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Original Article

Quantitative morphometric analysis of dorsal fin for species identification in sharks (Family: Carcharhinidae) from the Suez Gulf, Red Sea, Egypt

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ABSTRACT

Shark fins are essential for distinguishing various shark species; however, they may be visually tough to differentiate. This study introduces an innovative method for measuring and comparing the dorsal fins of sharks in the Suez Coastal region of the Red Sea, Egypt. Thirty-four shark specimens, encompassing 9 distinct species s were acquired from two fish markets, and their dorsal fins were documented by photography. We used a software program called Image for the purpose of evaluating images. This program can compute the ratios of certain fin properties. The species include *Carcharhinus brevipinna, C. sorrah, C. melanopterus, C. albimarginatus, C. altimus, C. amblyrhynchoides, C. falciformis, C. plumbeus, and C. limbatus*. Each species had differences in dorsal fin size, shape, and structure, with forms that ranged from triangular to falcate, with concave or convex anterior edges and concave posterior margins. The color varied from deep shades to lighter or reddish tones. Comprehensive measurements of the dorsal fin, including the free rear tip, fin base, and anterior and posterior edges, were examined. The ratios among these dimensions differed markedly between species, enabling categorization. *Carcharhinus melanopterus* had the largest M2/M4 ratio, signifying an elongated dorsal fin, but *C. altimus* possessed the best M15/M2 ratio, indicating an expanded fin base. Principal Component Analysis (PCA) and heat map studies elucidated morphological differences by grouping species according to fin measurements. The findings indicate that dorsal fin ratios may proficiently differentiate between species, establishing a foundation for shark categorization. This methodology, along with morphometric analysis, is essential for species identification and conservation initiatives.

Key Words: Quantitative morphometric analysis; Dorsal fin classification; Shark species differentiation; Suez Gulf; Red Sea; Carcharhinus sharks fin ratio measurement; Principal Component Analysis (PCA) and Shark conservation.

1. INTRODUCTION

The Red Sea is a slender body of water that divides Africa and Asia, situated approximately between 34°E and 43°E longitudes and 12°N and 28°N latitudes. The primary emphasis is on the Egyptian coastline, which spans about 1300 km from Suez in the North to Hala'ib in the South (Afifi *et al*., 2022). This region encompasses over 450,000 square kilometers, with an average depth of 0.5 kilometers and a total volume of 0.2 million cubic kilometers (UNEP, 2014). In these crystalline blue waters, a diverse array of sharks, classified under the Chondrichthyes group, coexists with batoids and chimaeras. The class Chondrichthyes has more than 1100 species, with sharks accounting for roughly 400 of them (Compagno, 1984). These remarkable animals are now confronting a significant hazard owing to the need for their first dorsal fin, used in the preparation of shark fin soup. To produce this soup, individuals slice and dehydrate shark fins, with the dorsal fin being the most esteemed portion, often offered whole **(El-Tabakh et al., 2024; Musick and Bonfil, 2005).**

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In addition to their nutritional significance, the dorsal fin is essential for the identification and classification of sharks. Sharks may be recognized by their dorsal fin, which is conspicuous in their native environments or when captured by fishermen **(Klimley *et al.*, 2024)**. Marine biology experts often use images of these fins to distinguish between different shark species at the water's surface. The ecological and conservation repercussions are significant, since fishermen often detach the fins and dump the remainder of the shark, endangering certain species. This highlights the pressing need for extensive data on shark dorsal fins. This research seeks to investigate the use of dorsal fin measures for differentiating shark species in the Egyptian Red Sea. By comprehending the complexities of these fins, we want to make significant contributions to the conservation and understanding of these intriguing aquatic creatures.

MATERIALS AND METHODS

Location:

Suez City is located at a latitude of 29.9737° N, placing it in the northern hemisphere, roughly 30 degrees North of the equator. Positioned at the southern end of the Suez Canal and on the northern coast of the Gulf of Suez along the Red Sea, Suez lies in northeastern Egypt. It serves as the administrative center of the Suez Governorate and hosts three ports: Suez Port, al-Adabiya, and al-Zaytiya. Historically, Suez was an important center for commerce **(**Figure 1).

Specimens' collection:

A total of 34 shark specimens, encompassing 9 distinct species (3 of *Carcharhinus brevipinna*, 4 of *C. sorrah*, 3 of *C. melanopterus*, 4 of *C. albimarginatus*, 3 of *C. altimus*, 3 of *C. amblyrhynchoides*, 5 of *C. falciformis*, 6 of *C. plumbeus*, and 3 of *C. limbatus)*, were periodically collected from the commercial catch at the fish market in Suez landmark, Red Sea **(Fig. 1& PLATE I).** Data collection occurred from May 2022 until October 2023. The shark specimens were recently analyzed. The length of each specimen was meticulously measured to the closest millimeter and recorded. Numerous images of each shark were captured for examination using Image J software. This program was used to compute different ratios derived from the morphological characteristics of the dorsal fin. The sharks were kept in a 10% formalin solution and then relocated to the Laboratory of Marine Biology inside the Zoology Department at the Faculty of Science, Al-Azhar University, Cairo, Egypt. The purpose of this move was to enable more investigation. The sharks were categorized in the laboratory according to the parameters established by **FAO (2005)**, followed by further examinations.

Fig. 1: Showing map location of Suez landmark, Red Sea, Egypt.

Dorsal fin measurements

Our research used the sophisticated functionalities of I-shark fin, an expert system that utilizes state-of-the-art machine-learning algorithms to classify shark species via the analysis of fin morphology. This application was enhanced to augment user-friendliness and elevate functionality. These enhancements enable users to choose categorical characteristics, such as fin tip color or shape.

