HONORS EXCELLENCE OCCASIONAL PAPER SERIES

SHARK SEX!
SHARK DIVERSITY, EVOLUTIONARY SUCCESS & VIVAPARITY

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THE HONORS COLLEGE
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Biographical Note

During 1985 and 1986, Dr. José Castro conducted a survey of shark species found off Trinidad and Tobago for the FAO (the Food and Agriculture Organization of the United Nations), in order to determine the feasibility of shark fisheries in the area. He discovered that living and fresh-caught Yellow or Golden Hammerhead are a striking bright yellow or orange and economically important in Trinidad, as it is one of the most abundant sharks in market catches; it also is part of the by-catch of shrimp trawlers and of various small gill net fisheries. Every day, Dr. Castro was able to examine dozens of specimens at the Port of Spain fish market. Castro also used mesh bottom gill nets to catch these sharks throughout most of the year, thereby filling in many gaps in our knowledge of the basic life history of this remarkably pigmented shark.

Dr. Castro is a resident scientist at the Mote Marine Laboratory (MML), an independent, nonprofit marine research institution with a nearly 50-year history of shark research. The Center for Shark Research (CSR) there is an international center for laboratory and field research, scientific collaboration, consulting, education, and public information on sharks and their relatives, the skates and rays. The CSR research mission includes basic and applied studies of all aspects of shark biology, from anatomy and physiology to ecology and fisheries science. CSR scientists investigate the various biological adaptations of sharks to their marine environment, with an emphasis on the role of sharks as an important marine resource. Included within the CSR is the MML Biomedical Research Program, which concentrates on sharks and skates as laboratory models for studies of disease-resistance. Designated by the U.S. Congress in 1991 as a national research center, the CSR conducts cooperative research with the National Marine Fisheries Service (NMFS) and other organizations.

Publications:


Early Sharks & Adaptation

Sharks are one of the most successful and enduring of vertebrate groups. Their fossil record extends unbroken from the Devonian period, some 400 million years ago, to the present. The earliest Devonian sharks known had already evolved as predators, based on their mouth and dentition that were adapted for seizing and tearing fish. These early sharks were not the dominant predators they are today, but small creatures that were probably preyed upon by the much larger armored fishes that dominated those seas. Sharks have maintained the role of marine predators throughout their long evolution, competing successfully against similarly adapted predators, such as ichthyosaurs and toothed whales, and against numerous groups of bony fishes. Today sharks are the aggressive, often large, predators that dominate the seas. What are the reasons for their evolutionary success? What are the adaptations that have enabled sharks to compete and survive through epochs that brought about the extinction or decline of their competitors?
Unfortunately, we can not turn to the fossil record for clear answers. The fossil record of sharks yields few clues about their evolution. Sharks belong to a class of fishes known as Chondrichthyes or cartilaginous fishes that are characterized by having entirely cartilaginous skeletons and by lacking true bones. This class of fishes also includes skates, rays, and chimaeras or rabbit fishes. Cartilage usually decays and disintegrates shortly after death; thus, the skeletons of cartilaginous fishes are seldom preserved as fossils. Parts of their skeletons (the skull, spines, and vertebrae) are often strengthened by the deposition of calcium salts. When they are well calcified, these parts become sufficiently hard to be fossilized. In most cases, only the teeth, spines and vertebrae are sufficiently hard to be fossilized; the softer body parts are preserved only under exceptional conditions. Consequently, the fossil record of cartilaginous fishes consists mainly of teeth, spines, and vertebrae. These are among the most abundant vertebrate fossils; however, it is difficult, and often impossible, to determine the characteristics of the fishes that bore them. The fossil record does yield one clue: most of the earliest sharks had internal fertilization.

**Reproduction & the Fossil Record**

In animals with internal fertilization, the male transfers its sperm to the female, thus fertilizing the eggs within the body of the female. In male sharks the pelvic fins are modified into hard, tube-like, copulatory organs known as claspers. During mating, one of the claspers is turned forward and inserted into the female’s vagina. Sperm is then forcibly ejected into the female. The claspers of mature sharks are calcified, and they have an expandable tip usually armed with claws or hooks; when expanded, the tip anchors the male securely to the female, hence the name claspers. Because
mature claspers are calcified and hard, they are often preserved as fossils. The fossil record shows that most Devonian sharks had already developed claspers, indicating that internal fertilization appeared very early in the evolution of sharks.

