The Life History of Fishes: Age, Growth, Reproduction, and Mortality[1]

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Let's start with a question. Imagine a fish (Species A) that lives to be 5 years old, grows quickly, reaches maturity at a young age, and produces many offspring that have low survival. Now imagine a second fish (Species B) that lives to be 50 years old, grows slowly, reaches maturity at an older age, and produces few offspring that have high survival. Which species can withstand an intense amount of fishing? To answer this question, we need to learn how these biological traits are calculated and what they mean to fisheries managers.

In the fisheries science world, to age a fish means to determine how old it is (typically in years). Age data are integral to fisheries management because they serve as the foundation for age-based stock assessments. Once enough fish of a given stock have been aged, we can look at the stock's age structure – a graphical depiction of the number of fish of each age. We can learn a considerable amount of information from the age structure, including the proportions of young, middle-aged, and old fish, the longevity of the fish, and – where applicable – the age at which the fish begin to be harvested by a fishery.

Since growth – defined as increasing length and weight with time – varies between species and among individuals within species, we cannot age a fish simply by looking at it. For example, imagine trying to guess someone's age simply based on his or her height and weight. Impossible. Instead, we examine a hardened structure from the fish's body, as described in the following four steps.

Step 1: Select a Structure

We choose a structure in which material accretes, or accumulates, over a fish's lifespan. This process creates annual rings inside the structure, like in a tree trunk. Those structures in fish include scales, otoliths, fin spines, and vertebrae.

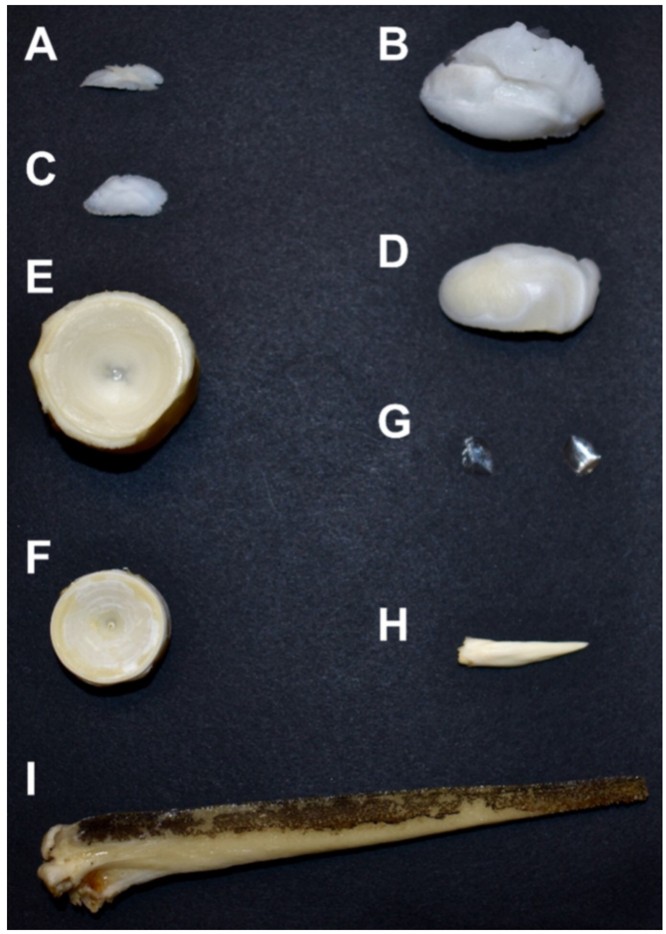

Figure 1. An assortment of aging structures: otoliths from (A) crevalle jack, (B) red snapper, (C) tripletail and (D) red drum; vertebrae from (E) great hammerhead and (F) blacktip shark; (G) scales from Gulf menhaden, and first dorsal spines from (H) tripletail and (I) gray triggerfish. Photo courtesy of Amanda Jefferson.

Scales have been used for aging fishes since the late 1800s. We can easily pull scales from a fish's body without sacrificing the animal. However, the rings inside the scales are difficult to interpret. Moreover, early rings can disappear, which can cause us to underestimate age. Therefore, we primarily use scales to age short-lived species, like Gulf menhaden.

Otoliths (from the Greek, "oto" = ear, and "lithos" = stone) are ear stones. Otoliths exist in pairs (one in each ear) in the inner ears of most vertebrates, and their size and shape vary by species. Unfortunately, we must sacrifice a fish to extract its otoliths. Sometimes otoliths might be difficult to access, extract, or age. Despite these downsides, otoliths work well for aging many fishes (e.g., snappers, groupers, drums). In fact, they represent the most popular structure used in aging studies today (Figure 1).

Fin spines and fin rays provide structural support to the fins. Spines are rigid and pointy, whereas rays are flexible. It isn't necessary to sacrifice a fish to extract a spine or ray. However, these structures often have one of the drawbacks of scales: disappearing early rings. Additionally, spines and rays sometimes contain false rings or sets of multiple rings stacked closely together. For these reasons, spines and rays are typically only used for aging when otoliths are unfit. Examples of fishes aged using spines include tunas, swordfishes, and triggerfishes.