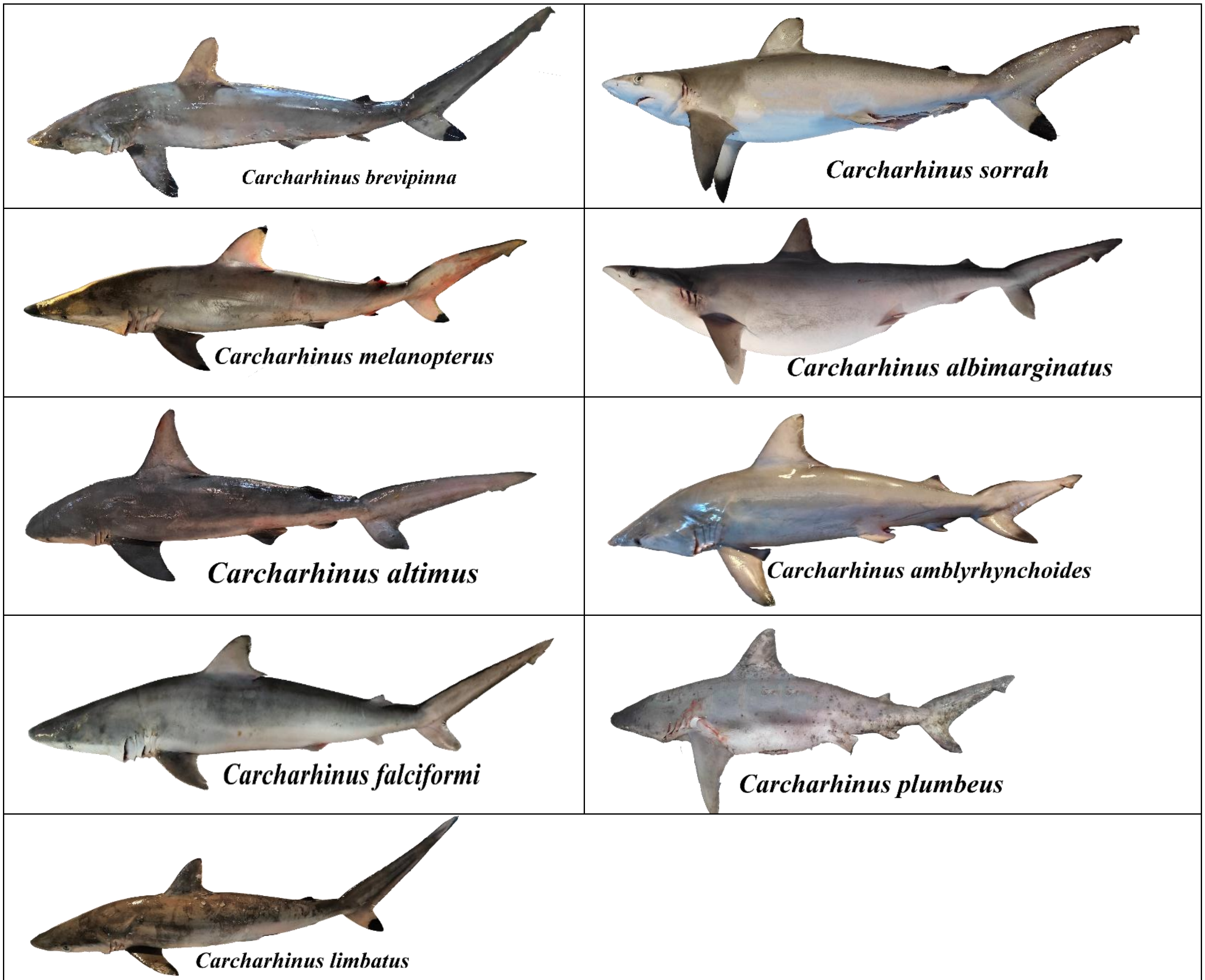

PLATE (I): Showing carcharhinid shark species (*Carcharhinus brevipinna, C. sorrah, C. melanopterus, C. albimarginatus, C. altimus, C. amblyrhynchoides, C. falciformis, C. plumbeus* and *C. limbatus*)**,** collected from Suez Gulf, from May 2022 until October 2023.

Dorsal fin measurements

Our research used the sophisticated functionalities of I-shark fin, an expert system that utilizes state-of-the-art machine-learning algorithms to classify shark species via the analysis of fin morphology. This application was enhanced to augment user-friendliness and elevate functionality. These enhancements enable users to choose categorical characteristics, such as fin tip color or shape. The methodology is perpetually advancing and is executed using the Rwizard program R packages (Azab et al., 2019; Guisande *et al*., 2014), R Development (R Core Team, 2021), and scripts delineated in prior studies (Guisande *et al*., 2011, and 2012). It is consistently updated with each new release of fin images, including both morphometric and meristic attributes, used for the evaluation and training (Figure 2).

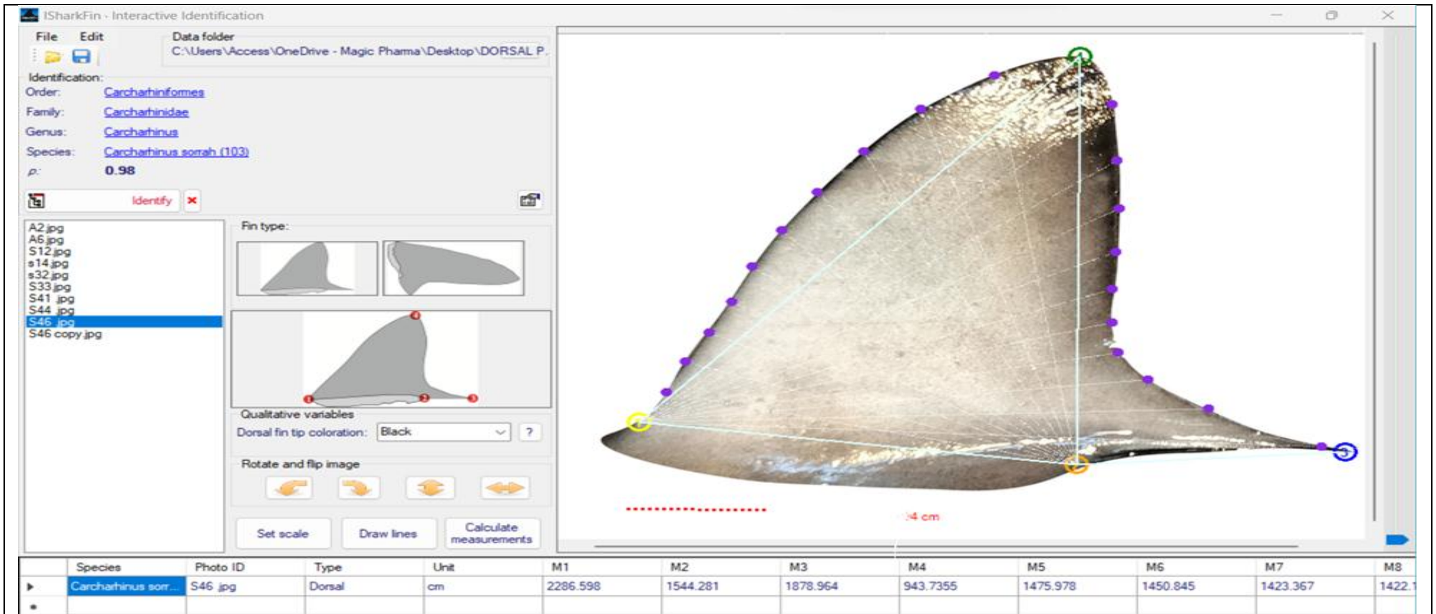

Fig. 2: Showing I-shark fin, a system that leverages cutting-edge machine-learning algorithms to identify shark species by analyzing the shapes of their fins.

i-Shark software employs measurements M1 to M24 to ascertain the distances between certain locations on the fin outline. The measurements are used to determine the fin's configuration and to compare it with reference fins archived in the database. More precisely, M5 to M14 indicate the measurements from the place of insertion to the front boundary of the dorsal fin, whereas M15 to M24 indicate the measurements from the starting point to the rear boundary of the dorsal fin. M1, M2, and M3 are metrics pertaining to the sides of a triangle. M1 denotes the distance from the apex to the origin, M2 signifies the distance from the origin to the insertion point, and M3 indicates the distance from the apex to the insertion point. M4 denotes the measurement of the distance from the insertion point to the unobstructed rear end (Figure 3).

