SCHOOLING FINFISH: AN OVERVIEW OF THE TUNAS, BILLFISHES AND SHARKS

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Contents

Summary

This article gives an overview of tunas, billfishes and sharks, and is primarily about all the species living in offshore pelagic areas. The systematics of each of these three groups is first discussed, and then their major biological and environmental peculiarities are described and reviewed. Movement patterns known for the various tuna and billfish species are compared. A description of the major fisheries exploiting tunas, billfishes and sharks is given, comparing the fishing zones, the trends in catches, and the levels of exploitation of the major stocks. The future prospects of the major stocks are discussed.

1. An Overview of the Tunas, Billfishes and Sharks

1.1. Systematics

Tunas and billfishes are all members of the Scombroidei suborder; tunas and related species comprise a single family, the Scombridae, while billfishes are members of two families, Istiophoridae and Xiphiidae.

The family Scombridae is composed of a limited number of 49 species belonging to 15 genera (see Figure 1).

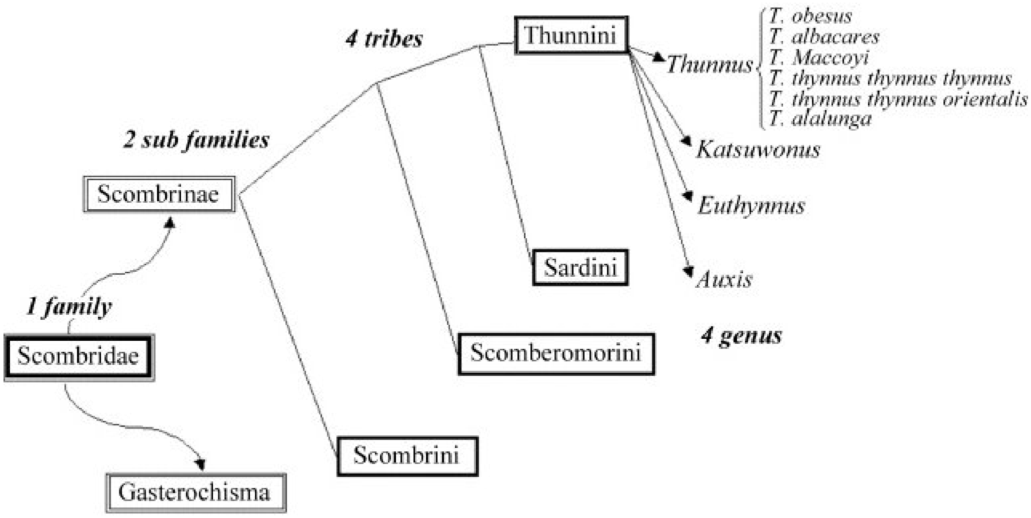

Figure 1. Classification of tunas within the Scombridae family.

The majority of commercial tuna species belong to the subfamily Scombrinae and the tribe Thunnini, the most evolved group of tunas. The main species members of this tribe are the following: skipjack tunas *Katsuwonus pelamis*, bigeye tuna *Thunnus obesus*, yellowfin tuna *Thunnus albacares*, albacore tuna *Thunnus alalunga*, the northern bluefin tuna *Thunnus thynnus thynnus* and *Thunnus thynnus orientalis*, and the southern bluefin tuna *Thunnus thynnus maccoyi*. Two other genera, the little tuna *Euthynnus alletteratus* and frigate or bullet tunas *Auxis thazard* and *A. rochei*, are also members of the same tribe, but they are of much less commercial importance. The same subfamily Scombrinae also has three other tribes, the Sardini, Scomberomorini and Scombrini, with a total of 35 tuna species, most of them of small sizes and of less commercial importance, being primarily fished in coastal waters, often significantly, but not used by the canning industry.

The main morphological characteristics of the Scombridae family are an elongated body and a deeply forked caudal fin, two dorsal fins, finlets behind the dorsal and the anal fins, and two small keels of each side of the caudal peduncle. The tribe Thunnini is the only one amongst the bony fishes to possess a thermoregulatory circulatory system allowing conservation of metabolic heat in their bodies.

The origin of tunas is still uncertain. However it is hypothesized that they are quite recent in terms of evolution, being closely linked with large pelagic ancestors (for instance the genus *Palaeothunnus*, *Woodwardella* or *Thunnus secretus*) from the late Miocene and early Oligocene (e.g.50 to 30 million years ago).

