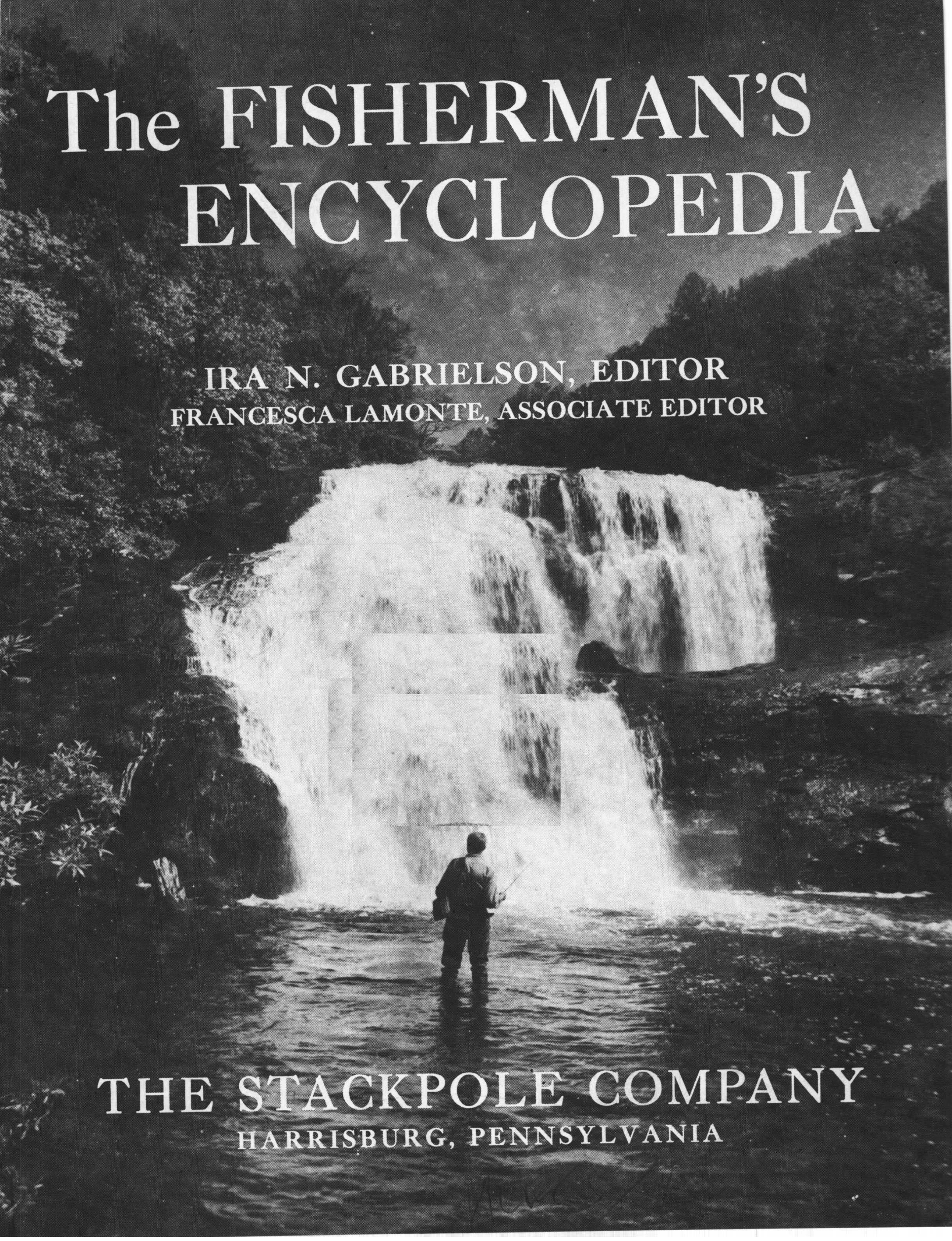
THE NEW FISHERMAN'S ENCYCLOPEDIA

the modern angler's complete answer library on what man knows about all kinds of fish and all kinds of good fishing

The FISHERMAN'S ENCYCLOPEDIA

IRA N. GABRIELSON, EDITOR

FRANCESCA LAMONTE, ASSOCIATE EDITOR



THE STACKPOLE COMPANY

HARRISBURG, PENNSYLVANIA

FIRST EDITION
First Printing, 1950
Second Printing, 1954
Third Printing, 1958

SECOND EDITION
First (Revised) Printing, 1963

Library of Congress Catalog Card Number: 63-22468

Printed and bound in the United States of America
By THE TELEGRAPH PRESS, *Established 1831*
Harrisburg, Pennsylvania

ACKNOWLEDGMENTS

The preparation of this volume would have been an impossible task without the wholehearted cooperation of a long list of anglers and writers who have contributed their knowledge and work to it.

In addition to those specifically listed, every state fish and game organization has furnished information or photographs, or both, either directly to the editors or to the writers assigned to develop certain subject matter. The conservation organizations of the Canadian Provinces did likewise. The U. S. Fish and Wildlife Service, the National Park Service, the U. S. Forest Service, the American Museum of Natural History, the International Game Fish Association, the Smithsonian Institution, the New York Zoological Society, and a host of organizations other than those mentioned have been helpful in many ways.

The fishing tackle industry and the boat building groups have likewise been generous with their help and information.

Every effort has been made to give suitable acknowledgment for drawings, diagrams, and photographs, and it is hoped that no mistakes or omissions have occurred.

The individuals who have contributed material, together with the subjects covered by them are listed in the Editorial Staff which appears opposite the title page.

The color plates of flies, plugs, spinners, spoons and odd lures are from original Kodachromes by Wagstaff and from art and photos by William F. Blades.

The fly patterns shown are based on original designs of Orvis and other pioneer fly dressers, as tied by Lucille Oliver.

The color plates of the panfishes, the Bass, the Walleye Pike, the Pickerel, and the Muskellunge are from original paintings by Fred Everett.

The color plates of the Salmon and Trout are from original paintings by Campbell Grant.

James B. Trefethen, Jr., in addition to subject matter credited to him, has been most helpful in various editorial tasks.

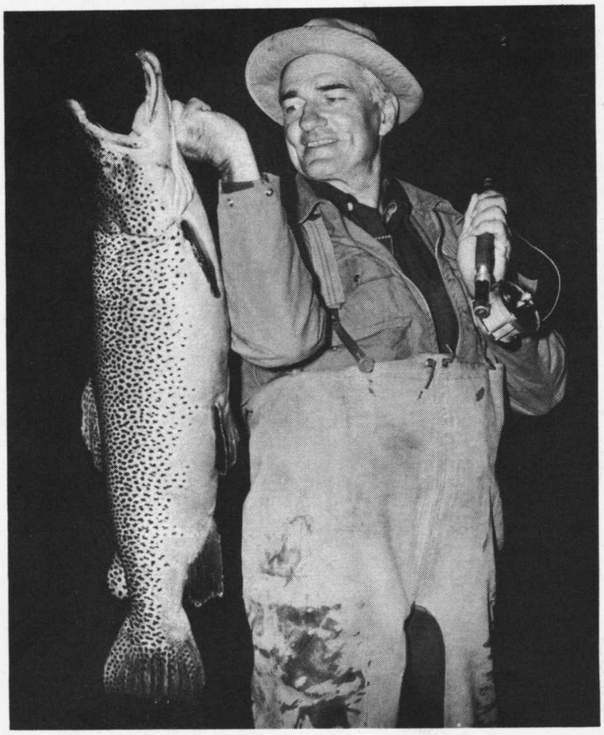
A large share of the burden of checking, editing, and proofreading has, however, been the responsibility of Peggy Wagner, to whom special credit and thanks are due.

The mechanical production of the book was under the direction of George F. Miley of The Telegraph Press, Harrisburg, Pennsylvania.

The editors wish to express their profound gratitude to these individuals listed above and to all others who have helped in this undertaking. They hope that the resulting book will be useful enough to North American anglers to justify such effort.

IRA N. GABRIELSON, *Editor*
FRANCESCA LAMONTE, *Associate Editor*

AN EXPERT SPEAKS



In this age of ever-increasing appreciation of the importance of water in our daily lives, especially with regard to its recreational value, there is a corresponding increase in interest in the creatures that swell in the water. Following right along with this, in logical sequence, comes a tremendous increase in interest in fishing. And every fisherman, whether he be a veteran of many years astream, or a tyro trying out his first rod, wants to know more about his favorite sport: what fish he will find, where, when, and how to catch them.

