FISHES

Fishermen Invested in Science, Healthy Ecosystems, and Sustainability

Edited by J. M. Drymon

Contributing authors: M. B. Jargowsky, A. E. Jefferson, and E. A. Seubert

MISSISSIPPI STATE UNIVERSITY EXTENSION

Sea Grant Mississippi-Alabama

About the Authors

Editor

J. Marcus Drymon, PhD, is an assistant Extension professor with the Mississippi State University Extension Service's Coastal and Marine Extension Program and a marine fisheries specialist with the Mississippi-Alabama Sea Grant Consortium. He earned bachelor of science degrees in biology and marine science from Coastal Carolina University in 2000, a master of science degree in marine biology from the College of Charleston in 2003 and a doctoral degree in marine sciences from the University of South Alabama in 2010. He is a fisheries ecologist whose research has focused on the ecological role of sharks, as well as species like red snapper and tarpon, in coastal ecosystems. The bulk of this work has taken place in the northern Gulf of Mexico, an ecosystem with an exciting diversity of species. He is a fellow of the American Institute of Fishery Research Biologists and has served as a member of the Gulf of Mexico Fishery Management Council's Reef Fish Science and Statistical Committee, the NOAA Fisheries Highly Migratory Species Advisory Panel, and the American Elasmobranch Society board of directors. Each summer he enjoys teaching a field course titled Shark and Ray Biology, where he can teach undergraduate students about the sharks that have captivated him since childhood.

Cover photos courtesy of David Hay Jones.

Design: Meaghan Grimm

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Amanda Jefferson, MS, is an Extension associate with MSU Extension's Coastal and Marine Extension Program and a marine fisheries specialist with the Mississippi-Alabama Sea Grant Consortium. She earned a bachelor of science degree in marine biology from the University of North Carolina Wilmington in 2013 and a master of science degree in marine sciences from the University of South Alabama in 2017. Her research focuses primarily on the biology and ecology of northern Gulf of Mexico fishes, including red snapper, gray triggerfish, and tripletail. She also authors Extension publications and leads outreach events to communicate fisheries science to the public. She appreciates opportunities to connect and work with Gulf of Mexico fisheries stakeholders and hopes to help ensure the sustainability of Gulf fisheries for future generations.

Emily Seubert, MS, is an Extension program associate with MSU Extension's Coastal and Marine Extension Program. She earned a bachelor of science degree in biological sciences with an emphasis in marine science from the University of California, Davis in 2013 and a master of science degree in marine sciences from the University of South Alabama in 2019. Her graduate work focused on the trophic relationships of north-central Gulf of Mexico predatory fishes. Her primary responsibilities involve serving as the field lead for the bottom longline surveys conducted off the coasts of Alabama and Mississippi. She also participates in outreach and education events throughout the community and is the teaching assistant for the summer field course *Shark and Ray Biology*. Her passion is the environment and the incredible creatures that inhabit it, and she strives to share that passion with others.

Acknowledgments

The editor and contributing authors are grateful to numerous individuals for their contributions to this work. First and foremost, we thank Catherine Cowan for creating the wonderful graphics used throughout this book, as well as Desaray Swanson for providing the fish outlines used throughout the graphics. We're grateful to David Hay Jones for his friendship and for allowing us to use his exceptional photographs. We owe thanks to Mississippi State University Extension, as well as the Mississippi-Alabama Sea Grant Consortium, for providing the time and funding needed to write this volume. We're grateful to the authors of two previous Sea Grant publications, *Fisheries Management for Fishermen* and *Understanding Fisheries Management*; this work was inspired by those volumes. A final thanks to Dr. Savanna Barry, Renee Collini, Melissa Schneider, Dr. Eric Sparks, and Dr. Doug Zemeckis for providing excellent feedback on previous versions of this work.

Contents

Figure 1. (A) A young Marcus Drymon alongside his grandfather with two barracuda, circa 1984.
(B) Marcus Drymon and his son with a greater amberjack, 2018.
Photos courtesy of Elizabeth Drymon (A) and Anna Havard (B).

PROLOGUE

Who We Are

I come from a family of fishermen. I can vividly recall fishing with my father and grandfather, hauling magnificent (and terrifying!) fishes from the depths of the sea (***Figure 1***). These early experiences fostered a childhood fascination with fishes that followed me into adulthood. Currently, I am a professor with the Mississippi State University Extension Service and a marine fisheries specialist with the Mississippi-Alabama Sea Grant Consortium. I lead the Marine Fisheries Ecology Program; we are a team of like-minded folks who love their fishes (***Figure 2***)! If you feel the same, then this book is for you.

This Book

The *FISHES (**F**ishermen **I**nvested in **S**cience, **H**ealthy **E**cosystems, and **S**ustainability)* book is designed to extend practical, science-based information to fish enthusiasts in an easy-to-digest format. For those who seek additional information, we encourage you to consider joining us for the in-person FISHES course, which this book was written to accompany. Throughout the book, words that require further definition are bolded when first mentioned and fully defined in the glossary. We've provided in-text hyperlinks when possible and also included a list of resources at the end of the book. This work builds on two excellent Sea Grant publications, *Fisheries Management for Fishermen*[1] and *Understanding Fisheries Management*.[2] We will begin this book by summarizing and updating the fisheries management information from those two manuals. From there, we will supplement our knowledge of fisheries management with material about fisheries science. By the end of this book, it should be clear how *fisheries management* and *fisheries science* work in tandem, much like two fillets from the same fish. But before we get started, let's consider where we've come from.

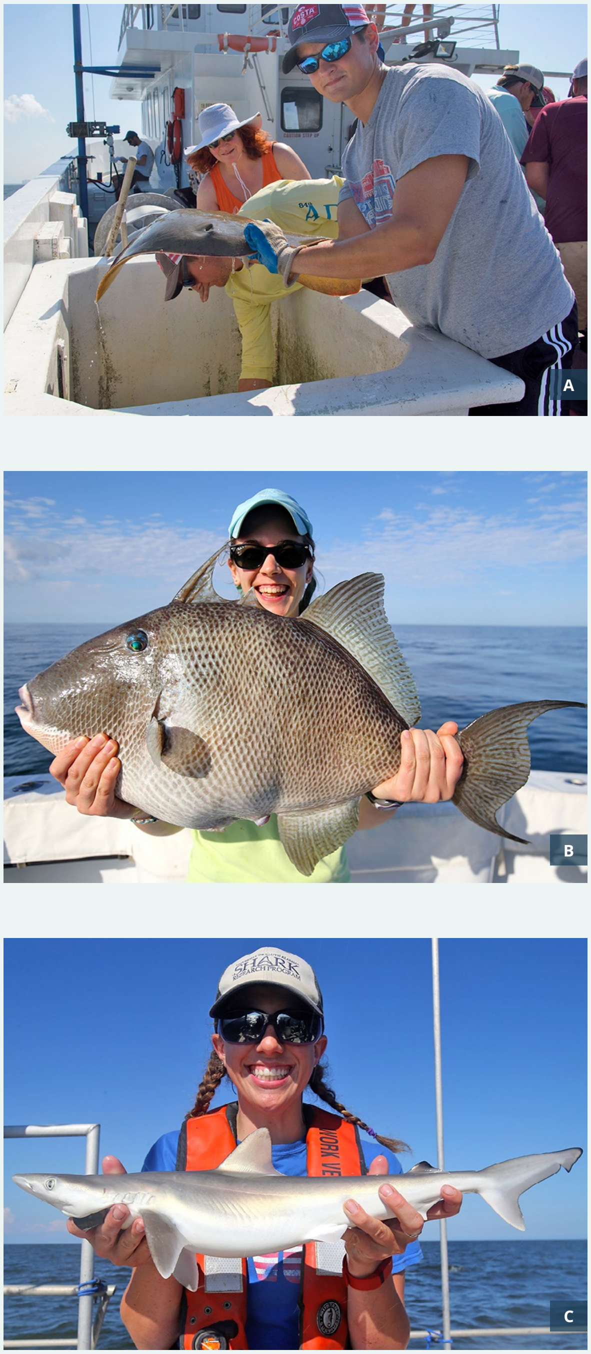

Figure 2. (A) Matthew Jargowsky, (B) Amanda Jefferson, and (C) Emily Seubert. Photos courtesy of Kevin Hudson (A) and David Hay Jones (B, C).

A Historical Perspective

In 1871, Spencer Baird (***Figure 3***) wrote to Congress calling attention to a "depletion of food fishes." In response, he was named the first commissioner of the U.S. Commission of Fish and Fisheries,* established on February 9, 1871. The "Fish Commission" was the first federal conservation agency, and its mission was to study, protect, manage, and restore fishes and fisheries. Congress's first charge to the Fish Commission was to investigate reports from fishermen regarding declines in New England groundfish, such as Atlantic cod.[3]

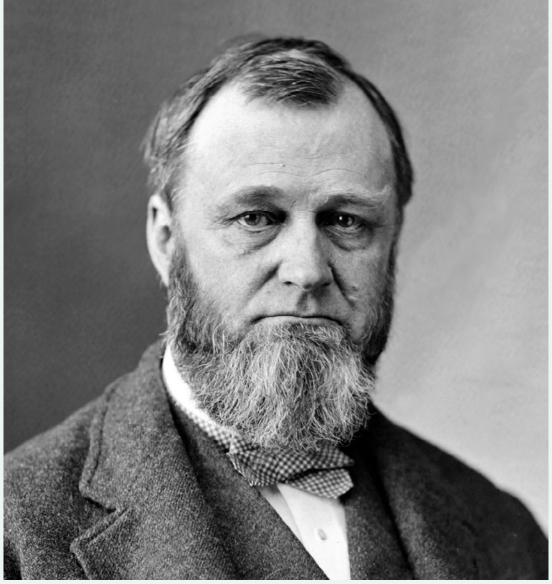

Figure 3. Spencer Baird, the first commissioner of the U.S. Commission of Fish and Fisheries. Photo courtesy of Mathew Brady/public domain.

On the other side of the Atlantic Ocean, a different perspective was raised on the status of cod and other fishes. In his 1882 inaugural address to the Fisheries Exhibition in London, Thomas Huxley famously stated:

> *I believe, then, that the cod fishery, the herring fishery, the pilchard fishery, and probably all the great sea fisheries, are inexhaustible; that is to say, that nothing we do seriously affects the numbers of fish. And any attempt to regulate these fisheries seems consequently, from the nature of the case, to be useless.*

Far from the viewpoint of a single individual, this concept was repeated in the 1955 book *The Inexhaustible Sea*, where the authors noted:

> *[T]he teeming waters of the oceans . . . are virtually untapped as a source of food . . . Much still remains to be learned. Nevertheless, we are already beginning to understand that what [the ocean] has to offer extends beyond the limits of our imagination—that someday men will learn that in its bounty the sea is inexhaustible.*[4]

Sadly, we now know the sea is far from inexhaustible; countless examples from across the world illustrate the devastating effects of overfishing. Fortunately, today's fisherman is more invested in science, healthy ecosystems, and sustainability than ever before. Throughout this book, we'll examine current advances in fisheries management and fisheries science through a regional lens focused on the northern Gulf of Mexico. Welcome!

DR. MARCUS DRYMON, 2020

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* The U.S. Commission of Fish and Fisheries is the precursor to National Oceanic and Atmospheric Administration (NOAA) Fisheries, the federal agency charged with "providing science-based conservation and management for sustainable fisheries and aquaculture, marine mammals, endangered species, and their habitats."

PART 1

Fisheries Management

Chapter 1: The Gulf of Mexico

HIGHLIGHTS

- ***The Gulf of Mexico contains a bounty of natural resources that includes more than 1,500 different types of fishes.***
- ***Dating back to the mid-1800s, commercial fishing has always been an important industry for residents along the Gulf Coast.***
- ***The diversity and abundance of fishes in the northern Gulf of Mexico makes it a recreational fishing hotspot.***

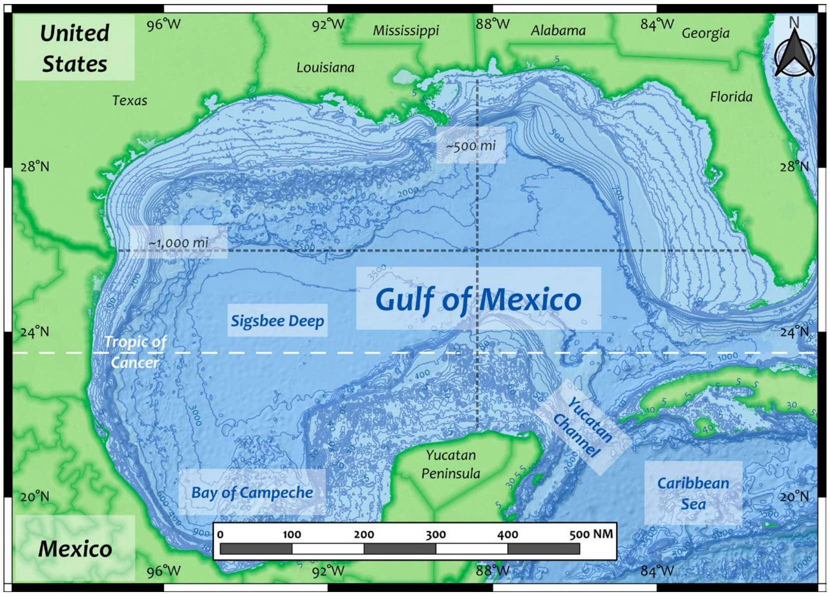
1.1 AN INCREDIBLY FISHY PLACE

The ninth largest body of water on the planet, the Gulf of Mexico is an excellent location for studying (and catching!) fishes. Simply put, the Gulf (***Figure 4***) is:

- large, covering an area in excess of 500,000 square miles.
- wide, measuring about 500 miles north to south and about 1,000 miles east to west.
- mostly shallow, with an average depth of less than 1 mile, compared to the average depths of the Atlantic Ocean (2.4 miles) and Pacific Ocean (2.7 miles).
- occasionally deep, with the Sigsbee Deep off Texas measuring a depth of nearly 2.5 miles.[1]

FIGURE 4. Bathymetric map illustrating the spatial extent of the Gulf of Mexico.

Depth contours are expressed in meters.



Map courtesy of Emily Seubert.

Figure 5. Commercial fisherman in the northern Gulf of Mexico.
Photo: Library of Congress, Prints and Photographs Division, National Child Labor Committee Collection/https://lccn.loc.gov/2018675702.

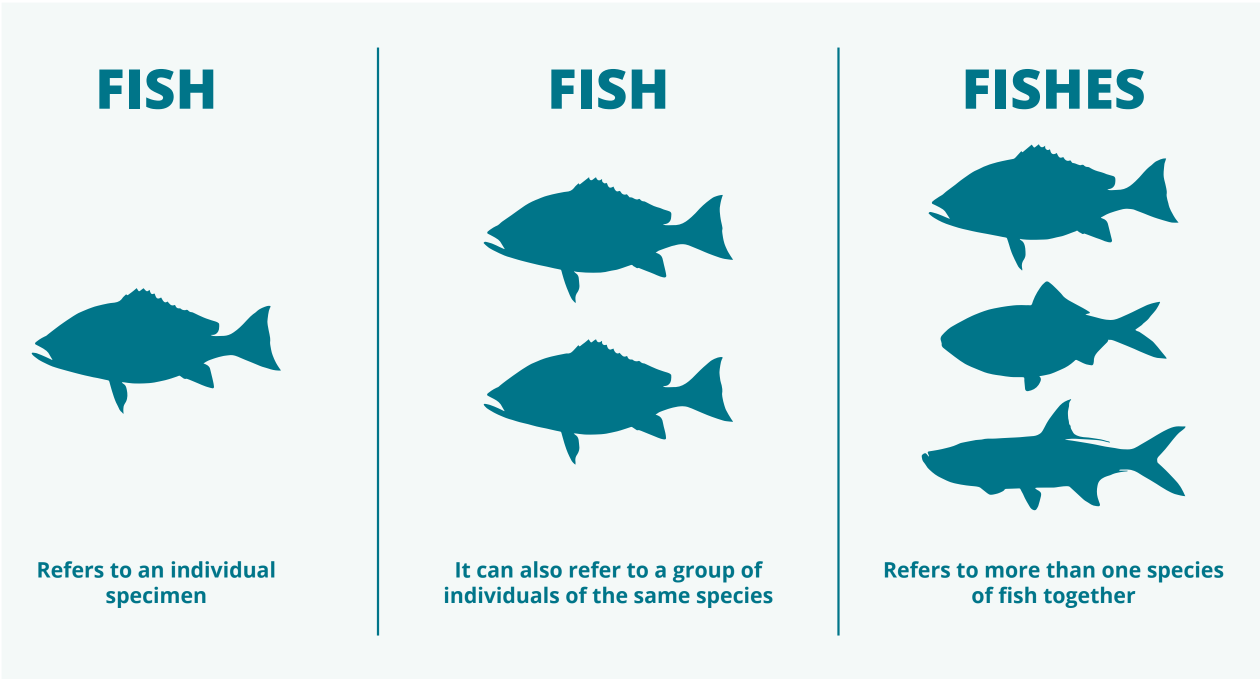
1.2 HISTORICAL GULF FISHERIES

Fisheries in the Gulf have existed for thousands of years, as described in rich prose in the 2018 Pulitzer Prize-winning book The Gulf: The Making of an American *Sea* by Jack Davis.[2] Davis described how Native Americans made use of these fisheries by weaving fishing nets out of "Spanish moss and palm fiber" and following the lunar cycles and seasons to predict optimal harvest times for each fishery. The Gulf's abundant fisheries led these natives to be of "robust physical stature and healthful existence," much to the chagrin of the Spanish, who referred to them as "raven-haired giants." Davis noted that one of the first descriptions of the Gulf's fisheries resulted from an early attempt to map the Gulf, when British surveyor Bernard Romans ran aground on an oyster reef and stated, "Sea fish are in such innumerable quantity as exceed even imagination."