1.2. Tuna Anatomy, Biology, Behavior and Physiology

Tunas and billfishes are pelagic fishes inhabiting the upper layers of the open seas in the Atlantic, Indian and Pacific oceans. They are biologically advanced species, remarkably well adapted to a wide range of ecosystems in the upper oceanic environment, primarily in the intertropical areas, and to a less degree, the temperate areas. Their body form is streamlined for rapid and continuous swimming, and also over large distances. All tuna species show, to a variable degree, a fusiform body and a high ratio forked tail, which is typical of fast swimming fishes, and elaborate keels which reduce drag and accelerate water movement. Maximum burst speeds over 70 km h^{-1} have been recorded for yellowfin and bluefin tunas. Most tuna species also show a typical color pattern, with a dark blue or green metallic back, changing to silver on the belly; these colors are typical of most pelagic fishes.

Tunas need to swim constantly with their mouth open in order to supply oxygenated water to their gill surfaces. Most tunas require a good supply of oxygen because of their high metabolic rates, but all tuna species have large hearts and large volume of blood. They are also fully efficient at absorbing the oxygen dissolved in the water, even at low oxygen rates, since they show a large absorbing surface in their gills and a high proportion of hemoglobin in their blood. The oxygen requirements are variable among the tuna species.

The circulatory system of tunas is unique among fishes, because they can either conserve or dissipate heat, when needed. They have a vascular heat exchanger allowing them to maintain an internal temperature warmer than the surrounding water (reaching a potential excess of more than 10°C for a temperate tuna like the bluefin tuna). This warm internal temperature has various advantages for tunas: it gives more flexibility to swim efficiently at a wide range of temperatures, allowing feeding within a larger zone, and giving access to more temperate and richer areas. The thermoregulatory systems are different for small tropical tunas, such as skipjack or small bigeye and small yellowfin, which swim in warm waters. Their daily metabolic priority is to eliminate calories. In contrast, large temperate tunas such as bluefin or albacore and adult bigeye or yellowfin, often face two opposite physiological problems:

- A need to eliminate calories when they are swimming in warm waters in which they must prevent overheating. This excessive warming can be compensated by two systems. First they can use a behavioral response, as most tunas can do short dives into the cold deep waters, which can quickly produce a rapid cooling of the body (this was well shown by sonic tagging done on bigeye by Holland). Second, they can also use vascular shunts, which bypass the heat exchanger when necessary.
- A need to reduce the loss of calories from their body, when they are swimming in cold waters. When these tunas are swimming in deep waters in tropical areas, they can move very quickly to the supra-thermoclinal waters, where they will warm up. When they are swimming in cold surface waters at high latitudes, they have no practical possibility of encountering warm waters in their immediate vicinity. In such areas, the conservation of calories becomes a vital issue.

These thermoregulatory devices allow the tuna family to occupy all the epipelagic layers of the world oceans, between the surface and a depth of approximately 500 meters or even deeper, between latitudes 60°N and 50°S.

Tunas show a very large spawning potential and most species are able to spawn millions of eggs during each spawning period, which is several times each year. Most tunas and billfishes show an amazing growth potential, especially during their juvenile stages.

Another major behavioral characteristic of most tuna species is their natural tendency to school: schooling is an aggregation by mutual attraction which provides protection against predation, facilitates efficient reproduction and reduces drag when moving. These tuna schools are often monospecific, but they are sometimes plurispecific, with tunas of similar sizes, generally small fishes. Tropical tuna schools also show a worldwide tendency to be associated with floating objects (natural or artificial, anchored or drifting). Large biomasses of tunas, for instance 20 to 50 tonnes of tunas, and often more, are commonly taken in each set done on such floating object. Various other species of fishes, such as dolphin fish, sharks, billfishes, triggerfish, etc., are also often associated with these flotsam schools. This behavior is not clearly understood, as the food available for tunas associated with these flotsams is not sufficient to feed such large biomasses of tunas. Furthermore, there is a good probability that small tunas may starve when they stay too long under the flotsam, and also possibly face a higher risk of predation by large tunas, sharks and billfishes living under the flotsam.