The new, revised Fisherman's Encyclopedia has the answers. This very complete compilation of practically everything to do with fishing is crammed with authentic information. It is a fine volume, a tome, in fact, covering all phases of angling from A: the beginnings of fish and fishing, to Z: the latest in tackle and technique and boating innovations. It provides all the pertinent data about many species of fish, both fresh and salt water dwellers, including their habitat, their habits, their food, the best time to go for them, the best methods; and it encompasses the complete range of interest to anglers, from tiny bream to giant oceanic swimmers which inhabit waters far out of sight of land.

If the beginner would take this encyclopedia, pick out a single fish he would like to catch, go through the information about it, step by step, the where, when, and how, he would be able to go astream with this new-found information, and catch fish.

Aside from the technical data regarding the species of fish, the angler will find many more items of interest and education, including up-to-date world record charts on many species of both lake and stream as well as ocean.

From the pages of the Fisherman's Encyclopedia you may discover how to fashion a fly, construct a rod, tie the many intricate knots that are so important to the angler. You may pick up a hundred other tips that give the reader a head start towards better fishing and greater enjoyment of the wonderful sport of fishing. Nothing is left out of this great book, in a text that covers many sidelines to fishing as well as the sport itself. You can find the kind of fishing craft you should use, and the motors. There is detailed information about camping, a chapter full of suggestions and points for more safety and greater comfort out of doors, informative matter about insect repellents, pack trips, what to do when lost in the woods—name it, look for it, and almost certainly you will find it here, in a truly great encyclopedia welded together from the contributions of a fine group of men each one of whom is an expert in his field.

The color plates add the finishing touch. These are excellent illustrations of flies and lures, as well as many species of fish, adding greatly to the beauty of a volume which should be in every fisherman's library.

Joe Brooks

PREFACE

Man, having always been an omnivorous animal, undoubtedly has caught and eaten fish along with other aquatic foods from earliest times. It is entirely probable that when the human ancestors first commenced to walk upright, they fished much as do the most primitive tribes known today by catching stranded fish in shallow pools with the hands, knocking shellfish from the rocks of the ocean beach with stones or prying them loose by means of sticks, even perhaps taking advantage of of fish already dead and washed up on the shores. Numerous tribes still fish with primitive traps made of sticks which are placed upright across the stream to form a blockade against which fish are driven by men wading up or down the stream. Long before historical records began, men had learned to make and use more efficient devices for catching fish. Some obscure early genius had developed a fish spear made of a stick, perhaps only sharpened at first, but later tipped with a stone or bone point; primitive lines were made of vegetable fiber and gorges which are the earliest known ancestors of the modern hook of wood or bone were in use. Some remote Eskimo tribes have fished with these gorges until recent times and perhaps some still do.

The point at which man first began to fish for fun as well as for food is likewise unknown. Earliest historical paintings and records from Assyria, Egypt, China, and the cave dwellers of Europe, all depict fishing scenes. In the earliest of these, the spear, the net, the rod and the line, were known and pictured. Obviously the rod and line were used as a device for sport, as well as for getting food.

Since these written records cover but a fraction of the period that man has lived on the earth, there has undoubtedly been a close, and for man a fortunate, association since his earliest days.

Zoologists are generally agreed that fish or fish-like creatures were the first to develop a backbone and are therefore the presumed forerunners of all vertebrate life. Fossil remains of fish have been found back into the Cambrian period of the Paleozoic era—that is almost as far back into the Paleontological record as any remains of living forms have been discovered.

While modern fishes have developed into forms far different from these earlier forms, primitive fish much like them still exist along side their more modern relatives.

Fish were an abundant and ancient group when ancestral forms of man first appeared. They are still an abundant and successful group that has furnished food and later both food and recreation to man throughout his entire existence.

Man has always used fish as a source of food and still utilizes a great many species for food. Fish provides the main source of protein foods in many lands and many more species are thus utilized than are considered sport fish.

Man undoubtedly had crude fishing implements many thousands of years before the historical record began. Since that time, changes in implements have been slow. For example, it required a period from about 2000 years B. C. to the 16th or 17th century to make the change from the Egyptian method of fastening the line to the end of the rod to a running line. This revolutionary new running line passed through a series of guides on the pole and was drawn in by hand and later stored on the first crude reels.

The first reel, according to Dr. Turrell was mentioned by T. Barker in a book entitled *The Art of Angling* printed in 1651. Dr. Turrell pays Mr. Barker the doubtful compliment of saying that in addition to writing about the first reel, he was also the father of poachers. Up to that time the running line was not used for salmon and big pike, and before the reel was developed, the anglers only hope of handling an exceptionally large fish was to throw rod, line, and all into the water, and hope to recover it later when the fish had worn himself out fighting the rod.

While progress was slow, development of modern tackle, which began in comparatively recent time, has greatly expanded the number of devices used successfully in fishing, as well as the number of people enjoying the sport.

Bone, stone, horns, and even wood were used successfully in forming the first crude hooks which were developed from the gorge, a straight piece of bone or stick of wood with a line about the middle. Naturally, artificial baits, such as spinners and flies, were among the last to appear, but there are now thousands of pattern variations of the few basic forms of artificial lures.

Many fishermen enthusiastically debate the merits of the various types of angling. Advocates of each form regard it as pleasurable above all others. In truth, the frame of mind of the angler and ability to enjoy the time out-of-doors is perhaps more important than the type of fishing. A growing number of people get their greatest enjoyment in using very light tackle in angling, but the old cane pole, bobber, and worm still have devotees by the hundreds of thousands. To these the bullhead and catfish furnish as much recreation and relaxation as the finest fly fishing for trout gives to the confirmed flyrod enthusiast.

This is the important element of fishing. Fishing has grown into the greatest single avocation pursued by those interested in the out-of-doors. There is no way to estimate the total number, but annual state fishing licenses in the United States are close to 20 million and growing each year. When those who can and do fish on their own lands without licenses, women who are still exempt from licensing provisions in many states, children under the minimum license age, and the other categories of persons who for one reason or another are not required to buy a license are included, it all adds up to a huge army fishing for recreation and relaxation. Angling, in one form or another, occupies the attention of more people than any other participation sport or recreation. Hunting undoubtedly comes next, and the total number of people who enjoy these forms of outdoor recreation exceed that of all other participation sports combined.

This, then, is the justification for this volume. It is an attempt to gather within the covers of one book useful and pertinent information for this great army of people who are interested in fishing in North American waters.

In preparing this volume, the "Standard Check List of Common Names for Principal American Sport Fishes," compiled by the Outdoor Writers Association of America, has been generally followed. In a few cases, particularly for Pacific Coast species and those found in Mexican waters, names are not included in this list. In such cases Miss Francesca LaMonte's *North American Game Fishes* or Special Publication No. 1 of American Fisheries Society entitled "A List of Common and Scientific Names of the Better Known Fishes of the United States and Canada" have been used. The first-named publication has been widely circulated among outdoor writers and anglers in a praiseworthy effort to reduce the confusion in common names for common game fish. It seems fitting that the *Fisherman's Encyclopedia* designed to aid anglers follow the same pattern. Some local names remain partly because of an effort to tie these names to those selected for general use. Some lapses have inevitably occurred despite every care to follow an established pattern.

IRA N. GABRIELSON, *Editor*

FOREWORD

Here it all is: everything that every fisherman ever needs to know about fishing. Here are the game-fish themselves, equipment and methods of angling, fishery management, places to go—the what, the where, the when and the how. Everything, in fact, but the why.

Why do people fish? The FISHERMAN'S ENCYCLOPEDIA doesn't say. Nary a word is to be found, amid all these voluminous contents, to explain what perverse impulse, what freakish strain, what incomprehensible urge causes an otherwise normal and sane citizen to don a pair of uncomfortable rubber waders, lace a dozen pounds of hobnailed boots onto his aching feet, truss himself helplessly in canvas-vest and landing net and creel, and hike upstream ten miles in a pouring rain, fighting midges and black flies, scratching his face on brambles, wincing whenever the elastic strap of his landing net catches on a twig and then lets go like a slingshot, smacking him smartly between the shoulder blades. Why does he undergo all this, in order to stand patiently all day in icy water up to his hubs, casting his rod back and forth till his arm aches, wet and sore and blistered and mosquito-bitten and hungry. And, in all probability, fishless.