A century later, the American poet Sidney Lanier mused, "There seems to be literally no end to the oysters, the fish, the sea-birds, the shells, the turtles, along these waters." Echoing those sentiments, American author Edward Smith King wrote, "There is such a multitude of oysters, fish, and game, that enterprises for supplying the market from that section should be very successful." With the widespread availability of ice beginning around 1870, vessels were able to venture farther and farther offshore and capture increasingly large quantities of fishes, which prompted a flourishing trade with consumers as far as New England to the north and Cuba to the south. Thus, commercial fishing became the Gulf's first industry of real importance (***Figure 5***).

However, the Gulf is also considered the birthplace of American saltwater sportfishing, a title that can be traced back to a single **species**. On March 19, 1885, William Halsey Wood landed what is thought to be the first tarpon in the Gulf of Mexico. Measuring 5 feet 9 inches and weighing in at 93 pounds, this fish sparked a recreational fishing frenzy that continues to this day. Sportsmen from President Franklin D. Roosevelt to Major League Baseball Hall of Famer Ted Williams have chased the enigmatic species across the Gulf. Entire towns were named after this fish, like Tarpon Springs, Florida, and Tarpon, Texas, which would later be renamed Port Aransas. The value of tarpon to the burgeoning recreational fishery in the Gulf is difficult to overstate. For example, in 1894, it was estimated that every tarpon landed was worth about $500 to local businesses,[2] or approximately $15,000 adjusted for inflation!

FIGURE 6. Proper use of the terms "fish" and "fishes."



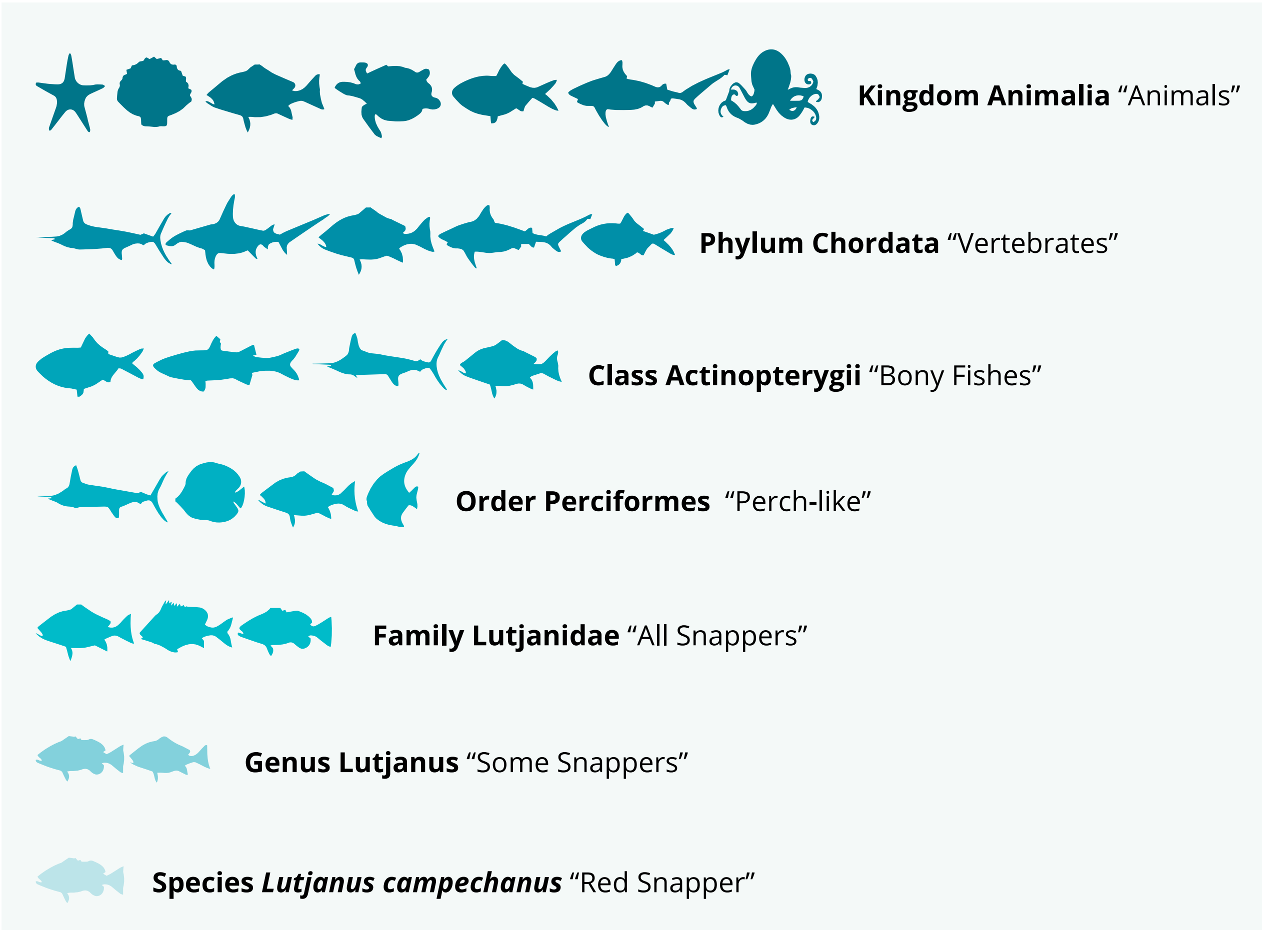
Graphic courtesy of Catherine Cowan, modified from Helfman et al. (2009).[5]

1.3 MODERN GULF FISHERIES

Commercial and recreational fisheries were clearly critical industries for residents in the early Gulf of Mexico. More than 100 years later, the same is true. For example:

- Approximately 18 percent of U.S. commercial landings by weight (17 percent by revenue) are from the Gulf.[3] Menhaden is the Gulf's largest commercial fishery by weight, and shrimp (white, brown, pink) is the largest by value.
- Approximately 40 percent of U.S. recreational landings are from the Gulf. Speckled trout and red drum are the most popular inshore species, while red snapper is the most popular offshore species.

FIGURE 7. Basic taxonomic categories as described by Swedish naturalist Carl Linnaeus.



Graphic courtesy of Catherine Cowan.

While these commercial and recreational fishery statistics involve just a handful of species, the Gulf has an extraordinary diversity of fishes as documented by the Census of Marine Life, “a 10-year international effort to document the diversity [how many different kinds], distribution [where they live], and abundance [how many] of marine life.” This massive undertaking revealed that the Gulf of Mexico has substantially higher biodiversity than any other marine region of the U.S.,[4] including 1,541 different fishes (***Figure 6***).

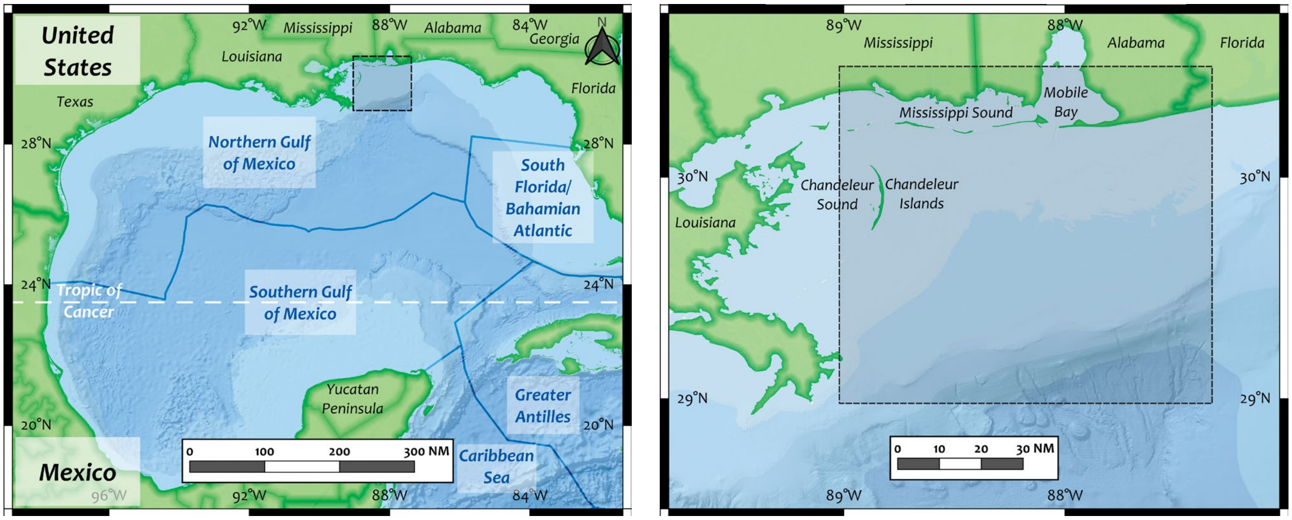
To appreciate this diversity, let’s examine the taxonomic breakdown of these species (remember the **K**ingdom, **P**hylum, **C**lass, **O**rder, **F**amily, **G**enus, **S**pecies routine; ***Figure 7***). The 1,541 species of fish comprise:

- 736 genera
- 237 families
- 45 orders

As you might guess, the distribution of these 1,541 species varies with depth; however, some species are only located in certain portions of the Gulf. For this book, we’ll narrow our focus to a particular region of the northern Gulf of Mexico.

FIGURE 8. Large marine ecosystems of the Gulf of Mexico.

The north-central Gulf of Mexico, the focal region for this book, is indicated by the gray box.



Map courtesy of Emily Seubert.

1.4 OUR FOCUS AREA

The Gulf of Mexico is characterized as one of 64 **large marine ecosystems (LMEs)** on the planet. The Gulf of Mexico LME can be further divided into five "ecoregions": the northern Gulf, the southern Gulf, South Florida/ Bahamas, the Caribbean Sea, and the Greater Antilles.[6] From here on, we will focus on a unique portion of the northern Gulf ecoregion, a portion we'll refer to as the north-central Gulf, located off the coasts of Mississippi and Alabama (***Figure 8***).

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Chapter 2: Foundations of Gulf of Mexico Fisheries Management

HIGHLIGHTS

- ***Without regulations in place to protect them, public natural resources are often exploited by individuals acting in their own self-interests.***
- ***As early as the late 1800s, some fisheries in the Gulf of Mexico were already locally overfished.***
- ***Several regulations guide fisheries management in the Gulf of Mexico, with the Magnuson-Stevens Fishery Conservation and Management Act of 1976 serving as the foundation.***

2.1 THE TRAGEDY OF THE COMMONS

Why does the government regulate the number of fishes a person can keep? To answer this question, we must first consider Garrett Hardin's economic theory, the "tragedy of the commons."[1] The tragedy of the commons occurs when a commonly shared natural resource (e.g., lumber, pastureland, fishes) is exhausted by individual people who are acting in their own self-interests, though not necessarily through selfish means. This theory is observed with the harvest of many different natural resources, including many fisheries. For a real-world example, let's take a look at the red snapper fishery in the Gulf of Mexico, starting from its beginning in the 1800s (***Figure 9***).

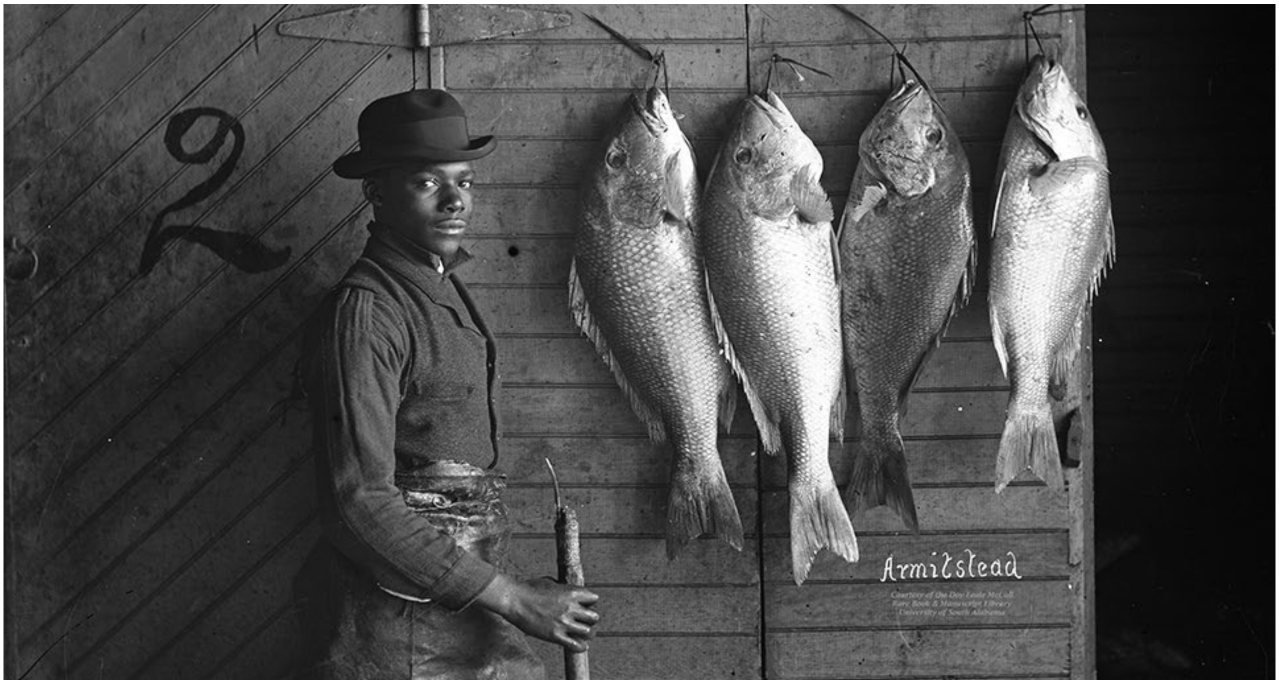


Figure 9. A young man posing with his day's catch of red snapper.
Photo courtesy of the T. E. Armitstead Collection, The Doy Leale McCall Rare Book and Manuscript Library, University of South Alabama.

