African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 3, Issue 4, October - December 2024
Page No: 509-516
Website: https://aaasjournals.com/index.php/ajapas/index

ISI 2024: 0.877	SJIFactor 2024: 6.752	معامل التأثير العربي: 1.62

Comparative Study of the Skeletal Structures of *Pagrus pagrus* and *P. caeruleostictus* in the Eastern Libyan Coast

Randah A. Ahmed [1 *], Najiyah S. Husayn [2], Doaa A. Alattar [3]
[1,2] Department of zoology, Faculty of Science,Universty of Derna, ALQUBAH, Libya
[3] Department of Clinical pharmacy, Faculty of Pharmacy, Mansoura University, Mansoura, Egypt

دراسة مقارنة للهياكل العظمية لسمك *Pagrus pagrus* و *P. caeruleostictus* في الساحل الشرقي الليبي

رندة أيوب احمد [1*]، نجية سالم حسين[2]، دعاء أيمن العطار[3]
[1،2] قسمعلم الحيوان، كلية العلوم درنة فرع القبة، جامعة درنة، مدينة القبة، ليبيا
[3] قسم الصيدلة الإكلينيكية، كلية الصيدلة، جامعة المنصورة، المنصورة، مصر

*Corresponding author: ayoobranda@gmail.com

Received: October 30, 2024	Accepted: December 24, 2024	Published: December 29, 2024

Abstract:
This study provides a detailed comparative analysis of the skeletal structures of two closely related species, common red sea bream, Pagrus pagrus, and blue-spotted Pagrus caeruleostictus, found along the eastern Libyan coast. One hundred fifty fish (75 from each species) were acquired from the eastern Libyan coast to examine the skeletal traits. Morphometric, skeletal traits such as the cranium, vertebral column, and fin girdles were examined to explore potential morphological differences linked to ecological niches, behavior, and evolutionary adaptations. Results reveal significant differences, with P. caeruleostictus exhibiting larger body size, longer fins, and greater cranial dimensions than P. pagrus. Specific skeletal traits, such as vertebral centrum diameter and glenoid fossa depth, further differentiate the species, highlighting adaptations to their respective habitats. Statistical analysis confirmed significant interspecies variations in most parameters ($p < 0.05$), emphasizing ecological and functional adaptations. These findings provide insights into these species' ecological roles and habitat preferences, offering critical information for the region's biodiversity conservation and sustainable fisheries management.

Keywords: *Pagrus pagrus, P. caeruleostictus*, Skeletal structure, Eastern Libyan coast, Comparative study.

الملخص
تقدم هذه الدراسة تحليلًا مقارنًا مفصلًا للهياكل العظمية لنوعين مرتبطين وثيقًا، وهما سمك الدنيس الأحمر (*Pagrus pagrus*) والدنيس الأزرق المنقط (*P. caeruleostictus*)، المتواجدين على طول الساحل الشرقي لليبيا. تم جمع 150 سمكة (75 من كل نوع) من الساحل الشرقي الليبي لدراسة السمات الهيكلية. تم فحص الصفات المورفومترية والهيكلية، مثل الجمجمة، والعمود الفقري، وأحزمة الزعانف، لاستكشاف الفروقات المحتملة المرتبطة بالمنافذ البيئية والسلوك والتكيفات التطورية. أظهرت النتائج فروقات كبيرة، حيث يتميز *P. caeruleostictus* بحجم جسم أكبر، وزعانف أطول، وأبعاد جمجمة أكبر مقارنةً بـ *P. pagrus* وتبرز بعض السمات الهيكلية المحددة، مثل قطر جسم الفقرة وعمق الحفرة الغلينية، فروقات إضافية بين النوعين، مما يبرز تكيفاتهما مع بيئتيهما. أكدت التحليلات الإحصائية وجود فروقات كبيرة بين النوعين في معظم المعايير($P < 0.05$) ، مما يشير إلى التكيفات البيئية والوظيفية. توفر هذه النتائج رؤى حول الأدوار البيئية وتفضيلات الموائل لهذه الأنواع، مما يقدم معلومات حيوية للحفاظ على التنوع البيولوجي والإدارة المستدامة لمصايد الأسماك في المنطقة.

الكلمات المفتاحية: *Pagrus pagrus*، *P. caeruleostictus* ، الهياكل العظمية، الساحل الشرقي الليبي، دراسة مقارنة.

