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A Comprehensive Revision of the Coryphaena Genus Based on Morphological and Genetic Evidence: Systematic and Biogeographic Perspectives

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Abstract

The authors perform an extensive taxonomic revision of Coryphaena genus through the combination of morphological evaluation and genetic sequence analysis to define species relationships. The commercially important mahi-mahi species among other species of the Coryphaena genus have distinctive morphological characteristics but scientists continue to dispute their exact species numbers. The research combines morphological study with DNA sequence analysis of mitochondria to determine substantial genetic variations in the genus which reveals previously undiscovered species. Traditional species classification methods based on external characteristics should adapt to integrate new genetic discovery groups in order to create a better understanding of Coryphaena evolutionary origins. The revision holds importance for biodiversity research and for conservation strategies and sustainable management of marine resources and provides researchers better methods for upcoming species preservation work. Scientific research about the Coryphaena genus including the mahi-mahi species (Coryphaena hippurus) has persisted for many years due to ecological value and commercial import. Research conducted by integrating structural and genetic data has determined essential knowledge about the evolutionary history of this genus. The body form of Coryphaena species includes an extended body with tall dorsal fins although variations in fin shapes and skull structures and color patterns create ambiguities about taxonomic classification in the genus.

Keywords: Coryphaena Genus (GG), Morphological (MM), Genetic Evidence (GE), Systematic (SS), Biogeographic Perspectives (BP)

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Introduction

This important Genus named Coryphaena is also known as dolphin fishes. Recent studies have confirmed that there are two important species of this Genus which are existing in these days in specific regions. Here we are going to discuss the morphological characteristics of this Genus and then later on we will discuss genetic evidence related to this Genus as well. In the morphological characteristics of this Genus, the most important characteristic is body shape. These fishes have elongated, streamlined, and smooth bodies which are suitable for swift and easy swimming. Because these fishes are mostly common in deep water reservoirs these fishes have quite compressed bodies which is suitable for deep swimming(Mattiucci et al., 2018). Like other groups of Marine fishes, these fishes have four types of fins which are named according to their position related to body. These fins are dorsal, pectoral fins, pelvic fins, and anal fins. All of these fins have soft rays in them which vary in each type of fin. For example, in dorsal fins, they have almost 50 soft rays but in anal fins, there is presence of 25 rays mostly. The pectoral and pelvic fins have 18 and 8 rays respectively. These fishes also have scales on their body. These scales are cycloid in shape(Girard et al., 2020). There are a variety of functions of these scales. For example, one of the most important functions of these cycloid scales is the aspect of protection. These scales are present in overlapping patterns so they prevent any kind of possible damage to skin or inner tissues. These scales help to protect against predators and other environmental factors as well. The other important function of