2.2 GULF OF MEXICO RED SNAPPER

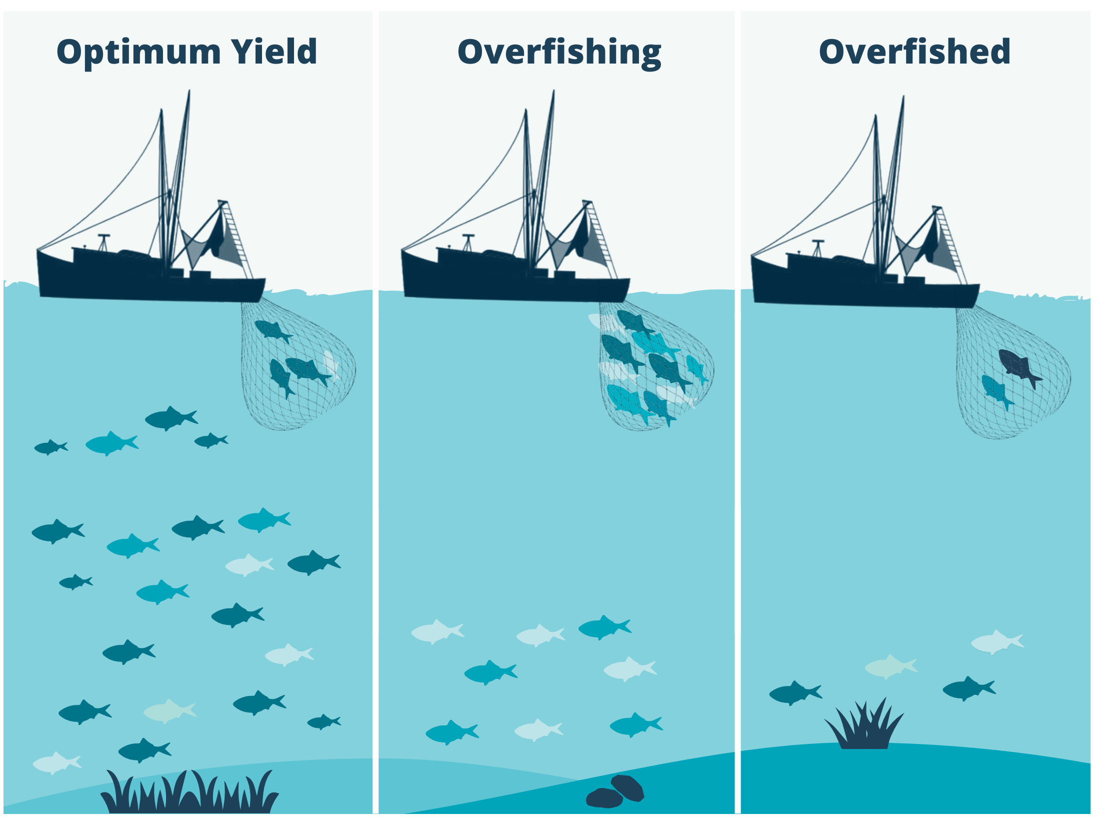
Red snapper was first introduced to the seafood market around 1840 and quickly became one of the most valuable and popular fisheries in the Gulf.[2] However, less than half a century later, renowned **ichthyologist** Silas Stearns already noted that red snapper were becoming locally **overfished**.[2] Likewise, Captain J. W. Collins, in his 1887 report to the newly minted U.S. Commission of Fish and Fisheries, wrote:

> *The character of the snapper grounds, so far as relates to the abundance of fish on them, and, of course, their consequent importance, has changed very materially, it is said, within the past three or four years. It is claimed that this change is still going on, and that localities that were remarkable for the abundance of fish on them only a year or two ago are now of comparatively little importance . . . vessels are continually obliged to extend their cruises further off in order to meet with success.*

Fortunately for red snapper, these fishermen were limited by their technology, which prevented them from depleting stocks located far offshore (a situational luxury that other species, like coastal and sedentary oysters, did not have).

However, as advances in technology after World War II enabled vessels to travel farther and farther offshore, both commercial and recreational red

Figure 10. "Optimum yield" is a level of harvest that provides the greatest overall benefit to the national economy while also taking into account the protection of marine ecosystems. "Overfished" refers to a stock that is too low in biomass. "Overfishing" refers to a stock that is being harvested at a greater rate than can be replaced through natural reproduction. A fish stock can be "overfished" and "undergoing overfishing" at the same time.



Graphic courtesy of Catherine Cowan.

snapper harvest increased substantially. As a result, the entire Gulf of Mexico red snapper stock eventually crashed, hitting a record low in 1990.[3] Thankfully, through limits placed on red snapper harvest and solutions to decrease **bycatch** of juveniles in the shrimp trawl fishery, red snapper are no longer considered overfished or experiencing **overfishing**, though the stock is still **rebuilding** (***Figure 10***).[4] The eventual goal for red snapper, as with all managed fisheries, is to improve and maintain the health of the stock and achieve **optimum yield**. Optimum yield occurs when a stock provides the greatest possible benefit to the economy and society as a whole while also remaining **sustainable**. Unfortunately, the restrictions required to rebuild fishery stocks to optimum yield can be a source of contention.

Figure 11. Renowned Chef Paul Prudhomme, who popularized the dish blackened redfish. Photo courtesy of Flickr photographer holga_new_orleans/Brett Rosenbach/CC BY 2.0.

As is often the case, the fishermen involved in the red snapper fishery weren't acting selfishly; they were simply trying to support their families and their livelihoods. One fisherman alone cannot possibly deplete an entire fishery, so each individual saw his take as negligible. However, if thousands—or in the case of saltwater anglers, millions—of individuals are using a single resource, the cumulative harvest eventually becomes significant. If a resource is available, individuals will continue to enter a market until its profits are no longer compelling or the resource itself is depleted.

2.3 GULF OF MEXICO RED DRUM

Let's look at another example of the tragedy of the commons: the northern Gulf of Mexico red drum fishery. Like red snapper, harvest of this species increased substantially following World War II. By the 1970s, the annual commercial harvest by some Gulf states had grown to over 1 million pounds and the fishery was starting to show early signs of overfishing. Then, in the 1980s, Chef Paul Prudomme introduced the public to blackened redfish, which caught the Gulf by storm and doubled the price of red drum (***Figure 11***).[3] As a result, from 1986 to 1987, Louisiana commercial fishermen harvested more red drum than they did throughout all of the 1970s.[3] This craze left the stock severely overfished and led the federal government to place a **moratorium** on commercial fishing for red drum in federal waters. The moratorium remains in place today.

Red snapper and red drum are just two examples of U.S. fisheries that have experienced such drastic declines, many of which follow a similar story: a new fishery was discovered, more individuals joined the fishery to make money or for personal use, harvest increased, harvest eventually reached a tipping point (overfishing), and then the stock crashed (overfished). Without close and careful monitoring, it is difficult to tell when a fishery reaches its tipping point. Once the tipping point has been exceeded, rebuilding a fishery is challenging. Perhaps the eminent fisheries scientists Ray Hilborn and Carl Walters said it best when they noted, "the hardest thing to do in fisheries management is reduce fishing pressure."[5]

Recent advancements in fisheries science have rendered today's scientists and managers better equipped to monitor fishery stocks than ever before. In addition, regulations have been established to help protect U.S. fishery stocks from experiencing overfishing or becoming overfished. In the next section, we will briefly review a few pieces of legislation that have helped define and shape U.S. fisheries management.

Figure 12. Senators Ted Stevens and Warren Magnuson, after whom the Magnuson-Stevens Fishery Conservation and Management Act was named.
Photo courtesy of the Ted Stevens Foundation.

2.4 WHAT ARE THE LAWS?

To ensure that U.S. fisheries remain sustainable, several laws have been enacted over the past 5 decades. The first of these was the Magnuson-Stevens Fishery Conservation and Management Act (MSA), which was led by Senators Warren Magnuson (Democrat of Washington) and Ted Stevens (Republican of Alaska) and signed into law in 1976 (***Figure 12***). The MSA was a huge step forward in fisheries management and still serves as the primary law governing U.S. marine fisheries management.

2.4.1 Magnuson-Stevens Fishery Conservation and Management Act (1976)

The MSA formed eight regional fishery management councils and authorized the federal government to regulate fisheries from state waters to 200 nautical miles offshore. Moreover, it required **fishery management plans (FMPs)** and established the 10 national standards of fisheries management:

1. Prevent overfishing and achieve optimum yield.
2. Make decisions based on best available science.
3. Manage stocks as single units throughout their range.
4. Do not discriminate between states.
5. Consider efficiency in utilization of resource.
6. Consider variation in fisheries, resources, and catch.
7. Minimize cost.
8. Create sustainability and minimize adverse economic impacts.
9. Minimize bycatch.
10. Promote safety of human life at sea.

Although the MSA was indeed a great step forward, it was not without its shortcomings. One of the most significant criticisms of the MSA was that it failed to do enough to prevent overfishing. Therefore, in 1996, an amendment to the MSA called the Sustainable Fisheries Act was passed.

2.4.2 Sustainable Fisheries Act (1996)

The Sustainable Fisheries Act required rebuilding plans, which are documents that explicitly describe the measures necessary to rebuild a stock that has been declared overfished. This act also required a **precautionary approach**, whereby harvest should always be maintained slightly below the theoretical maximum to prevent overharvest. Finally, it implemented reductions in bycatch by requiring catch of unintended or unmarketable species to be reduced to the greatest extent possible.

2.4.3 Magnuson-Stevens Reauthorization Act (2006)

In 2006, the Magnuson-Stevens Reauthorization Act was passed in an effort to further protect U.S. fisheries from being exploited by imposing specific deadlines. This act required that overfishing be ended in U.S. waters and stipulated rebuilding timelines of less than 10 years.

2.4.4 Modernizing Recreational Fisheries Management Act (2018)

The most recent fisheries legislation passed by Congress was the Modernizing Recreational Fisheries Management Act. This act was a result of frustration from the recreational fishing sector, which felt that current regulations too often favored commercial fishermen and did not do enough to protect recreational fishing interests. This act changed how recreational fisheries are managed by implementing new alternative fishery management measures, adding new data collection methods, and reassessing the allocations of mixed-use fisheries.

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Chapter 3: Current Gulf of Mexico Fisheries Management

HIGHLIGHTS

- ***The boundary separating state and federal waters in the Gulf of Mexico varies by state and sometimes by fishery.***
- ***The primary agencies in charge of managing fisheries in the Gulf of Mexico are individual state agencies, the Gulf States Marine Fisheries Commission, and the Gulf of Mexico Fishery Management Council.***
- ***Since most Gulf of Mexico fisheries are not limited to one jurisdictional boundary, cooperation between management organizations is key for ensuring sustainable fisheries.***

3.1 WHO IS IN CHARGE?

In the previous chapter, we discussed the fundamental nature of fisheries management—but who oversees this task? The answer is complicated. State agencies, such as the Alabama Marine Resources Division and the Mississippi Department of Marine Resources, manage fisheries located exclusively in state waters. Interstate commissions, such as the Gulf States Marine Fisheries Commission, are responsible for the cooperative management of inshore **migratory** species. Federal fisheries located outside of state waters in the U.S. **exclusive economic zone (EEZ)**, which extends out 200 nautical miles from shore, are managed by eight regional fishery management councils that are advised by NOAA Fisheries. These management councils were established by the MSA; in our region, the Gulf of Mexico Fishery Management Council manages Gulf of Mexico fisheries. Finally, **highly migratory species (HMS)**, including tunas, billfishes, and sharks, transcend the boundaries of the regional fishery management councils and are, therefore, managed directly by NOAA Fisheries. Before we discuss how these organizations actually manage fisheries in the Gulf, let's first define where state waters begin and end.

3.2 WHAT ARE STATE WATERS?

On the U.S. Atlantic and Pacific coasts, state waters simply extend 3 nautical miles out from shore; however, defining state waters in the U.S. Gulf of Mexico is more complex. Historically, Alabama, Mississippi, and Louisiana maintained state waters out to 3 nautical miles, while Texas and Florida maintained their state waters out to 9 nautical miles (a relic from when these Spanish colonies joined the U.S.). This difference led to contention among the Gulf states. As a result, Mississippi legislators passed a bill in 2013 that extended their state waters out to 9 nautical miles in defiance of the federal government.[1] Sensing the issue would not soon resolve itself, Congress passed legislation in 2017 to extend state waters for the management of reef fishes out to 9 nautical miles for Alabama, Mississippi, and Louisiana. Although this legislation only extended reef fish management out to 9 nautical miles, it satisfied the grievances of many anglers and fisheries managers from these states.

3.3 STATE AGENCIES

Fisheries in state waters are managed by individual state agencies, which oversee the management of the state's marine resources and the enforcement of regulations. These agencies use information provided by federal and state scientists to best determine the necessary regulations for each managed marine species. Some states, such as Alabama, appoint a single commissioner, while other states, such as Louisiana, appoint a multi-person commission. While organized differently, all of these agencies and organizations strive toward a common goal: ensuring that commercial and recreational fisheries are well managed and sustainable.

However, managing state fisheries is often more complicated than simply setting regulations or allocating resources to different fishing sectors. Fishes in state waters do not recognize state boundaries, and many inshore migratory species, like red drum, cross multiple state boundaries. Thus, if state A manages red drum more closely than neighboring state B, then state A is likely to feel that state B is putting the shared red drum populations at risk for decline. Although adjacent states often try to maintain similar harvest regulations, sometimes states disagree on the management actions needed for the **sustainability** of a given fishery. When this happens, interstate commissions come to the rescue.

3.4 INTERSTATE COMMISSIONS

The Gulf States Marine Fisheries Commission (GSMFC) is one of three U.S. interstate fisheries commissions formed in the 1940s. The GSMFC charge is

> *to promote better utilization of the fisheries, marine, shell, and anadromous, of the seaboard of the Gulf of Mexico, by the development of a joint program for the promotion and protection of such fisheries and the prevention of the physical waste of the fisheries from any cause.*[2]

The GSMFC is made up of 15 commissioners, with each state represented by three appointees: one state fishery resource agency appointee, one legislative appointee, and one governor-selected appointee. The commissioners work to safeguard overharvest of the Gulf's shared fisheries resources. One of the ways the GSMFC accomplishes this is by coordinating and monitoring data collection for the fisheries of the Gulf states. Using these data, the GSMFC works to create species profiles and plans, which they use to help advise states and ensure that they all share a common management goal.

3.5 REGIONAL COUNCILS

Federal fisheries in the Gulf are managed by the Gulf of Mexico Fishery Management Council (GMFMC). Similar to the structure of interstate commissions, regional councils consist of federal and state officials from organizations like NOAA Fisheries and the U.S. Fish and Wildlife Service, as well as people selected by state governors to represent nongovernmental groups (like fishermen, food processors, etc.). The GMFMC is advised by NOAA Fisheries, as well as state, academic, and international scientists, and works to ensure that federal fisheries in the Gulf are used as optimally as possible. To do this, the GMFMC creates FMPs for all stocks deemed to be in need of management.[3] The FMPs not only outline present-day management strategies, but also establish frameworks for achieving future management goals. Each FMP is incredibly detailed and consists of comprehensive information including the current status of a given stock, the entities who are using the stock, the management objectives for the stock, the proposed methods for meeting those management objectives, and the plans for reviewing the stock in the future to assess the FMP's successes and failures.

Figure 13. A fisheries scientist holds a large red snapper. Photo courtesy of David Hay Jones.

3.6 PROBLEMS WITH FEDERAL MANAGEMENT

While separate management for state and federal waters makes sense in theory, it creates issues when states presume the GMFMC is failing to correctly manage fishes in federal waters directly off their coasts. One example of this is red snapper management (***Figure 13***). Some Gulf states considered federal regulations for the species to be too strict in recent years, particularly in regard to the length of the season for the private recreational sector. For example, the federal fishing season for Gulf red snapper was only 9 days long in 2014. Given the differences in red snapper populations across the Gulf, each state felt that it should be allowed to determine how its quota would be met.

As a result of this conflict, after the 2017 red snapper season, NOAA Fisheries granted a 2-year exempted fishing permit (EFP) to each of the Gulf states. These large-scale modifications gave the states more control over their private recreational red snapper harvest. In essence, each state was assigned an annual red snapper recreational quota and was allowed to set appropriate season lengths, minimum size limits, and bag limits, as long as those regulations did not cause the state to exceed its quota. Following 2 years of successful red snapper management under these EFPs, the GMFMC amended the FMP for the reef fish resources of the Gulf of Mexico in 2019, thereby officially implementing the effective EFP strategies for the foreseeable future.[4] This change in management has largely been viewed by the states and red snapper anglers as a positive step. First, it eliminated a situation called “panic fishing,” when anglers felt rushed to get out on the water because they only had a few days per year to catch red snapper.[5] In addition, it lessened pressure on inshore reefs, as, in the past, anglers were forced to fish in state waters if they wanted to harvest red snapper after the brief federal season.

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PART 2

Fisheries Science

Chapter 4: Fisheries Science and Stock Assessment

HIGHLIGHTS

- ***Fisheries science is used to inform fisheries management.***
- ***Stock assessments involve mathematical models used to evaluate the current condition of a stock and predict future stock status.***
- ***Stock assessments can take many forms, but most are constructed using the ABCs: Abundance, Biology, and Catch.***

4.1 INTRODUCTION

We spent Part 1 of this book reviewing Gulf of Mexico fisheries management; in Part 2, we're going to switch gears and introduce a complementary concept: fisheries science. As we make our way through Part 2, remember and repeat the mantra, "fisheries science is used to inform fisheries management." Before we dive into the details, let's pause for a few definitions.