Why, indeed? Is it because he wants the fish to eat? I doubt it. For a few cents, and one-tenth the amount of time and trouble, he could walk down to the market and buy a pound of halibut. Moreover, I've seen too many fishermen work an hour to bring a trout to the net, reach down and grab him firmly behind the gills, release the fly—and then turn him loose again, to disappear under a rock with a final grateful wag of his square tail.

Is it for the sport of casting, then? Maybe, a little. There is no thrill like that of presenting a fly accurately, watching it ride well-cocked down a riffle, and suddenly seeing the water explode around it in a shower of iridescent drops, feeling the heavy weight on the line, hearing the skirl of the reel as the captive trout races for white water. I still remember the expression of profound pleasure on the face of Ted Townsend, who initiated me into the mysteries of dry-fly fishing several decades ago on the Beaverkill. Ted had paused on the bank and tied an exquisite copy of the fly that was on the water, a Female Beaverkill, and had cast it across the pool, setting it down as lightly as thistledown on the water. As we watched, a live male fly, with love-light shining in his eye, spotted the artificial female and settled down amorously beside her. A trout rose just then, but it didn't choose the real fly. It grabbed Ted's. You can't ask a nicer tribute to an angler than that.

But I think there is another and deeper reason why people fish. It is an age-old desire that moves all of us—whether the dry-fly purist, the spinner-fisherman, the salt water angler, or the kid with the willow pole and catawba worm. It is something that cannot be defined, even in an encyclopedia; but the urge is there whenever an angler wades into a new pool, or looks down from a bridge at the water below, or starts in his canoe across a silent lake at dusk. It has something to do with peace, and contentment, and soul-satisfaction, and the realization that for a moment, at least, nothing else in the world really matters.

So, if you are an angler, that is why you fish; and, if you fish, this book will tell you how and where and when, as described by the leading experts in their fields, gathered together and edited with loving care by one of the country's outstanding authorities on wildlife and the out-doors, Dr. Ira N. Gabrielson. Read it, study it in camp at night, take it along with you in your canoe.

But don't drop it overboard, I warn you. If a fish should happen to swallow this Encyclopedia, and digest all the information contained in its pages, there'd be no more taking him on a hook and line. He'd know as much as the fisherman.

—COREY FORD.

INTRODUCTION

Fish Biology and Evolution*

DEFINITION OF FISH

A lone fisherman on the end of a city dock was asked—

1) To define a fish: "A fish has scales and fins with sharp spines in them."

2) Why does a fish die so soon after it is caught? "Its gills dry up and it can't breathe."

3) Why can't it breathe? Isn't there lots of air? "Yes, but it can only breathe in the water."

4) Is an eel a fish? "Yes." Has it got gills? "Yes." Scales? "No."

5) Is a shark a fish? "No. What good is it?" Has it gills? "Maybe." Or scales? "No only little sharp points on the tough skin."

6) Is a whale a fish? "Yes." Has it scales? "No."

7) What is an animal? "Cats, dogs, cows." Is a fish an animal? "No. A fish is a fish." Is a bird an animal? "No. A bird is a bird—with wings."

8) Does a fish have a backbone? "Yes." How about an eel? "An eel is like a snake or a worm; no backbone."

9) Can you name any others with a backbone? "Cows, sheep, dogs."

10) What is a vertebrae? "Part of the backbone."

11) Does a fish suffer much when it is caught? "Not much. Their nerves ain't sensitive like ours."

Fishermen with a wider experience will note that the "lone fisherman's" answers are a mixture of truth and error. For example, not all fish have sharp spines on the fins. Many, such as Salmon, Trout, Bonefish and Pickerel have soft-rayed fins. It is, alas, much easier to *describe* a "typical" fish, such as a Striped Bass, than it is to give a brief comprehensive *definition* that will include all of the thousands of known species of fish and at the same time exclude all other known kinds of animals. Scales, for example, while characteristic of most fish are very small in Eels and entirely wanting in most Eels and Morays, as well as in Seahorses, Trunkfish, and others.

A relatively simple definition of fish is as follows: *A cold blooded, aquatic vertebrate animal with internal gills, which are supported in a segmental skeletal frame.*

This definition covers all known living and fossil fishes, which are comprised in the following super classes and classes, or main divisions:

1) Agnatha ("jawless") including fossil Ostracoderms and the living Lampreys and Hagfishes.

2) Chondrichthyes (cartilage fishes): Sharks, Rays, Chimaeroids.

3) Placodermi (plate skins): armored Devonian fishes with peculiar jaws.

4) Osteichthyes (bony fishes): fossil and recent Ganoids and Heleosts.

5) Choanichthyes (fishes with internal nares); fossil and recent Lobefins (Crossopterygii) and Lungfishes (Dipnoi).

THE PYRAMID OF OCEAN LIFE

The pyramid of fish life is based upon the billions of marine algae and other plants, including the microscopic diatoms. These contain chlorophyll or similar pigment, which under the influence of sunlight builds up carbohydrates and other food material. These minute plants with their food products are taken in by myriads of copepods or shrimplike crustaceans. The great schools of Herrings consume both diatoms and copepods, and are, in turn, pursued and devoured by many swift oceanic fishes, including Bonitos, Marlins and Swordfishes, as well as by flocks of sea birds. Even the greatest of the whalebone whales fill their vast mouth-cavities with the copepods and Herrings.

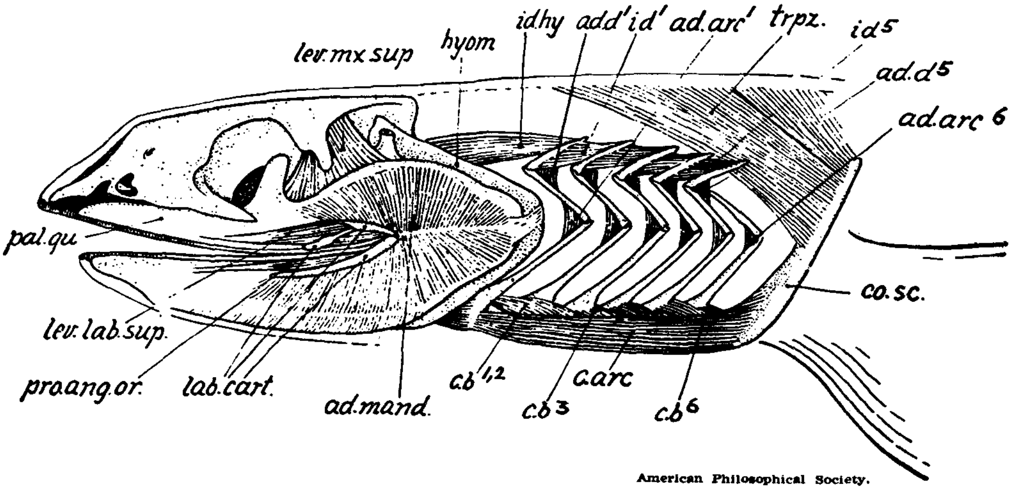
JAWS AND TEETH OF THE BONY FISHES

Most fish have sharp teeth and jaws for killing and cutting up smaller fish. The highly protrusile lip-jaws of some spiny finned fishes will be noted below.

In the Parrot-Wrasses, the front teeth are fused into a solid, parrotlike beak. These fish also have a crushing and grinding mechanism in the throat, for cracking and grinding the shells of crustaceans and mollusks. The Porgy and the Sheepshead have short, very strong jaws with cutting incisors and pebblelike molar teeth. Similar adaptations are found in the Drum *(Pogonias)*. The Marlins and Swordfish have the rostrum or front part of the skull prolonged into a great spear, cylindrical in the Marlins, flattened in the Swordfish, with which they can pierce or strike other fish. Swordfish, on account of their great weight and speed, develop a great momentum and piercing force, and there are authentic cases of Swordfish piercing the copper-sheathed sides of wooden ships. In the Spoonbill, a highly specialized Sturgeon, the huge rostrum forms a flat bill not unlike that of an ibis. It is probably used for probing in the mud for small creatures and is covered with sensory nerves. In the Seahorses and Tubefishes the very minute jaws are at the end of a long tubular structure, and only very small food bits can be taken into the tube.

Some fish with toothless jaws, including the Carp, have toothlike structures in the muscular pharynx

* By William K. Gregory, Curator Emeritus of Fishes and Comparative Anatomy, American Museum of National History. Da Costa Professor Emeritus of Vertebrate Paleontology, Columbia University.