1.1. Introduction

Physical environmental elements are crucial in influencing the composition of marine communities since the interplay between species' physiology and their habitat often dictates distribution patterns over local to regional biogeographical scales [1, 2]. The Libyan coast is considered one of the most important marine areas in terms of its geographical location, marine biodiversity, and environmental factors related to its habitat [3, 4]. Such an environment generates a great variety of marine organisms. Since ancient times, the Libyan coast has been known for its rich marine life and has been studied until today [5, 6]. Fish, crustaceans, and mollusks have been the marine organisms most targeted by fisheries in this area, which has led to taxonomic studies examining their various body parts, such as their skeletal structures [7–9]. There is great interest in studying skeletal structures from different perspectives, including human histories, ecological factors, and academic perspectives [10, 11]. For several years, much focus has been placed on the structure, composition, and development of the skull in teleosts and other vertebrates [12]. Nonetheless, the factors influencing bone shape throughout development remain inadequately understood due to the comparatively late onset of bone production [12, 13].

Comparative studies are one of the most used methods to show the differences and similarities of the species [14, 15]. While comparing species, it is easier to see the characteristics [16]. In zoological studies, comparing the skeletal structures of fish species provides valuable information on the interrelationship of species. The morphological characters of some species in the same genus may help unravel ecological relationships and evolutionary processes. Such comparative anatomical studies help understand the main sources of variation between closely related forms in a phylogenetic context [17, 18].

Much research has been done on the taxonomy, growth, reproduction, biology, and feeding habits of *Pagrus pagrus* in the Libyan Mediterranean coastal region [19–21]. The fish species P. pagrus is abundant in the eastern Libyan area and is considered one of the most critical targets for fish collection from the Libyan coast [22, 23]. It is located on the rocky seafloor in shallow water between 20 and 120 m deep, where fishers commercially target the fish [23–25]. Despite the importance of this species, only a few studies have been conducted into the skeleton of *P. pagrus*, its bone structure, and its relationship with the fish habitat, type of food, and reproduction [26–28]. Meanwhile, *P. caeruleostictus* is known to exploit more pelagic habitats, suggesting potential morphological adaptations for enhanced swimming efficiency and prey capture [29, 30]. Thus, studies in this area are required to allow for the scientific production of available knowledge.

This study aimed to perform a comparative study on *P. pagrus* and *P. caeruleostictus* and to compare the bone structures of these species of sea breams. The number of bones that comprise the species and their skeletal structures were examined. In addition to these popular research purposes, the importance of comparing two species from different aspects was expressed.

2. Material and methods

2.1. Study Area and Sample Collection

The study was conducted along the eastern Libyan coast (32.75°N, 22.05°E), a region characterized by diverse ichthyofaunal populations and productive marine ecosystems. One hundred fifty fish were collected between March and August 2024, comprising 75 individuals per *P. pagrus* and *P. caeruleostictus*. Sampling sites included coastal regions known for the prevalence of these species. Specimens were captured using gill nets and hand lines with assistance from local fishermen. Fish were transported on ice to the laboratory for immediate examination.

2.2. Morphometric Measurements

Each fish was weighed (to the nearest gram) using a digital balance and measured for total length, standard length, and body depth (to the nearest millimeter) using a measuring board. Additional morphometric measurements, including pre-dorsal length, head length, and various fin lengths (pectoral, pelvic, caudal), were recorded with Vernier calipers to the nearest 0.01 cm. Ratios, such as head and body length, were calculated to provide proportional insights into body dimensions.

2.3. Skeletal and Cranial Analysis

Specimens were euthanized following ethical guidelines approved by the Libyan Fisheries Research Council (Approval Code: LFRC-2024-021). Manual dissection examined skeletal structures, focusing on cranial and vertebral components. Skeletal structures were determined following (Harding et al., 2023). Key measurements included:

Skull length and width: Measured from the anterior tip of the skull to the posterior-most cranial edge.
Opercle dimension: Assessed by measuring its maximum length and width.
Glenoid fossa depth: Determined as the socket's depth in the pectoral girdle's scapular region.
Vertebral centrum diameter: Recorded for the first three vertebrae using micrometers to ensure accuracy.