Vertebrae – the bony or cartilaginous parts that protect the spinal cord – are useful for aging elasmobranchs (sharks, skates, and rays), which lack typical scales or otoliths. Elasmobranch vertebrae usually contain mineralized calcium phosphate, which provides a structure for aging. Unfortunately, we must sacrifice the animal to extract its vertebrae. Examples of species aged using vertebrae include finetooth shark, blacktip shark, and southern stingray.

Step 2: Extract the Structure

We use specific tools and methods to extract the various structures.

- To extract scales, we simply pull them from the fish's body using forceps, taking them from the same place on every fish for consistency.
- To extract an otolith, we generally use one of two methods. For the first method, we lift the operculum (bony gill cover), move the gills away from the otic capsule, use a sharp chisel to open the capsule, and pull the otolith out using forceps (Figure 2). For the second method, we saw through the skull with a serrated knife or butcher saw and then pull the otoliths out of the skull with forceps.
- To extract fin spines or rays, we use a sharp knife to cut the structure out of its anchor point at the base of the fin (where the fin meets the body).
- To extract vertebrae, we use a sharp knife to cut several consecutive vertebrae from the vertebral column (the backbone).

Figure 2. A fisheries scientist extracts an otolith from a large red snapper. Photo courtesy of David Hay Jones.

Step 3: Prepare the Structure

This is the most exciting part of the process because it reveals the rings within the structures.

- To prepare scales, we either flatten them (since they curl as they dry) or make impressions of them.
- To prepare otoliths, occasionally we leave them whole if they are small, thin, and relatively transparent. However, we usually cross-section them, by cutting through each otolith to obtain several thin slices (Figure 3).
- To prepare fin spines, fin rays, and vertebrae, we cross-section all of these structures.

Figure 3. A low-speed saw is outfitted with four consecutive blades to produce three sections from a tripletail otolith. Photo courtesy of Amanda Jefferson.

Step 4: Age the Structure

Once we've selected, extracted, and prepared the structures, we can age them. First, we place each structure under a microscope and examine it using light that passes upward through the structure. Next, we search for alternating translucent and opaque rings (Figure 4). This varying opacity results from differences in the rate and extent of growth throughout the year. One translucent ring plus its adjacent opaque ring usually represents one year of growth; we count these ring pairs to assign an age.

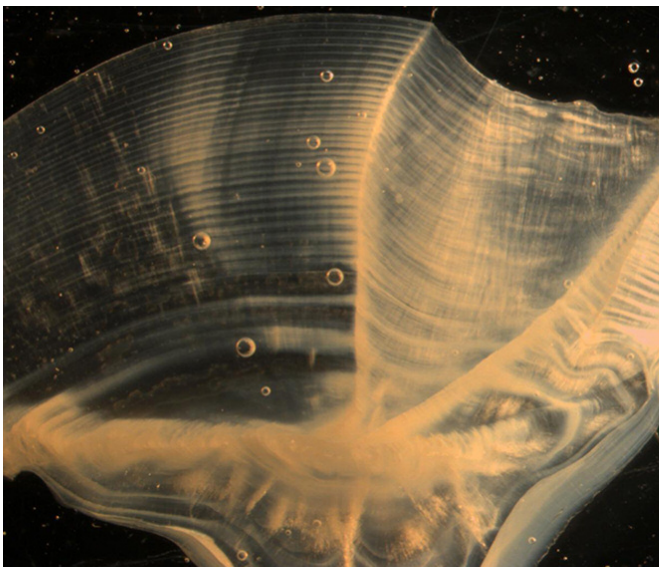

Figure 4. A red drum otolith section, as seen through a microscope. Scientists assigned an age of 33 years to this specimen. Photo courtesy of the Dauphin Island Sea Lab Fisheries Ecology Lab.

We frequently pair age data with other kinds of data to learn more about the stock. Most often we pair age data with length data to learn about individual growth. Specifically, we can fit mathematical growth models to the age and length data to estimate the growth rate and maximum size of the fish in a given stock. These patterns can show the effectiveness of past management strategies and predict future management needs.

Fecundity

Like age and growth, fecundity is an important component of stock assessment models. The fecundity, or reproductive potential, of fishes varies between species and among individuals within species. However, it is well-known that fecundity generally increases with length and weight (and age, since larger fishes are usually older).[2] In other words, the largest and likely oldest fishes tend to produce the most eggs and sperm. The focus is on female fecundity as eggs are the limiting factor in spawning events. Because eggs take more energy to produce and occupy more space inside a female's body, they are produced in lower quantities than sperm. We affectionately refer to the largest, most fecund female fishes as BOFFFs – big, old, fat, fertile females. It is important that a stock contains enough BOFFFs because they are responsible for producing lots of young fish. The current and future status of a stock largely depends on a healthy presence of BOFFFs.