A skull and branchial arches of frilled shark.

or throat. In most fish the inner surfaces of the gill-arches are studded with sharp, horny spines usually directed backward and serving to push the prey down the throat. In the Whale Shark these structures are organized into an enormous, complex sieve which permits the water to escape but retains the small creatures which form most of the food.

JAWS AND TEETH OF THE CARTILAGE FISHES

The cartilage fishes have also a very wide variety of jaws and dental apparatus. The teeth of Sharks correspond with the minute prickly denticles on the surface of their skins and are likewise formed in pockets on the embryonic skin. In typical Sharks the teeth have sharp points and/or jagged cutting edges, but in the Port Jackson or Heterodont Sharks the teeth are flattened down and arranged in transverse whorls around the margins of the upper and lower jaws. Such pavement teeth are used in breaking and crushing the shells of crabs and molluscs, and in some of the larger Eagle Rays they give rise to a powerful dental mill. In the giant Manta or Devil Ray, however, the teeth are reduced to a narrow strip of minute denticles running around the inner border of the jaws, and the huge mouth is used for engulfing small creatures.

The typical fish has the same *general* arrangement of the parts of the digestive tract as in higher animals, including man. That is, its digestive tract includes the mouth cavity, jaws, pharynx (containing the gills and gill arches), esophagus or gullet, stomach, intestine. The latter, however, in bony fishes usually has many fingerlike outgrowths or pyloric caeca. In Sharks and Rays there is a large "spiral" valve in the intestine which greatly increases the surface for absorption of the nutritive contents.

THE "JAWLESS" LAMPREYS AND HAGFISHES

The Lampreys and Hagfishes, although eel-like in external appearance, are not at all closely related to the Eels, but seem to be the sole existing representatives of a long extinct class, the Ostracoderms (see below). These voracious fish prey upon other fishes by fastening themselves to them with their suctorial lips and by rasping the flesh of their victims with their flexible filelike "tongue." Their dental apparatus consists of two main parts: 1) the circular sucker formed by the large lips which are studded with concentric rows of thornlike, horny teeth. Within these lips are three curved, smooth cartilaginous plates, one within the other, the first two sliding over each other and the third attached to the fore part of the skull which is braced to support them. 2) The long, narrow tongue bears a long strip of small, sharp horny teeth and it can be protruded and pressed against the victim and held there by the suction of the lips. Unless the rasplike "tongue" is really a much changed lower jaw, the Lampreys and Hagfishes have no internal jaws, and partly on this account they have been classified as a separate grand division, subphylum or superclass, Agnatha (jawless), whereas the subphylum or superclass Gnathostomata (jaw mouths) includes all the "normal" fishes, as well as the classes of Amphibia (frogs, toads, salamanders, etc.), Reptilia, Aves (birds), and Mammalia (mammals).

SOUNDS MADE BY FISHES

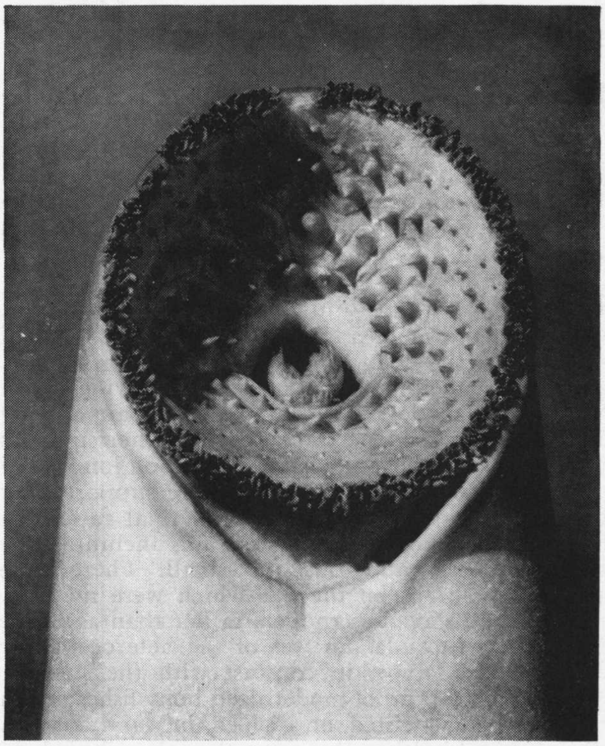
Many kinds of fish make sounds under water, some by grinding their molar teeth, as in the Drum, others by rubbing the strong front ray of the pectoral fin against part of the shoulder girdle. Malay fishermen, by submerging their heads, can hear these sounds and can distinguish the direction and type of fish that is making them.

FISH AS COLD-BLOODED ANIMALS

Fish are "cold-blooded" animals. The body temperatures of fishes vary with that of the environment. Some, including the Icefish *(Salanx)* of the far north, can even be frozen in ice and yet remain capable of resuscitation whenever the temperature of the water rises. At the other extreme, a few fishes live in the hot springs of volcanic regions. But in between are the multitudes which live in tropical and temperate waters while some thrive in arctic and antarctic waters. Even in the great ocean depths, where the temperature is barely above the freezing point, many kinds of deep sea fishes pass their lives in this chilly environment. Thus in fishes from cold climates or considerable depths, the temperature of the body is barely above that of the medium. This has the advantage that very little food has to be used in maintaining a high body temperature, while a relatively greater amount may be spent in searching for more food. However, in the Bonitos and Albacores which are swift and untiring in their pursuit of the Herring schools, the breast is partly insulated by a network of fine blood vessels beneath the corselet which comprises the scales of the pectoral region. This no doubt facilitates the greater oxidation in the gills and conserves part of the heat which is always generated by muscular action.

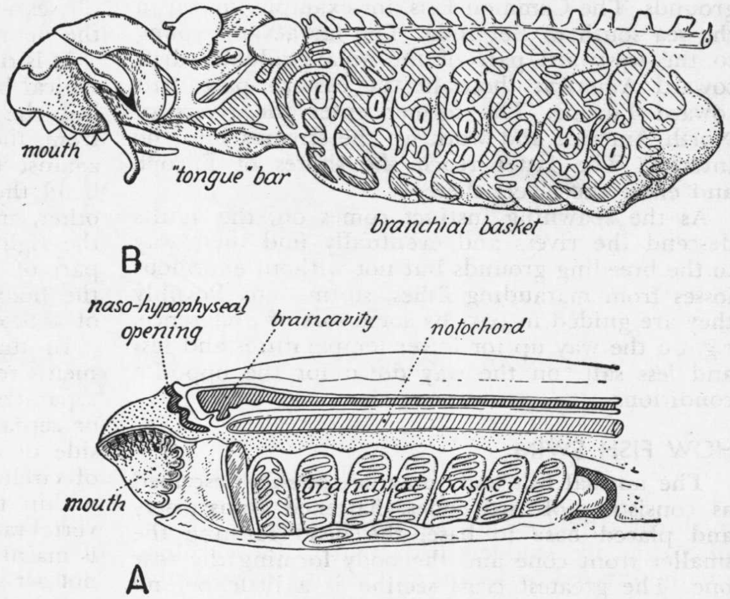
REPRODUCTION

The methods of reproduction also vary widely among fishes. Among the cartilage fishes (Sharks and Rays), the rear parts of the ventral fins of the males are rolled up into large grooved or tubular rods called claspers. In breeding, these are inserted into the cloaca of the female and serve for the passage of the sperms. Thus the ova in Sharks are fertilized *internally,* whereas in *typical* bony fishes they are fertilized *externally,* that is by the union of the eggs and sperm outside the body of the mother, namely in the water. A few highly specialized bony fishes have however become "live bearers," especially the Guppies and Swordtails (*Xiphophorus*) in which the males have developed copulatory tubes and fertilization is *internal.*



'World of Fishes," Amer. Mus. Nat. History.

The lamprey's suctorial, rasping mouth.



American Philosophical Society.

Cartilaginous skull of lamprey adult (A) and larval (B) stages.

In the cartilage fishes the yolk or nutritive material for the young (which is secreted in the uterus) is usually very voluminous and the egg when extruded is already covered with a tough fibrous horny shell. The shell is usually four cornered with spiral threads at each corner. The embryo slowly develops in the shell into a little Shark or Ray. In some Sharks and Rays, however, the egg shell is very thin and the young are long retained in the uterus, where they may even get additional nourishment by diffusion from the walls of the uterus through their yolk sac.

