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Editorial

Contemporary Ichthyological and Fisheries Research of Deepwater Fish: New Advances, Current Challenges, and Future Developments

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Deepwater fishes are a very diverse group of chondrichthyans and teleosts widely distributed in the world ocean from the Arctic to the Antarctic and inhabiting the water column and seabed of continental slopes, seamounts, and high seas usually at depths greater than 400 m. In some groups, only certain species and genera are deepwater, but whole families and orders are also known, representatives of which live at great depths.

Despite the long period of studies of deepwater fishes and commercial exploitation of their resources, their role in marine ecosystems is still poorly understood. Our knowledge of their taxonomy, biogeography, evolution, phylogeny, basic biological traits, physiology, condition of stocks, fisheries, management, and conservation needs remain scarce. Present Special Issue entitled "Deepwater Fishes" provides an overview of the current status of knowledge on the variety of topics related to fishes inhabiting deep waters worldwide. Additionally, research needs and perspectives for further advancement in this field are identified. This Special Issue comprises 10 collected papers [1–10], which provide new and previously unpublished data. This collection allows readers the opportunity to find considerable useful information on deepwater fishes in a single reference.

From a critical evaluation of the 10 different contributions of this Special Issue, it is possible to highlight four major connecting themes:

1. Taxonomy of particular groups of deepwater fishes [1,2];
2. Biodiversity and biogeography of deepwater fishes (species composition, range extensions, and new records) [3,4];
3. General biology, physiology, and fishing of deepwater fishes [5–7];
4. Development of non-invasive sampling tools for the study of deepwater fishes (ROV, AUV, baited camera, lander, deepwater towed camera platform, etc.) [8–10].

A paper by Møller et al. [1] deals with the description of a new species of viviparous brotula from the order Ophidiiformes, which is distinguished by high species diversity. Within this order, one of the most representative families is Bythitidae, accounting for over 30 genera and about 100 species. Due to the habitation of most of the species of this group at great depths, they are quite rare in ichthyological collections, and therefore, their systematics is poorly developed. The genus *Bidenichthys*, represented until recently by four valid species, was previously known only from the southern hemisphere (South Africa, Australia, and New Zealand). Individuals of these species live in coastal waters at relatively shallow depths (the maximum does not exceed 337 m). The description of the new species *Bidenichthys okamotoi* Moeller, Schwarzhans, Lauridsen & Nielsen, 2021 in the genus under consideration is a unique case in several ways. This is the only representative of the genus in the northern hemisphere, the location of which is about 7500 km from the closest congener. Unlike other closely related species, which are coastal fish, *B. okamotoi* is most likely endemic to the Emperor Seamounts in the open waters of the Northwest Pacific. Moreover, despite rather intensive studies in this area in the past, it has so far been found only on the Koko Seamount, where it is possibly a local endemic. The new species, in addition, demonstrates a greater depth record, compared with its congeners (the maximum known capture depth is 409 m). The description of a new species in geographic and ecological conditions different from its closest relatives allowed the authors to formulate a hypothesis of the dispersal of *Bidenichthys* species in the historical past, which seems quite plausible. It should also be noted the methodological approaches to the description of the new species, which, in addition to the traditional ones (analysis of morphological characters, X-ray imaging), also included the analysis of the shape of otoliths and scanning computed tomography. The advantage of this paper is also the identification keys of the species of the genus *Bidenichthys*, which will undoubtedly be useful to researchers who encounter representatives of this taxonomically complex group in their research.