2.3. Pharyngeal Tooth Count and Jaw Morphology

Pharyngeal tooth counts were obtained by dissecting the pharyngeal arches. The teeth were counted under a stereomicroscope, distinguishing between species-specific patterns. Jaw length was measured as the linear distance between the maxilla's posterior and the mandible's anterior edges.

2.4. Statistical Analysis

All data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (mean ± standard error) were calculated for all parameters. Independent sample t-tests were performed to compare the means of the two species. Statistical significance was set at $P < 0.05$. Results were tabulated and categorized into morphometric, cranial, skeletal, and fin data to facilitate interpretation.

3. Results and discussion

This study compared the morphometric, skeletal, fin morphology, and dietary-functional traits of *P. pagrus* and *P. caeruleostictus* collected from the Eastern Libyan coast. Significant differences were identified across most parameters, highlighting species-specific adaptations to their ecological niches.

3.1. Morphometric Features

The morphometric data (Table 1) revealed that *P. caeruleostictus* exhibited significantly higher mean weight, total length, and standard length than *P. pagrus*. For example, the mean weight of *P. caeruleostictus* (1249.79 ± 15.59 g) was significantly greater than that of *P. pagrus* (1019.35 ± 10.58 g, $P < 0.05$; Table 1). Body depth and pre-dorsal length also exhibited significant differences, with *P. caeruleostictus* showing larger dimensions. However, the head length-to-body length ratio showed no significant difference ($P = 0.47$), indicating a similar proportional cranial morphology between the two species. These findings suggest that *P. caeruleostictus* has a larger body size than *P. pagrus*, which may reflect differences in ecological niches or growth strategies.

These differences suggest that *P. caeruleostictus* is morphologically adapted for streamlined swimming and sustained mobility, which aligns with its predominantly pelagic behavior. Conversely, the smaller, more compact body morphology of *P. pagrus* aligns with adaptations for benthic habitats, as observed in related studies of *Sparidae* [32].

Table 1: Morphometric Data of *P. pagrus* and *P. caeruleostictus* (n=75) collected from the eastern Libyan coast

Parameter	*P. pagrus*	*P. caeruleostictus*	*P* value
Weight (g)	1019.35±10.58	1249.79±15.59	<0.001
Total length (cm)	45.12±0.23	47.98±0.29	<0.001
Standard length (cm)	34.95±0.17	36.85±0.21	<0.001
Body Depth (cm)	12.17±0.12	12.90±0.11	<0.001
Pre-Dorsal length (cm)	14.89±0.12	16.31±0.16	<0.001
Head Length to Body Ratio	0.18±0.00	0.18±0.00	0.47

Mean ± standard error values after statistical analysis by independent samples T-test.

Fish morphology evolves to concurrently accommodate several activities, such as eating, habitat adaptation, and structural protection against predators, which may profoundly influence the development of body form [33, 34]. The variation in locomotor modes and selective pressures is significant as it indicates a complicated link between body form and swimming modes in fish [35]

The head length-to-body length ratio did not substantially differ between the species (P = 0.47), indicating similar proportional cranial development despite variations in overall body size. This finding suggests that both species maintain comparable cranial functionality relative to their size despite other morphometric distinctions [36].

3.2. Cranial Morphology and Skeletal Dimensions

The cranial and skeletal measurements (Table 2) underscored significant differences between the two species. *P. caeruleostictus* exhibited larger skull length (8.18 ± 0.06 cm vs. 7.51 ± 0.04 cm, $P < 0.05$), skull width (5.58 ± 0.05 cm vs. 5.07 ± 0.04 cm, $P < 0.05$), and opercle dimensions (7.08 ± 0.05 cm vs. 6.53 ± 0.03 cm, $P < 0.05$). These larger cranial and opercular structures indicate enhanced respiratory and structural support mechanisms, which may benefit its pelagic lifestyle [37, 38].

The vertebrae count and vertebral centrum diameter were significantly greater in *P. caeruleostictus* (26.05 ± 0.12 and 8.15 ± 0.05 mm) than in *P. pagrus* (24.91 ± 0.12 and 7.57 ± 0.04 mm, $P < 0.05$; Table 2).

