasmoid type. Elasmoid scales are thought to derive from the surface “dental” tissues that covered rhombic scales in ancestral osteichthyan fish (Sire and Huysseune, 2003). Scale morphology has been used to identify inland fish of North America (Daniels, 1996), as well as to design taxonomic keys for species of freshwater ecosystems of various
highly relevant.

specimens to be screened without collecting scales is thus destructive, quick, and less costly methods that allow many species classification following easy, non-conservative, which increases uncertainty in the discriminations.

states of Veracruz and Tamaulipas. According to Eschmeyer (2012b), to use fish scale shape to determine the origin of fish catches take place in the Gulf of Mexico, off the coasts of the Gulf of Mexico. Two specific questions were addressed: (1) does the rhombic lamination pattern of fish scales discriminate two similar co-generic species? and (2) how many fish scales of the rhombic squamation pattern are necessary to obtain an adequate identification? This was assessed by applying GMM to the rhombic pattern of one, three, and six scales (6, 14, and 26 landmarks, respectively) of the longitudinal series on the left flank of the fish. These two Mugilidae species were selected for this study since they are abundant along Mexico’s coasts, they are important economically as a source of roe, and, as the rhombic lamination pattern has not been previously studied, we can use previous studies based on the one scale discrimination as comparison.

MATERIALS AND METHODS

Fish Scale Collection

Specimens were collected from one same area in order to minimize potential phenotypic differences due to the environment, as Ibáñez et al. (2007) specified. Specimens of M. cephalus (n = 64) and M. curema (n = 64) were collected from Alvarado Lagoon (N18°46′ and W95°46′), and were sexed, measured, and weighed. Most were adult specimens (87.5 and 89.1%) with average total lengths of 51.25 ± 6.46 and 41.30 ± 4.34 cm for females and males, respectively, for M. cephalus and 31.23 ± 2.52 and 29.67 ± 2.21 cm for females and males, respectively, for M. curema (Table 1). A piece of skin (with fish scales) was extracted from the left flank of the fish between the beginning of the first and second dorsal fins. Six landmarks per scale were considered following the TPSdig software (Rohlf, 2017). The landmarks were located on key structures of the ctenoid scale that are common to all scales of the species under study. The following landmarks were considered appropriate (Figure 1): landmarks 1 and 2 are the anterior points connected to the previous scale, landmarks 3 and 4 are the tips of the dorso-ventral portion of the scale, and landmarks 5 and 6 lie at the boundary between the marked and the posterior scale. Three analyses were run, the first was to describe the shape of one scale using 6 landmarks, the second to describe the shape of a configuration of three adjacent scales with 14 landmarks, and the third analysis described the shape of a configuration of six adjacent scale utilizing 26 landmarks. Since the total length was significantly different in the two species (p < 0.05), analyses were carried out for the shape and form (shape plus size).

Morphometrics

The configurations of the landmark coordinates for the sampled scales were scaled, translated and rotated using a generalized
TABLE 1 | Sample characteristics of fish mullets.

| Species         | Key  | Sex     | No. of fish | Total length range (cm) | Total length mean ± STD | Sample collection period |
|-----------------|------|---------|-------------|-------------------------|--------------------------|-------------------------|
| Mugil curema    | Mcu  | Female  | 28          | 27.4–36.5               | 31.23 ± 2.52             | July–December 2018       |
|                 |      | Male    | 29          | 27.0–34.4               | 29.67 ± 2.21             | July–December 2018       |
|                 |      | Und.    | 7           | 26.5–30.1               | 28.43 ± 1.31             | August–October 2018      |
| Mugil cephalus  | Mce  | Female  | 32          | 40.5–63.4               | 51.25 ± 6.46             | June–December 2018       |
|                 |      | Male    | 24          | 31.5–50.0               | 41.30 ± 4.34             | June–December 2018       |
|                 |      | Und.    | 8           | 30.0–41.5               | 35.46 ± 6.21             | June–August 2018         |

Und. = Undetermined.