Let's take a look at some of the female fecundity estimates used in the latest Gulf of Mexico red snapper assessment.[3] At age 2, when they are newly mature, female Gulf red snapper produce about 350,000 eggs per year. By age 5, this number increases to about 20 million eggs. By the time these fish grow to be 20-year-old BOFFFs, they are capable of producing more than 120 million eggs per year!

A key point about the relationship between fishing pressure and fish reproduction is that enough fish must survive the fishing pressure to spawn and replenish the stock. For each managed stock, stock assessment scientists determine the amount of fishing pressure that yields this balance using a metric called spawning potential ratio (SPR). The SPR compares the spawning ability of a fish where fishing occurs to its hypothetical spawning ability if it were completely unfished. This ratio is defined as the number of eggs that could be produced by an average fish over its lifetime in a fished stock divided by the number of eggs that could be produced by an average fish in its lifetime in an unfished stock. This results in a fraction between zero and one. Generally speaking, SPR should be at least 0.2-0.3 (20-30%), if not higher, to prevent stock declines.[4] Once scientists have calculated the SPR for a stock, they can advise how to ensure that fishing pressure does not exceed the threshold of maintaining a healthy SPR, and thus, a healthy stock.

Mortality

Mortality is the scientific measurement of the death rate of fishes. We use age structure to determine the mortality rate of the fish in the stock. This is usually expressed as the annual mortality rate (the proportion of fish that die each year). However, age structure only tells us about the total mortality occurring in the stock due to all possible causes. Total mortality combines two main types of mortality: natural and fishing.

- Natural mortality is defined as the death of fishes from all causes except fishing, such as predation, aging, and disease. We can estimate natural mortality based on life history parameters, such as growth rate, maximum age, and maximum length.
- Fishing mortality is defined as the proportion of the fishable stock that is caught in a year, or the rate of removal from a population by fishing. We can estimate fishing mortality by conducting tagging studies.

Figure 5. A SeaQualizer is used to return a captured red snapper to depth. Photo courtesy of SeaQualizer.

By definition, fishing mortality technically only involves fishes that are kept by fishers – in other words, the fishes that are brought home and baked, fried, pan-seared, or grilled. Yet, there is another, more cryptic type of mortality that results from fishing activities: discard mortality. Often, anglers must discard fishes to comply with management regulations – such as when fish are too small. Not all discarded fishes survive, however. Research shows that discarded fish can die from the trauma related to fishing events (for example, gut-hooking and barotrauma). For example, the most recent red snapper stock assessment models incorporated a discard mortality of 12-16% – about one in every seven red snapper that is caught and released dies.[5]

Discards that die are a waste. Therefore, it is important that we take earnest steps to mitigate discard mortality. Using non-stainless steel circle hooks instead of J-hooks reduces gut-hooking. This is already required when using natural baits to fish for reef fishes in federal waters.[6] To help with barotrauma recovery, we can either vent a fish by releasing air from its swim bladder using a hollow needle inserted behind the pectoral fin or use a descending device (such as a SeaQualizer, Figure 5) to return the fish to depth safely and quickly.

Conclusion

Now that we've learned about the life history of fishes, let's answer our initial question: Which species can withstand higher fishing pressure? The answer is Species A because fishes with short lifespans and the ability to produce lots of offspring are more resilient to fishing pressure. Even if many individuals of Species A are removed via fishing, there will still be plenty of young individuals left in the population. These youth will mature quickly and produce many offspring themselves. In contrast, if many individuals of Species B are removed, sufficient numbers of offspring may not be produced and the stock's sustainability may be placed in jeopardy.

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Endnotes

1. This article is excerpted from J.M Drymon, et al., *FISHES: Fishermen Invested in Science, Healthy Ecosystems and Sustainability* (In Press). Sections of the article relied in part on Wallace and Fletcher, *Understanding Fisheries Management: A Manual for Understanding the Federal Fisheries Management Process, Including Analysis of the 1996 Sustainable Fisheries Act*, Mississippi-Alabama Sea Grant Legal Program (2d ed. 2005) for background. The authors recommend that source for those seeking more in-depth discussion of these issues. The Third Edition of *Understanding Fisheries Management* will be available in 2021 from the Mississippi-Alabama Sea Grant Legal Program.
2. *NOAA Fisheries Glossary* (2006 ed.).
3. Southeast Data Assessment and Review, *SEDAR 52 Gulf of Mexico Red Snapper Final Stock Assessment Report* (April 2018).
4. *NOAA Fisheries Glossary.*
5. *SEDAR 52 Gulf of Mexico Red Snapper Final Stock Assessment Report.*
6. Gulf of Mexico Fishery Management Council, *Recreational Fishing Regulations for Gulf of Mexico Federal Waters for Species Managed by the Gulf of Mexico Fishery Management Council.* Other FMPs in the Gulf require circle hooks, which limit bycatch of sea turtles and dolphins.