- An oceanic **ecosystem** is a system of living (e.g., fishes, corals, invertebrates) and nonliving (e.g., currents, nutrients, sediments) components.
- Healthy ecosystems sustain many **communities** (including fishermen!), which can be thought of as interacting populations.
- **Populations** are groups of organisms that live in the same area and can interbreed.
- A **stock** is a harvested or managed unit of fish within a population (***Figure 14***).

Ecosystems and their components can be assessed using a variety of approaches. For example, NOAA Fisheries has recently begun conducting **integrated ecosystem assessments**, which not only consider a particular species, but also predator-prey interactions of that species, habitat associations, pollution, and a number of additional factors. Co-occurring species can be assessed simultaneously, as is sometimes the case with **multi-species assessments**. Most commonly, though, assessments are performed on individual stocks. A **stock assessment** is

> *the process of collecting, analyzing, and reporting demographic information to determine changes in the abundance of fishery stocks in response to fishing and, to the extent possible, predict future trends of stock abundance.*[1]

The integrated ecosystem assessment, multi-species assessment, and more traditional single-species stock assessment all share common elements, detailed below.

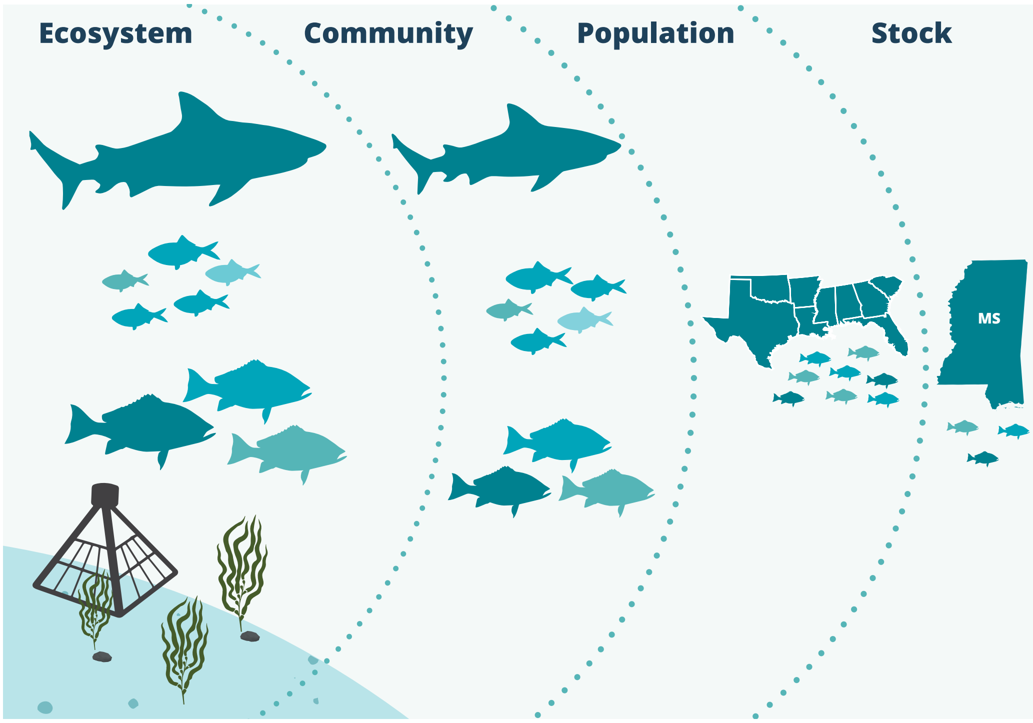
4.2 DATA COLLECTION

Each stock assessment is different, but nearly all rely on the ABCs: Abundance, Biology, and Catch (***Figure 15***). Let's elaborate on each of these data types.

4.2.1 Abundance

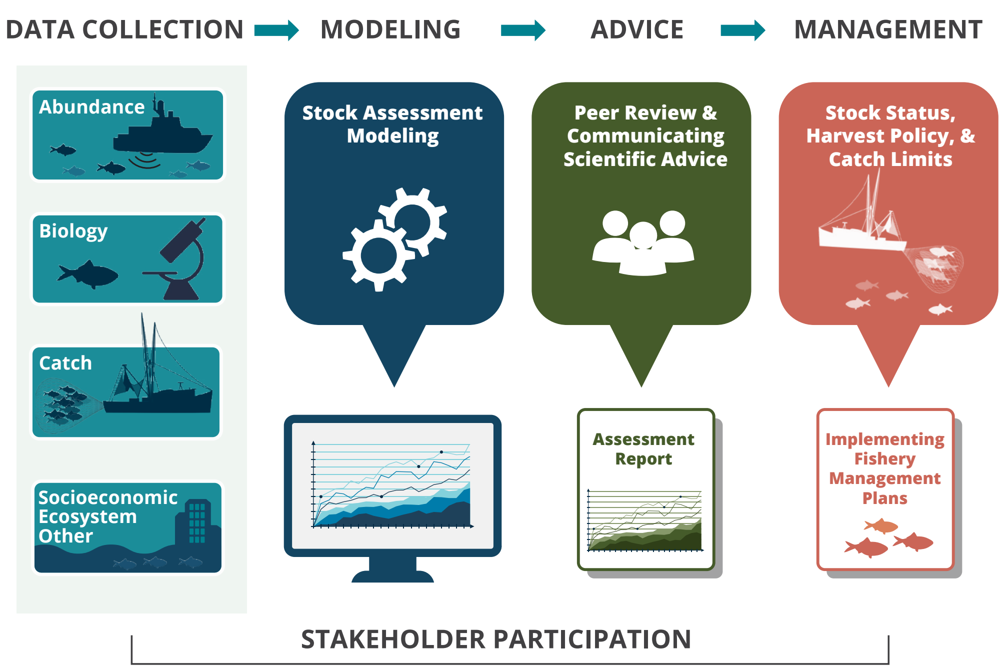
In fisheries science, *abundance* refers to the quantity of a species, regardless of how plentiful it is. In most instances, counting the absolute (i.e., true) abundance of fish in a population is nearly impossible. Most often, we estimate the **relative abundance** of fish in a population instead, ideally through specially designed scientific surveys. These scientific surveys are also known as **fishery-independent** surveys because they are conducted independently of any commercial or recreational fishing activity. Fishery-independent surveys use consistent methods over space and time to guarantee an accurate depiction of a fish population. Because of this consistency, yearly

FIGURE 14. Hierarchy illustrating the relationship between an ecosystem (e.g., many fishes and their habitats), community (e.g., several different groups of fishes), population (e.g., several individuals of a single species), and stock (e.g., a geographically defined portion of a population).



Graphic courtesy of Catherine Cowan.

FIGURE 15. The ABCs of stock assessment.



Graphic courtesy of Catherine Cowan, modified from Lynch et al. (2018).[2]

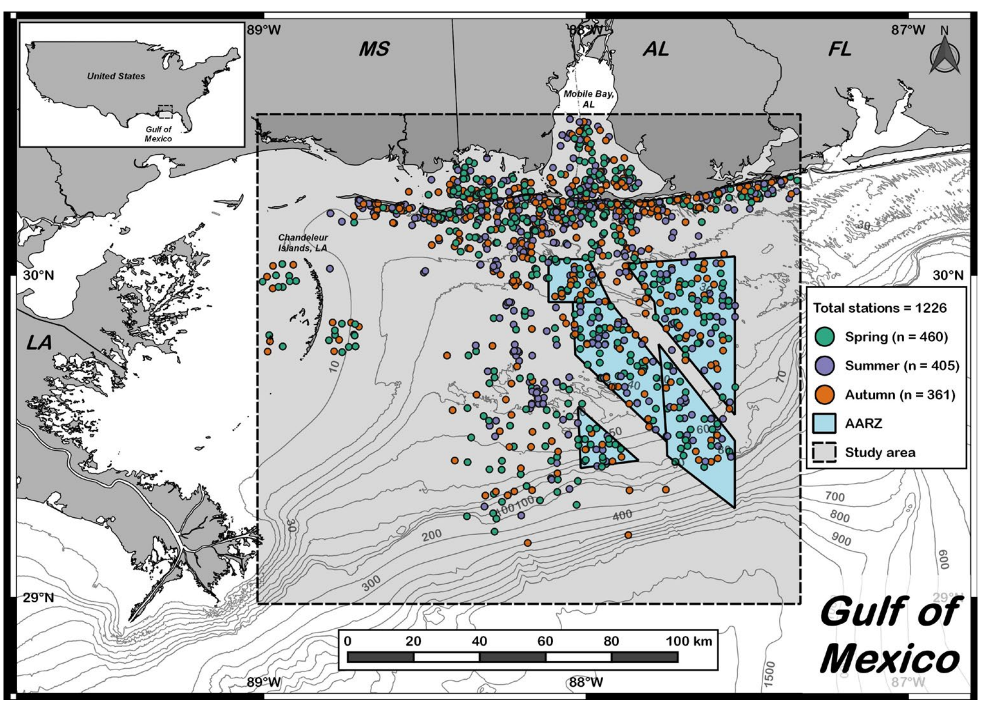
changes in the observed catch can be attributed to true changes in the population, as opposed to changes in gear type, bait, or fishing location.

Several long-term fishery-independent surveys are conducted in the northern Gulf of Mexico. For example, the Mississippi State University Marine Fisheries Ecology Program conducts a long-term, fishery-independent bottom longline survey. This survey began in 2006 and samples approximately 50 stations each year (***Figure 16***).[3] In addition to our bottom longline survey, the primary function of the NOAA Fisheries Laboratory in Pascagoula, Mississippi, is to conduct fishery-independent surveys, which they have done for over four decades (***Figure 17***). In fact, when we designed our bottom longline survey, we were careful to make sure all aspects of our survey, including the site selection process, the monofilament size and length, the hook size and manufacturer, and

Figure 17. The NOAA Fisheries R/V Gordon Gunter, based in Pascagoula, Mississippi. Photo courtesy of NOAA NEFSC/Jennifer Gatzke.

FIGURE 16. An example of the design for a long-term monitoring program.

The dashed line denotes the extent of the bottom longline study area. Each dot denotes an individual set made between 2006 and 2018 (n = 1,226). Spring sets are shown in green (n = 460), summer sets are shown in purple (n = 405), and autumn sets are shown in orange (n = 361). Depth contours are expressed in meters. The blue region bounded by the solid line denotes the Alabama Artificial Reef Zone (AARZ).



Map courtesy of Emily Seubert, from Drymon et al. (2020a).

the bait type and size were identical to the NOAA Fisheries Lab's bottom longline survey. In other words, these two bottom longline surveys are **standardized**, which ensures that an apples-to-apples comparison can be made between the catch data from these two programs.

Fishery-independent surveys use a multitude of different gear types, like shrimp trawls and plankton nets. Regardless of the type of gear, data from these (and many other) fishery-independent surveys are used to construct time series known as **indices of relative abundance** for several Gulf of Mexico species including coastal sharks, red drum, and red snapper, to name a few. The indices of relative abundance created from these data are the foundation of stock assessments.

Technologically sophisticated, noninvasive approaches are increasingly being used to augment data collected using the traditional fishery-independent techniques described above. For example, **remotely operated vehicles (ROVs)** are frequently used to collect video data that can be used to develop an index of relative abundance. This approach is particularly useful for indexing fishes that are too small to be sampled with hooks or are too near structure to be sampled with nets. Similarly, **bioacoustics** uses sonar to estimate fish **biomass**, which can then be used to generate indices of relative abundance. This approach is particularly useful for smaller, schooling **pelagic** fishes, especially in turbid environments where ROVs are impractical. Finally, aerial surveys and drones can be used to develop an index of abundance for larger species, like marine mammals and large sharks.

4.2.2 Biology

The primary purpose of the fishery-independent surveys described above is to generate the indices of relative abundance used in stock assessments. However, these fishery-independent surveys also offer an opportunity to collect biological samples, another critical component of stock assessment. The most fundamental samples provide information on fish age, growth, reproduction, and mortality; this information is collectively known as *life history* information and will be covered in detail in Chapter 5. Increasingly sophisticated stock assessments can also incorporate diet data (Chapter 6) to inform predator-prey dynamics, and movement data (Chapter 7) to describe stock structure and mixing.

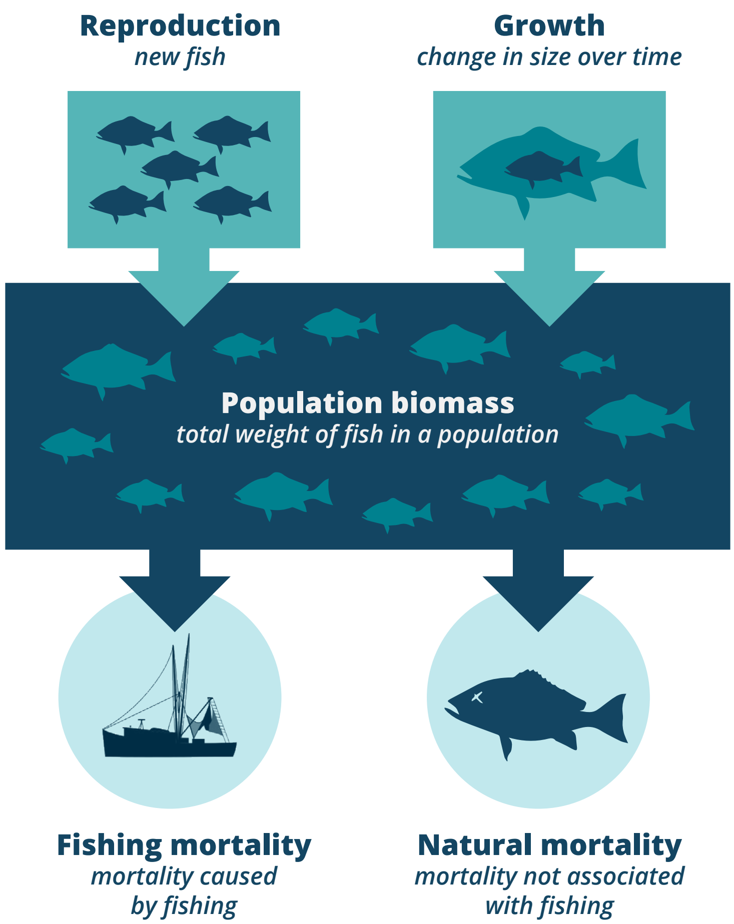
4.2.3 Catch

Most of the data used in the stock assessment are catch data, also known as **fishery-dependent** data. These data are collected from both commercial and recreational fisheries in several ways. Commercial fishermen are required to submit logbooks or reports (manually or digitally) that document their catch. Moreover, some proportion of the commercial fleet carries a fishery observer (a fishery biologist trained by NOAA Fisheries who measures and records additional details about the catch, as well as collects biological samples). Similarly, state agencies like the Mississippi Department of Marine Resources often train and employ port samplers to interview recreational anglers and sample their catch once they return to the docks. These **creel surveys** work well at regional scales and are often complemented by smartphone apps specific to each state. For example, Mississippi uses "Tails n' Scales," while Alabama's "Outdoor AL" app has a section called "Snapper Check." On a larger scale, in-person surveys can be combined with mail and telephone surveys; an example of this is NOAA Fisheries' Marine Recreational Information Program (MRIP). Using this combination of logbooks, fishery observers, port samplers, and reporting apps, catch data are collected and used for stock assessments.

4.3 DATA ANALYSIS

Once the ABCs have been gathered, they are combined into a mathematical model (a stock assessment model) to simulate the dynamics of past and future fish populations. Stock assessment models can take various forms, but the most fundamental is

FIGURE 18. Conceptual model illustrating how additions to and removals from a population affect biomass.