In the typical bony fishes the fertilized eggs floating in the water develop rapidly into minute actively swimming larvae. These feed on very small food until they grow large enough to change into young fishes that can seize, take in and digest the same kind of food that sustains their parents. Although Sharks and Rays richly endow their young with nutritive material they care little for the young after the latter are hatched or born. A few of the bony fishes, on the contrary, make nests (*e.g.* Bowfins, Sticklebacks) in which the female lays the eggs. The Gouramis make "bubble nests," the female Seahorse (*Hippocampus*) deposits her eggs in a broad pouch on the ventral surface of the male where they develop into miniature Seahorses. Certain male Catfishes and Cichlids hold the eggs in their mouths until the young are large enough to be hatched. On the whole, however, the bony fishes have, as it were, chosen to produce very large numbers of small yoked eggs, running up to over 400,000 (as in the case of the Codfish). Most of them are lost or devoured, but a very few live to go through the larval and young stages and grow up to reproduce their kind.

FISH MIGRATION

Some fishes make long migrations from the place where they are hatched to the distant breeding grounds. The Common Eels, for example, spawn in the sea south of Bermuda. The larvae and young to the westward part of the area gradually drift toward America; those in the eastern part drift toward Europe. The former enter the rivers of North America and work up the streams into the interior. The latter reach the shores of Europe and enter the rivers there.

As the spawning instinct comes on, the adults descend the rivers and eventually find their way to the breeding grounds but not without enormous losses from marauding fishes, storms, etc. Possibly they are guided in part by some sort of preference, *e.g.* on the way up for lower temperatures and less and less salt; on the way down for the opposite conditions.

HOW FISH SWIM

The normal fish body may be roughly described as consisting of two cones, flattened transversely and placed base to base, the head forming the smaller front cone and the body forming the rear one. The greatest cross section is a little behind the head, through the shoulder-girdle and bases of the pectoral fins. In high backed, deep bellied forms such as the Angelfish, this section is a high narrow oval; in wide low-headed forms it is more transversely oval as in certain Cottids *(Myoxocephalus)*. Nearer the tail the cross-section narrows and the ovals become higher, ending in the vertically placed tail fan.

The height and width of the cross-section behind the head are determined by the dimensions of the muscles of the back, back and flanks and in the lower part by 1) the amount of food in the digestive tract, 2) the quantity of eggs in the oviduct, and especially by 3) the position of the ventral fins. If the latter are attached beneath the pectoral fins, the belly is usually deep; if they are far behind the pectoral fins, the depth is usually slight, as in many long-bodied fishes. Sometimes the dorsal fin becomes very high and its right and left muscles extend on to the top of the skull. Meanwhile the skull-roof has grown upward to form a supraoccipital crest which braces the skull-roof and affords anchorage for the dorsal fin muscles.

In side view, the two cones with a common base are adjusted to each other and enclosed in a flowing streamlined skin, the "entering angle" being greater than the "run" or slope of the back.

The head, including the jaws, cranium, gill arches and gill covers, being swung a little to one side by the muscles of the same side, then serve as the fulcrum for starting a wave along the side of the body toward which it is turning; at the next instant the head is pulled toward the opposite side to start a wave along that side of the body. The body itself is not limp or inert but possesses more or less elasticity, spring or recoil, due in part to the resistance of the dice-boxlike vertebral centra, to the relative incompressibility of the interarticular discs, and to the tensions and compressions that are set up in the ligaments that tie one centrum to the next. In Marlins the strength of the recoil is greatly increased by the overlapping of long vertical bladelike processes called zygapophyses which pass on either side from the base of the neural arch of one vertebra to the next.

It is often thought that the fanlike caudal fin of typical bony fishes is the chief organ of propulsion, but the fact is that the principal thrusts come from the sides of the body. These are pressed against the water by the muscle segments which bend the body now on one side and then on the other, much as a skater thrusts alternately with the right or left leg. The caudal fin may deliver part of these thrusts which pass like waves down the body to the tail, but its chief service is that of a flexible rudder.

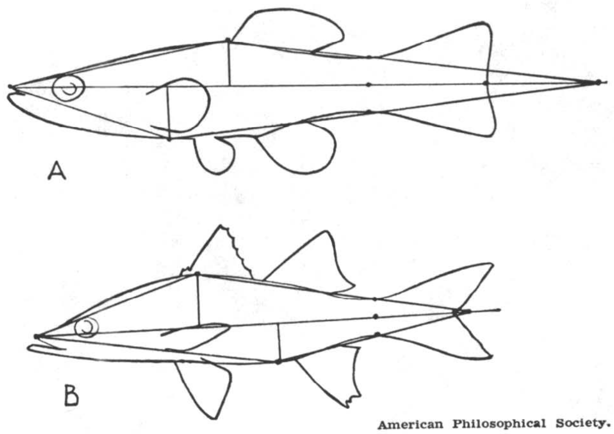
In the side view the myomeres or muscle-segments reveal a zigzag arrangement, each one being separated from the next by connective tissue sheets or septa. In cross-section the myomeres on either side of the mid plane appear as concentric series of circles, for they are like conical foolscaps, one within the other, each extending forward several vertebrae beyond the one to which each myomere is mainly tied. The myomeres of opposite sides do not act simultaneously, like the rowers in an eight-oared shell, but in succession and alternately. In general the muscles of locomotion and those of the jaws and gill-bars are arranged in opposing pairs, like flexors and extensors of the human arm. Thus one muscle can act as a brake on its opponent, permitting fast action or slowing down and preventing jerkiness, or dislocation at the joints.

The rib-like processes springing from the sides of the vertebrae are formed in the spaces between the septa surrounding the myomeres and serve both to protect the abdominal cavity and to transmit the tensions from the myomeres to the vertebral centra. The slender neural arches perform a similar service for the spinal nerve cord and its lateral branches, the spinal nerves.

The core of the vertebral column is the notochord, which is formed in the embryo as a cylinder of connective tissue filled with vacuolated cells. As growth proceeds, the vertebral centra form around in notochord which contracts in the middle of each centrum to a thread and expands between the centra to form the intervertebral discs or buffers.

PRINCIPAL BODY-FORMS

Among the more ancient and primitive types of bony fishes the body was fairly elongate or spindle-shaped, not eel-shaped, and already provided with single median dorsal and anal fins, a pair of long based rather short pectoral fins with their muscles mostly inside the body, and a pair of long-based rather low pelvic fins. The fins were supported by rows of little scales united into dermal rays. The muscles that moved the median fins including the tail fins were numerous and small. There were little or no webs on the fins which were not very flexible and served as rudders rather than as prime movers. The caudal fin was of the heterocercal or low sharklike type, in contrast with the strongly muscled fantail fin of modernized bony fishes which can be bent, twisted or cupped in various ways. From this primitive type arose the following, along different branches.



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Body forms of fishes.

1) Many short, highbacked, quick-dodging forms, with wide fantails and long-based vigorously waved dorsal and anal fins, on the steep rear slopes of the back and anal regions.

2) Heavy, long-bodied, sinous eel-like forms, with all fins reduced.

3) Short and deep bodied forms, with the abdominal fins moved forward and tied by the rod-like pelvic bones to the lower arch of the pectoral girdle. These are the spiny finned bony fishes which in turn gave rise to very many kinds of body-form from short and high to very long and eel-like.

4) Short bodied, plump or boxlike forms covered with prickles (Porcupine Fish) or enclosed in a mosaic of bony plaques (Trunkfish). In these the greater part of the backbone is immobilized and the pectoral fins have become the principal motors, the caudal section serving chiefly as a rudder, but partly for sculling.

5) The Ocean Sunfish *(Mola)* type, in which the body became extremely short, the backbone nearly immobilized and the dorsal and anal fins, becoming enormously high, took over the chief locomotor function. Extensions of these fins meeting behind the stump of the original caudal fin fused to form a large new or false caudal fin.