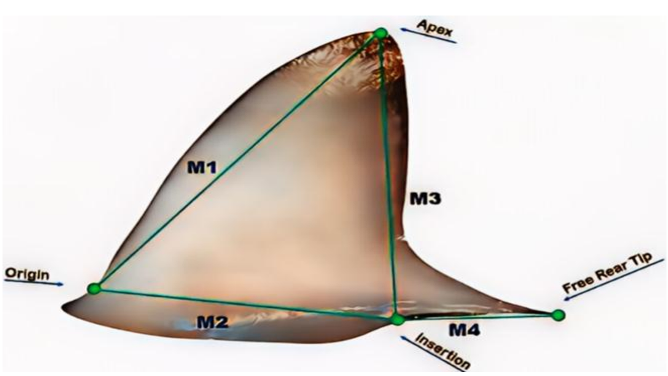

Fig. 3: Morphometric measurements of shark fin outline.

Free rear tip (M4): The distance between fin insertions to the end of the free rear tip.

Fin base (M2): The distance between the fin origin and the fin insertion, i.e., the length of the dorsal fin base.

Anterior margin (M1): The distance between the dorsal fin origin and the fin apex.

Upper posterior margin (M3): The distance between the tip of the fin and the insertion.

3.RESULTS

In this study, researchers collected 9 different species of sharks: *Carcharhinus brevipinna*, *C. sorrah*, *C. melanopterus*, *C. albimarginatus*, *C. altimus*, *C. amblyrhynchoides*, *C. falciformis*, *C. plumbeus*. and *C. limbatus* from the waters of the Egyptian Red Sea, specifically at Suez Gulf. These shark species are classified inside a single family and order. The provided text is a reference to Table (1).

Table (1): Systematic position of some shark species collected from Suez Gulf, from May 2022 until October 2023.

Order	Family	Genus	Species
Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus brevipinna* (Müller and Henle, 1839) *Carcharhinus sorrah* (Valenciennes, 1839) *Carcharhinus melanopterus* (Quoy and Gaimard, 1824) *Carcharhinus albimarginatus* (Rüppell, 1837) *Carcharhinus altimus* (Springer, 1950) *Carcharhinus amblyrhynchoides* (Whitley, 1934) *Carcharhinus falciformis* (Bibron, 1839) *Carcharhinus plumbeus* (Nardo, 1827): *Carcharhinus limbatus (?????)*

The dorsal fin of the examined shark species has one or two segments and varies in size from tiny to moderate or big. The fin configurations include triangular, rectangular, sail-like, leaf-shaped, and sickle-shaped forms. The front edge may be concave or convex, but the rear border is always concave, with rounded, blunt, or sharp points. The rear margin has a concave configuration. A solitary spine may be present on the front dorsal fin, or it may be lacking. The fin has a profound pigmentation, characterized by gradients of darkness and brightness, together with a lustrous sheen, often revealing a dark reddish tint. The central region is white with dark borders, the top section is dark, and the bottom portion is brilliant, including black dots and lighter sections. The dimensions of the free rear tip vary from tiny to moderate to huge.

Carcharhinus brevipinna **(Müller & Henle, 1839):**

Dorsal fin diagnostic feature: fairly tall and falcate (sickle-shaped) dorsal fin; a round apex; darker tip; a small free rear tip **(PLATE II).**

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 3.96 cm, the fin base (M2) was 8.21 cm, the anterior margin (M1) was 11.39 cm, and the upper posterior margin (M3) measured 9.72 cm **(Table 2).**The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.35±0.01) and (1.17±0.04), respectively, by analyzing the measurements of the dorsal fin. In addition, the ratio between the free rear tip (M4) and the Fin base (M2) was determined to be 2.39±0.077. These findings enhance our understanding of the specific properties of the dorsal fin in *Carcharhinus brevipinna* **(Table 2).**

Carcharhinus sorrah **(Valenciennes, 1839):**

Dorsal fin diagnostic feature: being moderately tall and falcate (sickle-shaped). It typically features a rounded apex and may exhibit a darker tip. Additionally, *Carcharhinus sorrah* is known for having a relatively small free rear tip in its dorsal fin **(**PLATE II).

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: The free rear tip (M4) measured 3.12 cm, the fin base (M2) was 10.22 cm, the anterior margin (M1) was 12.17 cm, and the upper posterior margin (M3) measured 9.83 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.34±0.08) and (1.05±0.08), respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the fin base (M2) was determined to be (2.47±0.52). These findings enhance our understanding of the dorsal fin features of *Carcharhinus sorrah* in a comprehensive manner (Table 2).

Carcharhinus melanopterus **(Quoy and Gaimard, 1824):**

Dorsal fin diagnostic feature: The dorsal fin is moderately tall and falcate (sickle-shaped), exhibiting a noticeable curve. It typically has a pointed apex and a well-defined, slightly concave trailing edge. One prominent feature is the black or dark colouration on the fin's tips, particularly on the dorsal side, giving rise to the common name "blacktip reef shark." The free rear tip is relatively **small compared to the overall height of the fin (PLATE II).**

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 3.62 cm, the fin base (M2) was 12.34 cm, the anterior margin (M1) was 17.55 cm, and the upper posterior margin (M3) measured 11.92 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were calculated as 1.42 and 0.96, respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the fin base (M2) was determined to be 3.4. These findings enhance our understanding of the specific properties of the dorsal fin in *Carcharhinus melanopterus* (Table 2).

Carcharhinus albimarginatus **(Rüppell, 1837)**

Dorsal fin diagnostic feature: being fairly tall and falcate (sickle-shaped). It typically exhibits a rounded apex and is noteworthy for having a distinct white or pale margin on the posterior edge, contributing to its specific identification. The dorsal fin of this species may also display a darker tip, and a relatively small free rear tip is a distinguishing feature (PLATE II).

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: The free rear tip (M4) measured 3.76 cm, the fin base (M2) was 10.98 cm, the anterior margin (M1) was 12.96 cm, and the upper posterior margin (M3) measured 11.17 cm **(**Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.29±0.21) and (1.08±0.24), respectively, by analyzing the measurements of the dorsal fin. In addition, the ratio of the free rear tip (M4) to the fin base (M2) was determined to be 2.88±0.05. These findings enhance our awareness of the specific properties of the dorsal fin in *Carcharhinus albimarginatus*, leading to a more complete comprehension of this **species (Table 2).**

Carcharhinus altimus **(Springer, 1950):**

Dorsal fin diagnostic feature: Fairly tall and falcate (sickle-shaped) dorsal fin; a blunt apex; darker tips; a small free rear tip (PLATE II).