The GPA/PCA resulted in a set of PCs that describe the patterns of form and shape variability of the three scales of the rhombic lamination pattern. Specifically, we were concerned to know the extent to which scale form and shape variability relates to species. This was assessed directly by a quadratic discriminant analysis (see below), and was explored initially by an examination of the PCs. The first PC explained 41.2, 64.8, and 79.5% of the total variance, while the second accounted for 25.6, 9.5, and 3.8% in the GPA/PCA analysis of one, three, and six scales of the rhombic lamination pattern examined for the form analysis (79.4, 80.9, and 86.5% for the first three PCs, respectively). The first PC explained 43.7, 35.5, and 26.6% of the total variance while the second accounted for 21.1, 17.3, and 14.1% in the GPA/PCA analysis of one, three, and six scales of the rhombic lamination pattern examined for the shape analysis (79.2, 61.7, and 51.5% for the first three PCs, respectively) (Table 2).

The variation in shape between species is represented in Figure 2 where the leftmost grids are the mean shape of *M. curema*, the rightmost grids are that of *M. cephalus*, and the reference shape is in the central grid for one, three, and six scales as mentioned above. Also, multivariate regressions of all PCs on species confirmed these general trends. Finally, differences were assessed by a full MANCOVA with all PC scores of shape and form (shape plus size) as dependent variables, total length as the covariate, and species and sex as grouping factors.

RESULTS

The GPA/PCA resulted in a set of PCs that describe the patterns of form and shape variability of the three scales of the rhombic lamination pattern. Specifically, we were concerned to know the extent to which scale form and shape variability relates to species. This was assessed directly by a quadratic discriminant analysis (see below), and was explored initially by an examination of the PCs. The first PC explained 41.2, 64.8, and 79.5% of the total variance, while the second accounted for 25.6, 9.5, and 3.8% in the GPA/PCA analysis of one, three, and six scales of the rhombic lamination pattern examined for the form analysis (79.4, 80.9, and 86.5% for the first three PCs, respectively). The first PC explained 43.7, 35.5, and 26.6% of the total variance while the second accounted for 21.1, 17.3, and 14.1% in the GPA/PCA analysis of one, three, and six scales of the rhombic lamination pattern examined for the shape analysis (79.2, 61.7, and 51.5% for the first three PCs, respectively) (Table 2).

The variation in shape between species is represented in Figure 2 where the leftmost grids are the mean shape of *M. curema*, the rightmost grids are that of *M. cephalus*, and the reference shape is in the central grid for one, three, and six scales.
TABLE 2 | Explained variance of PCs for each landmark configuration analysis.

| Landmark configuration analysis | PC1  | PC2  | PC3  | Accumulative variance (%) |
|---------------------------------|------|------|------|---------------------------|
| Form analysis                   |      |      |      |                           |
| One scale                       | 41.2 | 25.6 | 12.6 | 79.4                      |
| Three scales                    | 64.8 | 9.5  | 6.6  | 80.9                      |
| Six scales                      | 79.5 | 3.8  | 3.2  | 86.5                      |
| Shape analysis                  |      |      |      |                           |
| One scale                       | 43.7 | 21.1 | 14.4 | 79.2                      |
| Three scales                    | 35.5 | 17.3 | 8.9  | 61.7                      |
| Six scales                      | 28.6 | 14.1 | 10.8 | 51.5                      |

of the rhombic lamination pattern under study (Figures 2A–C). The one scale pattern (Figure 2A) was characterized by a relative bending to the right of landmarks 1, 2, 5, and 6 for M. curema, and a similar bending to the left of the same landmarks for M. cephalus. An analogous trend was observed for the three and six scales of the rhombic lamination pattern (Figures 2B,C). The key difference was the relative location of the central landmarks which bent more to the right for M. curema than for M. cephalus. Furthermore, the anterior–posterior edge was concave in M. curema and convex in M. cephalus.