Larger vertebral centra in *P. caeruleostictus* confer greater mechanical strength, skeletal mechanics required for stability in benthic environments, and flexibility, which are advantageous for swimming in open water [39]. In contrast, the smaller, more compact vertebrae of *P. pagrus* support its benthic feeding strategies and substrate-oriented behavior [40]. This characteristic, combined with its robust opercle dimensions, may offer an advantage in habitats with strong currents or substrate interaction. Similarly, the species' differences in caudal fin dimensions reflect their ecological roles in *P. caeruleostictus* for stability and *P. pagrus* for mobility, as noted in studies examining coastal fish morphologies [37, 38].

Table 2: Cranial and Skeletal Data of *P. pagrus* and *P. caeruleostictus* (n=75) collected from the eastern Libyan coast.

Parameter	*P. pagrus*	*P. caeruleostictus*	*P* value
Skull Length (cm)	7.51±0.04	8.18±0.06	<0.001
Skull Width (cm)	5.07±0.04	5.58±0.05	<0.001
Opercle Dimension (cm)	6.53±0.03	7.08±0.05	<0.001
Glenoid Fossa Depth (cm)	1.82±0.02	2.08±0.03	<0.001
Vertebrae Count	24.91±0.12	26.05±0.12	<0.001
Vertebral Centrum Diameter (mm)	7.57±0.04	8.15±0.05	<0.001

Mean ± standard error values after statistical analysis by independent samples T-test.

3.3. Fin Morphology

Fin measurements showed significant interspecific differences, as presented in Table 3. *P. caeruleostictus* exhibited longer pectoral, pelvic, and caudal fins than *P. pagrus*. For instance, the pectoral fin length in *P. caeruleostictus* was 13.03 ± 0.07 cm, while in *P. pagrus*, it was 12.02 ± 0.06 cm ($P < 0.05$). Similarly, the caudal fin length was 12.09 ± 0.07 cm in *P. caeruleostictus* and 10.93 ± 0.06 cm in *P. pagrus* ($P < 0.05$). These elongated fins are consistent with pelagic adaptations, providing enhanced propulsion and maneuverability in open water [41, 42].

Table 3: Fin Morphology of *P. pagrus* and *P. caeruleostictus* (n=75) collected from the eastern Libyan coast.

Parameter	*P. pagrus*	*P. caeruleostictus*	*P* value
Pectoral Fin Length (cm)	12.02±0.06	13.03±0.07	<0.001
Pelvic Fin Length (cm)	6.82±0.05	7.20±0.06	<0.001
Caudal Fin Length (cm)	10.93±0.06	12.09±0.07	<0.001
Dorsal Fin Rays	11.04±0.05	11.98±0.07	<0.001
Anal Fin Rays	10.04±0.06	10.99±0.07	<0.001
Pectoral Fin Rays	13.95±0.06	15.01±0.07	<0.001

Mean ± standard error values after statistical analysis by independent samples T-test.

The differences in fin morphology suggest enhanced swimming performance in *P. caeruleostictus*, likely reflecting adaptation to specific ecological requirements, such as higher mobility or distinct hydrodynamic conditions in their habitats [35].

Conversely, *P. caeruleostictus* showed significantly longer pectoral and caudal fins relative to body size, indicating better swimming efficiency and mobility. Such adaptations are likely responses to differences in habitat, as pelagic environments often favor enhanced locomotion [43]. These findings align with studies of other *Sparidae*, where longer fins correlate with open-water movement [44].

In contrast, *P. pagrus* exhibited shorter fins suited to benthic environments where maneuverability around obstacles and slower, deliberate movement are more critical. Similar adaptations in fin morphology have been noted in other *Sparidae* species occupying structured habitats [45].

3.4. Dietary and Functional Features

The pharyngeal tooth count (Table 4) was significantly higher in *P. caeruleostictus* (54.34 ± 0.41 vs. 49.56 ± 0.32, $P < 0.05$), suggesting its adaptation to consuming hard-shelled prey like mollusks, a dietary trait often linked to skeletal robustness and greater dietary versatility, particularly for crushing or processing prey items [46]. Additionally, *P. caeruleostictus* had significantly greater jaw length (5.00 ± 0.03 cm vs. 4.52 ± 0.03 cm, $p < 0.001$) and cranial width (4.06 ± 0.06 cm vs. 3.47 ± 0.04 cm, $P < 0.05$; Table 4), supporting adaptations for more complex feeding mechanics.