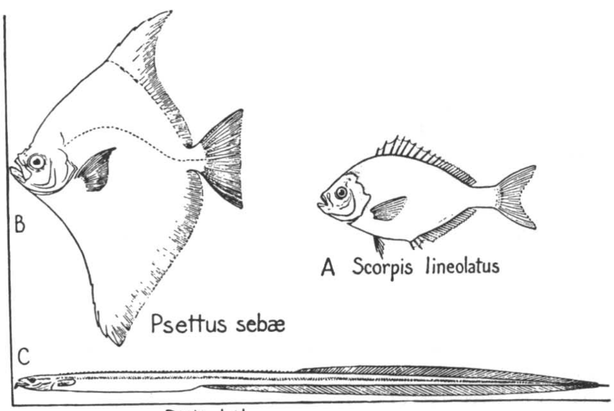
6) Some originally compressed deep-bodied forms of the Scorpaenoids of Bonefish family, became secondarily elongate while their heads were widened and enclosed in a bony helmet or shield. Here belong the bottom-feeding members of this family, including the Gurnards and some of the Cottids and related families.

There are many other strange body-forms, such as those of the Tubefish and Seahorses already noted, but the more central types from which they seem to have been derived are in numerous cases still existing.

Among the cartilage fishes, the relatively large pectoral and pelvic fins suggest that the most primitive forms lived in shallow water and rested on the bottom. Some of them, however, developing a more spindle shaped body and a large crescentic tail, took to ranging on the open seas, as in the Tiger Sharks, Mackerel Sharks, and others.

The tail in primitive Sharks is *heterocercal,* that is, long and rather slender, turned up more or less, the end with a long web on the lower border, and a very small fin on the tip. The tail-fin like all the other fins is supported by blocks, rods, or rays of cartilage, not by scales fused into dermal rays.

At the other extreme, the ancestral Skates specialized in searching for shellfish on the bottom. In them the pectoral fins became enormously large and finally acted somewhat like wings, thrusting against the water both on the upstroke and down-



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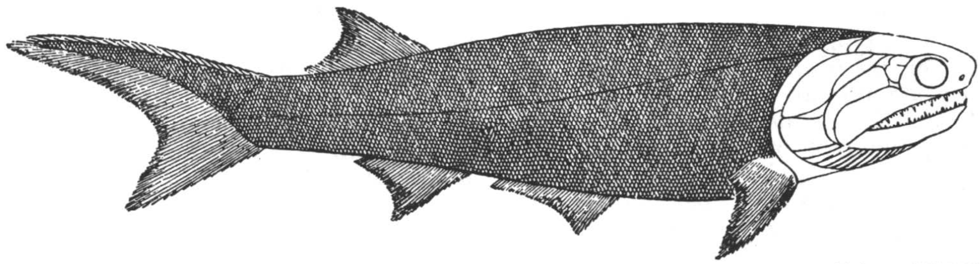
Body forms of fishes.

stroke and culminating in *Pteroplatea,* the "Butterfly" Ray, with very wide pectorals, reduced pelvics and a vestigial tail.

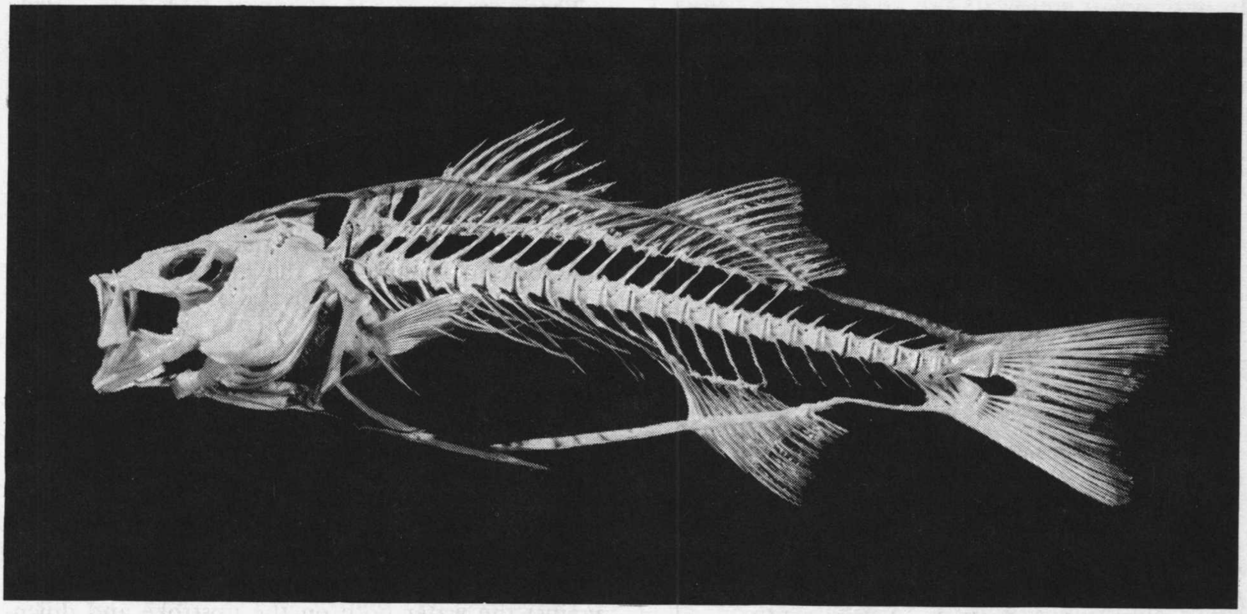
THE SKELETAL FRAME

There is a close correlation between the outer body-form and its skeletal frame. As noted above, in fish with a small entering angle the skull is low, and usually the back and its neural spines are also low. In the Opah or Moonfish the back is only



Parker and Haswell.

Primitive Devonian Ganoid.



Mounted by Mr. Theo. Schneider, Amer. Mus. Nat. History.

Skeleton of striped bass.

moderately high, but the belly is extremely deep, and with it the lower part of the shoulder girdle is enlarged and produced far downward. Again both the dorsal and the anal fin of the short-bodied *Psettus sebae* are exceedingly high, so that the upward slope of the forehead and the downward slope of the throat and belly are very steep, and the skeletal frame closely follows these contours.

The skull, as a whole, forms the prow or entering wedge, but experience shows that this wedge is usually rounded in front and that the greatest transverse diameter of the body is across the shoulder girdle just behind the skull and the skull and the gill covers. A long bill, flattened from above downward, as in the Swordfish, must have a considerable effect as a bow rudder, and in swift swimming it must tend to keep the fish from pitching up and down. The upwardly sloping skullroof consists mainly of the right and left frontal bones fused in the midline and usually strengthened by oblique ridges. The frontal rests in front on two stout tranversely wedgelike bones, the parethmoids; these in turn rest on the long keel bone (parasphenoid) in the midline of the skull floor. The lower front part of the wedge is formed by the median vomer and behind this by the ethmoid bone containing the smelling organs and braced against the frontals and parethmoids. The latter also form the front part of the great orbital depression or socket for the eyes. The nasals are small surface bones lying above the nostrils. They rest in the rear on the frontals and in front on the ethmoid. They are usually tunneled by the forepart of the lateral line canals which are continued backward along the roof of the skull, over the shoulder girdle and along the sides of the body. The lateral-line organs which they enclose are said to respond to vibrations of low frequency, such as those reflected from other objects. Thus, they may be useful either in pursuit or avoidance.

The core of the upper and lower jaws of bony fishes, and the entire upper and lower jaws of Sharks, have essential structural features in common with the hyoid and branchial arches behind them, and are believed to be parts of two much modified gill arches which have lost their gills. In the Acanthodians (ancient fossil fishes of the late Paleozoic era, estimated age 250 million years) there were rows of little gill-covers attached to the rear of the upper and lower jaw-bones as well as others on the upper and lower segments of the hyoid arch, and on all the branchial arches. This arrangement further supports the view that the inner jaws and hyoid arches were once part of the "oralo-branchial" (mouthgill) apparatus.

The front part of the upper jaw in such typical spiny-finned fishes as the Perch and Bass consists of two bones, the "premaxilla" and "maxilla," on each side. These bones are sometimes called "lip-jaws" but they are not fleshy lips. When such a fish gets near its prey the sudden lowering of the jaws and protrusion of the lip-jaws creates a partial vacuum in the water and the prey is sucked into the mouth-cavity where further movements of the hyoid and branchial arches tend to pull and push it down the throat. This sucking adaptation is much less developed in the less progressive, more old fashioned types of surviving fishes, such as the Garpike and the Bowfin *(Amia),* where the upper lip-jaws are firmly attached to the cheeks.