The ancestral mode of reproduction in both bony and cartilaginous fishes probably involved egg laying or oviparity and external fertilization. Oviparous fishes usually produce large numbers of eggs and sperm that are released into the water during spawning. Fertilization occurs in the water, thus it is said to be external. The embryos of oviparous bony fishes are usually provided with only a small amount of yolk that is insufficient to nourish the embryo through complete development. Therefore, these embryos hatch in an undeveloped or larval condition, and require weeks or months after hatching to complete development. Both eggs and young are highly vulnerable to predators and environmental factors for prolonged periods and suffer heavy mortality. Most bony fishes are oviparous, and must produce very large numbers of young to insure the survival of the species. The evolutionary success of sharks is due, in part, to their adaptations that depart from simple oviparity. The most significant of these adaptations are internal fertilization and the production of small numbers of large young, which hatch or are born as fully developed, active, miniature sharks. Internal fertilization insures that the embryos spend their earliest stages inside their mothers, and because adult sharks have relatively few predators, the embryos are protected during their most vulnerable stages. Most species of sharks produce small broods, usually composed of two to a dozen young, although some of the large pelagic species may produce up to forty or fifty young per brood, and a few large deep water species are known to produce over one hundred young per brood. Shark young hatch, or are born, at a relatively large size. Large size reduces their number of potential predators and competitors, while increasing the number of potential prey. Thus, their large size at birth enhances their chances of survival.
The production of large, fully developed young requires that large amounts of nutrients be available to the developing embryo. Sharks have evolved diverse strategies of nourishing their embryos to large size, such as the production of eggs with very large yolks, the ingestion of yolk or fluids by the embryo, and the direct transfer of nutrients from mother to offspring through a yolk-sac placenta. Sharks are either oviparous (egg layers) or viviparous (live-bearers); most species are viviparous.

Oviparous sharks lay large eggs that contain sufficient yolk to nourish the embryo through complete development, allowing it to hatch as a fully developed, miniature shark. Their large eggs are laid, usually in pairs, shortly after being fertilized. The eggs are enclosed in leathery egg cases. The egg cases are made of collagen fibers produced by the shell gland portion of the uterus. Egg cases are rectangular or conical, and are soft and pale when freshly laid; they harden and turn opaque in a few hours. The egg cases are deposited on the bottom or attached to bottom structures by means of adhesive tendrils. Rectangular cases have long adhesive tendrils on each corner for attachment to bottom structures. Conical egg cases have a spiral flange around them which probably serves for burying in soft bottoms or for wedging among rocks. In species whose egg cases have adhesive tendrils, females seek upright bottom structures for egg case attachment. As egg laying approaches, the adhesive tendrils of the egg case protrude through the female’s vent. During egg laying, the female swims in tight circles around an upright structure, causing the trailing tendrils to adhere to it. Once the tendrils have adhered, she increases her swimming speed and the egg is pulled out from her cloaca. The tough, leathery case is the only protection that the embryo receives during its long development, for parental care is unknown in sharks. Development is temperature dependent and usually lasts from a few months to a year. The embryo is nourished by yolk stored in a yolk sac that is attached to the embryo by a yolk stack. Both of these
structures are fully absorbed prior to birth. The young of oviparous sharks are relatively small at hatching because their growth is limited by the small amount of yolk nutrients stored in the egg.

Most species of sharks are viviparous and retain their embryos until development is complete and then give birth to fully developed, live young. Viviparous species can be divided into aplacental and placental species, depending on the absence or presence of a placental connection between mother and embryo. Most viviparous species are aplacental and nourish their embryos without forming a placental connection. The eggs of aplacental sharks
hatch in the uterus before the embryos are fully developed. The embryos continue to grow free in the uterus, without becoming attached to the mother, and are born after they have completed development. There is a great deal of variation of modes of embryonic nutrition within the aplacental species and some species have evolved interesting means of nourishing their embryos.