Graphic courtesy of Catherine Cowan, modified from Svedäng (2019).[4]

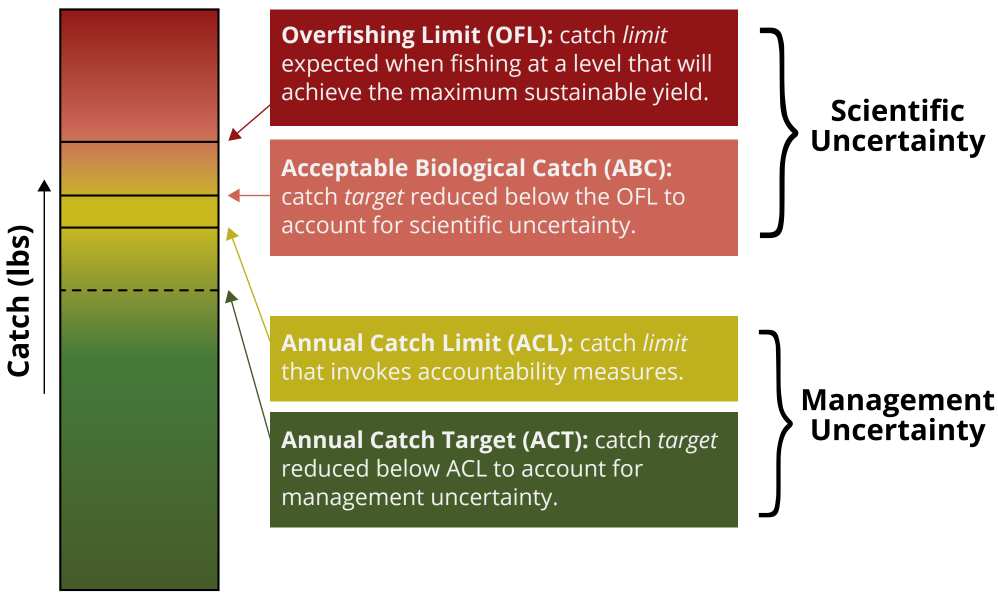
a population model, also known as a demographic model. This type of model describes aspects of the population, such as individual fish growth, mortality, reproduction, and movement. For example, the number of fish in the population next year is equal to the number of fish in the population this year, plus additions through birth and immigration minus removals through death and emigration (***Figure 18***).

4.4 QUOTAS

The outputs from stock assessments are used to establish **quotas**, which are the total numbers of fish (generally by weight) that are allowed to be sustainably harvested. Quotas are allocated to each fishing group, or sector (i.e., commercial, charter-for-hire, or private recreational), depending on a combination of factors. Unfortunately, there are several aspects of the stock assessment that can't be known definitively. This inherent variability (referred to as uncertainty in the stock assessment) must be accounted for to avoid overfishing the stock. In addition to this scientific uncertainty, management uncertainty must also be considered. To incorporate both scientific and management uncertainty into the quota-setting process, a multi-tiered system of limits (overfishing limit, annual catch limit) and targets (**acceptable biological catch**, annual catch target) is used to establish a series of buffers (***Figure 19***).[5]

FIGURE 19. Framework showing the relationships between thresholds determined by fisheries scientists (overfishing limit and acceptable biological catch) and fisheries managers (annual catch limit and annual catch target).

Graphic courtesy of Catherine Cowan, modified from Patrick and Cope (2014).[5]



In summary, fisheries science is used to inform fisheries management, and the clearest example of this is evident in the stock assessment process. Abundance data (ideally fishery-independent) and catch data (most often fishery-dependent) are two of the three basic types of information that are used in the stock assessment process. Results from the stock assessments are then used to establish quotas. With samples collected from both fishery-independent and fishery-dependent data sources, scientists are able to glean information about the biology of fishes, which is also beneficial to stock assessments. In Chapter 5, we'll take an in-depth look at aspects of a fish's biology collectively known as *life history*.

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Chapter 5: Life History

HIGHLIGHTS

- ***Fishes can be aged using various hardened body structures, and the resulting data indicate the growth rate, maximum size, and longevity of the fish in a given stock.***
- ***By estimating reproductive capacity, scientists can evaluate the maximum amount of fishing pressure that a stock can sustain while sufficiently replenishing itself.***
- ***Knowing the sources of mortality in a given fish stock permits managers to predict how changes in regulations could affect fish survival.***

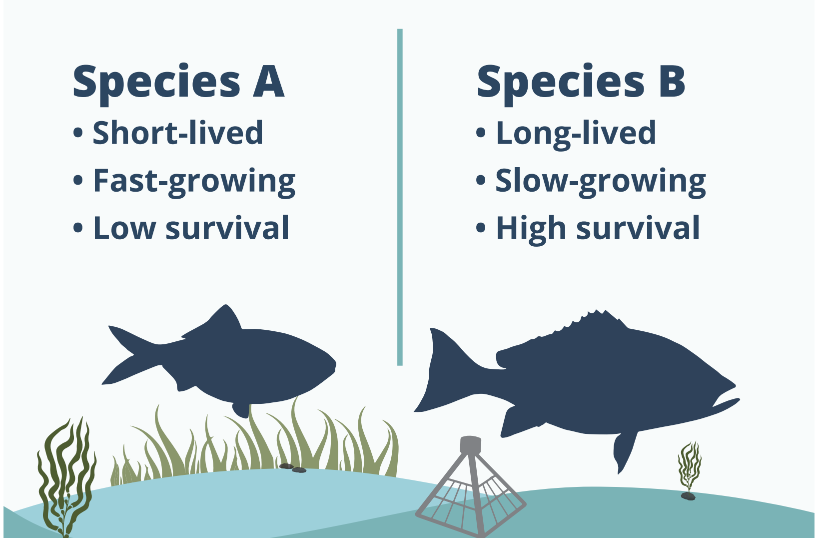
5.1 WHICH FISH?

Let's start with a trivia question (***Figure 20***). 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 greater fishing pressure? To answer this question, we first need to learn how these biological traits are calculated and what they mean to fisheries managers.

5.2 AGE ISN'T "BUT A NUMBER"

In the fisheries science world, to **age** a fish means to determine its age (typically in years). Age data are integral to fisheries management because they serve as the foundation for modern, age-based stock assessments. Once enough fish of a given stock have been aged, we can look at the stock's **age structure**—in other words, 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.[1]

FIGURE 20. Which fish can withstand higher fishing pressure?



Graphic courtesy of Catherine Cowan.

5.3 AGING FISHES

Since **growth** varies between species and among individuals within species, we cannot age a fish simply by looking at it.[1] For example, imagine trying to guess someone's age simply based on their height and weight (impossible). Instead, we must examine a hardened structure from the fish's body, as described in the following four steps.

5.3.1 Step 1: Select a Structure

We must always choose a structure in which material **accretes** over a fish's lifespan. This process creates annual rings inside the structure, like in a tree trunk. Depending on the species of interest, various structures can be used for aging, including scales, **otoliths**, **fin spines**, **fin rays**, and **vertebrae** (*Figure 21*).

5.3.2 Step 2: Extract the Structure

We use specific tools and methods to extract the various structures. For example, to extract otoliths, we lift the **operculum**, move the gills away from the **otic capsule**, open the capsule using a sharp chisel and pull the otolith out of the capsule using **forceps** (*Figure 22*).

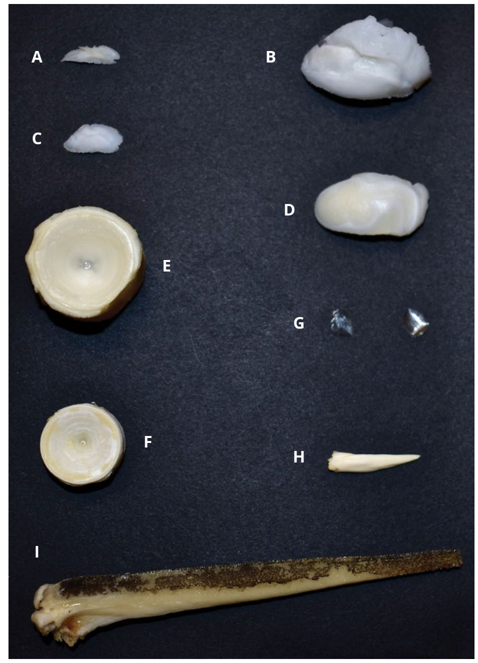


Figure 21. An assortment of aging structures: otoliths from (A) crevalle jack, (B) red snapper, (C) tripletail, and (D) red drum; vertebrae from (E) great hammerhead and (F) blacktip shark; scales from (G) Gulf menhaden; and first dorsal spines from (H) tripletail and (I) gray triggerfish. Photo courtesy of Amanda Jefferson.

Figure 22. A fisheries scientist extracts (A, B) an otolith (C) from a large red snapper. Photos courtesy of David Hay Jones.

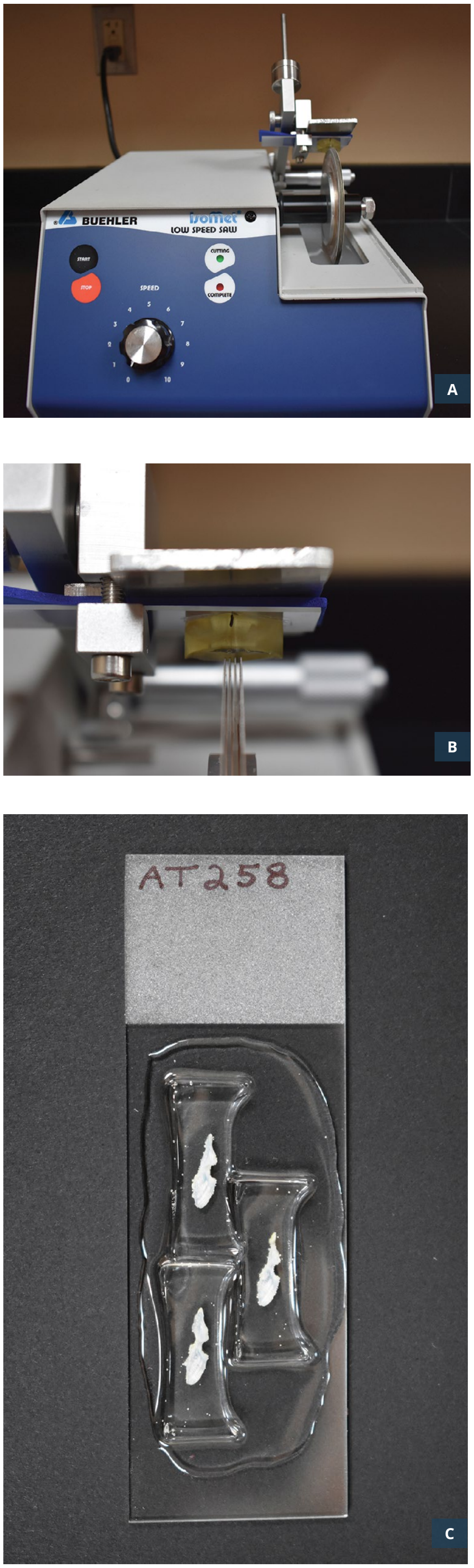


Figure 23. A low-speed saw (A) is outfitted with four consecutive blades (B) to produce three sections from a tripletail otolith (C). Photos courtesy of Amanda Jefferson.

5.3.3 Step 3: Prepare the Structure

This is the most exciting part of the process because it reveals the rings within the structures. We use specific methods to prepare the various structures. To prepare scales, we either flatten them (since they curl as they dry) or make impressions of them. To prepare otoliths, we occasionally can leave them whole if they are small, thin, and relatively transparent. However, we usually must **cross-section** them (***Figure 23***). We must cross-section fin spines, fin rays, and vertebrae.

5.3.4 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 **transmitted light**. Next, we search for alternating **translucent** and **opaque** rings (***Figure 24***). This varying **opacity** results from differences in the rate and extent of growth throughout the year. Since one translucent ring plus its adjacent opaque ring usually represents 1 year of growth, we count these ring pairs to assign an age, in years, to the structure—and the associated individual fish.

5.4 MODELING GROWTH

We frequently pair age data with other kinds of data to learn more about the stock. The type of data most often paired with age data is length data. With paired age and length data from a set of fish, we can 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. Once we gain a comprehensive understanding of these patterns, we can use this insight in stock assessments to determine the effectiveness of management strategies.

5.5 FISH REPRODUCTION

Most fishes reproduce via **sexual reproduction**. For bony fishes (excluding **elasmobranchs**), this occurs through **external fertilization**. First, males and females of a given species release large quantities of eggs and sperm into the water at the same time and in the same place—this is termed **spawning**. Then, in the water, the eggs are fertilized by the sperm. With few exceptions, external fertilization results in an absence of parental care, meaning that the fertilized eggs must grow and develop on their own. In contrast, elasmobranchs reproduce via **internal fertilization**, which involves the male inserting his **clasper** (the male reproductive organ) into the **cloaca** of the female. Numerous different reproductive modes are expressed in elasmobranchs and can include both live birth and egg laying. Some of these

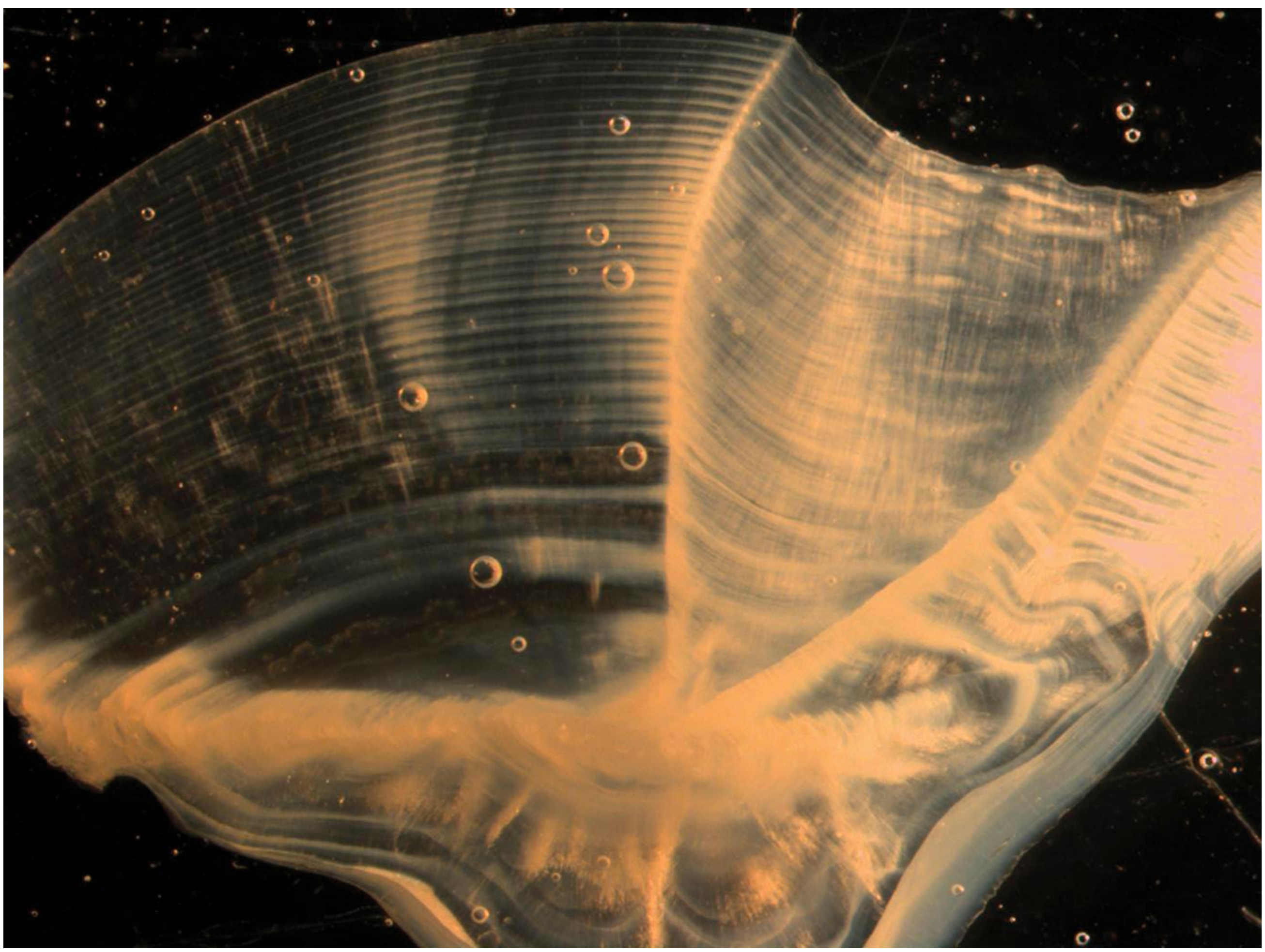


Figure 24. A red drum otolith section, as seen through a microscope. Scientists assigned an age of 33 years to this specimen. Photo courtesy of Matthew Jargowsky/Dauphin Island Sea Lab Fisheries Ecology Lab.

species can **gestate** for months, while some are pregnant for years. The reproductive strategies and patterns of both bony fishes and elasmobranchs are important factors to consider for setting appropriate harvest limits, given that these dynamics factor into populations' productivity and, therefore, resiliency to fishing pressure.