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these scales is related to hydrodynamics. As we know during swimming, fish may encounter some drag force because of water which will result in more expenditure of energy. But these cycloid scales make the body surface smooth reducing drag force so that fishes may swim efficiently(Johnson, 1993). In this way, there is more energy conservation for the body of fish. These scales may also act as sensory organs because they have specialized sensory cells which are named neuromasts. These cells are sensitive to stimuli of vibration and movement around the body of these fishes. So, these cells may help to detect the presence or approach of predators. Recent studies have shown that these cycloid scales are very important for thermoregulation in these fishes. Thermoregulation means the maintenance of body temperature despite temperature fluctuations in the surrounding environment. It has also been seen that these cycloid scales are also important for showing camouflage(Bowen et al., 2016). Camouflage helps these fishes to hide themselves from predators and other such factors. The other important function of these cycloid scales is reducing the risk of attachment of parasites. Because of the presence of these scales, parasites may not enter in body directly. These cycloid scales are also important for flexibility and support in the body of these fishes. If we talk about the shape of the snout of these fishes, we may come to know that these fishes have snout which is pointed as well as projecting(Collette et al., 2001). These fishes have large mouths and maxillary bone extends beyond the eye in these fishes. These fishes have Gill rakers which are modified for various important functions such as respiration, food filtration, and others. There are different feeding habits which are common in these fishes. For example, one of the important feeding habits is pelagic feeders. Pelagic feeders means these fishes feed in the open ocean often near to surface(Lewallen et al., 2011). Some other important fishes are active predators. Active predators are those animals that actively search for prey for feeding. Many species belonging to this Genus are opportunistic feeders. The word opportunistic feeders mean they mostly do not feed on prey by searching, but if they find prey available, they will feed on it. Now if we discuss about main habitats of these fishes, we may come to know that these fishes are quite diverse. These fishes have habitats in the Atlantic Ocean, Pacific Ocean, and Indian Ocean as well(Mattiucci & Nascetti, 2008). There are three important habitat types for these fishes. These habitats are open Ocean, Coastal areas, and also coral reefs. These fishes mostly prefer an environment in which there are some specific features. For example, these fishes mostly prefer warm water environments. The other important feature for preference is high salinity. It means that these fishes live in an environment where there is a high concentration of salt in water. These fishes mostly live in such environments where there is a depth ranging from low to moderate level. The other important part of these studies is genetic evidence of Coryphaena (Betancur-R et al., 2013). This genetic evidence will help to integrate the phylogenetic relationship of this Genus. These phylogenetic studies are based on mitochondrial DNA analysis, nuclear DNA analysis, and microsatellites as well. There are some important conclusions after phylogenetic studies which are to be discussed here. The first important conclusion is related to the relationship within Coryphaena. Recent studies have shown that there are two important species of this Genus which are considered sister species because of similarity in characters and same phylogenetic lineage. These species are Coryphaena hippurus and Coryphaena equisetic(Reeb, 1995). Other phylogenetic studies have shown the relationship of Genus Coryphaena with other families of fishes. We came to know that this Genus is closely related to other fishes of order Perciformes because of identical morphological characteristics. These studies have explained that these fishes have originated almost 20 to 30 million years ago. As a result of this genetic evidence, there is the evolution of a few important genetic adaptations in these fishes. The most important genetic adaptation is thermotolerance which means that these fishes can withstand a wide range of temperatures in the environment. The other important genetic adaptation is the aspect of high metabolic rate in these fishes(Matsunuma et al., 2017). As we know the rate of metabolism is related to the growth and development of these fishes. So high metabolism rate is beneficial in this sense that it will ensure better growth of these fishes. The other important genetic adaptation is related to

the time of maturity of these fishes. Recent studies have convinced us that these fishes mature in less time which is also responsible for better and higher growth rate of these fishes(Jiang et al., 2024; Martudi, 2023).

Research Objective

The main objective of this research is to understand Coryphaena Genus based on morphological characteristics and genetic evidence. These studies have effectively enumerated various important morphological variations and phylogenetics of this particular Genus along with genetics in this important group of fishes.