The front upper "lip-jaws" (premaxillae) rest on top of the vomer and against the ethmoid. They are movably tied by ligaments to the neighboring bones. The rear upper lip-jaws (maxillae) were originally fastened to the surface bones of the cheek below the eye, but in the typical spiny-finned fishes they have become separated from the cheek bones at their rear ends and remodelled into levers for protruding the front upper lip-jaws (premaxillae). Their rear ends are tied by ligament both to the rear part of the premaxillae and to the upper part of the lower jaw. Their front or upper end bears two knobs: the front inner one on each side slides and rolls upon the upper surface of the vomer, and has an upper roller bearing surface for the premaxilla. The rear outer knob rolls chiefly on the ethmoid and is held in place by an overlapping fork coming up from the palatine. When the lower jay is lowered in front, the rear ends of the maxillae are depressed and the premaxillae are automatically rolled and pushed forward and downward by the maxillae.

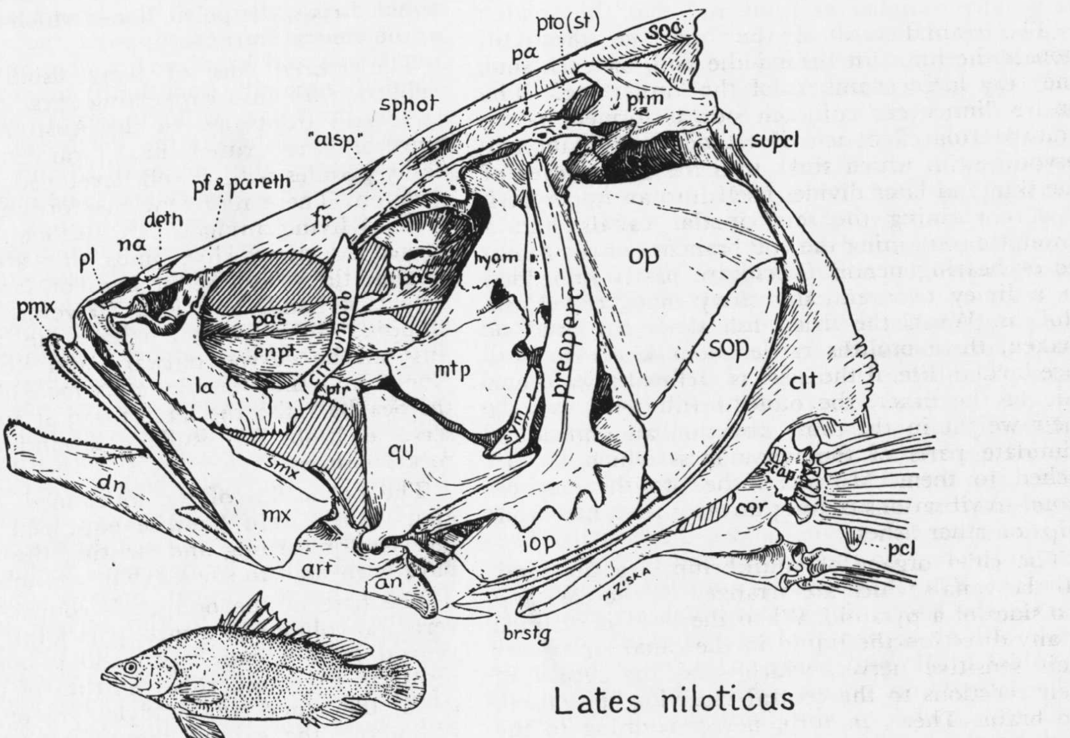
Protrusile premaxillae of a somewhat different type have been evolved convergently among the Carps. In these fishes the lower jaw is both thrust forward and lowered and its large ascending processes on each side push forward the maxillae and premaxillae.

The inner upper jaws of bony fishes form the Bony palate or roof of the mouth and are divided on each side into paired bony plates named palatines, pterygoids, entopterygoids, and metapterygoids. They converge in front, the palatines fitting behind the median vomer, while the entopterygoids spread out toward the sides and the rear, and attach themselves above to the metapterygoids and below to the quadrates. The metapterygoid of each side extends upward to the upper front border of the hyomandibular, and the quadrate extends to the lower front border of that bone. Consequently when the hyomandibulars are swung outward like elbows by their muscles, they spread the rear parts of the palate outward and, through the quadrate bones, they widen the space between the rear sides of the lower jaw. Meanwhile the muscular floor of the jaws may be contracting or relaxing. Thus the whole walls and floor of the mouth chamber can be expanded or contracted in dealing with the food and in breathing.

The rear lower part of the inner upper jaw consists in part of the large quadrate bones on either side; these are braced in front by the heavy plates of the palate and in the rear by the large hyoid arch; the main part of the latter is called the hyomandibular. This important bone of the skull fits above into two sockets on the under surface of the skull roof, and by means of these knuckle-like joints and appropriate muscles the opposite hyomandibulars can be bowed out away from the skull at their lower ends, spreading apart the opposite sockets in the quadrates for the lower jaw and thus adding to the pumping, sucking, and swallowing effects of the branchial apparatus and jaws as noted below.

In the embryo bony fish, the core of the lower jaw on either side is a bar of cartridge, called Meckel's cartilage, which corresponds with the cartilaginous lower jaw in the Sharks, Skates, and Rays. The rear part of the Meckel's cartilage on either side is replaced by bone cells and that part is called the articular bone. The articular bone on either side bears on its rear end a paired groove into which fit the knuckle-like condyles of the quadrate bones. The front parts of the Meckel's cartilage become enclosed on each side in a sheath of dermal bones bearing teeth on their upper surfaces and called dentary bones.

Thus the jaws of bony fishes are complex mechanisms including the outer upper lip-jaws, the inner or palato-pterygoid plates, the quadrates with which the lower jaws articulate; while parts of the hyoid arch (hyomandibular and symplectic) impart lateral swallowing movements to the jaws.



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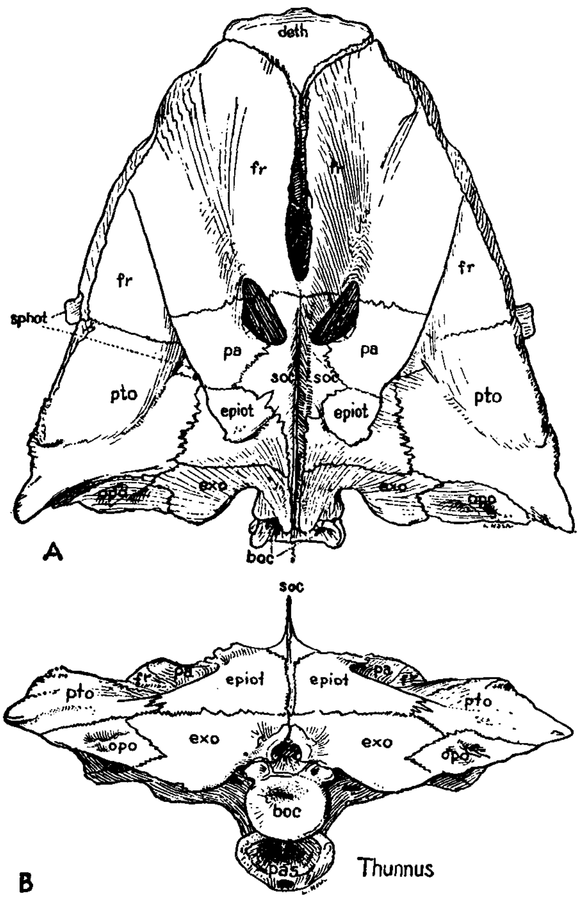
Skull of Lates niloticus.



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Skull of Thunnus.

The cranial vault or rear part of the skull houses the brain in the middle and, on each side, the very large chambers of the "inner ear." The entire "inner ear" of each side is formed in the embryo from a pouch of ectoderm or outer embryonic skin, which sinks into the lower layer of the skin and later divides itself into an upper division, containing the semi-circular canals, and a lower sac containing the end-branches of the acoustic or hearing nerves. These are partly imbedded in a limey or eventually stony mass, called the otoliths. When the dried fish skull is moved or shaken, these otoliths rattle about like dice in a dice box. In life, if the head is inclined toward one side or the other, the otoliths will tend to shift their weight in the same direction and no doubt stimulate parts of the nerve mass which are attached to them. Moreover, the otoliths may respond to vibrations coming through the water from ships or other fishes.

The chief organs of equilibrium are the semi-circular canals which are arranged on the base and two sides of a pyramid. When the head is inclined in any direction the liquid in the canals runs over their sensitive nerves, which send the record of their reactions to the central receiving stations in the brain. There, in turn, nerves running to the motor system start its complex adjustments.