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 2.03 cm, the fin base (M2) was 5.97 cm, the anterior margin (M1) was 8.08 cm, and the upper posterior margin (M3) measured 5.99 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.41±0.058) and (1.13±0.135), respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the fin base (M2) was determined to be 2.55±0.379. These findings enhance our grasp of the dorsal fin traits of *Carcharhinus altimus*, providing a more complete and thorough comprehension (Table 2).

Carcharhinus amblyrhynchoides **(Whitley, 1934):**

Dorsal fin diagnostic feature: moderately tall with a gently curved profile, a pointed apex, and a contrasting colouration at the fin tip. The dorsal fin may exhibit a defined trailing edge, and the free rear tip is typically moderate in size (PLATE II).

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 4.95 cm, the fin base (M2) was 12.23 cm, the anterior margin (M1) was 16.78 cm, and the upper posterior margin (M3) measured 13.83 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.35±0.01) and (1.17±0.04), respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the fin base (M2) was determined to be 2.39±0.077. These findings enhance our knowledge of the specific dorsal fin traits of *Carcharhinus amblyrhynchoides*, leading to a more complete understanding of this species (Table 2).

***Carcharhinus falciformis* (Bibron, 1839):**

Dorsal fin diagnostic feature: The dorsal fin is relatively high and falcate (sickle-shaped), displaying a distinct curvature. It has a pointed apex and a gently concave trailing edge. The fin may have a dusky or dark tip, and the free rear tip is typically well-developed (PLATE II).

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 2.72 cm, the fin base (M2) was 8.00 cm, the anterior margin (M1) was 9.23 cm, and the upper posterior margin (M3) measured 5.42 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were determined as (1.3±0.14) and (0.92±0.24), respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the Fin base (M2) was determined to be (3.03±0.09). These findings enhance our understanding of the specific properties of the dorsal fin in *Carcharhinus falciformis* (Table 2).

***Carcharhinus plumbeus* (Nardo, 1827):**

Dorsal fin diagnostic feature: Fairly tall and falcate (sickle-shaped) dorsal fin; a blunt apex; a small free rear tip **(PLATE II).**

Dorsal fin measurements and ratios: In the analysis of dorsal fin measurements, the following values were observed: the free rear tip (M4) measured 8.75 cm, the fin base (M2) was 23.00 cm, the anterior margin (M1) was 29.42 cm, and the Upper posterior margin (M3) measured 23.73 cm (Table 2).

The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were calculated as (1.28±0.004) and (1.09±0.058), respectively, by analyzing the measurements of the dorsal fin. Furthermore, the ratio between the free rear tip (M4) and the fin base (M2) was determined to be (2.75±0.13). These findings enhance our grasp of the dorsal fin traits of *Carcharhinus plumbeus*, providing a more complete and thorough comprehension (Table 2).

***Carcharhinus limbatus* (Valenciennes, 1839)**

Dorsal fin diagnostic feature: The dorsal fin is relatively tall, falcate (sickle-shaped), and has a rounded apex with a small free rear tip. These features are characteristic of the species and aid in identification (PLATE II).

Dorsal fin measurements and ratios

In analyzing the dorsal fin measurements, the free rear tip (M4) was measured at 7.90 cm, the fin base (M2) at 21.50 cm, the anterior margin (M1) at 27.30 cm, and the upper posterior margin (M3) at 22.10 cm. Ratios of these measurements further elucidate the fin's proportions. The ratios of the anterior margin (M1) and upper posterior margin (M3) to the fin base (M2) were calculated as 1.27±0.005 and 1.03±0.045, respectively. Additionally, the ratio of the free rear tip (M4) to the fin base (M2) was determined as 2.61±0.11 (Table 2).These findings contribute to a detailed understanding of the morphological characteristics of *C. limbatus*, highlighting its distinctive dorsal fin features. This morphological data is essential for species identification and comparative studies within the genus *Carcharhinus* (Table 2).

The heat map (Figure 4) provides a comprehensive depiction of the dorsal fin measurement ratios for the nine shark species within the Carcharhinidae family. The heat map depicts the comparative magnitudes of diverse measurement ratios, using a color gradient from dark blue (indicating lower values) to bright yellow (indicating higher values) to highlight variations across distinct fin dimensions.

The hierarchical clustering seen in the heat map indicates that some species cluster based on the similarity of their fin measurement ratios. *C. falciformis and C. melanopterus* are closely related, indicating a resemblance in their fin structure. Likewise, the species *C. limbatus* and *C. altimus* demonstrate proximity in their cluster, signifying similar characteristics in their dorsal fin (Figure 4).
The heat map reveals distinct patterns in dorsal fin measurements, with some species exhibiting greater ratios in certain parameters. *C. albimarginatus and C. brevipinna* are differentiated in their clusters, highlighting their unique fin morphologies and measurement ratios. The M2/M4 ratio, shown in the rightmost column, demonstrates significant variety across species, with *C. melanopterus* exhibiting the highest value, indicated by the vibrant yellow hue (Figure 4).