In the discriminant analyses, similar cross-validated classification rates were obtained using the shape and the combined scale size and shape (form space; Tables 3, 4). Furthermore, the shape alone performed slightly better than the form when using the rhombic lamination pattern of one fish scale (Table 4). The cross-validated quadratic discriminant analysis using the form (Table 3) correctly classified 72.7, 75.8, and 75% for the rhombic lamination pattern of one, three, and six scales, respectively (Wilks’ $\lambda = 0.676, p < 0.001$; Wilks’

TABLE 3 | Cross-validated predicted species membership using form (indicated as treatment; see text) from the rhombic lamination pattern of one, three, and six fish scales.

| Predicted group membership | One scale | Three scales | Six scales | Total |
|----------------------------|-----------|--------------|------------|-------|
| Species                   | M. cu     | M. ce        | M. cu      | M. ce |
| Percent                   | 73.4      | 26.6         | 100.0*     |       |
| M. ce                     | 78.1      | 21.9         | 100.0*     |       |
| M. cu                     | 26.6      | 73.4         | 100.0†     |       |
| M. ce                     | 73.4      | 26.6         | 100.0†     |       |
| M. cu                     | 73.4      | 26.6         | 100.0‡     |       |
| M. ce                     | 76.6      | 23.4         | 100.0‡     |       |

M. cu = Mugil curema; M. ce = Mugil cephalus. *Of cross-validated grouped cases, 72.7% were correctly classified (Wilk’s lambda = 0.676, $p < 0.001$) for the rhombic lamination pattern of one scale. †Of cross-validated grouped cases, 75.8% were correctly classified (Wilk’s lambda = 0.467, $p < 0.001$) for the rhombic lamination pattern of three scales. ‡Of cross-validated grouped cases, 75.0% were correctly classified (Wilk’s lambda = 0.313, $p < 0.001$) for the rhombic lamination pattern of six scales.

**FIGURE 2** | Shape variation in each species visualized using transformation grids. Middle grid shows the regular reference grid in each rhombic squamation pattern showing the landmark utilized for the Procrustes analysis for one (A), three (B), and six (C) scales. Left, deformed grid drawn over the estimated shape for Mugil curema individuals; right, deformed grid drawn over the estimated shape for M. cephalus. Scales orientation are the same as in Figure 1.
TABLE 4 | Cross-validated predicted species membership using shape (indicated as treatment; see text) from the rhombic lamination pattern of one, three, and six fish scales.

| Predicted group membership | One scale | Three scales | Six scales | Total |
|-----------------------------|-----------|--------------|-----------|-------|
| Species                     | M. cu     | M. ce        | M. cu     | M. ce |
| Percent                     |           |              |           |       |
| M. cu                       | 75.0      | 25.0         | 100.0*    |       |
| M. ce                       | 23.4      | 76.6         | 100.0*    |       |
| M. cu                       | 76.6      | 23.4         | 100.0†    |       |
| M. ce                       | 26.6      | 73.4         | 100.0‡    |       |
| M. cu                       | 73.4      | 26.6         | 100.0     |       |
| M. ce                       | 26.6      | 73.4         | 100.0     |       |

M. cu = Mugil curema; M. ce = Mugil cephalus. *Of cross-validated grouped cases, 75.8% were correctly classified (Wilk’s lambda = 0.680, p < 0.001) for the rhombic lamination pattern of one scale. †Of cross-validated grouped cases, 75.0% were correctly classified (Wilk’s lambda = 0.482, p < 0.001) for the rhombic lamination pattern of three scales. ‡Of cross-validated grouped cases, 73.4% were correctly classified (Wilk’s lambda = 0.327, p < 0.001) for the rhombic lamination pattern of six scales.