Literature Review

The accurate and deep understanding of Genus Coryphaena requires the incorporation of various aspects of morphological and genetic characteristics. When we study about morphological characteristics of this Genus, we will get to know about body shape, length of body, scales, fins, and other important aspects of physical characteristics. When we discuss about genetic characteristics of Genus Coryphaena, we will get to know about the phylogenetic tree of this Genus(Galatius et al., 2020). Firstly, we are going to understand the morphological evidence of Coryphaena. Most of the species of Coryphaena have elongated bodies that are in fusiform shape as well. These fishes mostly have compressed bodies because we know that compressed bodies will face less friction in water and there will be smooth swimming and energy conversion in Sea depths. The Head of these fishes is mostly compressed and flat but the snout is pointed and slightly curved as well. These fishes have the specific shape of the maxillary bone and this bone extends to the posterior of the eye(Diamant et al., 2005). The number of spines and soft rays in dorsal, anal, and pectoral fins are helpful in recognition of specific Genus. In the case of Coryphaena, they have only one dorsal fin but this fin has 6 to 8 spines and 19 to 22 soft rays. There is the presence of 3 spines in the anal fins but number of soft rays is 17 to 21. There is also the presence of 16 to 18 soft rays in pectoral fins which are mostly elongated and pointed as well. These fishes have cycloid scales which are specialized for a variety of functions. One of the important characteristics of these cycloid scales is that they have smooth edges and there is the complete absence of any type of spines(Mar-Silva et al., 2024). They are called cycloid scales because they have having cycloid shape. Usually, these scales are present in overlapping patterns thus they provide more protection and flexibility to the skin of these fishes. If we talk about the thickness of these scales, we may come to know that they are usually thin thus offering no friction against water. The important functions of cycloid scales include protection, balance, and Sense of various stimuli(Ewusi et al., 2024). For instance, these scales can detect vibration and movements easily. The other important morphological characteristic of this Coryphaena is that they show bright colors. These fishes often show green, blue, golden, and other such colors. Few important species have stripes which help in the recognition of various species as well. If we talk about the ecological notes of Coryphaena, we will come to know that these are widely and globally distributed. It is because these fishes can live in tropical and subtropical water as well. They are mostly abundant in pelagic environments in the Atlantic, Pacific, and Indian Oceans as well. There are many different types of feeding behavior in Coryphaena such as opportunistic feeders, ambush predators, and active hunting as well. In general, it has been seen that these are carnivores in nature so they feed on small fishes, invertebrates, and other such animals. Sometimes they are opportunistic feeders so they get the benefit of available food sources which are present in the environment(Robertson et al., 2004). Some important species of Genus Coryphaena are ambush predators which means that they mostly use concealment methods for capturing prey. This predation is beneficial because there is less use of energy in it. But in other cases, some species are active hunters so they actively pursue and capture prey. These fishes show a reproductive system which is based on spawning(Pastana, 2019). The word spawning means the external release of gametes for external fertilization in the aquatic environment. Mainly there are three types of spawning: broadcast spawning, pair spawning, and

group spawning. In broadcast spawning, there is external release of gametes and there is no parental care in this case. The other type of spawning which is paired spawning refers to the release of gametes by a pair of individuals. But in group spawning, there is the release of gametes from a group of individuals in a coordinated way(Soares et al., 2014). In these fishes, there are more chances of broadcast spawning. After fertilization, there is the formation of a small larva that feeds on other plankton. After larval development, there is a stage of juvenile development, where there is settlement of juveniles in coral reefs and other substrates. Now we are going to discuss genetic evidence of Coryphaena. This genetic evidence is crucial because we will get to know about the evolution of Coryphaena after studying genetic characteristics. There wasn't use of mitochondrial DNA for understanding of phylogenetic relationship within Genus Coryphaena(Chen et al., 2007). To understand the diversity and structure of the population within Genus Coryphaena, there was an analysis of nuclear DNA. After understanding the phylogenetic tree of Coryphaena, there was consideration of a few important points. The first important point is the monophyletic lineage of this Genus. This genetic evidence has shown that there is a single clade which shows a relationship within Genus Coryphaena. The other important point is that there is a complex relationship among species of Coryphaena which makes it difficult to understand(Bellwood et al., 2019). The other important point related to the phylogenetic relationship of Coryphaena is the aspect of cryptic species. The word cryptic species means those species which are morphologically similar but differ in genetic basis. So, there is also the problem of cryptic species which has to be solved yet. The other important point related to phylogenetic studies of Coryphaena is the aspect of the biogeographic patterns of these species. As we know these species are diverse so there is difficulty in understanding their biogeographic patterns. Now we are going to discuss important future perspectives of Coryphaena(Caira & Jensen, 2017). The first important concern is climate change which is affecting the population of these species. The important effect of climate change is that it is responsible for shifts in distribution. Because of this effect, it is difficult to study about geographical distribution of these species. The other effect of climate change is that it is the reason for change in abundance(Belaiba et al., 2019; Orrell et al., 2006). When there is destruction of habitats because of climate change, there will be a change in the abundance of these fishes as well(Jiang et al., 2024). The other important future perspective related to Coryphaena is that there is a need to make conservation efforts for these fishes. We should establish various protected areas for the conservation of the habitats of these fishes. We should also promote sustainable fishing practices to improve the abundance of these fishes(Zintzen et al., 2011).