Like growth, 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 (and highest quality) eggs and sperm. Although we can measure reproductive potential of both males and females, we tend to focus our efforts on female fecundity. This is because eggs take more energy to produce and occupy more space inside a female's body, which means they are produced in lower quantities than sperm. As such, eggs are often considered the limiting factor in reproductive success. We affectionately refer to the largest, most fecund female fishes as **BOFFFFs**—big, old, fat, fertile female fishes. It is important that a stock contains enough BOFFFFs because they are responsible for producing lots of young fish.

Fecundity is another important component of stock assessment models. 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 BOFFFFs, they are capable of producing more than 120 million eggs per year!

A key point to remember about the relationship between fishing pressure and fish reproduction is that enough fish must survive the fishing pressure to spawn and replenish the stock.[1] In fact, seasonal and size limits are enacted primarily to ensure that some portion of the population can reproduce before being harvested. For each managed stock, stock assessment scientists determine the amount of fishing pressure that yields this perfect balance using a metric called **spawning potential ratio (SPR)**. This ratio is defined as the number of eggs that could be produced by an average **recruit** over its lifetime in a fished stock divided by the number of eggs that could be produced by an average recruit in its lifetime in an unfished stock (resulting in a fraction, always between 0 and 1).[1,2] In other words, the SPR compares the spawning ability of a real-life fished stock to its hypothetical spawning ability if it were completely unfished.[1] Generally speaking, SPR should be at least 0.2–0.3 (20–30 percent), if not higher, to prevent stock declines.[2] Once scientists have calculated the SPR for a given stock, they can provide management advice to ensure that fishing pressure does not exceed the threshold of maintaining a healthy SPR and, thus, a healthy stock.

5.6 FISH MORTALITY

Fishes live . . . and fishes die. **Mortality** is the scientific measurement of the death rate of fishes. Earlier, we listed some of the types of information we can gather from a stock's age structure. We can also use the 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, the age structure only tells us about the **total mortality** occurring in the stock—in other words, mortality due to all possible causes (commonly referred to as "Z"). In reality, total mortality represents a combination of two main types of mortality:[1,2]

- **Natural mortality (M)** is defined as the death of fishes from all causes except fishing, such as predation, aging, and disease. We can estimate natural mortality through tagging studies or based on life history parameters such as growth rate, maximum age, and maximum length.
- **Fishing mortality (F)** 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. This parameter is sometimes estimated during a stock assessment. Alternatively, it can be estimated from tagging studies, which will be further discussed in Chapter 7.

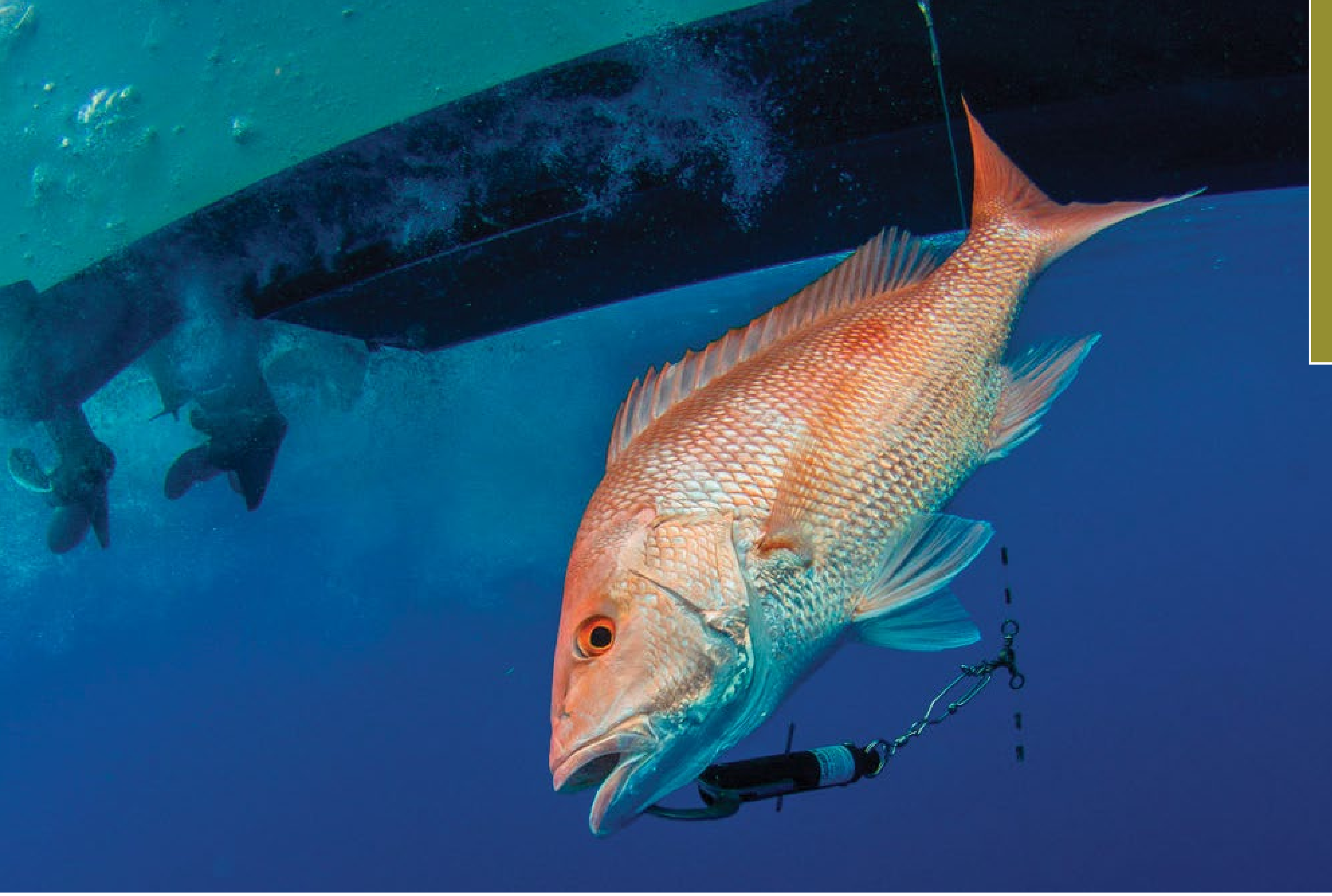


Figure 25. A SeaQualizer is used to return a captured red snapper to depth. Photo courtesy of SeaQualizer.

Fishing mortality primarily involves fishes that are kept by fishermen—in other words, the fishes that are brought home and baked, fried, pan-seared, or grilled. But there is another type of mortality that results from fishing activities: **discard mortality**. Often, anglers must **discard** fishes to comply with management regulations, or they choose to do so given personal conservation ethics. While we hope that 100 percent of discarded fishes survive and return to the population, this isn't necessarily true. Research has shown that trauma related to fishing events (for example, **gut-hooking** and **barotrauma**) can cause discarded fishes to perish upon their return to the sea. For example, the most recent red snapper stock assessment models incorporated a discard mortality of 12–16 percent. In other words, the models assumed that about one in every seven released red snapper dies after being caught and released.[3]

Importantly, discards that die represent individuals that can neither a) return to the population and reproduce nor b) be caught and kept by future anglers. Therefore, it is important that we take earnest steps to mitigate discard mortality. To reduce instances of gut-hooking, we can use non-stainless steel circle hooks instead of J-hooks. This is actually required when using natural baits to fish for reef fishes in federal waters.[4] 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 25***) to return the fish to depth safely and quickly. We will discuss more techniques for effective catch-and-release practices in Chapter 10.

Figure 26. A golden-colored juvenile tripletail (A) and a bronze-colored adult tripletail (B). Photos courtesy of Dylan Kiene (A) and Charlene Dindo (B).

5.7 CASE STUDY: GULF OF MEXICO TRIPLETAIL

Tripletail occur in the north-central Gulf of Mexico during the summer months. Recreational anglers capitalize on the unique habitat associations of tripletail by sight-casting for these palatable fish. The species has become increasingly popular over the past few decades, indicating that the stock's status should be monitored. Two previous Gulf of Mexico tripletail age studies exist; however, they were conducted decades ago (in the 1990s) and did not evaluate growth patterns. Therefore, we decided to conduct an up-to-date age and growth study for Gulf of Mexico tripletail (***Figure 26***).[5]

From 2012 to 2019, we collected measurements and biological samples from 230 north-central Gulf of Mexico tripletail. Many of the fish were weighed in at the Alabama Deep Sea Fishing Rodeo, some were donated by local charter captains and recreational anglers, and one was a **near record-size specimen** (37 inches, 39 pounds) landed in Louisiana. Since previous studies drew conflicting conclusions regarding the most appropriate structure for aging (otoliths or first dorsal spine), we examined both of these structures in our study.

We found that otoliths are better suited for aging than first dorsal spines. The age range of fish in our study was 0–5 years, but more than half of the fish were just 1 year old. The 39-pound fish from Louisiana was the only 5-year-old specimen and represents the oldest tripletail ever aged in the Gulf of Mexico. Based on these results, Gulf of Mexico tripletail are very short-lived. Our growth models indicated that Gulf of Mexico tripletail are very fast-growing, potentially reaching 18–24 inches during their first year of life. Also, legal-size tripletail (at least 18 inches in Alabama and Mississippi) are as young as 1 year old. The models predicted a maximum length of approximately 27–31 inches for Gulf of Mexico tripletail, with females reaching greater lengths than males. This is a common example of **sexual dimorphism** and is typical across many fishes because big females are advantageous for reproductive purposes.

5.8 ANSWERING OUR TRIVIA QUESTION

Now that we've finished Chapter 5, let's answer our trivia question: Which species can withstand greater 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 likely be plenty of young individuals left in the population. These young fish will mature quickly and produce many offspring themselves, thereby continuing the circle of life.

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Chapter 6: Diet

HIGHLIGHTS

- ***Diet is important to fisheries managers because it provides information about a species' role in an ecosystem.***
- ***Stomach content analysis is the most common approach used to examine a species' diet; DNA barcoding can aid in this process.***
- ***Stable isotopes are a nonlethal method of examining the sources of a species' diet, as well as its trophic position.***

Figure 27. A photo of a sandbar shark, along with a red snapper it had consumed, that we caught on our bottom longline survey. Photo courtesy of David Hay Jones.

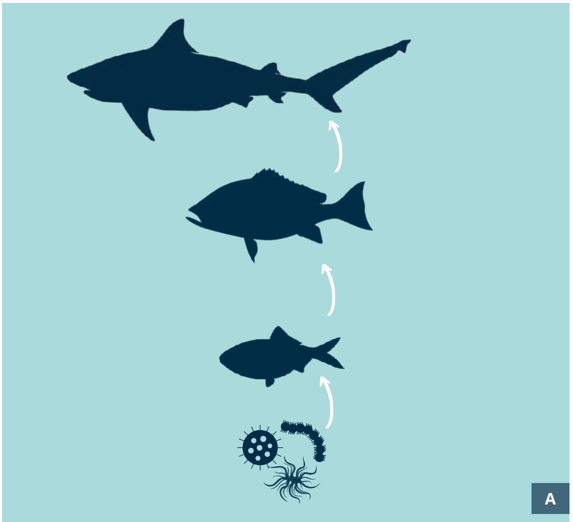
6.1 WHAT IS DIET?

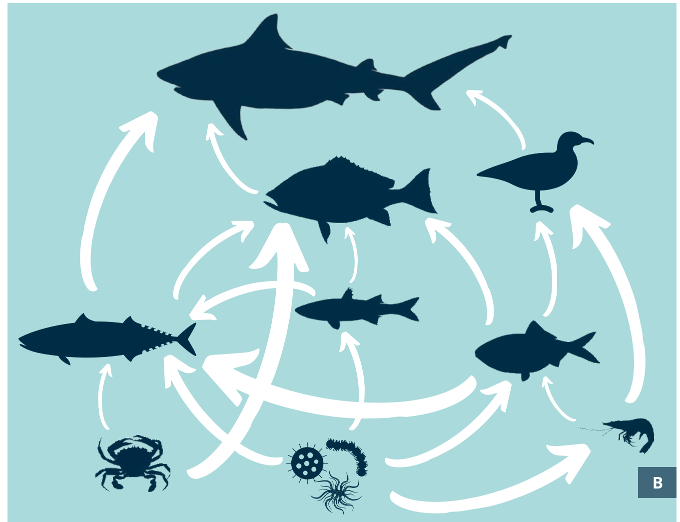
When we talk about diet in humans, it is usually in reference to weight loss or excluding/limiting certain food types like meat or gluten. However, when we discuss diet in regard to fishes or other animals, we are referring to the items they eat for nourishment. The diets of fishes vary greatly depending on species. Some fishes feed on small microscopic organisms, whereas others are voracious predators (***Figure 27***), feeding on the largest prey that they can possibly fit into their mouths. Some fishes are specialized, consuming a very narrow range of food items, while others are generalist feeders, feeding on whatever food is available.

6.2 WHY IS DIET IMPORTANT FOR FISHERIES MANAGEMENT?

Describing the diet of a species is important because diet can define relationships between species. For example, increases in the population of one species can lead to decreases in others, either through competition for resources or through direct predation. Often, the decline of a species can be directly linked to declines in its food or prey. Similarly, an increase in a species can often be linked to a decline in one of its consumers or predators. Simply put, we must understand diet so that we can understand dietary relationships expressed as **food chains** and **food webs** (***Figure 28***).

FIGURE 28. While food chains (A) and food webs (B) are similar in that they describe energy transfer from one species to another, there are a few key differences. Notably, food chains advance one species at a time in a single linear direction, whereas food webs are complex and often advance from one species in multiple different directions.





Graphic courtesy of Catherine Cowan.

6.3 HOW DO SCIENTISTS EXAMINE DIET?

If diet is so important, how do we study it? The simplest approach is to examine the stomach contents of a species. Newer methods such as DNA barcoding, gastric lavage, and stable isotope analysis can also be used. In the next few sections, we will discuss the details of these methods along with the subsequent data interpretation procedures.

6.3.1 Stomach Content Analysis

Stomach content analysis is the simplest form of diet analysis and has been used by scientists for centuries as a means of building aquatic food webs. This method involves surgically removing and opening the stomach of a fish, which requires sacrificing the individual. Next, we sort the stomach contents into prey categories (i.e., fishes versus other animals like crustaceans, bivalves, and marine worms) and then count and weigh each prey type. Each individual stomach acts as a snapshot of a species' diet. Once we obtain enough snapshots over time and across different regions, we can piece them together to draw dietary conclusions, including how diet changes seasonally and spatially. However, a limitation inherent to stomach content analysis is that prey items are often highly digested, making precise prey identification next to impossible. In these instances, DNA barcoding can be a valuable tool.

6.3.2 DNA Barcoding

While the visual characteristics of highly digested prey items are often absent, their DNA is typically still present. Therefore, scientists can use a technique called DNA barcoding to identify the prey. In fact, this technique is so powerful that scientists often can determine not only the family or genus, but the precise species of prey. DNA barcoding involves obtaining each species' unique genetic marker, or barcode, and then matching that barcode with an already identified species using a barcoding database (think of scanning an item's barcode at a grocery store to bring up the item's price). The ability to identify highly digested prey items is helpful for two important reasons. First, it increases the amount of information we obtain per stomach, which means we can sacrifice fewer individuals. Second, it can help identify rare prey species, which can have important conservation implications. As technology has improved, DNA barcoding has become a fairly convenient and cost-effective technique to identify otherwise unknown prey to the species level.

Figure 29. Marcus Drymon and Emily Seubert use gastric lavage to flush a juvenile tiger shark's stomach. Photo courtesy of David Hay Jones.

6.3.3 Nonlethal Stomach Content Analysis

Newer, nonlethal methods have been developed to sample stomach contents, including a method known as **gastric lavage** (also called "stomach pumping" or "gastric irrigation"). Gastric lavage involves flushing out the stomach of an animal using water or saline solution to collect the prey items from the stomach. This method is highly preferable in situations where the species of interest is threatened or endangered, or if the species is recreationally or commercially important. However, this technique is difficult or impossible to perform on some individuals.