The size of the fish (total length) did not change the shape significantly (Table 5) or improve species discrimination, as well as the number of scales scanned (Tables 3, 4). This means that one may use one single rhombic lamination pattern for species discrimination without having to consider the size. This is a useful finding in practical terms since the form (shape plus size) requires data on body length. Accordingly, it also raises the possibility of using an ocular adaptor on a camera or cell phone allowing many specimens to be easily screened without having to collect a fish scale. This approach may also prove useful in a situation where it is not possible to quantify the size of the specimens. Nevertheless, the non-normality of the canonical scores of the rhombic lamination pattern for the three scales certainly reduced the effect of the MANCOVA analysis.
Ibáñez et al. (2009), in a study that did not take into account fish size, verified the efficacy of the identification of scales from nine regions along the flank of teleost fish, and obtained the highest rates of correct identification using scales from the central–dorsal region of mature fish and scales from the same body region (Ibáñez et al., 2007, 2009; Garduño-Paz et al., 2010). Correct classification rates were as high as 98% for some species. In the present study, the scales analyzed for the rhombic lamination pattern were collected from the same body area belonging to the lateral series, and most were of sexually mature individuals. Although the rate of correct identification is reduced under some conditions, it compares reasonably with the rate of over 80% recorded in studies using otoliths to categorize co-generic species (Torres et al., 2000; Stransky and MacLellan, 2005). Variations among different species are regularly greater than those within a species; however, it has been suggested that *M. curema* and *M. cephalus* are not a single species but a species complex (Durand and Borsa, 2015). In this sense, a wide phenotypic variability is present (Ibáñez et al., 2006, 2007), which could reduce discrimination.

In order to explain the squamation pattern, Sire and Arnulf (1990) proposed that the tension transmitted to the skin during swimming may induce scale development as a means of resisting excessive bending. The rhombic lamination pattern of the scales may also be functionally related to the swimming mode. Both mullet species look similar and present a subcarangiform swimming mode (Breder, 1926). In this sense, the rhombic lamination pattern is also similar. Other similarities are present in these two mullets, such as the number of lateral scales, which is 36–40 in *M. cephalus* and 35–40 in *M. curema*, with modes 38 and 37, respectively (Harrison, 2002). Thus, differences in the rhombic lamination pattern could be due to the shape of the fish, with *M. cephalus* being a more robust species with a projectile shape and *M. curema* having a slimmer body. These differences were recognized by Jordan and Evermann (1896) in the specific description of these species from Central America and North America. Also, the *ctenii* of the scales are different in these species and have been used to discriminate them (Ibáñez and Gallardo-Cabello, 2005). Likewise, the roughness of the scale surface has been studied from the point of view of hydrodynamics (Sudo et al., 2002). Thus, the variations in shape of the scale lamination pattern could arise from adaptations to fluctuating hydrodynamic conditions. Supplementary studies that include biomechanical evaluations will offer a possibility to study the function–form relationship.

Scale morphology and squamation have been used to study scale morphology in different parts of the body (Chen et al., 2012; Mondejar-Fernández and Clément, 2012), to describe the squamation pattern of osteichthyans providing new insights into the early evolution of osteichthyan scales, to understand the early osteichthyan body plan (Cui et al., 2019), and to study the morphology and articulated squamations of extinct species (Zigaite and Goujet, 2012). However, to our knowledge, no other analysis has used the rhombic lamination pattern to discriminate between species as is presented in this study.

Species identification is vital in the conservation of biodiversity and fisheries management, particularly considering the urgent need of correct species identification experienced by a fisheries control officer on the high seas (Fischer, 2013). Thus, this method is useful and non-destructive; it makes it possible to screen rare, museum specimens and endangered species, it allows many individuals in a community to be screened quickly, and it is an inexpensive method to discriminate species. In order to use such an approach effectively in fisheries management, it is important to have described and made available the rhombic lamination pattern of each species.

### DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

### ETHICS STATEMENT

Research was carried out in accordance to Mexican laws and regulations. Striped and white mullet was collected under the Official Mexican Norm (NOM-016 PESC-1994) for commercial species. Fish were euthanized humanely by being placed directly into an ice water bath upon capture. No non-target or by-catch specimens were collected during the study.

### AUTHOR CONTRIBUTIONS

AI and EP-A conceived the research. AI conducted the field work. EG processed and prepared the fish and performed the statistically analysis. EP-A reviewed the process and preparation of samples. AI prepared the initial manuscript and all authors contributed to later revisions.
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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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