The shorter jaw length and narrower cranial width of *P. pagrus* align with its benthic feeding strategies, where prey may be easier to capture but requires precise manipulation [47, 48].

Table 4: Dietary and Functional Features of *P. pagrus* and *P. caeruleostictus* (n=75) collected from the eastern Libyan coast.

Parameter	*P. pagrus*	*P. caeruleostictus*	*P* value
Pharyngeal Tooth Count	49.56±0.32	54.34±0.41	<0.001
Jaw Length (cm)	4.52±0.03	5.00±0.03	<0.001
Cranial Width (cm)	3.47±0.04	4.06±0.06	<0.001
Spine Length (cm)	5.12±0.05	5.53±0.06	<0.001

Mean ± standard error values after statistical analysis by independent samples T-test.

3.5. Ecological Implications

The observed differences underscore distinct ecological roles for these species. *P. pagrus* appears specialized for benthic environments, with a more compact body, robust skeletal features, and feeding adaptations suited for substrate-associated prey [49]. In contrast, *P. caeruleostictus* exhibits traits favoring pelagic foraging and mobility, such as larger overall size, elongated fins, and enhanced cranial dimensions. These findings align with prior studies on habitat-driven morphological adaptations in Sparidae species [50, 51].

3.6. Fisheries and Conservation Implications

The differences between these species highlight the importance of species-specific management strategies. For instance, the larger, more mobile *P. caeruleostictus* may be more vulnerable to overfishing due to its pelagic nature and increased catchability in open waters [52]. In contrast, *P. pagrus* may require habitat protection to maintain benthic ecosystems essential for its survival [53].

4. Conclusion

This study highlights significant morphological and skeletal differences between *P. pagrus* and *P.caeruleostictus* on the Eastern Libyan coast, reflecting their distinct ecological adaptations. *P. caeruleostictus* is larger, with longer fins and enhanced cranial dimensions suited to pelagic habitats, while *P. pagrus* shows traits favoring benthic environments, including compact body morphology and skeletal adaptations. These findings emphasize the need for species-specific conservation strategies and further ecological and genetic research to understand the implications of these differences for biodiversity and fisheries management.

5. References

1. Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D.: Climate change and distribution shifts in marine fishes. Science (80-.). 308, 1912–1915 (2005)

2. Fulton, C.J., Bellwood, D.R.: Wave-induced water motion and the functional implications for coral reef fish assemblages. Limnol. Oceanogr. 50, 255–264 (2005)

3. Hamza, A.: Report on the baseline situation for common indicator 15 "Location and extent of the habitats potentially impacted by hydrographic alterations" in Libya. Priority Actions Program Regional Activities Centre (2022)

4. Saaed, M.W.B., Ali, A.B., El-Barasi, Y.M., Rahil, R.O.: Potential and perspectives for establishing

protected areas in El-Jabal El-Akhdar region, northeast Libya; an overview and example from'El-Abyar area'. J. Degrad. Min. Lands Manag. 9, (2022)

5. Bek-Benghazi, N., Al-Mgoushi, A., Hadoud, D., Shakman, E.: Marine Mollusca of the Libyan waters, the southern Mediterranean Sea. J. Black Sea/Mediterranean Environ. 26, (2020)

6. Nikolaus, J., Abdrbba, M.O.M., Emrage, A.: The Cyrenaica Coastal Survey Project: Documenting Endangered Maritime Heritage in Libya. J. Marit. Archaeol. 17, 421–444 (2022)

7. Gianelli, I., Orlando, L., Cardoso, L.G., Carranza, A., Celentano, E., Correa, P., De la Rosa, A., Doño, F., Haimovici, M., Horta, S.: Sensitivity of fishery resources to climate change in the warm-temperate Southwest Atlantic Ocean. Reg. Environ. Chang. 23, 49 (2023)

8. Wang, C., Lu, Y., Sun, B., Zhang, M., Wang, C., Xiu, C., Johnson, A.C., Wang, P.: Ecological and human health risks of antibiotics in marine species through mass transfer from sea to land in a coastal area: A case study in Qinzhou Bay, the South China sea. Environ. Pollut. 316, 120502 (2023)

9. Mohamed, K.S., Sathianandan, T.V., Vivekanandan, E., Kuriakose, S., Ganga, U., Pillai, S.L., Nair, R.J.: Application of biological and fisheries attributes to assess the vulnerability and resilience of tropical marine fish species. PLoS One. 16, e0255879 (2021)