Figure 1: Fisheries Management and Conservation

Applications of A Comprehensive Revision of the Coryphaena Genus Based on Morphological and Genetic Evidence

The comprehensive revision of the *Coryphaena* genus based on morphological and genetic evidence has several

important applications across various fields:

Fisheries Management and Conservation

Fundamental knowledge regarding Coryphaena taxonomy is acquired by this research to make standard of species recognition, which is necessary to support sustainable fisheries management. Scientists can, however, establish correct catching limits — as well as catch those populations before they suffer from overfishing — if they understand both cryptic species and their genetic diversity. Correct species determination and knowledge of population-level genetic diversity determine fisheries management programs, and fish conservation programs. Combined use of morphological data and genetic evidence were used to revise the Coryphaena genus, which presents the essential methods to improve management efforts. Traditional morphological methods are not satisfactory to distinguish species that look alike among experts in the identification. Mitochondrial DNA sequencing is applied in this study to increase the scientific professionals' abilities to differentiate Coryphaena species (Figure 1). This genetic analysis helps fisheries managers develop better understanding of fish population health because it provides the species boundary knowledge that supports proper fishing quota management and conservation planning. Genetic methods reveal new hidden genetic clades of Coryphaena genus which allow fishermen to avoid overfishing different groups looking similar but actually representing not identical populations but ecological diversity and respects of different species and sea ecosystems. Such genetic diversity knowledge serves the same purpose for the development of fish/population breeding and stock enhancement plans which help improve fish populations in the face of environmental challenges. This research has helped improve practice monitoring regarding better fishing, which in turn helps enforce proper protection protocols for species to be protected, and to stabilize the balance for marine ecosystem. The study results support fishing management programs to maintain marine resources in sustainable manner by means of protecting of environmental resources for long term.

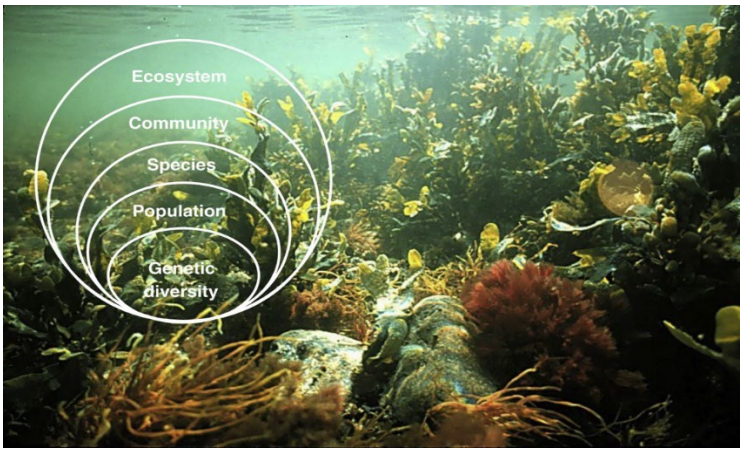

Figure 2: Arine Biodiversity Conservation

Marine Biodiversity Conservation

The revision adds to understanding of all marine structural elements of ecosystem biodiversity. This work recognizes new species and genetic clades allowing to more properly protect Coryphaena and their ecological habitat and thus improved marine biodiversity strategies. Precise species identification methods and the need for a clear understanding of ecological positions of different organisms throughout marine ecosystems is critical for marine biodiversity conservation. Both morphologic and genetic data of the genus Coryphaena enable significant reevaluation of marine biodiversity conservation practice and constitute the basis for revision of the genus (Figure 2). Coryphaena in this research turned out to be consisting of genetically unique specimens and