The eyes in most fishes seem to be the dominant directive organs, and doubtless play an an important part in the capture of a dodging fish. By keeping one or both his eyes on the target, the fish may, as it were, automatically make the right adjustments as he dashes at the prey.

Near the upper end of the hyomandibular on each side on the rear border of that bone is a prominent ball-like eminence upon which fits the socket on the inside of the large curved operculum or lid; the operculum, sub and inter-operculum together with the branchiostegals below, cover the branchial apparatus and the operculum projects backward so as to overlap the outer curved margin of the main bone of the shoulder girdle, which is called the cleithrum. This cleithrum is a crescent-shaped bone with a long lower horn directed forward under the throat and tied to its fellow on the opposite side. The cleithrum of either side is overlapped on top by a lathlike bone and this in turn leads to a rodlike bone, the post temporal, which ends above in three forks each of which is attached by ligaments to different points of the occiput or rear wall of the skull. Thus the entire complex shoulder girdle in the typical fish is tied to the skull above; below it is embedded in the muscles of the floor of the throat. The shoulder girdle not only forms the bony frame for the body wall but also protects the heart and gives anchorage to the coracoid and scapular plates. These in turn are the bases for the muscles that raise and lower the pectoral fins and at the same time they furnish the row of sockets for the several small bones at the base of the fin.

The pelvic fins usually form a horizontally placed double fan on either side of the vent and are based upon a pair of forward and inwardly directed rods, the pelvic bones which are imbedded in the ventral muscles.

The paired fins of bony fishes are usually webbed, with thin supporting rays, except for the large stiff front ray. In the Australian Lungfish, however, the paired fins form large muscular fleshy paddles with a well developed jointed inner skeleton. These represent the fore-and-hind limbs of land living animals, but although they can be turned downward, like limbs, they are not able to support the weight of the body on land; moreover, they lack hands and feet. However, in the Mud Skipping Goby of the Far East, the large pectoral fins can be curved outward and downward like elbows and their fanlike ends look like hands. In the Sea Bats also the large pectoral and pelvic fins serve as limbs for shuffling around on sandy or rocky bottoms.

The pelvic fins of the lobefinned (Crossopterygian) fishes, were likewise equipped with strong muscles for turning and twisting the fin and may have been used to some extent as limbs.

The base of the occiput is connected with the vertebral column by a three-part joint; one median ventral joint is cup-shaped and is bound by ligaments to the checkerlike centrum of the first vertebra, the other two condyles are on either side just above the exit of the spinal cord from the skull to the vertebral column. These lateral condyles are tied by ligaments on either side to the centrum of the first vertebra and they prevent both vertical and oblique dislocation of the spinal column, while permitting enough sliding movements for turning the head and undulating the column.

Below the tail end of the vertebral column are attached two triangular bony plates, called urohyal bones and several rodlike bones (hypurals); from these arise the complex muscles that move the tail fan. This is composed chiefly of strong dermal rays forking at the lower ends where they are fastened to the tail-bones. The tail-fan is provided with several strong straight or oblique muscles at the base on the urohyal bones, which can elevate or depress or twist the fan. There are also smaller stringlike muscles running radially outward to the individual fin-rays. These undulate the outer border of the fin, somewhat as the human fingers can run up and down along five white keys of a piano.

Thus the skeleton of a typical fish is very complex and composed of a great many pieces; but it is full of meaning and interest if studied as part of a living mechanism. But it should not be overlooked that most of the individual bones resist bending or compression, while the tendons and ligaments transmit to the bones the tensional forces generated by the muscles. Hence a dried skeleton without the ligaments, tendons, and muscles presents a very imperfect picture of the entire machine.

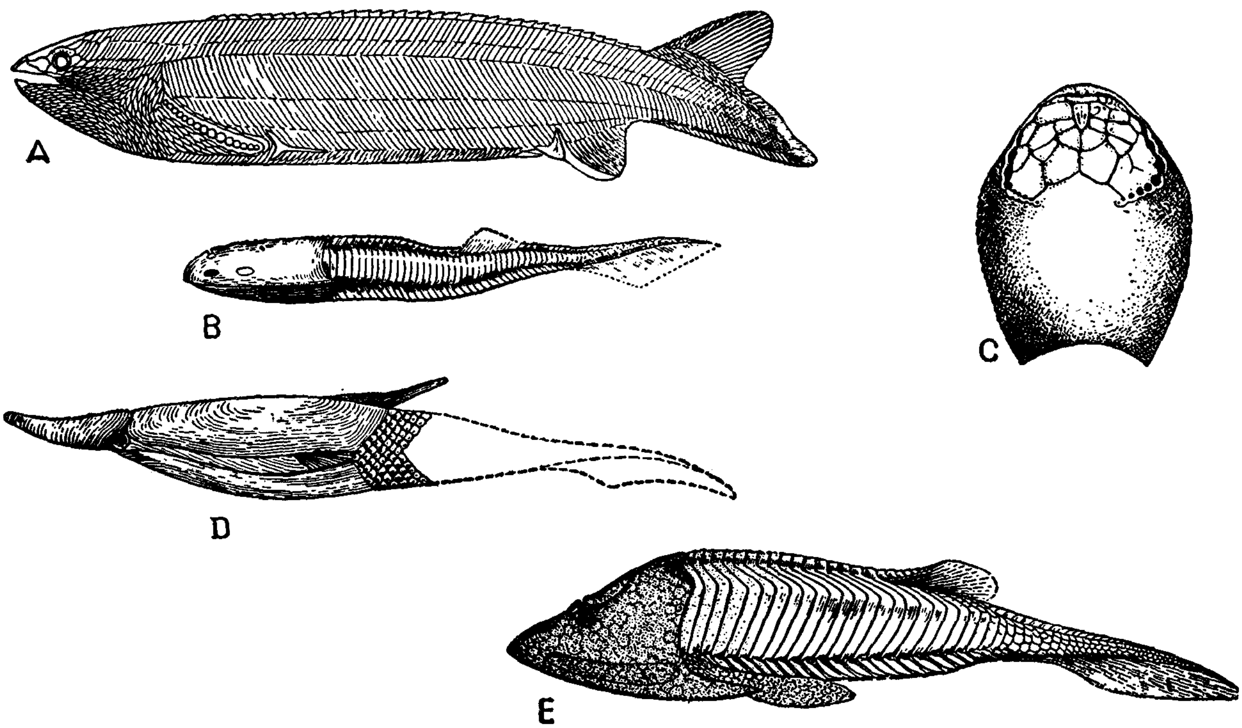
FOSSIL HISTORY, EVOLUTION, AND MAIN DIVISIONS

The oldest known fossil fish-remains consists of minute scales and part of a small head shield, found in sandstones of the Ordovician period near Boulder, Colorado. Physicists and geologists estimate that these sandstones were deposited about 380 million years ago, long before the Rocky Mountains were uplifted.

More and better preserved fossil material of the same class is found in rocks of the succeeding Silurian and Devonian ages, especially in Russia, Great Britain, and North America.

These earliest fishes are called Ostracoderms (literally, shard skins) because their fossilized scales and head shields now look like small fragments of pottery. In the family Cephalaspidae (head shield) true bone cells, secreting concentric layers, may be seen under the miscoscope in thin sections of the head shields. The base of the head shield consisted of horizontally deposited layers; the middle parts were perforated by numerous larger canals and smaller blood vessels; the outer layer comprised rows of tiny blocks, each with a bushlike system of fine canals in the middle and a thin layer of glassy enamel on the surface. This very complex many-layered, hard crust was less fully developed in the Coelolepids (hollow scales) and Thelodonts. Here the front part of the body was somewhat skatelike and the surface was covered not with continuous armor, but with small thorny or flattened denticles resembling those on the skin of Sharks.

The heavily armored Cephalaspid Ostracoderms were probably slow moving bottom-living fishes, grubbing in the muddy sands for small creatures. The Anaspid Ostracoderms on the other hand had small heads and thinner scales and were gracefully formed, not unlike small Herring, but with downturn tails and apparently lacking a bony inner skeleton. Another group of Ostracoderms included the Pteraspids, which had a many layered shield around the head and thorax but were lacking in bone cells. In some of them the shield was



From "Our Face From Fish to Man" by Dr. W. K. Gregory.

Ostracoderms.