In the publication by Ho [2], a taxonomic revision of the genus *Halieutopsis* (Ogcocephalidae, Lophiiformes) was carried out with a description of five new species. The deepwater batfishes of the genus *Halieutopsis* are a very distinctive group of deepwater fish, distributed mainly in the Indo-Pacific region. These are bottom fish of small size (usually no more than 10 cm), living at depths from 100 m to 4 km. Due to the rarity of representatives of the genus in ichthyological collections, their taxonomy was poorly developed, and many species remained unknown to science. Until recently, 11 valid species were known in the genus: *Halieutopsis andriashevi*, *H. bathyoreos*, *H. ingerorum*, *H. margaretae*, *H. nasuta*, *H. nudiventer*, *H. oblonga*, *H. simula*, *H. stellifera*, *H. galatea*, and *H. tumifrons*. The study of numerous collections from various museums around the world allowed for the review of all previously known species of *Halieutopsis* and for providing diagnostic characters and new morphological and distributional data for each of them. As a result, five new species were described: *Halieutopsis echinoderma*, *H. kawaii*, *H. okamurai*, *H. murrayi*, and *H. taiwanea*. These species differ from other congeners in morphometric characters, squamation, and morphology of esca. The results of the research conducted by the author allowed him to provide a key to the species of *Halieutopsis*, which will be useful for specialists for the species identification of this taxonomically diverse and complex group. The paper in question is an example of a classic taxonomic study based on the analysis of morphometric and meristic characters. It is well illustrated, with drawings of the most important distinctive morphological characters and maps of the geographical distribution of the studied species. Additionally, noteworthy is the superior quality of photographs, mainly of type specimens. It seems that the next step in the study of the group under consideration should be the clarification of the taxonomic position of the genus *Halieutopsis* in the family Ogcocephlidae and the phylogenetic relationships of its representatives, both within the genus and at higher taxonomic levels, with involvement of methods of molecular genetics.

Bañón et al. [3] address the important topic of studying the biological diversity of deepwater fish communities in the Porcupine Bank using integrative taxonomy methods. Even though the ichthyofauna of this area is considered to be well studied, the authors managed to find several species that had not previously been recorded here. In addition to traditional morphological analysis, the use of DNA barcoding also allowed the authors to identify cases of potential cryptic speciation, misidentification, synonymy, or recent diversification. One of the results of this publication is the need to revise the taxonomic status of *Paraliparis hystrix* (Liparidae), which should be considered a junior synonym of *P. garmani*. Of the 14 rare deepwater fish species in the Porcupine Bank area, 12 are well known from the Mid-Atlantic Ridge (MAR) and adjacent North Atlantic, including two species also found in the Pacific and Indian Oceans. The exceptions are *Paraliparis histrix* and *Lycodes terranovae*, which have not yet been recorded in MAR waters. Thus, the integrative taxonomy method should be recognized as quite effective in studying the diversity of local deepwater ichthyofauna, which makes it possible to revise its species composition.

The paper by Orlov et al. [4] addresses one of the manifestations of the borealization of the Arctic. As a result of the global warming observed in recent years, species not typical for high latitudes are increasingly being recorded in the Arctic basin. One of these species is the walleye pollock *Gadus chalcogrammus*, which is widespread in the North Pacific and is also known from the Norwegian and Barents Seas by few records. Analysis of new captures of this species in the seas of the Siberian Arctic (the Kara and Laptev Seas) using traditional ichthyological approaches (study of external morphological features and otoliths) in combination with DNA barcoding allowed authors to draw several important conclusions. On the one hand, the walleye pollock caught in the Siberian Arctic do not differ, both morphologically and genetically, from the North Pacific and North Atlantic individuals, confirming previous conclusions about the conspecificity of the walleye pollock and Norwegian pollock *Theragra finnmarchica*. On the other hand, the species under consideration has an almost uninterrupted range from the coasts of Norway in the North Atlantic to the coasts of Korea, Japan, and California in the North Pacific. New records of walleye pollock in the Siberian Arctic allow concluding that its individuals caught in the Norwegian and Barents seas originate from the North Pacific. Its early pelagic juveniles are transported to the Siberian Arctic by currents from the North Pacific spawning grounds (most likely from the northern Bering Sea) through the Bering Strait. Further, when individuals have switched to a benthopelagic mode of life, they start to actively migrate westward, reaching the Barents and Norwegian seas. The results of this study reveal that large specimens of walleye pollock that have reached the North Atlantic regions have mature gonads in the pre-spawning and post-spawning conditions, which may indicate the possibility of its reproduction here. However, the survival of eggs and larvae under conditions of significantly lower temperatures, compared with the North Pacific, raises great doubts. However, if warming in the Arctic and adjacent regions of the North Atlantic continues, it is possible that spawning of walleye pollock here may be effective. The emergence of new spawning grounds due to global warming is known in other areas. Thus, in the late 1990s–early 2000s, in the Northwest Pacific, the captures of sablefish *Anoplopoma fimbria* ready for spawning became more frequent, indicating the possibility of its reproduction here, but the survival of its progeny was questioned. Subsequently, as warming progressed in this area, fingerlings and yearlings of sablefish, which originate from this area, began to be captured more and more often testifying for successive sablefish spawning and survival of its progeny.

