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WHO IS WHO? OTOLITH SHAPE ANALYSIS TO DIFFERENTIATE TWO EXTERNALLY IDENTICAL SCABBARDFISH (*APHANOPUS* SPP.)

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INTRODUCTION

Two important commercial scabbardfish, *Aphanopus carbo* and *A. intermedius* were considered the same species in the archipelago of Madeira (NE Atlantic) till 2010, since no external differentiation is noticeable to discern both taxa. The conventionally differentiation using dorsal fin and vertebral counts is time consuming and not practical. We here proposed new complementary method to identify the two species.

MATERIAL & METHODS

We here analyzed otoliths of 779 of *Aphanopus carbo* and 179 *A. intermedius* (**Fig. 1**) sampled between 2010 and 2021 (**Table 1**). The Synthetic Minority Oversampling Technique (SMOTE) was used to address the imbalanced datasets. Age&Shape software (v1.0; Infaimon SL©) was used for image processing. Otolith shape analysis was based on wavelet functions (5th wavelet). Four classifiers were compared: (i) Support Vector Machine (SVM); (ii) K-nearest neighbors (KNN); (iii) Linear discriminant analysis (LDA); and (iv) artificial neuronal networks (ANN). We here use a fourfold cross-validation resampling method to improve model performance of each classifier from the collected data **[1]**. Additionally, 100 repetitions of the whole process were conducted using a bootstrap approach with independent resampling **[2]**. The R package "caret" **[3]** was used to perform classifications and compare performances of selected classifiers.

Table 1 | Number (n) of individuals and otolith (OL, mm) mean lengths (± standard deviation, SD) of *Aphanopus carbo* and *A. intermedius* sampled in the archipelago of Madeira (NE Atlantic).

Species	n	OL Mean ± SD	OL Min.–Max.
A. carbo	327	8.70 ± 0.634	7.30 – 10.6
A. intermedius	152	8.83 ± 0.656	7.22 – 10.8

RESULTS and DISCUSSION

The average of the 5th wavelet by species revealed that *A. carbo* otoliths are wider in the dorsal (see axis *ca*. 250-300) and ventral (from 310-350) margins. The *antirostrum*, when present, is smaller in *A. intermedius* (**Fig. 2**). In short, we pointed out that both otolith patterns are similar, but slight differences were noticeable, e.g. *A. intermedius* is more elongated (see **Fig. 1**). Regarding model performance, SVM and KNN classifiers showed the higher accuracy and kappa index values (**Table 2**).

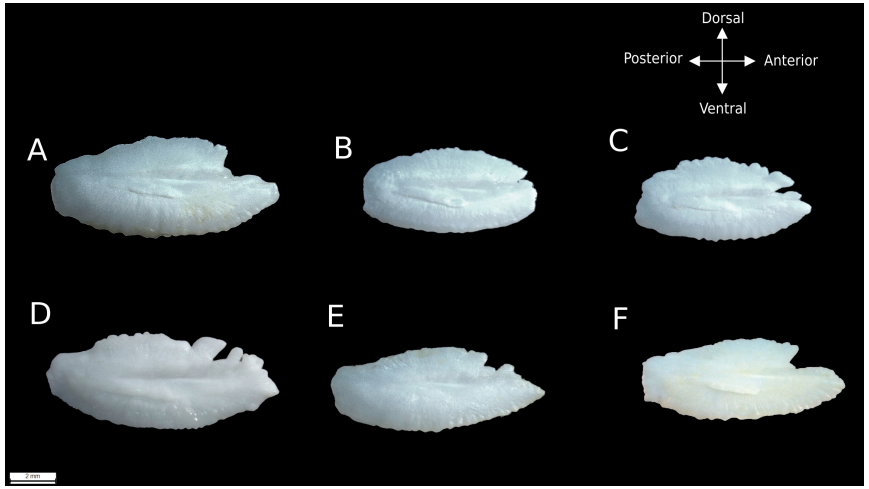

Figure 1 | Otoliths of *A. carbo* (A-C) and *A. intermedius* (D-F). Otolith lengths: A, 10.0 mm; B, 7.6 mm; C, 7.7 mm; D, 10.0 mm; E, 9.4 mm; F, 8.9 mm.

Table 2 | Confusion (error) matrix, classification accuracy (the percentage of fish correctly assigned to their predicted group, in bold) and kappa index obtained by different classifiers of *Aphanopus carbo* (AC) and *A. intermedius* (AI) sampled in the archipelago of Madeira (NE Atlantic).

		Prediction		Performance measures			
Classifier	Species	AC	AI	% Accuracy	Accuracy	95% CI	Kappa
SVM	AC	327	0	100	1	0.99-1	1
	AI	0	152	100			
KNN	AC	252	7	77.06	0.83	0.79-0.86	0.65
	AI	75	145	95.39			
LDA	AC	206	54	62.99	0.63	0.60-0.68	0.25
	AI	121	98	64.47			
ANN	AC	201	60	61.47	0.62	0.57-0.66	0.20
	AI	126	92	60.53			

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The accuracy and kappa index differed significantly between classifiers, except for SVM and KNN for kappa index (**Table 3**). Discrimination system did not show the expected high values to clearly differentiate both *Aphanopus* species (LDA and ANN <70%), as previously shown by other authors using wavelets [4]. The low discrimination was explained by the high variability of within each species that overshadow the observed differences between *A. carbo* and *A. intermedius*.

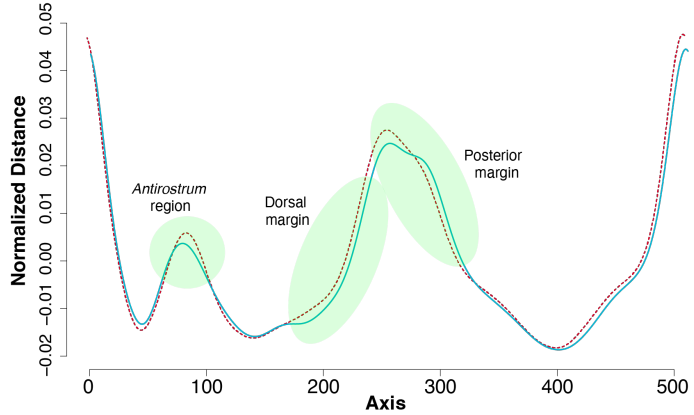

Figure 2 | Average decomposition of otolith contour using the 5th wavelet for *A. carbo* (blue line) and *A. intermedius* (red line).

Table 3 | Comparison of algorithm accuracies and kappa for scabbardfish. Estimates of the difference are reported in the upper diagonals, while p values (Bonferroni adjustment) for the hypothesis of no difference are reported in the lower diagonals

	Classifier	KNN	LDA	SVM	ANN
Accuracies	KNN	-	-0.0637	-0.1632	-0.2235
	LDA	<0.001	-	-0.0995	-0.1598
	SVM	<0.001	<0.001	-	-0.0603
	ANN	<0.001	<0.001	<0.001	-
Kappa	KNN	-	-0.1173	0.0026	-0.2530
	LDA	<0.001	-	0.119831	-0.1358
	SVM	1	<0.001	-	-0.2556
	ANN	<0.001	<0.001	<0.001	-

REFERENCES [1] Smolinski et al. 2020. Can. J. Fish. Aquat. Sci. 77(4): 674-683; **[2]** Hastie et al. 2009. The elements of statistical learning — Data mining, inference. doi:10.1007/B94608; **[3]** Kuhn, 2008. J. Stat. Soft. 28: 1–26; **[4]** Tuset et al. 2021. Can. J. Fish. Aquat. Sci. 78: 681–692