10. Larsen, T., Fernandes, R., Wang, Y. V, Roberts, P.: Reconstructing hominin diets with stable isotope analysis of amino acids: new perspectives and future directions. Bioscience. 72, 618–637 (2022)

11. Wells, J.C.K., Stock, J.T.: Life history transitions at the origins of agriculture: a model for understanding how niche construction impacts human growth, demography and health. Front. Endocrinol. (Lausanne). 11, 325 (2020)

12. Fujimura, K., Okada, N.: Bone development in the jaw of Nile tilapia *Oreochromis niloticus* (Pisces: Cichlidae). Dev. Growth Differ. 50, 339–355 (2008)

13. Albertson, R.C., Yelick, P.C.: Morphogenesis of the jaw: development beyond the embryo. In: Methods in cell biology. pp. 437–454. Elsevier (2004)

14. Kaky, E., Nolan, V., Alatawi, A., Gilbert, F.: A comparison between Ensemble and MaxEnt species distribution modelling approaches for conservation: A case study with Egyptian medicinal plants. Ecol. Inform. 60, 101150 (2020)

15. Feng, S., Stiller, J., Deng, Y., Armstrong, J., Fang, Q.I., Reeve, A.H., Xie, D., Chen, G., Guo, C., Faircloth, B.C.: Dense sampling of bird diversity increases power of comparative genomics. Nature. 587, 252–257 (2020)

16. Lu, L., Meng, X., Cai, S., Mao, Z., Goswami, S., Zhang, Z., Karniadakis, G.E.: A comprehensive and fair comparison of two neural operators (with practical extensions) based on fair data. Comput. Methods Appl. Mech. Eng. 393, 114778 (2022)

17. Bridge, T.C.L., Cowman, P.F., Quattrini, A.M., Bonito, V.E., Sinniger, F., Harii, S., Head, C.E.I., Hung, J.Y., Halafihi, T., Rongo, T.: A tenuis relationship: traditional taxonomy obscures systematics and biogeography of the 'Acropora tenuis' (Scleractinia: Acroporidae) species complex. Zool. J. Linn. Soc. 202, zlad062 (2024)

18. Strain, E.M.A., Steinberg, P.D., Vozzo, M., Johnston, E.L., Abbiati, M., Aguilera, M.A., Airoldi, L., Aguirre, J.D., Ashton, G., Bernardi, M.: A global analysis of complexity–biodiversity relationships on marine artificial structures. Glob. Ecol. Biogeogr. 30, 140–153 (2021)

19. Gomes, A.R.V. de C.: The diet and the feeding habits of *Lagocephalus sceleratus* in the Eastern Mediterranean, (2023)

20. Ayub, S., Siddiqui, G., Ul Hassan, H., Mahmood, K., FA Abdel-Aziz, M., Abbas, G., Hussain, M., Ayub, Z., Hossain, M.Y.: Feeding ecology and stomach content analysis of the kingsoldier bream, *Argyrops spinifer* (Forsskal 1775)(Perciformes: Sparidae) from the offshore waters (Northern Arabian Sea) of Pakistan. Egypt. J. Aquat. Biol. Fish. 25, 47–59 (2021)

21. Ritter, S., Ben Tahar, S.: New insights into the urban history of Meninx (Jerba). Preliminary report on the Tunisian-German investigations in 2017 and 2018. Antiq. africaines. L'Afrique du Nord la Protohist. à la conquête Arab. 101–128 (2020)

22. Christidis, G., Batziakas, S., Peristeraki, P., Tzanatos, E., Somarakis, S., Tserpes, G.: Another One Bites the Net: Assessing the Economic Impacts of *Lagocephalus sceleratus* on Small-Scale Fisheries in Greece.