The study by Longo et al. [5] deals with the determination of the age and description of growth characteristics of one of the members of the lanternfish family Myctophidae. The collection site and the method of obtaining the materials deserve special attention. The Strait of Messina is a narrow strait between the eastern tip of Sicily and the western tip of Calabria in southern Italy. It connects the Tyrrhenian Sea to the north with the Ionian Sea to the south, within the central Mediterranean. The strait's maximum depth is about 250 m. Due to its unique hydrogeological condition, the Strait of Messina is characterized by high levels of biodiversity. In its waters, there is a strong presence of many deepwater fish species that, due to the particular and peculiar currents of the strait, are occasionally found stranded on the shore. This allows researchers to regularly collect deepwater fish without going out to sea and to study various aspects of their life cycle. The article in question is undoubtedly of great interest. The family Myctophidae includes about 250 valid species and, in terms of its taxonomic composition, is probably the most diverse among deepwater fish, as well as among marine teleost fish in general. Meanwhile, studies dealing with the age and growth of lanternfishes are still scarce, which does not allow for a complete picture of the ecological characteristics of this large and important group of deepwater fish. Hopefully, research in this field will be further developed in the coming years.

A special place in this Special Issue is occupied by a paper by Pauly et al. [6], which reviewed the biology of mesopelagic fishes and attempted to provide their global catch for the last almost 70 years taken in commercial (industrial and artisanal) and experimental fisheries. At present, the biomass of mesopelagic fishes according to recent estimates exceeds 1 billion tons. Taking into account the latest acoustic studies, this figure may be even greater, since the underestimation of abundance by the trawl method can reach two orders of magnitude. Mesopelagic fishes have the greatest prospect for deepwater fisheries in the high seas. The development of this colossal resource is of undoubted interest due to the growing volume of aquaculture, which requires an increase in feed production. It should not be forgotten, however, that mesopelagic fishes are important components of food chains in the ocean and active participants in the transport of organic matter and energy between the surface and deep layers of the ocean. Therefore, the large-scale removal of mesopelagic fishes from ecosystems can have critically unpredictable, negative consequences for them. The discussed article is of undoubted interest from the point of view of closing certain gaps in our knowledge about the biology, state of stocks, and the fishery of mesopelagic fish in the world ocean. Future research should probably focus on studying the place and role of mesopelagic fish in marine ecosystems (1); conducting extensive research of the most productive regions of the world ocean, where sustainable and profitable fishing for mesopelagic fish is possible (2); developing effective methods of their capture (3); conducting technological research aimed at obtaining, first of all, high-quality feed for aquaculture (4).

Interesting and practically important is the study carried out on sablefish *Anoplopoma fimbria* [7]. This species is widely distributed in the North Pacific and is a commercially important target of both western and eastern North Pacific Ocean fisheries. Its rapid growth, high market prices, and delicious flesh make sablefish a potentially promising aquaculture species. It is known that sablefish tolerates sudden changes in pressure and remains viable for a long time after lifting the catch on the deck of a vessel, which opens up wide opportunities for its transportation alive. The experiments carried out on the influence of the presence of sablefish out of the water on its mortality and tissue health by the authors of the paper under consideration will be useful in terms of a better understanding of the physiology of this fish species. Ultimately, the results of this research should contribute to the development of breeding methods, keeping, and transporting sablefish in aquaculture.

The use of technology in modern research of aquatic biota that does not harm the studied organisms and their habitat is gaining momentum in the world today. From this point of view, studies by Carluccio et al. [8] are well within the trend of the modern development of marine biodiversity research. Additionally, given the fact that cartilaginous fish are most susceptible to the fishing impact, especially deepwater species (sharks, rays, and chimeras), the study under consideration acquires special relevance. The deepwater fauna of cartilaginous fishes of even the most studied North Atlantic Ocean and the Mediterranean Sea remains insufficiently studied, while many species are threatened. Meanwhile, the need to monitor the state of cartilaginous fish species and their habitat under conditions of increasing anthropogenic impact and climate change is becoming more and more urgent. Traditional research methods such as trawl surveys are irrelevant to threatened species. Therefore, the introduction of non-invasive research methods into the practice of ichthyological and fishery research can only be welcomed. For future studies of cartilaginous fishes in various regions of their habitat (including freshwater bodies), it is likely that, in addition to landers, the use of other non-invasive approaches can be recommended, for example, ROV, AUV, baited cameras, environmental DNA (eDNA), etc.