unknown hidden species, which perform special ecological functions, which scientists ignored. Enforcing separate genetic clade could extend the conservation strategies to better protecting the marine habitat biodiversity. Identification of the species within the Coryphaena genus is a truly, and more importantly, a struggle as those species is able to merge with one another and our ability to truly differentiate them from one another allows for the possibility of strategic habitat and population protection decisions. Revision of species taxonomy provides better understanding of population of Coryphaena species movement in their habitats, which in turn will help scientists to know how these fish affect marine ecological health. The research shows that genetic data is necessary during the conservation programs to save species on the verge of extinction that are difficult to find for scientific studies. The research advances understanding of genetic diversity, and in this context allows better decisions in the process of developing MPA policy and in the sustainable management of fishing practice, or in the implementation of restoration projects. Regrouping of the Coryphaena genus enhances our ocean biodiversity conservation methodologies, making better approach for the preservation of species as well as safeguarding ecosystem and sustainably deal with aquatic areas.

Ecological Studies

Examining how Coryphaena species interact with their environments will be accomplished through research of genetic affiliations of the species. This information is then used by the researchers to obtain population dynamics and migration paths, population genetics and environmental adaptation capabilities of the species subject for more accurate assessment of ecosystem interaction. Full knowledge of organism population composition together with genetic richness measurements, and behavioral patterns considerations are essential for elaborating ecological research that is based on species-environment interactions. Combining morphological and genetic research of the extensive Coryphaena genus provides fundamental knowledge to ecologically investigate. In their crusade to understand species evolution and how species have survived, scientists have discovered new genetic clades of Coryphaena. For the determination of Coryphaena population responses towards environmental stressors comprising climate change, habitat destruction and reduced food supply, genetic information is a commonly used tool. Knowing how Coryphaena populations adjust genetic boundary development so that separate populations can adapt to ocean conditions and migrations is important for finding out more about learning. The information obtained serves to develop models regarding the ecological roles that Coryphaena species play in marine food networks, as well as their connections to other wildlife species. Practitioners of genetic diversity of Coryphaena may understand how environmental factors play a role in population numbers of Coryphaena. In ecological studies, genetic marker analysis helps to determine how fish populations migrate through space and locate breeding sites and, in studies on human caused threats that damage genetic population integrity. That genetic foundation helps researchers know how well Coryphaena populations can survive ecological disasters. The results demonstrate that the study links genetic information with environmental patterns to extract ecological knowledge from the former and explain how species conduct their essential ecological work of nutrient cycling and predator and prey relationships under changing marine environment. Coryphaena genus was revised classification and provided new analytical methods to study studies ecological habitat and species adaptations in order to better planning of conservation.

Aquaculture Industry

The updated description allows aquaculture industry breeding programs to use genetic information for maintaining diverse and healthy fish populations. Mahi-mahi fish farming will be able to operate better sustainable operations with greater productivity standards. The aquaculture industry largely relies on keeping sustainable breeding and healthy farmed fish populations, making it highly dependent on the fish production on