1.3. Tuna Migration and Movement

Both biologists and lawyers most often classify tunas and billfishes as being “highly migratory species” (Caracas law of the sea). This biological characteristic is really a major one for most tuna species. Tuna migratory behavior has been well proven by various tagging programs conducted worldwide on several tuna species and stocks. These tagging data have provided the strongest and most convincing evidence that most tunas (and also billfishes) can easily move over large distances, often within short periods of time. Various tagging techniques have been used to study the tuna movements; these include:

- Plastic spaghetti tags, have been widely used worldwide to tag great numbers of tunas, allowing the evaluation of the movement patterns of entire populations. This traditional tagging technique was the most commonly used by scientists during the last 50 years.
- Significant numbers of individual tunas have also been tagged with sonic tags since the early 1970s. Research vessels followed each of the tagged tunas over several hours or days, in order to follow their short-scale vertical and horizontal movements. These sonic taggings have provided large amounts of information on most tuna and billfish species in the three oceans.
- Archival tags were developed more recently by Australian scientists, and have been used to provide records of the daily vertical and geographical movements of large individual tunas (bluefin tuna and bigeye) over long periods of time.
- Pop up archival tags are tags which can be released after a given period, planned in advance by scientists. They can also transmit data by satellite after being released from the fishes, thus increasing the amount of information collected during the study period. These new tags are highly valuable, because they can be recovered at a given time, independently of the fisheries. This characteristic is extremely useful, as tunas can often move into unfished areas (where they cannot be recovered), or because some fishermen may not be cooperative in reporting their tag recoveries.

Migration patterns are highly different among the various tuna species. The potential to migrate over large distances tends to be in proportion to the size of the fishes: small tunas (juveniles of large species, or small tuna species) in general tend to show smaller movements than large individuals. This is, for example, the case when comparing skipjack and bluefin movements:

- Individual skipjack can do large-scale movements (well proven by various long distance recoveries of tagged skipjack), but it appears that on the average, the real exchange of skipjack biomasses between remote areas is quite limited. Small tunas, again such as skipjack, cannot survive a long period in cold waters (for instance less than 20°C). They will then stay most of their life in the vicinity of warm waters, showing a more or less continuous spawning activity when they are in those warm waters (above 25°C).
- The opposite behavior is shown by large tunas such as bluefin or adult yellowfin (or billfishes) which will more frequently conduct long distance migrations. These large adult tunas tend to seasonally migrate each year between the feeding zone (most often in cold waters, often located at temperate latitudes) and the spawning zones. The spawning zones are most often located in warm waters, in the subtropical or equatorial areas. These spawning areas are often typical of each species, or each subpopulation. In each of these spawning zones, tunas are searching, often over a short period of time, for the combination of the specific environmental conditions that will allow good survival for their larvae and early juveniles. It appears that many tunas show very precise spawning and feeding locations (for instance yellowfin, albacore and bluefin). They are probably sensitive to the earth's magnetic fields, since they use magnetite particles which work as a compass. This internal compass is probably used in combination with other environmental clues (visual, olfactory, water currents, etc.). These biological facilities allow tunas to carry out fast and efficient transoceanic migrations between their spawning and their feeding zones. It is not proven whether tunas show a strict homing behavior, allowing each individual to return to the precise stratum of its birth (exact location and date). This hypothesis is probably realistic for various tuna species, such as bluefin, albacore and possibly yellowfin tuna. The homing behavior is, for instance, quite clear for southern bluefin, as the adults of this stock, which are scattered at around latitude 40°S around the Antarctic, need to migrate in to their small and unique spawning zone located south of Java. Homing is also a realistic hypothesis for the Atlantic yellowfin, since multiple transatlantic recoveries have been observed each year, from spawning yellowfin tagged off the US coast, and recovered off West Africa in spawning condition.

Various studies have been developed since the early 1980s, using various genetic techniques, to better evaluate the genetic heterogeneity within each tuna species (between samples taken in various geographic areas). Among other goals, these analyses target a better evaluation of the genetic homogeneity (or heterogeneity) of the various tuna stocks. The studies have provided, for various tuna species and stocks, especially during recent years, a much better understanding of the genetic structure within and between oceans. Further improvement of the analytical technique, and the analysis of larger samples covering larger zones, are expected in the near future, to provide more valuable information on the structure of tuna populations and stocks. However, most tuna experts think that these genetic techniques will never replace the tagging programs, since tagging will remain the only way to provide a huge amount of diverse quantitative information on the various tuna movements (at various scales). Modern tagging using the various types of tags, and genetics, will probably both be used in future tuna investigations.