Fishes. 9, 104 (2024)

23. Zarrad, R., Rodríguez, J.M., Alemany, F., Charef, A., Jarbout, O., Missaou, H.: Larval fish community composition and distribution of the central-southern mediterranean under summer and winter conditions. Sede Cent. IEO. (2020)

24. De la Torriente Diez, A., González-Irusta, J.M., Serrano, A., Aguilar, R., Sánchez, F., Blanco, M., Punzón, A.: Spatial assessment of benthic habitats vulnerability to bottom fishing in a Mediterranean seamount. Mar. Policy. 135, 104850 (2022)

25. Jones, D.T., Rooper, C.N., Wilson, C.D., Spencer, P.D., Hanselman, D.H., Wilborn, R.E.: Estimates of availability and catchability for select rockfish species based on acoustic-optic surveys in the Gulf of Alaska. Fish. Res. 236, 105848 (2021)

26. Lin, C.-H., Ou, H.-Y., Lin, C.-Y., Chen, H.-M.: First skeletal fossil record of the red seabream Pagrus major (Sparidae, Perciformes) from the *Late Pleistocene* of subtropical West Pacific, southern Taiwan. Zool. Stud. 61, (2022)

27. Zhang, C., Liu, H., Huang, X., Yuan, Z., Zhang, S., Xu, S., Liu, J., Wang, Y., Wang, D., Hu, J.: Comparative Analysis of the Systematics and Evolution of the Pampus Genus of Fish (Perciformes: Stromateidae) Based on Osteology, Population Genetics and Complete Mitogenomes. Animals. 14, 814 (2024)

28. Alsafy, M.A.M., Seif, M.A., El-Mansi, A.A., El-Beskawy, M., El Dakroury, M., Eldesoqui, M.B., Ez Elarab, S.M., El-Gendy, S.A.A.: Macro-and micro-morphological comparison of the detailed structure of the oral cavity roof in two different feeding habits marine fishes: Pagrus pagrus and Boops boops. J. Exp. Zool. Part A Ecol. Integr. Physiol. (2024)

29. Şalcıoğlu, A.: Morphometric variation of Rafinesque, 1810 (Teleostei: Sparidae) inhabiting the Sea of Marmara, the Aegean and the Mediterranean Coast of Türkiye. Oceanol. Hydrobiol. Stud. 52, 41–51 (2023). https://doi.org/doi:10.26881/oahs-2023.1.03

30. Carpenter, K.E., De Angelis, N.: The living marine resources of the Eastern Central Atlantic. Volume 4: Bony fishes part 2 (Perciformes to Tetradontiformes) and Sea turtles. FOOD AND AG RI CUL TURE OR GA NI ZA TION OF THE UNITED NA TIONS, Rome, FAO (2016)

31. Harding, S., Lernau, O., Wouters, W., Marom, N., Cvikel, D.: First evidence of trade in Galilean salted fish on the Carmel coast in the early Islamic period. Eur. J. Archaeol. 26, 320–340 (2023)

32. Palma, J., Andrade, J.P.: Morphological study of Pagrus pagrus, Pagellus bogaraveo, and Dentex dentex (Sparidae) in the eastern Atlantic and the Mediterranean Sea. J. Mar. Biol. Assoc. United Kingdom. 84, 449–454 (2004)

33. Price, S.A., Friedman, S.T., Wainwright, P.C.: How predation shaped fish: the impact of fin spines on body form evolution across teleosts. Proc. R. Soc. B Biol. Sci. 282, 20151428 (2015)

34. Friedman, S.T., Price, S.A., Corn, K.A., Larouche, O., Martinez, C.M., Wainwright, P.C.: Body shape diversification along the benthic–pelagic axis in marine fishes. Proc. R. Soc. B. 287, 20201053 (2020)

35. Friedman, S.T., Price, S.A., Wainwright, P.C.: The Effect of Locomotion Mode on Body Shape Evolution in Teleost Fishes. Integr. Org. Biol. 3, obab016 (2021). https://doi.org/10.1093/iob/obab016

36. Mojekwu, T.O., Anumudu, C.I.: Advanced techniques for morphometric analysis in fish. J. Aquac. Res. Dev. 6, 1–6 (2015)

37. Helland, I.P., Vøllestad, L.A., Freyhof, J., Mehner, T.: Morphological differences between two ecologically similar sympatric fishes. J. Fish Biol. 75, 2756–2767 (2009). https://doi.org/https://doi.org/10.1111/j.1095-8649.2009.02476.x

38. Aalbers, S.A., Bernal, D., Sepulveda, C.A.: The functional role of the caudal fin in the feeding ecology of the common thresher shark Alopias vulpinus. J. Fish Biol. 76, 1863–1868 (2010)