In the simplest case of aplacental viviparity, as in the case of the familiar spiny dogfish, Squalus acantbias, the female retains the eggs after hatching, providing protection for the embryos but no additional nutrients other than those stored in the egg or yolk sac. All the nutrients necessary to bring the embryo to term appear to be found in the egg. The embryos of the spiny dogfish can be removed from the female long before completion of their two year gestation; and if gently placed in a well aerated, cool aquarium or plastic bag, they will eventually complete their two year development, provided they have not been injured in the transfer and bacteria are not allowed to attack them.

In other aplacental species, such as the sand tiger, Carcharias taurus, and the porbeagle shark, Lamna nasus, the yolk sac is very small and its contents are absorbed very early in development. Thereafter, the embryos nourish themselves by eating eggs and smaller embryos in the uterus, in a form of embryonic cannibalism known as oophagy ("egg-eating"). In oophagous sharks, the ovary of a pregnant female reaches an enormous size, weighing about 3 kg in a 90 kg shark. The eggs, about 7-10 mm in diameter, are packed into soft egg cases each containing seven to fifteen eggs. The embryos acquire a precocious dentition that allows them to break the egg cases and ingest their contents. As the oldest embryo grows, it feeds on eggs and smaller embryos in the uterus. Although as many as twelve embryos may be found in each uterus during the early stages of pregnancy, in a few weeks only one
embryo will survive in each uterus, having consumed its smaller siblings (this type of embryonic cannibalism has been referred to as “the ultimate answer to sibling rivalry”). After consuming all the other smaller embryos in the uterus, the surviving embryos, one in each uterus, feed on eggs constantly being released by the ovary. By mid-term, or when the embryos are 50-60 cm in length, the embryos have acquired distended throats and huge, yolk filled stomachs, appropriately named yolk stomachs. This large, distended stomach persists for a few months; it is absorbed before birth. At term, sand tiger young measure up to 100 cm, a proportionally large size compared to their 230 cm mothers. In some aplacental species, such as the shortfin mako, Isurus oxyrinchus, the embryos, although oophagous, are not cannibalistic, and as many as ten embryos coexist peacefully in each oviduct.

Placental viviparity is the most advanced mode of reproduction in sharks. The embryos of placental sharks are initially dependent on yolk stored in the egg or yolk sac, just as the embryos of aplacental sharks. Their yolk sac is of modest size and its contents are absorbed after a few weeks. As its contents are consumed, the yolk sac grows flaccid and its surface becomes high vascularized. The yolk stalk grows long, having the large, vascularized yolk sac at its distal end. At the point where the yolk sac contacts the uterine wall, the uterine tissues also become highly vascularized and engorged with fluid. It is at this point that the yolk sac becomes firmly implanted to the uterine wall, forming the yolk sac placenta. Then, with maternal and fetal tissues in intimate contact, the nutrients can be shunted directly from the blood stream of the mother to the offspring. In most species, the uterus becomes compartmentalized, each compartment holding one embryo firmly attached to the uterine wall by the yolk sac placenta. Placental viviparity allows many embryos to be nourished simultaneously to large size with a
continuous supply of nutrients, a clear advantage over the limited supply available to oviparous species, or the limited number of embryos of oophagous species.

**Gestation & Evolutionary Success**

Sharks pay a price for the reduction of predation on their large embryos: very long gestation periods and very long ovarian cycles (or how often the females produce eggs). Most sharks have
gestation periods of one to two years. These are the longest gestation periods known in vertebrates (the gestation period of the elephant is 22 months). The ovarian cycle may last one to three years. In some cases the ovarian cycle and gestation occur concurrently; in others, the cycles follow each other. For example, in the spiny dogfish, two year cycles are superimposed. Females carry developing young and developing ovarian follicles concurrently. After a two year gestation, the females have term pups and ripe follicles, both ready to be released. After parturition, the females mate and conceive again. A few species, such as the Atlantic sharpnose shark and some of the hammer-heads, have concurrent one year ovarian cycles and one year gestation periods. In early summer, females carry term embryos and ripe ovarian follicles at the same time. Shortly after parturition, the females mate and conceive again. Thus, females can give birth every year. In most cases of large coastal sharks, such as the sandbar, black-tip, and lemon shark, the cycles follow each other. Females carry developing young or developing follicles. After a one year gestation period, females carry only term embryos; their ovary is in a restive state and carries only immature follicles. After parturition in early summer, these follicles begin development, and will mature the following summer, when the females will mate and conceive again. Thus, a female can produce a litter every other year (biennially). These long ovarian and gestation cycles reflect the long time required for these fishes to accumulate the necessary energy to be transferred to eggs and developing embryos. The long times required are offset by the greater survival rate of offspring.