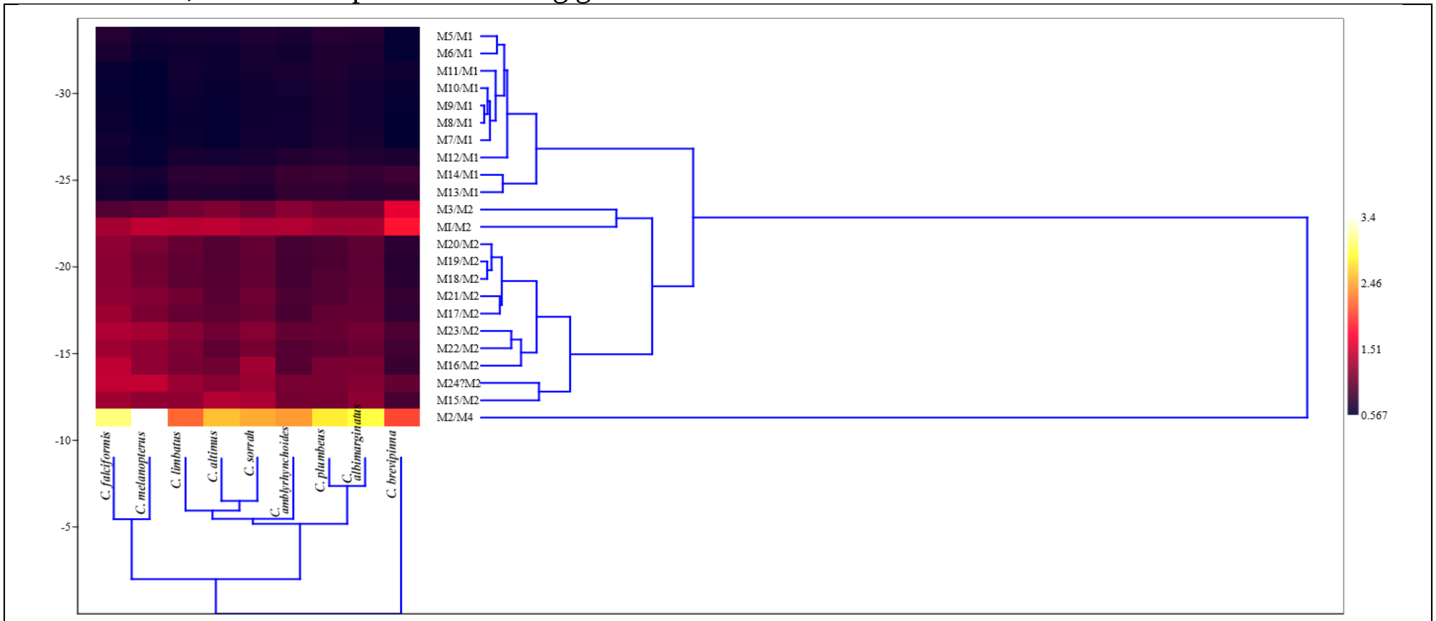

Fig. 4: Showing a heat map representation of the dorsal fin measurement ratios for the nine shark species to indicate the differences across different fin dimensions.

The dendrogram accompanying the heat map offers an additional visual depiction of the connections among the measurement ratios. The ratios M5/M1, M6/M1, and M11/M1 are tightly aligned, indicating a robust linkage in their contribution to the formation of the fin structure. M2/M4 and M15/M2 represent distinct branches, indicating their divergent impact on the development of the dorsal fin. The heat map analysis verifies that each species has a distinct set of dorsal fin measurement ratios, which may be effectively used for classification and identification (Figure 4).
The network diagram (Figure 5A) clearly depicts the relationships among these species, based on their dorsal fin characteristics. The line thickness connecting the species in the network graphic reflects the degree of similarity in their fin measurements. *C. melanopterus and C. limbatus* have a closer relationship, indicating a stronger resemblance in their dorsal fin ratios, whilst *C. brevipinna* is more distantly related to the other species. Furthermore, the dendrogram (Figure 5B) illustrates a hierarchical grouping of the species based on their fin measurement ratios. The picture depicts the distinct dorsal fin morphology of each species, with *C. falciformis and C. melanopterus* closely together, whilst *C. brevipinna* is differentiated by its unusual fin shape. The statistical analyses have shown significant differences in fin ratios across the various species. This finding demonstrates that measuring the dorsal fin may effectively identify and differentiate diverse shark species within the Carcharhinidae

family. The Shark Fin Program's reliability as a credible instrument for shark identification is underscored by the diverse measurement ratios and unique fin shapes characteristic of each species. This initiative facilitates the study and conservation of these marine predators. The findings underscore the need to use morphological metrics to distinguish among various shark species. Moreover, they provide essential data for the enhancement of automated categorization systems that depend on the characteristics of the dorsal fin. Employing dorsal fin ratios for species differentiation facilitates accurate identification and enhances our understanding of the anatomical variety within the Carcharhinidae family.

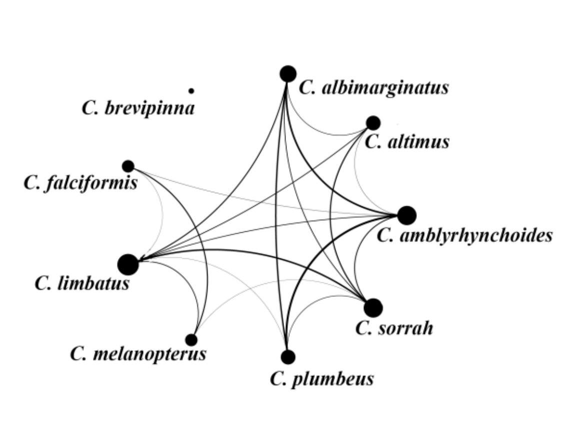

Fig. 5A: The network diagram illustrates the connections between shark species.

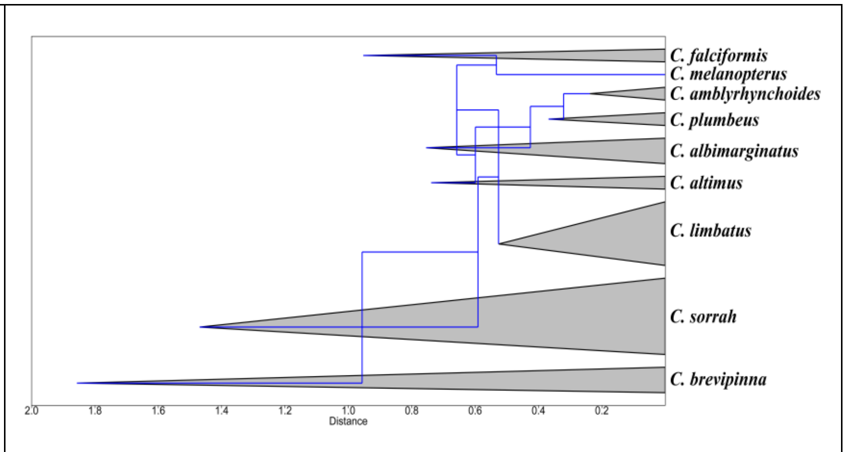

Fig. 5B: Dendrogram showing hierarchical clustering of the species, which is determined by their fin measurement ratios.

PCA analysis (Figure 6) confirms that dorsal fin measures may consistently differentiate among several shark species. The PCA map clearly demonstrates the morphological diversity within the Carcharhinidae family via its many groupings and distinctions. In our research on the classification and identification of several shark species based on their dorsal fins, we used Principal Component Analysis (PCA) to graphically illustrate the measurement variations across nine species within the Carcharhinidae family. The PCA figure (Fig. 6) illustrates the distribution of shark species according to their dorsal fin shape, using two main components (Component 10 and Component 17). It efficiently illustrates the differences and similarities among the species (Figure 6). The PCA map shows clear differentiation among the species based on their fin dimensions. *C. amblyrhynchoides* and *C. brevipinna* have distinct placement, indicating significant differences in their dorsal fin characteristics relative to other species. The regional distribution of *C. falciformis and C. altimus* has considerable overlap, suggesting similarities in their fin architecture with distinct traits that identify species (Figure 6).