Another example of the use of non-invasive techniques in deepwater fish research is the publication by Koeda et al. [9]. The advantages of the research methods used by the authors are probably not worth discussing again (see above). It should only be noted that concerning the fauna of seamounts, the use of non-invasive techniques such as ROV and AUV is of particular relevance. The fauna of seamounts is very diverse and often characterized by a high degree of endemism. Seamount ecosystems are extremely fragile and can be considered vulnerable marine ecosystems (VMEs). The impact of fishing, especially bottom trawling, on such ecosystems often leads to severe negative and sometimes irreversible consequences, after which recovery takes decades. In addition to the lack of direct impact on the studied ecosystems, the use of ROV and AUV provides researchers with additional benefits. Comparison of the results of trawl surveys and video observations using ROV shows differences in the composition of the observed ichthyofauna, as well as in different densities of individual species. Such differences may be due to different responses of particular species to ROV and trawl. In addition, during underwater observations, it is possible to register animals that, due to their small size, eel-like body shape, high speeds, secretive lifestyle, etc., are not captured by trawl fishing gear. Modern methods of underwater observations make it possible to obtain high-quality images, which is necessary for correct species identification of animals, as well as to accurately measure their size. In some cases, it is possible to obtain a certain set of measurements of environmental parameters (temperature, salinity, dissolved oxygen, individual nutrients), which is not always possible during traditional trawl surveys. In addition, in some areas of the world ocean with a complex bottom topography (deepwater canyons and trenches, rocky areas of the continental slope, most seamounts, abyssal and hadal areas, etc.), studies of deepwater fauna are possible exclusively with the use of underwater observation equipment. It seems that as the cost of such a technique becomes cheaper, research with its involvement will only expand.

Another example of research of the seamounts ichthyofauna using underwater observations (in this case, the deepwater towed camera platform), as well as hydroacoustic equipment, is demonstrated by Williams et al. [10]. Sea eels belonging to the order Anguilliformes are a very heterogeneous taxonomic group, widespread in the oceans from coastal waters to the hadal depths. The taxonomy of deepwater eels is poorly developed, and knowledge about many aspects of their lifecycle, especially reproductive biology, remains very limited. The value of this study is the discovery of large spawning aggregations of basketwork eel *Disatobranchus capensis* within a very limited area of the seabed of a local seamount. The absence of such concentrations in neighboring areas may indicate that this site is the only spawning ground of the species under consideration, which makes the local population of eel very vulnerable under the influence of certain types of human activities (fishing, mining, shipping, etc.) and requires the adoption of protective measures. The use of non-invasive research methods in combination with the use of hydroacoustic equipment made it possible to quantify the density and abundance of spawning aggregations without causing harm to the studied spawning population and the habitat of eels. Future research is likely to be aimed at elucidating the reasons for the formation of local high-density spawning aggregations of deepwater eels. Deepwater eels and closely related species have pelagic leptocephalic larvae in their ontogenesis. The formation of spawning accumulations off the local seamount may be associated with the specific oceanological and forage conditions here. Eddies are often formed around seamounts, which mechanically accumulate forage organisms, improving the feeding conditions for pelagic juveniles and preventing their dispersal. It seems that carrying out ichthyoplankton and oceanological surveys in the area of such spawning aggregations will help to better understand the reasons for their formation and, in general, the reproductive biology of deepwater eels.

Undoubtedly, studies of deepwater fishes will continue and extend in the future, accompanied by descriptions of new species, taxonomic revisions, new records, and acquisition of new data on their general biology and physiology with the use of both traditional and advanced methodologies. Recently, certain progress in the study of deepwater fish in various regions of the world ocean has been achieved. This is associated, first of all, with the widespread introduction of new technologies into the practice of ichthyological and fishery research (scanning computed tomography, scanning electron microscopy, mass spectrometry, otolith shape analysis, eDNA, DNA barcoding, molecular phylogenetics, population genetics, means of underwater video surveillance, etc.). It seems that technical progress in this direction will continue to develop. However, I would very much like to hope that the traditional methods of ichthyological research will not lose their significance.

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