The Amazing Sperm Race

"Lone Parents: Parthenogenesis in Sharks"

MATERIALS AND RESOURCES

None

ABOUT THIS EXTENSION

This is an extension piece to the lesson, "The Amazing Sperm Race." It includes an article on parthenogenesis (females reproducing without sperm) with higher-level questions that provide students an opportunity to not only apply what they have learned to a real-world context but, more importantly, allow them to predict future implications of this process on shark populations in the wild.

OBJECTIVES

Students will:

- Apply what they have learned to a real-world example in a cross-curricular context

LEVEL

Biology

COMMON CORE STATE STANDARDS

RST.9-10.1

Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

RST.9-10.2

Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

RST.9-10.4

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9–10 texts and topics.

RST.9-10.5

Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

RST.9-10.8

Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

RST.9-10.10

By the end of grade 10, read and comprehend science/technical texts in the grades 9-10 text complexity band independently and proficiently.

ACKNOWLEDGEMENTS

Holtcamp, Wendee. "Lone Parents: Parthenogenesis in Sharks." Copyright © 2009 Wendee Holtcamp. Originally published in *BioScience*, Vol. 59, No. 7, July/August 2009, pp. 546–550. Permission pending.

ANSWER KEY

QUESTIONS

1. Answers may vary but a well-crafted student response may include the following differences:

Apomictic Parthenogenesis	Automictic Parthenogenesis
Offspring produced by diploid germ line cells (gametocytes) going through mitosis	Offspring produced by egg cell (ovum) combining with a polar body to make diploid zygote
Process includes mitosis only	Process includes meiosis and mitosis
No oogenesis required	Oogenesis required
Offspring are clones of the mother	Offspring are half clones of the mother
Offspring are genetically identical to the mother	Offspring are genetically distinct from the mother

2. Ed Louis knew that it was unlikely that the three female bonnethead sharks had mated while they were juveniles, and even if they had they would not have been able to store sperm for three years.
3. Homozygosity means that the offspring would have identical copies of the same allele for a specific gene, i.e., homozygous (AA or aa). Even under automictic parthenogenesis, the pup would receive two copies of the X chromosomes, making it female.
4. Both parthenogenesis and inbreeding result in a loss of genetic diversity.
5. The first reason is that male and female sharks are not usually around each other unless they are mating. This phenomenon causes the second reason, which is that usually shark fisheries catch only one species due to the fact that they usually only fish one particular area.

WRITING PROMPT

Answers will vary. The students should comment on the struggle between sustaining a viable population and maintaining adequate genetic diversity.

The Amazing Sperm Race

"Lone Parents: Parthenogenesis in Sharks"

NATIONAL MATH + SCIENCE INITIATIVE

The discovery that sharks can reproduce asexually means that mammals are the only jawed vertebrate lineage incapable of parthenogenesis. But can this surprising capacity make any difference to shark survival as their populations decline?

On an ordinary Midwestern morning in December 2001, the aquarium staff at Omaha's Henry Doorly Zoo began their regular morning rounds of feeding. What they discovered made their jaws drop. Inside a 45,000-liter aquarium containing three female bonnet head sharks was an 18-centimeter bonnethead pup. Any shark birth is exciting, but in this case, it was a colossal mystery. The bonnet heads, a species of hammerhead (*Sphyrna tiburo*), had been collected in the Florida Keys as juveniles three years earlier, at just 33 centimeters in length, well before sexual maturity. None had been exposed to a male bonnethead in captivity. If by some odd chance one of the females had mated with another of the tank's species, which included wobbegongs and bamboo sharks, mating scars would have been evident. Could this pup be the world's first documented virgin shark birth?

Parthenogenesis, Greek for "virgin birth," occurs when an egg develops without fertilization by sperm. It does not include self-fertilization by hermaphrodites, which have both male and female parts within the same organism. Many invertebrate species reproduce parthenogenetically, including mites, bees, aphids, walking sticks, and parasitic wasps, but that is exceedingly rare among vertebrate species. Scientists have documented parthenogenesis in a handful of reptilian, amphibian, avian, and teleost (bony fish) species, but it was unheard of in cartilaginous fishes—sharks, rays, and chimaeras—or mammals.

The pup did not survive long; the aquarists immediately sent the carcass for necropsy, where it was determined that a stingray in the tank had bitten the pup, leading to its death. The carcass was then handed over to the zoo's genetics department. Ed Louis, the zoo's head of genetics, had a hunch this would be a scientific breakthrough. "I thought it was parthenogenesis from the beginning," he says, despite scientific naysayers. "The potential to have sperm storage was almost impossible." It seemed unlikely that a juvenile shark would mate, and even if somehow it had, storing sperm for three years seemed a stretch. The chain cat-shark is the only species known by scientists to store sperm longer than a year.

NO MALE REQUIRED

Two different types of true parthenogenesis exist. In apomictic parthenogenesis, common in plants, the diploid germ line cells (gametocytes) do not undergo meiosis to create gametes but rather undergo regular cell division, or mitosis; offspring are clones of the mother. In automictic parthenogenesis, or automixis, the offspring are half clones of the mother.