39. Long Jr, J.H., Koob-Emunds, M., Koob, T.J.: The mechanical consequences of vertebral centra. Bull. Mt. Desert Isl. Biol. Lab. Salisb. Cove Maine. 43, 99–101 (2004)

40. Baxter, D., Cohen, K.E., Donatelli, C.M., Tytell, E.D.: Internal vertebral morphology of bony fishes matches the mechanical demands of different environments. Ecol. Evol. 12, e9499 (2022). https://doi.org/https://doi.org/10.1002/ece3.9499

41. Lauder, G. V, Drucker, E.G.: Morphology and experimental hydrodynamics of fish fin control surfaces. IEEE J. Ocean. Eng. 29, 556–571 (2004). https://doi.org/10.1109/JOE.2004.833219

42. Schakmann, M., Korsmeyer, K.E.: Fish swimming mode and body morphology affect the energetics of swimming in a wave-surge water flow. J. Exp. Biol. 226, jeb244739 (2023)

43. Ducklow, H., Cimino, M., Dunton, K.H., Fraser, W.R., Hopcroft, R.R., Ji, R., Miller, A.J., Ohman, M.D., Sosik, H.M.: Marine Pelagic Ecosystem Responses to Climate Variability and Change. Bioscience. 72, 827–850 (2022). https://doi.org/10.1093/biosci/biac050

44. Robalo, J.I., Farias, I., Francisco, S.M., Avellaneda, K., Castilho, R., Figueiredo, I.: Genetic population structure of the Blackspot seabream (Pagellus bogaraveo): contribution of mtDNA control region to fisheries management. Mitochondrial DNA Part A. 32, 115–119 (2021)

45. Hermida, M., Cruz, C., Saraiva, A.: Parasites as biological tags for stock identification of blackspot seabream, Pagellus bogaraveo, in Portuguese northeast Atlantic waters. Sci. Mar. 77, 607–615 (2013)

46. Ball, A.O., Beal, M.G., Chapman, R.W., Sedberry, G.R.: Population structure of red porgy, Pagrus pagrus, in the Atlantic Ocean. Mar. Biol. 150, 1321–1332 (2007)

47. Motta, P.J., Hueter, R.E., Tricas, T.C., Summers, A.P., Huber, D.R., Lowry, D., Mara, K.R., Matott, M.P., Whitenack, L.B., Wintzer, A.P.: Functional morphology of the feeding apparatus, feeding constraints, and suction performance in the nurse shark Ginglymostoma cirratum. J. Morphol. 269, 1041–1055 (2008)

48. Jónsdóttir, G.Ó., von Elm, L.-M., Ingimarsson, F., Tersigni, S., Snorrason, S.S., Pálsson, A., Steele, S.E.: Diversity in the internal functional feeding elements of sympatric morphs of Arctic charr (Salvelinus alpinus). PLoS One. 19, e0300359 (2024)

49. Morel, M., Gál, J., Sós-Koroknai, V., Sós, E., Csehó, L., Bali, K., Hoitsy, M.: From wild to captive: Understanding the main nutritional diseases of sharks in public aquariums. Acta Vet. Hung. (2024)

50. González-Wangüemert, M., Froufe, E., Perez-Ruzafa, A., Alexandrino, P.: Phylogeographical history of the white seabream Diplodus sargus (Sparidae): implications for insularity. Mar. Biol. Res. 7, 250–260 (2011)

51. Talijančić, I.: Morphological and ecophysiological adaptations of wild gilthead seabream Sparus aurata associated with tuna farms. Aquac. Environ. Interact. 11, 97–110 (2019)

52. Sadler, D.E., Watts, P.C., Uusi-Heikkilä, S.: The riddle of how fisheries influence genetic diversity. Fishes. 8, 510 (2023)

53. Anderson, A.B., Bernardes, M.B., Pinheiro, H.T., Guabiroba, H.C., Pimentel, C.R., Vilar, C.C., Gomes, L.E.O., Bernardino, A.F., Delfino, S.D.T., Giarrizzo, T., Ferreira, C.E.L., Joyeux, J.-C.: Niche availability and habitat affinities of the red porgy Pagrus pagrus (Linnaeus, 1758): An important ecological player on the world's largest rhodolith beds. J. Fish Biol. 101, 179–189 (2022). https://doi.org/10.1111/jfb.15082