The closeness of *C. melanopterus, C. limbatus, and C. plumbeus* to the beginning of the plot indicates a greater degree of morphological resemblance in their dorsal fins. The clustering observed in the heat map analysis corresponds with the hierarchical clustering, hence reinforcing the results of similar dorsal fin ratios across these species. The distinction between Component 10 and Component 17 indicates that these components proficiently encapsulate a considerable degree of variance in the dorsal fin measurements, which is essential for species differentiation.

The narrative highlights the unique physical traits of each species, with *C. sorrah and C. albimarginatus* displaying distinct orientations that align with their specific fin measurements (Figure 6).

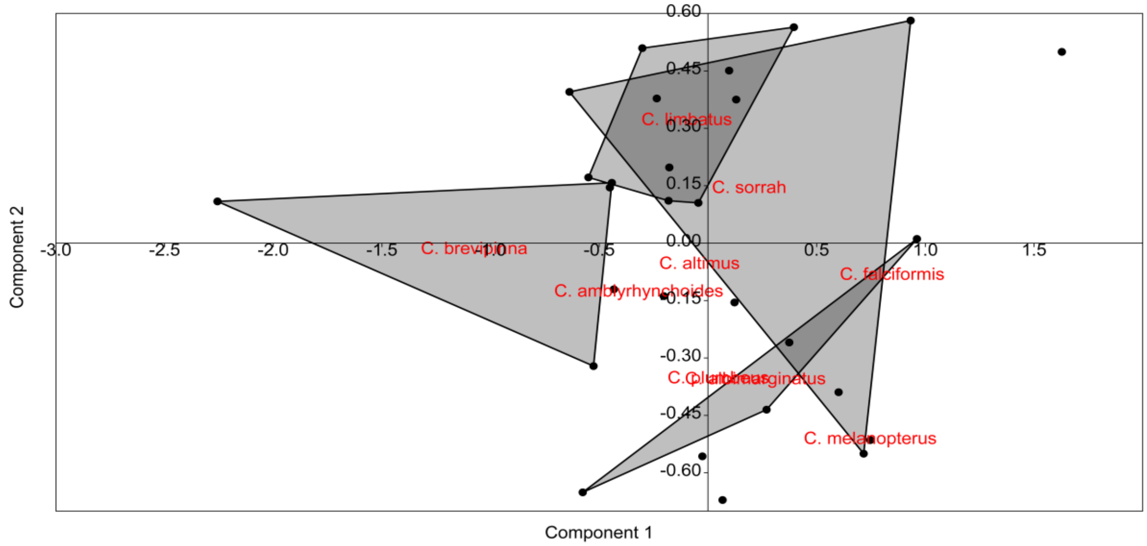

Fig. 6: Showing principal component analysis (PCA) morphological variety within the Carcharhinidae family through its various groups and separations.

Data in **Table (2)** illustrates that *Carcharhinus albimarginatus* had a distinct pattern with elevated ratios in M5/M1 (0.73±0.09), M14/M1 (0.81±0.03), and M2/M4 (2.88±0.05). *Carcharhinus altimus* had the highest M15/M2 ratio at 1.36±0.11, indicating a somewhat elongated dorsal fin base in comparison to the fin insertion compared to other species. *Carcharhinus amblyrhynchoides* regularly exhibited ratios with little variation, namely in M14/M1 (0.83±0.032) and M17/M2 (0.89±0.03). *Carcharhinus brevipinna* had the greatest variability, especially in the M5/M1 (0.59±0.15) and M14/M1 (0.84±0.07) ratios, indicating significant differences across individuals of this species. *Carcharhinus falciformis* had elevated ratios in the measures M17/M2 (1.25±0.31) and M18/M2 (1.18±0.28), indicating a distinctive dorsal fin morphology.

Conversely, the ratios of *Carcharhinus limbatus* exhibited more consistency, with notable values in M14/M1 morphometric (0.76±0.07) and M2/M4 (2.15±0.15). The measurements for *Carcharhinus melanopterus* were consistent across all ratios, with the M2/M4 ratio notably elevated at 3.4, indicating a significantly elongated dorsal fin. *Carcharhinus plumbeus* exhibited elevated ratios of M5/M1 (0.73±0.009) and M14/M1 (0.84±0.03), with a large M2/M4 ratio of 2.75±0.13.

Carcharhinus sorrah demonstrated increased M17/M2 (1.03±0.07) and M24/M2 (1.24±0.07) ratios, as well as a notable M2/M4 ratio of 2.47±0.52. These samples illustrate the variability and unique patterns in the size of dorsal fins among several shark species. These measures may be effectively used to categorize and identify sharks according to their dorsal fins.

The distinctive measurement ratios serve as reliable indications for species differentiation, highlighting the efficacy of analysis in shark identification.

Table (2): Shows dorsal fin ratios (Mean ± SD) of nine shark species collected from Suez Gulf, from May 2022 until October 2023.