Other adaptations certainly played a role in the evolutionary success of sharks. Unfortunately again, the fossil record tells us little about these. We must turn to present-day sharks to try to determine what adaptations may have contributed to the evolutionary success of sharks. Their efficiency as predators has probably contributed greatly to their evolutionary success. Sharks have evolved
exquisitely sensitive organs that allow them to detect injured or sick prey at long distances. Using their keen senses of smell, hearing, and electrosensitivity, sharks can locate such prey easily, thus, reducing the amount of energy used in pursuing and overtaking prey, because injured or sick animals require less energy to overcome than healthy ones. Furthermore, sharks possess extremely powerful jaws and very sharp teeth. Their teeth are replaced periodically, so that sharks always have sharp teeth. Armed with their formidable jaws and dentition, sharks have a wide range of prey available. They are not confined to smaller prey that can be swallowed whole like many fishes, but they can attack prey that is too large to swallow, rending a large fish into pieces that can be swallowed, or, at least, carving a large chunk of flesh out of very large prey. Most sharks are opportunistic feeders that will take whatever prey is locally abundant or easily available. Thus, by avoiding dependence on a given prey species, sharks may have survived the many climatic changes that brought about the extinction of many species along with their specialized predators.

All these adaptations have allowed sharks to compete and survive for eons and to become the supreme predators at sea. Today, however, new predators in the oceans, humans, threaten to exterminate many species of sharks. Humans are consuming many species of sharks at such rapid rates that many species are in danger of eventual extinction.
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The Honors College at Florida International University in Miami offers the best of two worlds. It is a small community of outstanding students, dedicated scholars, and committed teachers who work together in an atmosphere usually associated with small private colleges. Yet, we do so with all the resources of a major state university, which is one of the nation's top doctoral/research extensive universities. Only 152 universities in the United States hold this superior rank.

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A student may pursue almost any major available in the University and at the same time complete the honors curriculum. The curriculum emphasizes the following activities: critical, integrative, and creative thinking; group and independent research; oral presentation; close contact between students and faculty; and integration of class work with the broader community.

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Honors Place, a living-learning community in Panther Hall, University Park, is the “in” place to live on campus. Provided space is available, all Honors College students are eligible to live in this great community of local, national, and international students. These multi-talented and multi-interested students are what makes Honors Place the “Best Living and Learning Community” in the state, as recognized by Florida Leader magazine.
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The Honors College has been conducting study abroad programs since 1994 and currently offers opportunities for its students in Spain, Italy, Jamaica, and Trinidad. They are all designed to fulfill one year (six credits) of The Honors College curriculum requirement. The Honors College Study Abroad Programs offer students the opportunity to experience immersion in another culture while pursuing a rigorous academic program integrated with the Honors curriculum. Instruction is in English in all the programs.

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The aims of the Honors College are to

1. Attract the "best and brightest" students from within and outside FIU and provide them a high quality trans-disciplinary educational experience.

2. Enable students to develop critical, integrative, and creative thinking skills and to make connections among domains of knowledge.

3. Facilitate engagement of students in applied and other research collaboration with the finest research faculty as learners and teachers in the scholarly community.

4. Provide mentoring and internship experiences to complement and enrich the knowledge acquired in the classroom and through research collaboration.

5. Offer scope for service learning engagement as a way to build bridges between domains of knowledge and service activity that enhances civic responsibility.

6. Foster a sense of community among students and faculty as citizens with special talents and responsibilities to self, the scholarly community, and society.