Normally during meiosis, one diploid gametocyte replicates its chromosomes and splits into four gametes. In females, only one gamete becomes the ovum, or egg cell; this gamete receives the bulk of the cytoplasm and nutrients, while the others become nonfunctioning polar bodies, which typically degenerate. In automictic parthenogenesis, one of the polar bodies fuses with the ovum, stimulating embryonic development. Because chromosomal crossing over—in which genetic material gets exchanged between the mother's paternal and maternal chromatids—occurs during the first meiotic cell division, each polar body differs genetically from the ovum. Each embryo resulting from this process has a unique genome, with half the genetic diversity of the mother. However, automictic parthenogenesis tends to increase homozygosity across most of the offspring's genome. Simply because of statistical probability related to chromosomal assortment and recombination within the same genome, the offspring ends up with two copies of the same allele for most genes. This also means that all offspring are the homogametic sex. Since sharks have an XY sex determination system, all parthenogenetically derived offspring are female, XX.

Louis started genetic analysis, first ruling out the possibility that another species in the tank had delivered a hybrid bonnethead offspring, since no one actually saw the pup being born. This was exceedingly unlikely since no male bonnethead was in the tank, and hybridization has never been documented in sharks. "It was obvious from the beginning that we could eliminate any other species from mitochondrial DNA. That was pretty simple," he explained. Next, they needed to identify which of the three bonnethead females was the mother and determine whether the pup had any unique genes that would have come from a father.

As it happened, Mahmood Shivji, director of the Guy Harvey Research Institute and Save Our Seas Shark Center at Nova Southeastern University in Florida, and Demian Chapman, his graduate student at the time, were in the process of developing DNA fingerprinting for wild bonnethead sharks as part of their research on mating systems. The zoo gave tissue samples to Chapman, who completed the analysis while working as a visiting scientist at Queens University in Belfast, in the lab of collaborator Paulo Prodohl.

"When I saw the DNA fingerprint, I about fell off the chair. None of the profile came from the father. Everything in the DNA profile you could see in the mother." Chapman's microsatellite and AFLP analyses confirmed that the bonnet-head had not hybridized with another species, showed unambiguously which of the three bonnethead females was the mother, and revealed the pup was homozygous at each microsatellite locus tested, conclusively showing the pup was produced by automictic parthenogenesis.

IS PARTHENOGENESIS GOOD OR BAD?

With the rash of virgin births, it appears that shark parthenogenesis may be far more common than previously suspected. With most shark species in dramatic decline around the globe as a result of intense demand for shark fins, the ability of females to reproduce without a male may seem a good alternative reproductive strategy. "The obvious [thought] is, oh, this is cool because sharks can reproduce without mating. Well it's not that simple," Shivji explains. "If sharks are doing this in nature more commonly than people have known about, that would not be a good thing in term of the fitness of the population."

Virgin birth, on the other hand, is akin to extreme inbreeding: Because the offspring are half clones of the mother, widespread parthenogenesis could substantially reduce genetic diversity in shark populations. "There are many cases in other wildlife where animals have a lot of inbreeding, so there's a lot of homozygosity," Shivji says. "As a result of this low diversity, they often have physiological and anatomical defects which make them less capable of functioning in the environment. The Florida panther is a good example." Besides the physical defect of deformed tails, Florida panthers also have reduced sperm counts and motility and, hence, reduced fecundity.

"The conventional paradigm says that you can get much more genetic diversity as a result of sexual reproduction. You've got genes from two different animals, but you have a lot of recombination going on. Crossing over in meiosis generates much more diversity, which produces a healthier, fitter population," Shivji explains. "Now, having said that, there are also organisms that seem to function extremely well with parthenogenesis."

Two factors increase the likelihood that sharks may experience difficulty finding mates as shark numbers decline worldwide. First, in most shark species, males and females do not hang out together except when they mate. "Sexual segregation in sharks is more the rule than the exception," Shivji says. Second, shark fisheries often intensively fish a particular location which, Shivji explains, also increases the chance that all of one sex could be wiped out in a particular region.

Parthenogenesis has a further disadvantage for sharks: Through sexual reproduction, sharks can deliver up to 15 pups per litter; with parthenogenesis, in every case only one pup has been delivered. With egg-laying species, only a few develop from a clutch.

Yet the shark virgin birth discovery gives fair warning: in science, never say never. The Japanese research group led by Tokyo University of Agriculture professor Tomohiro Kono recently manipulated a mouse genome so that a parthenogenetic offspring grew into a healthy and reproductively viable mouse. The process required many steps and was anything but simple, but regardless, it surprised many by showing that under certain conditions, a healthy mammalian offspring can develop with no male genetic contribution.

Holtcamp, Wendee. “Lone Parents: Parthenogenesis in Sharks.” Copyright © 2009 Wendee Holtcamp. Originally published in *BioScience*, Vol. 59, No. 7, July/August 2009, pp. 546–550. Permission pending.

QUESTIONS

Read the following questions and then read the article, "Lone Parents: Parthenogenesis in Sharks." Answer the questions using complete sentences, evidence from the article, and using appropriate vocabulary.

1. Explain three differences between *apomictic* and *automictic* parthenogenesis.

2. Explain why the aquarium staff and Ed Louis thought that the bonnethead shark pup was the product of parthenogenesis.

3. The article argues that "automictic parthenogenesis tends to increase homozygosity across most of the offspring's genome." Using context clues from the article and "The Amazing Sperm Race" activity, determine the meaning of *homozygosity*. Why would this lead to the shark pup being female?

4. How are parthenogenesis and inbreeding similar?

QUESTIONS (CONTINUED)

5. Discuss two factors that might cause sharks difficulty in finding mates in the wild.

WRITING PROMPT

Using evidence from the article and your previous answers, discuss the pros and cons of a shark population undergoing parthenogenesis and then write an argument for one side or the other.