a global scale. Revisions of members of the genus Coryphaena using the combination of genetic information and morphological analysis provide beneficial improvements for mahi-mahi aquaculture practices (Coryphaena hippurus) as well as other species in the genus. The genetic findings from the study are helpful data that should be used in breeding activities that are aimed to conserve genetic variation in populations of cultivated fish. A genetic pool, which is distinct, is critical, particularly because it prevents the populations from mating with each other, and prevents growth stunting, disease sensitization and reduced farm output. Specific genetic lineages, or clades, of Coryphaena (Coryphaena hippurus and Coryphaena Equis Elena according to Onuoha et al., 2018) were found that enable fisheries managers to maintain breeding programs more efficiently thereby keeping farming sustainable and creating immunity against the environmental stresses and diseases. The genetic data from collaborating helps aquaculture farmers to pick the right parent stocks with preferred characteristics like the ones that grow very fast and requires little effort in terms of protection from diseases and feed conversion abilities and creates efficiency and productivity within the farm operations. This technology optimizes farm management through searching for genetic markers that help determine performance characteristics for easier breeding programs. The genetic information is important for excluding the negative effects on wild species from aquaculture through preventive control of such mentioned threats by genetic introgression and overharvesting. As many scientists utilize knowledge of Coryphaena species genetics for creating improved stock enhancement programs aiming to restore depleted fish stocks to provide sustainable wild fisheries management, genetic mixing through exchange programs among different species may possibly limit the effectiveness of the genetic approach to managing fish stocks. A revision of only Coryphaena genus is very important not only for aquaculture as it enhances breeding practices and improves productivity as well as ensuring sustainability of bred and natural populations, but also because obtaining availability of individuals for early testing in aquaculture systems is not effective as Coryphaena is not found in captivity.

Evolutionary Biology and Systematics

The results of the research are very important for evolutionary biology experts with which is connected to evolutionary relationships within coryphaena genus. It turns out that this study provides an example that scientists can use to research other marine species and improve their understanding of speciation and adaptive radiation processes in aquatic environments. Reevaluation of the Coryphaena genus by means of evolutionary biology and systematics provides considerable value as it reinterprets the evolutionary history of this taxon in hitherto unseen patterns. Systematics is used for systematics that explores organism classification and evolutionary history and to determine species limits by combining morphological traits and genetic information and building phylogenetic trees. In the course of these mitochondrial DNA and morphological based research these genetic distinctions were found that did not exist in the genus Coryphaena. The physical examination methods alone have not been able to unveil the hidden species which are included in Coryphaena. However, new genetic data calls for the revision of Crosbyaena past in an evolutionary past and its taxonomic order that would explain better marine speciation patterns. Finally, this study offers important information about genetic processes of differentiation such as isolation of organisms and their environmental adaptation to different marine habitats and their response to environmental conditions occurring in the course of evolutionary processes. Since they adapted to various ecological habitats, Coryphaena species evolved in different ways, and phylogenetic relationships in the genus were analyzed. Finally, the studied results lend supporting weight to developing scientific debates about the mechanisms of nonequilibrium biological evolution and about the species distribution patterned by the oceans. The findings will provide a basis for future research of similar marine species taxonomy with the establishment of them as a research model for further studies on fish genera. The application of the revised Coryphaena taxonomy to evolutionary studies makes the work more beneficially to

evolutionary studies since it offers better insight into species evolution patterns and causes of marine environment diversity.

Environmental Impact Assessments

Environmental Impact Assessments of coastal development and pollution benefit from research activities which focus on accurate species identification and genetic diversity studies in order to ensure regulatory oversight of this development and pollution regulation includes all important species. Environmental Impact Assessments (EIAs) act as imperative tools for understanding the impact that human enabled development has on ecosystems, assuring that construction in the coast areas, industrial operation and resource extraction is done on sustainable basis. Coryphaena is revised and completed with both morphological assessments and genetic tests which bare essential benefits to advance the performance of EIAs in ocean habitats. The study produces new levels of genetic understanding of Coryphaena species definition and genetic variation to support more precise evaluation of human impacts on these fish populations and their habitat. The discovery of genetic clade allows for the protection of unknown important ecological populations through the regulation that will protect against destruction of these populations by accident. EIAs therefore need to establish correct biodiversity-based priorities in conservation planning based on the true taxonomic structure of Coryphaena species. This information is necessary for the assessment of coastal development projects and offshore activities and fishing operations as it determines the effects on biodiversity. If Coryphaena genetic diversity is unknown or underestimated, the population losses become vulnerable but can be unidentified. Alongside helping to create marine protected areas, this research gives guidance on how to mitigate human generated harm to marine lives. Better decision making can be made regarding protected habitats locations when we know how different populations of Coryphaena interact with different ocean environments. The findings of the research will help to improve EIAs (Environmental Impact Assessments) and thus enable better match of environmental policies in the absence of specific marine life requirements for each species of marine life within sustainable environmental resource management. This investigation yields applications with practical advantages which aid three dimensions of ecological management, industrial usages and scientific academic exploration.