1.4. Ecosystem Overview of Tunas and Other Species in the Pelagic Offshore Ecosystem

Tunas are fishes perfectly well adapted to the oceanic environment worldwide. The interesting ecological peculiarity of this group is that few tuna species have colonized most of the epipelagic waters in the World Ocean. Each tuna species is now perfectly adapted to live within a combination of the various pelagic ecosystems worldwide. As a consequence, it is striking to observe that the major tuna species are distributed in the three oceans—Pacific, Indian and Atlantic, where each species occupies similar ecosystems. Skipjack tunas, for instance, are mostly abundant in the warm equatorial ecosystems, while the albacore occupies each of the oceanic gyres (north and south of the equatorial ecosystems). Bluefin tunas primarily occupy the temperate ecosystems at the northern and southern limits of the gyre occupied by the albacore, while various small tunas, such as the genus *Sarda*, or the little thunny genus *Euthynnus*, are mostly abundant in the epipelagic waters of the coastal ecosystems. The behavior and migratory patterns of each species are also very similar in the three oceans. These ecological similarities are not surprising, as they are simply the consequence of homogeneous biological characteristics for each tuna species, independently of the ocean, and of the great similarities between the various pelagic ecosystems.

Tunas, billfishes and sharks are the major and few top predators fished in the offshore pelagic ecosystems. Few other species (such as squids or salmon) are significantly fished in these offshore areas. Large mammals, with very large biomasses, much larger than tunas, are not significantly caught by any fishery. The various mammal populations are presently (at the beginning of the twentieth century) showing a slow increasing trend in their biomasses, and probably increasing competition with tunas. All these apex predators—tunas, billfishes, sharks and mammals—are consumers of pelagic fauna, primarily relatively smaller individuals: a wide and heterogeneous group of epipelagic (including small size and juvenile tunas) and mesopelagic fishes, mollusks (squids) and crustaceans (pelagic shrimps and crabs). Part of this food targeted by tunas, such as herring, mackerels, sandeels or anchovies, is also taken from the continental shelf ecosystems. All tunas and billfishes also show a wide flexibility in their feeding behavior: most of these species are opportunistic predators feeding on a large range of suitably sized forage fishes, crustaceans, squids and even siphonophores (medusae). They can be described as opportunistic feeders. Most tuna species can target a wide range of potential preys at different seasons or in its range of habitat and feeding areas. Most of this food available to the predators in the offshore epipelagic or mesopelagic layers is still primarily unfished, since most of the world fisheries are targeting mainly the coastal or bottom resources. It should also be noted that large adult tunas have few predators because of their sizes, and are only the potential preys of toothed whales, large billfishes and large sharks. Juvenile tunas must face a potential predation from a much larger group of species including various species of adult tunas, and their own parents (cannibalism being significantly observed among tunas). A peculiar case of predation, frequently observed on longliners, is the predation by mammals (mainly from the genera *Orca* and *Pseudorca*) of tunas and billfishes which are already hooked on the lines. This predation is highly variable in time and area strata, but predation rates of 30% and more have been observed during some fishing operations by longliners.

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Biographical Sketches

Alain Fonteneau is a French scientist working for the Institut de Recherches pour le Développement (IRD), a governmental agency conducting multidisciplinary research in various developing countries of the intertropical areas. He has been working on various tuna species, primarily in the Atlantic, but has also done various comparative analyses between tuna stocks and fisheries in the Atlantic, Indian and Pacific oceans. He did his Ph D thesis on stock assessment on the Atlantic yellowfin tuna in 1981 (University of Paris), and has actively participated in all the scientific work done on the Atlantic tunas within ICCAT since 1970. He has published various papers and chapters of books on tuna biology and stock assessment methods or analysis of tuna stocks.

Tom Nishida is a Japanese scientist working at the National Research Institute of Far Seas Fisheries, in Shimizu, Japan. He earned his M. Sc.. at the University of Washington (School of Fisheries). He has since been studying the biology, stock structure and dynamics of tunas, primarily in the Indian Ocean, since 1985. He did his dissertation on the Indian ocean yellowfin tuna at Tokyo University, and is working on southern bluefin tuna and other species.

Izumi Nakamura is a Japanese scientist who is associate professor at Kyoto University. He graduated from the Department of Fisheries at Kyoto University and obtained a master's degree (Relationships of fishes referable to the subfamily Thunninae on the basis of the axial skeleton). In 1980, he obtained his doctoral degree on the systematics of the billfishes (Xiphiidae and Istiophoridae) from Kyoto University. He has participated in multiple research cruises on board various Japanese research vessels to study tunas and billfishes.

Bernard Séret is a French scientist working for the Institut de Recherches pour le Développement (IRD) on the systematics, fisheries and conservation of sharks. Since 1980, he has been involved, in taxonomic studies on elasmobranch fishes (sharks, skates and rays) for the IRD (ex ORSTOM), first, those from the eastern tropical Atlantic, then those from the Indo-Pacific region (Madagascar, Philippines, Indonesia and New Caledonia). He took part in numerous oceanographic and deep trawling cruises in the tropical Atlantic and in the southeast Pacific, and has worked with several institutions and museums around the world.