6.3.4 Stable Isotope Analysis

Another nonlethal method for examining diet is **stable isotope analysis (SIA)**, which is typically performed on small amounts of fish tissue (e.g., muscle or blood). Isotopes are simply two or more forms of the same element (e.g., carbon or oxygen) that have slight variations in atomic weight because of additional neutrons. Take carbon, for example. While most of the carbon on our planet has six neutrons, the stable isotope of carbon has seven neutrons, and the radioactive isotope of carbon has eight neutrons. For ecologists, the additional neutrons in the stable isotope of carbon makes it a useful "chemical tracer" in dietary studies. While SIA does not provide scientists with species-level dietary data like stomach contents do, it can provide us with information like the species' **trophic level** or the location (e.g., estuarine versus marine) where individuals obtained their prey. Think of stomach content analysis as drawing the arrows in a food web and SIA as describing the location of a species on the food web (i.e., top, bottom, left, or right).

6.4 CASE STUDY: GULF OF MEXICO TIGER SHARKS

In 2010, while we were conducting our shark monitoring survey off the Mississippi/Alabama coast, we caught a juvenile tiger shark. Surprisingly, it coughed up bird feathers. Intrigued by this, we began using gastric lavage to examine the diets of juvenile tiger sharks when we caught them during our longline surveys. To do this, we gently placed a PVC pipe down the shark's throat, filled it with saltwater, turned the shark upside down and caught the flushed-out prey items in a sieve (***Figure 29***). Remarkably, 41 of the 105 tiger sharks we sampled over the course of 9 years contained bird remains.

Our next step was to identify what species of birds these tiger sharks were consuming. Most of the bird remains were simply feathers, making it essentially impossible to visually identify the bird species. However, through DNA barcoding, we were able to identify 11 different bird species from the feathery remains. Amazingly, all of these bird species were land-based (e.g., songbirds) and not marine birds (e.g., pelicans or gulls) like we had previously suspected.[1]

This seemed counterintuitive to us, so we decided to investigate bird sightings data from **eBird**, a Cornell University-run online database of bird observations logged by the birding community. Interestingly, peaks in sightings for each identified bird species along the Mississippi/Alabama coast aligned almost perfectly with the dates when the species was consumed by a tiger shark. Using the sightings data, we were able to align the dates of bird and tiger shark interactions with fall bird migrations for these species. We concluded that, as the birds prepare to leave the Mississippi/Alabama coast to fly south for the winter, they sometimes encounter unexpected storms, which disrupt migration. Once the songbirds fall from the sky and land in the ocean, they are unable to resume flight, making them easy meals for hungry juvenile tiger sharks.

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Chapter 7: Movement Studies

HIGHLIGHTS

- ***Tagging studies provide information on fish movement, biology, ecology, abundance, and stock structure.***
- ***Scientists often reach out to local recreational and commercial fishermen to help deploy and report tags; these approaches are known as angler-based or fishery-dependent tagging programs.***
- ***Tags come in many forms, from conventional plastic tags to more expensive acoustic and satellite tags.***

7.1 A TAG AS OLD AS TIME

People have been tagging wild animals since 200 BC.[1] The first animals tagged were birds—swallows and falcons that carried messages tied to their feet. The first record of fish being tagged was published in 1653; it described how researchers tagged Atlantic salmon using ribbons on their tails to track their movement. The scientists determined that these salmon returned to spawn in their **natal** rivers after moving out to sea.[1] Fully marine fish species, such as flatfishes (e.g., flounders and halibut) and cod, were first tagged in 1894, while pelagic species, like pacific herring and bluefin tuna, were first tagged in the early 1900s. Elasmobranchs (sharks, skates, and rays) were not tagged until the 1930s.[2] While many initial tagging endeavors were intended to reveal information on the movement of species and to identify different stocks, modern tagging studies have been developed to help answer many other complex questions regarding animal behavior, mortality, and movement ecology. In this chapter, we will discuss how different tagging programs are designed to answer different questions, with a specific focus on studies conducted along the Gulf Coast.

7.2 WHY TAG FISHES?

While many farmers and even pet owners may be familiar with the concept of tagging their animals for easy identification, scientists tag fishes to understand more about their movement, abundance, stock structure, growth, and mortality (see Chapter 5). This information can be used to aid fisheries managers in improving regulations to help enhance wild populations. However, successful tagging programs often require extensive thought and planning before implementation. It is necessary to consider several factors when designing a large-scale tagging program, including: What are the objectives of the study? Who will tag the fishes? Who will recapture the fishes? Which type of tag will be most effective for achieving the study objectives?

7.3 TYPES OF TAGGING PROGRAMS

Once we have determined the study objectives, we must then decide who will be doing the tagging and recapturing. In general, there are three types of tagging programs: angler-based (fishermen tag and recapture), biologist-based (scientists tag and recapture), and fishery-dependent (a hybrid where scientists tag and fishermen recapture).

7.3.1 Angler-Based Tagging Programs

Angler-based tagging programs rely solely on anglers. These programs are a cost-effective way to encourage **community science** (also known as citizen science) while also discovering new information about fish movement and fishing mortality. Typically, these programs focus on specific species and offer training for volunteer anglers on proper tagging and reporting techniques. An excellent example of a local angler-based tagging program is the Sport Fish Tag and Release Program at the University of Southern Mississippi's Gulf Coast Research Laboratory. This program began with cobia in 1989 but has expanded to include speckled trout and tripletail, as well.

7.3.2 Biologist-Based Tagging Programs

Biologist-based tagging programs involve more detailed collection of data when tagging the fishes. For example, scientists may be interested in tagging a fish not only to track its movement, but also to track its growth. In this case, trained researchers take precise measurements (fish length, fish weight, and exact catch location), apply the tag and record its unique identifier, release the individual, and, later, recapture it. These programs are also called "capture-recapture" programs. For example, the International Commission for the Conservation of Atlantic Tunas (ICCAT) runs a large-scale, biologist-based tagging program that tags tunas and billfishes with the goal of obtaining information about their movements, migrations, stock structure, growth, population size, and more.

7.3.3 Fishery-Dependent Tag-Return Programs

Fishery-dependent tagging programs are a combination of angler- and biologist-based tagging programs, wherein trained scientists measure and tag the animals but rely on recreational and commercial fishermen to report any recaptures. Our shark tagging program (Chapter 4) follows this approach. We measure, weigh, tag, and release individuals during our research surveys. Our tags list our contact information and a unique identifier. When anglers recapture tagged sharks, they use the information on the tags to contact us and report their catch, along with any pertinent observations. More on what to do if you catch a tagged fish can be found in Chapter 10.

7.4 WHAT TYPE OF TAG WILL BE USED?

Another important factor to consider when designing a tagging program is tag type. Tag designs can range from relatively inexpensive plastic tags to expensive electronic tags (essentially mini-computers). In general, tags fall into three categories.

7.4.1 Conventional Tags

Conventional tags are inexpensive and straightforward. They are applied to a fish externally and contain a unique identifier and instructions for reporting the fish's recapture. Some conventional tag types include disc tags, rototags (think of the ear tags used to identify livestock), T-bar tags (similar to what retailers use to attach price tags to clothing), dart tags (plastic or metal streamers), and cinch tags (***Figure 30 A–C***).

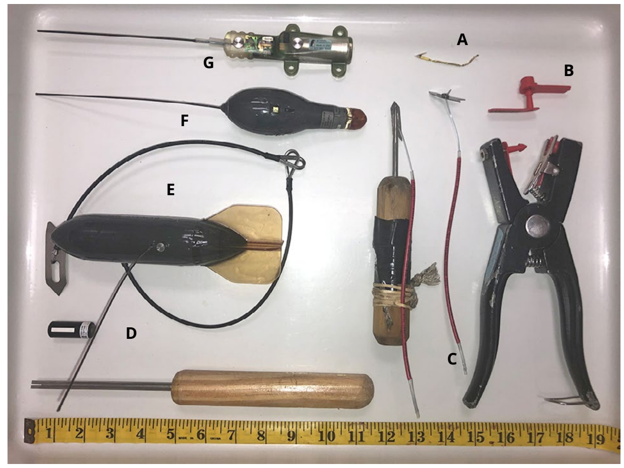

Figure 30. Conventional tag types include plastic dart (A), rototag (B), and metal dart (C). Telemetry tag types include acoustic tags (D), towed SPOT tags (E), PAT tags (F), and fin-mounted SPOT tags (G). Photo courtesy of Emily Seubert.

7.4.2 Telemetry Tags

In ecology, **telemetry** is defined as the process of remotely tracking an animal's movement and behavior. Telemetry tags offer researchers the opportunity to collect a detailed track of a fish's movement, but at a cost. Since these electronic tags record and provide a lot of information, they are far more expensive than simple, conventional tags. The most common types of telemetry tags used for fishes are **acoustic** and **satellite tags**.

Acoustic telemetry requires two components: a transmitter and a receiver. The acoustic transmitter (i.e., acoustic tag, ***Figure 30 D***) emits an acoustic signal that is unique to an individual fish. That signal is recorded by an acoustic receiver, or listening station, when the transmitter is within range (generally around 1,500 feet). The details of these transmissions can be obtained by downloading the data from the acoustic receiver. Due to the cost of acoustic receivers and the time and resources required to physically download data from a receiver (a process that often involves scuba diving), the placement of each receiver in a region is incredibly important and warrants careful consideration.

Satellite telemetry offers a different approach for tracking fishes. Once a satellite transmitter (i.e., satellite tag) is attached to a fish, movement information from that fish is then relayed to a satellite system known as Advanced Research and Global Observation Satellite (ARGOS), which is specifically implemented for tracking wildlife. Those data are then shared with the researcher through the Internet. Two common types of satellite tags are SPOT (Smart Position or Temperature) tags and PAT (Pop-off Archival Transmitting) tags (***Figure 30 E–G***).

7.4.3 Natural Tags

These "tags" are more accurately described as "tracers." They occur naturally in the environment and can be used to track the movement of fishes in a (usually) noninvasive manner. Recently, fisheries researchers have increasingly turned to using these tracers because they are more cost-effective than manufactured tags and don't rely on a recapture like conventional tags. One example of a natural tag is known as **eDNA**, or environmental DNA.[3] The basic premise is that scientists can collect a water sample, examine it for degraded bits of DNA present in shed skin cells, urine, feces, and so forth using specific DNA primers, and determine if a certain fish is present in that water body. Other natural tags include the chemical markers in otoliths or vertebrae of bony fishes and sharks. The elements in these structures can assume the unique chemical signature of the surrounding environment as the structures grow.

7.4.4 Other Tags

The conventional, telemetry, and natural tags mentioned above are just a few of the tag types available to fisheries scientists or fishermen. Other tags not discussed include passive integrated transponders (PIT tags), archival data storage tags (DSTs), acceleration data loggers (ADLs), electronic mark-recapture tags (mrPATs), and many more. With increases in technology, this list will undoubtedly continue to grow.

7.5 CASE STUDY: GULF OF MEXICO TARPON

In 2018, we began deploying towed SPOT tags on adult Atlantic tarpon (***Figure 31***). Tarpon have been tracked throughout Florida for many years, but little is known about their migratory behavior off the coasts of Mississippi and Alabama. This makes it difficult to implement effective management and harvest regulations on the 6-foot sportfish. Our goal was to better understand the movement and habitat use of adult tarpon in the northern Gulf of Mexico.

Figure 31. Successful deployment of a towed SPOT tag on an adult Atlantic tarpon. Photo courtesy of David Hay Jones.

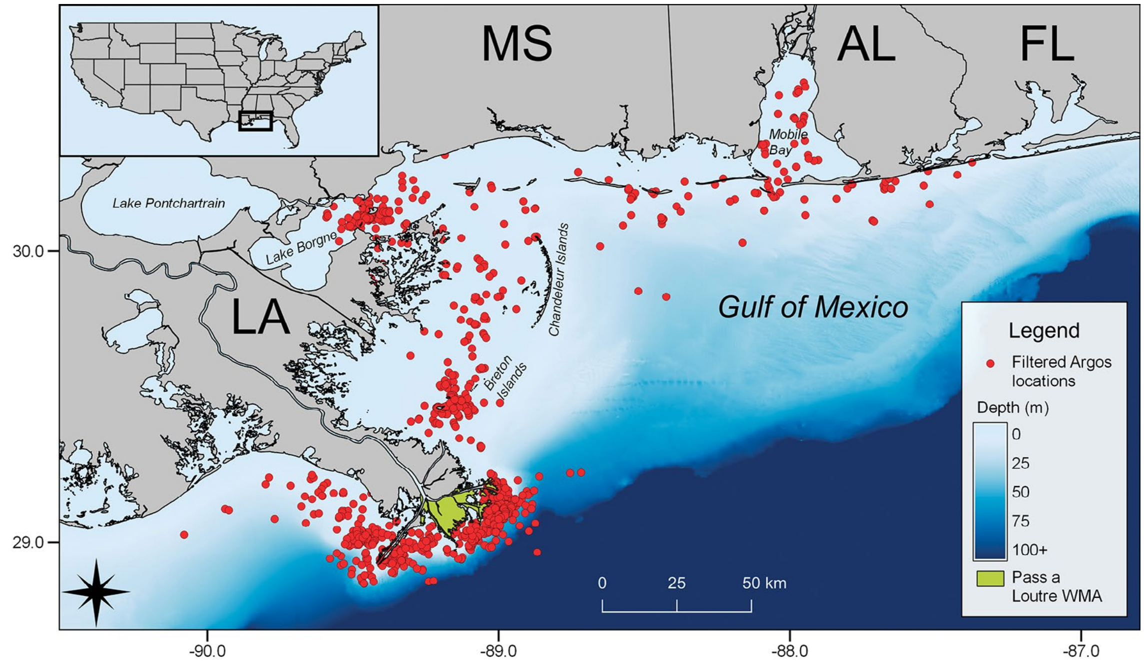

Figure 32. Filtered location information for the 22 tagged Atlantic tarpon gathered from the towed SPOT tags. Each red dot represents a location estimate for an individual fish. Map courtesy of Matthew Jargowsky.

Over the course of 2 years, we successfully deployed 22 satellite tags on tarpon in Alabama and Louisiana. These tags are towed about 2 feet behind the tarpon and transmit location estimates to satellites overhead anytime the tarpon is at the surface. Tarpon frequently surface to gulp air and obtain oxygen (using their modified swim bladders), giving these tags multiple opportunities to transmit location estimates throughout the day (***Figure 32***).

Many of the 22 tarpon were caught, tagged, and released just off of Alabama's coast during summer fishing rodeos. After release, these individuals continued their migrations westward through Mississippi and into Louisiana waters, sometimes traveling more than 50 miles in a single day. Eventually, all of them ended up in Louisiana; one even ventured into Lake Pontchartrain along the way.[4]

We're still learning about the movement patterns of the silver king. If you're interested in seeing the paths taken by some of these tarpon, visit our Mississippi State University Marine Fisheries Ecology Program **Facebook** page.