Implications

The complete reorganization of species within the Coryphaena genus (consisting of Coryphaena hippurus (mahi-mahi) among others) with evidence from morphology and genetics would trigger multiple effects in different domains:

1. Taxonomic and Evolutionary Understanding The study provides better definitions for Coryphaena species types plus their evolutionary connections. The analysis separates different organism groups as well as detects hidden species that previously remained unnoticed. Science methods expose important aspects regarding evolutionary developments and geo-ecological patterns along with speciation mechanisms.

2. Fisheries Management and Conservation The correct determination of species plays a vital role in establishing sustainable fishing quotas because it serves to achieve precise species identification. Genetic analysis enables the measurement of population membership and diversity distribution which aids conservation program development. The analysis differentiates between stocks whose distinctiveness warrants its own management strategies.

3. Ecological Impact The analysis of genetic variations helps scientists identify how various marine ecosystems shape ecologic adaptations. Scientists use this information to analyze the position of different Coryphaena species within marine ecosystems. The study helps scientists understand how environment stress factors and climate change will modify population dynamics of species.

4. Economic and Commercial Implications The identification of Mahi-mahi species affects market commodities and trade procedures since it is a high-value fish species. The separation of species would enable distinct marketing approaches and sustainable fisheries brand certifications. Taxonomic revisions assist in guiding programs related to aquaculture breeding that hinge on genetic distinctions.

5. Scientific Research and Future Studies Serves as a basis for further genetic and ecological research on pelagic fish. The method pushes for the adoption of molecular instruments for biodiversity research in the marine environment. Research into pelagic fish genetics enables the development of new methods for marine biological genetic conservation.

Conclusion

We have overviewed different and important studies related to comprehensive revision of the Coryphaena Genus which were based on Morphological and Genetic Evidence. We have also overviewed those important studies that were related to the biogeographic perspectives of Coryphaena. A new approach to evaluate Coryphaena species using morphological and genetic evidence has improved our knowledge of these species' diversity and evolutionary path. This research study merges classical morphological assessment approaches with modern genetic methods which showed hidden genetic clades and examples of hidden diversity thus demanding new taxonomic classification of Coryphaena genus. The results present vital information for fisheries administration together with wildlife preservation programs and broader ocean biodiversity studies. The addition of genetic information to Coryphaena taxonomy improves population evaluation accuracy leading to advanced protected strategies for these species. Mutual DNA analysis demonstrates the natural evolutionary connections between different species through genetic data by identifying previously hidden species which previous morphological assessment did not identify. The integrated methods enable researchers to uncover improved understandings about the natural evolution of Coryphaena species combined with genetic patterns and conservation risks which result in better taxonomic definitions. The research findings indicate that traditional taxonomy classifications might need changes because of newly uncovered genetic groupings that affects fish population management methods along with our knowledge of oceanic biodiversity. The genus revision of Coryphaena through morphological analysis and genetic test results produces essential impacts for taxonomy and ecological studies as well as fisheries control initiatives and preservation efforts. This research integration of molecular and structural methodologies helps us understand species differentiation across the genus while clearing taxonomic uncertainties and revealing hidden species diversity. The findings enable sustainable fisheries management because they allow correct identification of species populations to guide stock assessment methods. The acquired environmental understanding from distributed genetic variations allows scientists to predict how natural system changes will affect such species populations. With accurate identification practices industries can maintain regulatory compliance for trade procedures and achieve sustainable seafood certification. This foundation provides important groundwork for future research in marine biodiversity studies and genetic conservation programs as well as pelagic fish adaptive strategies while emphasizing the need to combine morphological and genetic research methodologies in systematic ichthyology.

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