Measurements	**M5/M1**	**M6/M1**	**M7/M1**	**M8/M1**	**M9/M1**	**M10/M1**	**M11/M1**	**M12/M1**	**M13/M1**	**M14/M1**	**M15/M2**	**M16/M2**
C. albimarginatus	0.73±0.09	0.69 ± 0.08	0.66±0.07	0.65±0.07	0.65±0.06	0.65±0.06	0.67 ± 0.04	0.71±0.02	0.75±0.03	0.81±0.03	1.2 ± 0.22	1.11±0.25
C. Altimus	0.65±0.02	0.62±0.02	0.59±0.01	0.59±0.006	0.59±0.0007	0.6±0.003	0.62±0.01	0.65±0.023	0.71±0.037	0.77±0.04	1.36 ± 0.11	1.05±0.07
C. amblyrhynchoides	0.68±0.01	0.65±0.01	0.64±0.016	0.64±0.01	0.63±0.01	0.65±0.008	0.68±0.008	0.72±0.001	0.79±0.029	0.83±0.032	1.08±0.068	0.94±0.04
C. brevipinna	0.59±0.15	0.58±0.15	0.57±0.15	0.58±0.15	0.58±0.15	0.6±0.14	0.64±0.14	0.69±0.12	0.77±0.09	0.84±0.07	0.88±0.25	0.82±0.14
C. falciformis	0.73±0.08	0.68±0.05	0.64±0.04	0.61±0.02	0.6±0.008	0.6±0.008	0.6±0.02	0.62±0.045	0.65±0.073	0.68±0.09	1.28±0.29	1.41±0.4
C. limbatus	0.66±0.02	0.63±0.03	0.61±0.03	0.6±0.03	0.61±0.04	0.63±0.04	0.64±0.04	0.68±0.05	0.72±0.06	0.76±0.07	1.2±0.1	1.1 ± 0.09
C. melanopterus	0.65	0.61	0.59	0.57	0.56	0.56	0.57	0.59	0.62	0.66	1.21	1.2
C. plumbeus	0.73±0.009	0.71±0.02	0.69±0.01	0.68±0.025	0.68±0.02	0.69±0.02	0.71±0.04	0.74±0.04	0.79±0.04	0.84±0.03	1.09±0.04	1.1±0.09
C. sorrah	0.71±0.06	0.67±0.06	0.64±0.05	0.63±0.04	0.63±0.03	0.64±0.03	0.66±0.03	0.68±0.03	0.71±0.03	0.75±0.03	1.33±0.35	1.27±0.43
Measurements	M17/M2	M18/M2	M19/M2	M20/M2	M21/M2	M22/M2	M23/M2	M24/M2	MI/M2	M3/M2	M2/M4	
C. albimarginatus	1±0.19	0.98±0.18	0.96±0.18	0.97±0.17	0.99±0.17	1.03±0.17	1.08±0.16	1.14±0.13	1.29±0.21	1.08 ± 0.24	2.88±0.05	
C. Altimus	0.98±0.07	0.94±0.07	0.93±0.08	0.93±0.08	0.95±0.1	0.99±0.11	1.05±0.12	1.16±0.14	1.41±0.058	1.13±0.135	2.55±0.379	
C. amblyrhynchoides	0.89±0.03	0.86±0.01	0.86±0.008	0.87±0.002	0.91±0.004	0.94±0.006	1.01±0.01	1.1±0.03	1.35±0.01	1.17±0.04	2.39±0.077	
C. brevipinna	0.78±0.09	0.75±0.08	0.74±0.08	0.76±0.1	0.79±0.11	0.85±0.13	0.91±0.12	1.01 ± 0.08	1.77±0.59	1.59±0.51	2.01 ± 0.34	
C. falciformis	1.25±0.31	1.18±0.28	1.18 ± 0.27	1.19±0.26	1.19±0.24	1.27±0.27	1.33±0.27	1.42±0.27	1.3±0.14	0.92±0.24	3.03±0.09	
C. limbatus	1.01±0.09	0.98±0.1	0.99±0.1	1.02±0.11	1.06 ± 0.11	1.12±0.12	1.17±0.12	1.25±0.12	1.4±0.05	1.08±0.09	2.15±0.15	
C. melanopterus	1.11	1.07	1.07	1.11	1.15	1.21	1.3	1.42	1.42	0.96	3.4	
C. plumbeus	1±0.08	0.93±0.06	0.9±0.04	0.91±0.05	0.93±0.07	0.97±0.0671	1.02±0.057	1.1 ± 0.04	1.28±0.004	1.09±0.058	2.75±0.13	
C. sorrah	1.03±0.07	1±0.07	0.99±0.07	1.02±0.07	1.05±0.07	1.09±0.07	1.16 ± 0.07	1.24±0.07	1.34±0.08	1.05±0.08	2.47±0.52	

4. DISCUSSION

Sharks may be recognized by their dorsal fin, which is conspicuous in their native environments or when captured by fishermen (Klimley *et al*., 2024). This study examines the morphological traits of the dorsal fin across many species within the Carcharhinidae family, namely *Carcharhinus brevipinna*, *C. sorrah, C. melanopterus, C. albimarginatus, C. altimus, C. amblyrhynchoides, C. falciformis, C. plumbeus, and C. limbatus.* This illustrates the potential significance of these depictions in identifying different shark species (Azab *et al*., 2019; Dedman *et al*., 2024). An examination of the dorsal fin traits in *Carcharhinus altimus* and *C. brevipinna* reveals notable distinctions that are essential for species differentiation. Although the top section of the upper caudal lobe is flattened in both species, it is notably raised at its anterior margin. The acquired measurements are M4 = 2.03 cm (distance from the rear tip), M2 = 5.97 cm (distance from the fin base), M1 = 8.08 cm (distance from the front edge), and M3 = 5.99 cm (distance from the top back edge). The ratios determined in this study are as follows: the anterior margin to fin base ratio is 1.41±0.058, the upper posterior margin to fin base ratio is 1.13±0.135, and the free rear tip to fin base ratio is 2.55±0.379. These ratios correspond with the results of Ayas *et al.* (2020), who earlier investigated the prevalence and distribution of this fish in Mersin Bay and supplied comprehensive morphometric data. Their research expands upon the contributions of previous scholars in the Northeastern Mediterranean Sea.

C. brevipinna has an elongated, arched dorsal fin characterized by a rounded apex and darker margins. The dimensions of the components are as follows: the free rear tip (M4) measures 3.96 cm, the fin base (M2) measures 8.21 cm, the anterior border (M1) measures 11.39 cm, and the higher posterior margin (M3) measures 9.72 cm. The computed ratios are as follows: the anterior margin to fin base ratio is 1.35±0.01, the higher posterior margin to fin base ratio is 1.17±0.04, and the free rear tip to fin base ratio is 2.39±0.077. These findings pertain to the variations in fin morphology across different shark species, and our results are consistent with those of Dulvy *et al*. (2014).

Accurate species identification necessitates distinguishing the fin ratios of *C. altimus* and *C. brevipinna*, which is essential for successful conservation and management measures as outlined by Ayas *et al.* (2020). A new instance of *C. altimus* was documented in Turkish waters, accompanied by data on its physical measures and distribution. The distinguishing characteristic of *C. plumbeus* is its large dorsal fin, which is elevated, bent, has a rounded apex, and features a diminutive free posterior tip. The recorded measurements were: free rear tip (M4) at 8.75 cm, fin base (M2) at 23.00 cm, anterior boundary (M1) at 29.42 cm, and higher posterior margin (M3) at 23.73 cm. The ratios of the anterior edge to the fin base (1.28±0.004), upper posterior border to the fin base (1.09±0.058), and free rear tip to the fin base (2.75±0.13) elucidate the dorsal fin's morphology. The results above correspond with the previous study by Irschick *et al.* (2017), which examined the body and fin morphology of nine shark species, including the sandbar shark (*C. plumbeus*), using non-lethal field techniques. Notwithstanding significant lifestyle disparities, it was observed that these carcharhiniform and orectolobiform species had a very uniform overall body structure, indicating a substantial degree of conservation. The height of the dorsal fin, the length of the lower lobe of the caudal fin, and the overall body girth exhibited little variation across species, and these discrepancies are improbable to have significant ecological implications.

The primary differentiating characteristic among the species was the variation in body length, sometimes associated with food type or range. *C. sorrah* has a dorsal fin that is comparatively elevated and falcate, with a rounded apex and a darker margin. The documented measures were: free rear tip (M4) at 3.12 cm, fin base (M2) at 10.22 cm, anterior boundary (M1) at 12.17 cm, and higher posterior margin (M3) at 9.83 cm. The computed ratios—anterior margin to fin base (1.34±0.08), higher posterior margin to fin base (1.05±0.08), and free rear tip to fin base

(2.47±0.52)—underscore the unique morphology of its fins. The discovered morphological traits correspond with the results of Anderson *et al.* (2011), who endorse the use of dorsal fin morphology as a dependable method for long-term individual identification. The dorsal fin of *C. albimarginatus* is elongated and sickle-shaped, including a rounded apex, a conspicuous white or pale margin, and a darker border. The measures consist of a free rear tip (M4) of 3.76 cm, a fin base (M2) of 10.98 cm, an anterior border (M1) of 12.96 cm, and an upper posterior edge (M3) of 11.17 cm. The ratios—anterior margin to fin base (1.29±0.21), upper posterior margin to fin base (1.08±0.24), and free rear tip to fin base (2.88±0.05)—are essential in differentiating and comparing fin and body morphologies, as examined by Irschick *et al.* (2017).

C. amblyrhynchoides has a dorsal fin of moderate elevation, distinguished by a pointy apex and a distinctively hued tip. Measurements indicate a free rear tip (M4) of 4.95 cm, a fin base (M2) of 12.23 cm, an anterior border (M1) of 16.78 cm, and an upper posterior edge (M3) of 13.83 cm. The computed ratios include the anterior margin to fin base (1.35±0.01), upper posterior margin to fin base (1.17±0.04), and free rear tip to fin base (2.39±0.077). Hicks and Lobel (2024) emphasize the significance of these ratios, examining the influence of tagging on dorsal fin development. Their results highlight the need for precise measurements of the free rear tip, fin base, anterior edge, and higher posterior margin to enhance morphometric analysis. Their work mainly examines the great white shark, although the methodologies outlined may potentially improve the accuracy of morphometric ratios for other species, such as *C. amblyrhynchoides*.

C. falciformis has a comparatively elevated dorsal fin, characterized by its sickle shape, pointed apex, and a prominent black tip. Measurements reveal the following dimensions: a free rear tip (M4) of 2.72 cm, a fin base (M2) of 8.00 cm, an anterior border (M1) of 9.23 cm, and an upper posterior edge (M3) of 5.42 cm. The computed ratios—anterior margin to fin base (1.3±0.14), upper posterior margin to fin base (0.92±0.24), and free rear tip to fin base (3.03±0.09)—function as differentiating characteristics.

These results corroborate Compagno (1984) study, which underscores the significance of dorsal fin traits in distinguishing shark species. The dorsal fin of *C. melanopterus*, or the blacktip reef shark, is of intermediate height, with a curved form, a pointy tip, and a subtly inwardly curved trailing edge. A prominent black marking at the fin tips serves as a crucial distinguishing characteristic. The proportions of the dorsal fin include a free rear tip (M4) of 3.62 cm, a fin base (M2) of 12.34 cm, an anterior border (M1) of 17.55 cm, and a higher posterior margin (M3) of 11.92 cm. Morphometric ratios—anterior margin to fin base (1.42), upper posterior margin to fin base (0.96), and free rear tip to fin base—are essential for identification. Chin *et al.* (2013) underscore the significance of these physical characteristics, elucidating the development processes and life cycle of blacktip reef shark.

C. plumbeus has a prominent, arched dorsal fin with a rounded tip and a brief, detached posterior section. The measurements include a free rear tip (M4) of 8.75 cm, a fin base (M2) of 23.00 cm, an anterior border (M1) of 29.42 cm, and an upper posterior edge (M3) of 23.73 cm. The morphometric ratios—anterior margin to fin base (1.28±0.004), upper posterior margin to fin base (1.09±0.058), and free rear tip to fin base (2.75±0.13)—offer a comprehensive depiction of its structure, aligning with the findings of Last *et al.* (2016).

C. sorrah has a relatively tall, falcate dorsal fin characterized by a rounded apex and a darker tip. The dimensions consist of a free rear tip (M4) measuring 3.12 cm, a fin base (M2) measuring 10.22 cm, an anterior border (M1) measuring 12.17 cm, and an upper posterior edge (M3) measuring 9.83 cm. The morphometric ratios—anterior margin to fin base (1.34±0.08), upper posterior margin to fin base (1.05±0.08), and free rear tip to fin base (2.47±0.52)—underscore the unique fin architecture of this species. These ratios correspond with the results of Joung *et al.* (2022), who investigated the age, growth, and intricate morphology of *C. sorrah* in the Taiwan Strait.

C. albimarginatus is distinguished by an elongated, arched dorsal fin with a rounded apex, a prominent white margin, and a darker extremity. The measurements include a free rear tip (M4) measuring 3.76 cm, a fin base (M2) measuring 10.98 cm, an anterior border (M1) measuring 12.96 cm, and an upper posterior edge (M3) measuring 11.17 cm. The morphometric ratios—anterior margin to fin base (1.29±0.21), upper posterior margin to fin base (1.08±0.24), and free rear tip to fin base (2.88±0.05)—are essential characteristics for species identification. Green *et al.* (2019) emphasize that these ratios provide essential insights into the genetic linkage and population organization of *C. albimarginatus.*

C. amblyrhynchoides has a dorsal fin of moderate elevation, distinguished by a pointed apex and notable pigmentation at the tip. The measures consist of a free rear tip (M4) of 4.95 cm, a fin base (M2) of 12.23 cm, an anterior border (M1) of 16.78 cm, and an upper posterior edge (M3) of 13.83 cm. The morphometric ratios—anterior margin to fin base (1.35±0.01), upper posterior margin to fin base (1.17±0.04), and free rear tip to fin base (2.39±0.077)—correspond with the findings of Dulvy *et al.* (2014), underscoring the significance of accurate morphological assessments.

C. falciformis has a comparatively elevated, sickle-shaped dorsal fin characterized by a pointed apex and a prominent black tip. The measurements are a free rear tip (M4) of 2.72 cm, a fin base (M2) of 8.00 cm, an anterior border (M1) of 9.23 cm, and an upper posterior margin (M3) of 5.42 cm. The morphometric ratios—anterior margin to fin base (1.3±0.14), upper posterior margin to fin base (0.92±0.24), and free rear tip to fin base (3.03±0.09) are essential distinguishing characteristics, as indicated by Azab *et al.*, 2019 and Compagno (1984). These results underscore the significance of fin measurements for species identification and conservation initiatives. This study's physical traits provide significant additions to shark taxonomy and bolster current developmental attempts.

CONCLUSION

In conclusion, the study provides a comprehensive analysis of the dorsal fin morphology and measurement ratios across nine species of sharks from the Carcharhinidae family, collected from the Suez Gulf. The findings emphasize the distinct morphological characteristics of each species, with significant variability in dorsal fin measurements, such as the free rear tip, fin base, and anterior margin ratios. The heat map, PCA analysis, and dendrograms further support the identification and classification of these species, demonstrating the effectiveness of dorsal fin measurements as a reliable tool for species differentiation and enhancing our understanding of the anatomical diversity within the Carcharhinidae family.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of Competing Interest

The authors declare no conflict of interest.

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