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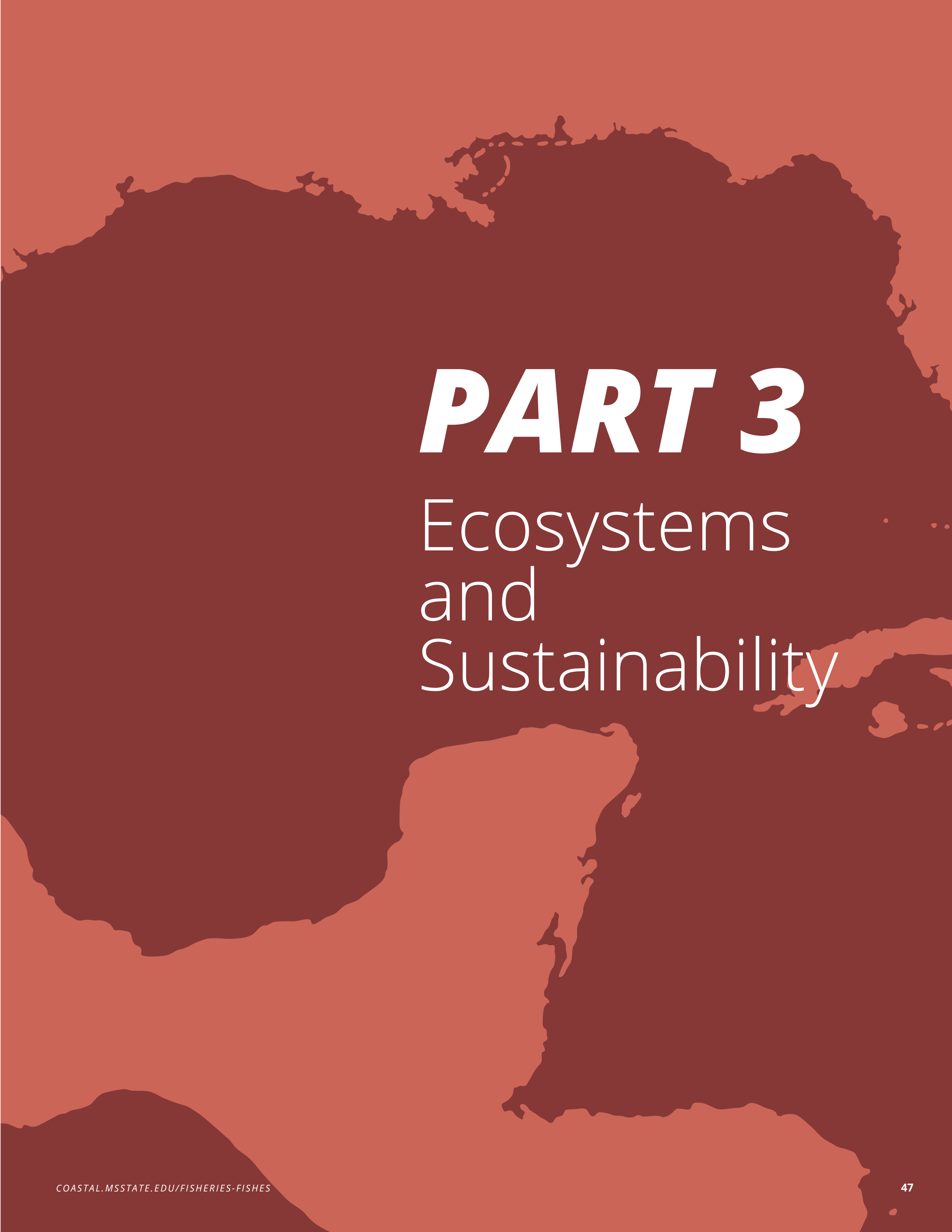

PART 3

Ecosystems and Sustainability

Chapter 8: Anthropogenic Alterations to the Gulf of Mexico Ecosystem

HIGHLIGHTS

- ***A variety of anthropogenic activities, including the Deepwater Horizon oil spill, the dead zone, the Bonnet Carré Spillway, and marine debris, have altered the entire Gulf of Mexico ecosystem.***
- ***Some anthropogenic activities occurred during a discrete period of time, but others are ongoing and producing increasingly severe impacts over time.***
- ***It is important to act as good stewards of the Gulf ecosystem by participating in efforts to mitigate the impacts of anthropogenic activities and by supporting local fishing and tourism industries.***

Until now, we've largely focused on the impacts of fishing on marine resources. In this chapter and the next, we'll discuss how other factors can affect the sustainability of fish populations. **Anthropogenic** activities significantly, and often detrimentally, alter the Gulf of Mexico ecosystem. Some of these activities occur within or alongside the Gulf itself. However, many happen across a larger scale, which can complicate mitigation efforts. Regardless of origin, it is important to note that some ecosystem-level impacts are becoming increasingly disastrous as time progresses. Moreover, these ecosystem-level impacts can, in turn, have similarly destructive consequences for our seafood industries, economy, and personal health. In this chapter, we will focus our discussion on four examples of anthropogenic alterations that are particularly relevant to the north-central Gulf: the Deepwater Horizon oil spill, the dead zone, the Bonnet Carré Spillway, and marine debris.

Figure 33. Vessels equipped with water cannons battle the Deepwater Horizon blaze. Photo courtesy of U.S. Coast Guard/public domain.

8.1 THE DEEPWATER HORIZON OIL SPILL

The Deepwater Horizon oil spill (DWHOS) was one of America's worst environmental disasters to date (***Figure 33***). On April 20, 2010, the oil platform Deepwater Horizon exploded and sank, killing 11 workers and leading to a blowout of the Macondo well. Over the following 87 days, approximately 200 million gallons of oil flowed into the Gulf of Mexico, eventually spreading across 29,000 square miles (about 4.5 percent) of the Gulf's surface and impacting 1,313 miles (about 37 percent) of the Gulf's coastline.[1]

While some studies found toxins from the oil and dispersants to harm fishes and other marine life, other studies reported these impacts to be minor.[2] Unfortunately, there was a lack of **baseline** data for many species, which made it difficult or impossible for researchers to quantify the true impacts of the spill on those species. Therefore, following the spill, a massive amount of funding was allocated to scientists across the northern Gulf who were tasked with acquiring baseline data in preparation for another DWHOS-scale environmental disaster, should one occur.[3]

Although the biological impacts of DWHOS were difficult to quantify, the economic impact was not. Immediately following the spill, large portions of the Gulf were closed to commercial and recreational fishing, resulting in a loss of revenue for commercial fishers and tourism dollars for coastal communities.[4] Even after the fisheries were reopened, consumers were hesitant to purchase Gulf seafood or spend time on the water, as they were still fearful of the contaminants from the spill. Fortunately, the stigma surrounding Gulf seafood has mostly been erased since then.

For more information about the DWHOS, please visit Sea Grant in the Gulf of Mexico's oil spill science website.

8.2 THE DEAD ZONE

Fishermen across the northern Gulf of Mexico are all too familiar with the "dead zone," one of the largest recurring **hypoxic** zones in the world.[5] The dead zone is a product of the mighty Mississippi River, which drains an area that spans approximately 40 percent of the continental U.S., or roughly 1.2 million square miles. The Mississippi River borders or passes through 10 different states, including the Midwestern states of Iowa, Illinois, Minnesota, Missouri, and Wisconsin. Nutrient-rich material, such as fertilizer, drains via runoff from these Midwestern states into the Mississippi River in the spring and summer and is then discharged into the northern Gulf of Mexico.[5] This influx of nitrogen and phosphorus triggers algal **blooms**—explosions of microscopic organisms (**phytoplankton**) that eventually die and sink to the bottom.[5] The process whereby anthropogenic nutrients fuel excess algal production is termed **eutrophication**. Once on the bottom, the phytoplankton decompose, which depletes the available oxygen near the seafloor. Without oxygen, mobile fishes and invertebrates leave the area, while creatures that can't leave die.

Not only is the Gulf of Mexico dead zone massive (approximately 7,000 square miles or roughly the size of the landmass of Massachusetts), it is also growing in size.[5] Each summer, it renders an entire region off the southern coast of Louisiana unusable by fishermen at considerable expense to Gulf seafood industries. Luckily, efforts are taking place to mitigate the issue. For example, the Mississippi River/Gulf of Mexico Hypoxia Task Force, established in 1997, involves members from federal agencies, state agencies, and tribes.[6] Its mission is "to understand the causes and effects of eutrophication in the Gulf of Mexico, coordinate activities to reduce the size, severity, and duration, and ameliorate the effects of hypoxia." Additionally, midwestern farmers and coastal fishermen are collaborating to better understand how farming practices in the Midwest affect fishing practices in the Gulf of Mexico, as well as to explore potential solutions. These include enhancing conservation practices to reduce nutrient runoff and increasing funding for conservation programs at both state and national levels.

8.3 THE BONNET CARRÉ SPILLWAY

The Bonnet Carré Spillway, constructed just west of New Orleans in 1931, redirects floodwaters from the southernmost portion of the Mississippi River into Lake Pontchartrain to prevent flooding in New Orleans (***Figure 34***).[7] The structure serves its intended purpose well, yet possesses a tremendous capacity to abruptly and severely alter the health of the northern Gulf of Mexico. In 2019, heavy rainfall and snowmelt from the Midwest led to three major events in the spillway's history: 1) the first time the spillway was opened in two consecutive years (it was also opened March 8–30, 2018), 2) the first time the spillway was opened twice in the same year (February 27–April 11 and again May 10–July 27) and 3) the longest duration the spillway has ever remained open in one year: 123 days.[7,8] To put these statistics into perspective, the spillway was only opened 10 times during its first 80 years in existence, but from 2015 to 2020, it has been opened four times. In other words, despite being nearly a century old, almost a third of the spillway's openings have occurred from 2015 to 2020.[7]

The massive influx of over 10 trillion gallons of nutrient-laden fresh water between February and July 2019 caused adverse effects on marine life, the seafood industry, and the tourism industry across the Mississippi Gulf Coast.[8] The precipitous decline in salinity was harmful in itself, but to make matters worse, it was accompanied by hypoxia and algal blooms throughout the Mississippi Sound.[8] More than 300 dolphin and sea turtle carcasses washed up along Mississippi beaches. Many surviving animals exhibited lesions on their bodies due to bacterial infections from the fresh water. The Mississippi Department of Marine Resources reported up to 90 percent oyster mortality on Mississippi reefs and an 82 percent reduction in brown shrimp catches in the first four weeks of the season compared to the 5-year average.[9] These shellfish impacts spelled disaster for the livelihoods of oystermen and shrimpers and for the economy as a whole. Ultimately, the overall dockside values of direct losses of shrimp, oyster, and crab landings in the region resulting from the 2019 prolonged Bonnet Carré Spillway opening totaled more than $100 million.[10] Tourism in coastal

Figure 34. The Bonnet Carré Spillway diverts excess Mississippi River water into Lake Pontchartrain. Photo courtesy of TeamNOLAcoe at English Wikipedia/GFDL.

Mississippi suffered, as well, with Mississippi's public beaches closed for the entire summer.

The decision to open and close the spillway currently rests with the chief engineer of the U.S. Army Corps of Engineers.[7] However, officials in Mississippi and Louisiana hope to change this decision-making process. They fear that increased rainfall may call for more frequent spillway openings in future years.

8.4 MARINE DEBRIS

While inexcusable, the presence of waste along our beaches and in our estuaries, bays, and oceans has become commonplace. **Marine debris** is defined as "persistent solid materials that are manufactured or processed and directly or indirectly, intentionally or unintentionally disposed of or abandoned into the marine environment."[11] Marine debris comes from both land- and ocean-based sources, and, sadly, it has become one of the worst pollution problems facing today's oceans.[11] Indeed, in coastal Mississippi alone, approximately a dozen tons of marine debris are collected during annual, 1-day Coastal Cleanup events. Below, we'll outline the types of marine debris, elaborate on its diverse impacts, and share ways to prevent and reduce those impacts.[11]

8.4.1 How Is Marine Debris Categorized?

- **Trash.** This includes many types of materials, such as plastics, cloth, glass, metal, paper, wood, and rubber. Plastics make up a large portion of marine debris because they are so prevalent in today's society. Unfortunately, most plastics never fully degrade—they simply break down into smaller and smaller pieces called **microplastics**.
- **Derelict vessels.** A variety of factors, from natural disasters to boat ownership neglect, can lead to derelict vessels. Derelict vessels can persist for years, and the debris associated with them can become widespread.
- **Derelict fishing gear** (***Figure 35***). This includes nets, fishing line, buoys, traps, and other recreational or commercial fishing equipment. **Ghost fishing** occurs when lost or discarded fishing gear traps and kills marine life.

8.4.2 What Are the Potential Impacts of Marine Debris?

- **Environmental.** Fishes and other marine life may eat marine debris, which irritates and damages their digestive systems. If the debris is not passed, this can lead to malnutrition or starvation. Microplastics in particular could negatively impact fish physiology and larval survival and could even impact human health if incorporated into edible tissues.
- Marine debris can also cause wildlife entanglement, which in turn can result in injury, suffocation, and death. Marine debris, particularly derelict gear, can damage habitats and kill endangered and threatened species. Moreover, if a plant or animal attaches to marine debris, it can be carried hundreds of miles in the currents and land in a nonnative area, thus becoming an invasive species (more on this in Chapter 9).
- **Economic.** Ghost fishing can cause economic losses from mortality of target species and costs associated with replacing lost gear. Marine debris on beaches can cause economic losses if the beaches are popular tourist destinations.

Figure 35. Marine debris, such as derelict crab traps, is becoming a big problem for shrimpers and oystermen. Photo courtesy of Ryan Bradley, Mississippi Commercial Fisheries United.

- **Navigation safety.** If marine debris is floating below the surface, it can result in damage to a vessel's hull or motor as well as injury or death to the vessel operator.
- **Human health and safety.** Scientists are conducting research to determine how marine debris, especially microplastics, might impact our health and safety.

8.4.3 How Can Boaters and Fishers Prevent and Reduce Marine Debris?

- Eliminate (or minimize) single-use plastics.
- Do not dispose of any garbage into the water while at sea.
- Properly stow and secure trash on your boat or at your fishing site.
- Dispose of fishing gear properly.
- Recycle used fishing line.
- Create a storm plan that is unique to your boat, fishing activities, and local weather conditions.
- Report illegal dumping to the U.S. Coast Guard.
- Support environmentally responsible marinas ("clean marinas").
- Care for your boat by performing regular maintenance and creating an end-of-life plan.

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Chapter 9: Anthropogenic Alterations to Gulf of Mexico Species

HIGHLIGHTS

- ***In addition to modifying entire ecosystems, anthropogenic activities can influence the distribution and abundance of individual species.***
- ***The introduction of nonnative species to new areas can negatively impact native fauna; this is particularly true for red lionfish in the Atlantic Ocean and Gulf of Mexico.***
- ***The warming of the world's oceans has caused a global decline in fisheries productivity and will continue to impact the future sustainability of fisheries.***

As we learned in Chapter 8, some anthropogenic activities have produced broad, ecosystem-level impacts across the entire Gulf. However, other anthropogenic activities have altered the distribution and abundance of individual marine species. In this chapter, we will focus on two important concepts related to anthropogenic activities: **invasive species** and **tropicalization**.

9.1 INVASIVE SPECIES

Invasive species of plants and animals occur in terrestrial, freshwater, and marine environments. These nonnative species can be introduced to new areas by natural processes but are more commonly transported by anthropogenic activities. Given the interconnectedness of today's world, the vast majority of Earth's ecosystems are vulnerable to attack by invasive species.[1] Indeed, even Antarctica is considered to be at risk of invasion by more than a dozen nonnative species, most of which are marine, by the year 2030. In this section, we will discuss two invasive marine species that have had a major impact on the Gulf: red lionfish and Asian tiger shrimp.

9.1.1 Red Lionfish

The red lionfish (hereafter, "lionfish"), a species of scorpionfish native to the Indo-Pacific, was introduced to southeastern Florida waters in 1985 (***Figure 36***).[2] Given the importance of lionfish in the global aquarium trade, these first specimens probably escaped from, or more likely were intentionally released from, aquaria.[2] After proliferating along the southeastern U.S. Atlantic coast and throughout the Caribbean, lionfish invaded the northern Gulf of Mexico in 2010.[3] Given a perfect blend of traits that facilitate expansion into new regions and promote dominance over native species, the species has become a major threat to Gulf fisheries.[4] Below, we'll outline some of those traits and their consequences.

Figure 36. A red lionfish. Photo courtesy of Alexander Vasenin/CC BY-SA 3.0.

- **Lionfish have a vast potential invasion range.** The warm water temperatures from North Carolina south to Uruguay, including the Gulf of Mexico, are favorable for lionfish occupation. Lionfish can also inhabit a huge depth range—from shallow nearshore waters up to 1,000 feet deep.
- **Lionfish grow and reproduce quickly.** They can grow more than a quarter of an inch per week and reach reproductive maturity at less than 1 year of age. Lionfish also spawn frequently, and females can spawn more than 2 million eggs per year. These high rates of growth and reproduction result in high densities of lionfish, particularly on natural and artificial reefs, such as those in Alabama's Artificial Reef Zone. Furthermore, lionfish eggs float, which enables them to drift with ocean currents and colonize new, potentially distant areas.
- **Lionfish are less constrained by limiting factors (e.g., native predators, native pathogens) in the Atlantic Ocean and Gulf of Mexico.** Therefore, lionfish can grow to larger sizes and reach higher abundances in this part of the world compared to the Pacific Ocean. This allows them to easily displace native reef fishes.
- **Lionfish are a new and powerful type of predator in the Atlantic Ocean and Gulf of Mexico.** They consume a broad range of native crustaceans and fishes, becoming more **piscivorous** as they grow and devouring prey at detrimentally high rates. Not only do lionfish directly consume native reef fishes (including red snapper), but they also diminish the amount of prey available to those native fishes.
- **Lionfish have few natural enemies in the Atlantic Ocean and Gulf of Mexico.** Most of their fins have venomous spines, which deter potential predators, including large fishes like groupers and sharks.

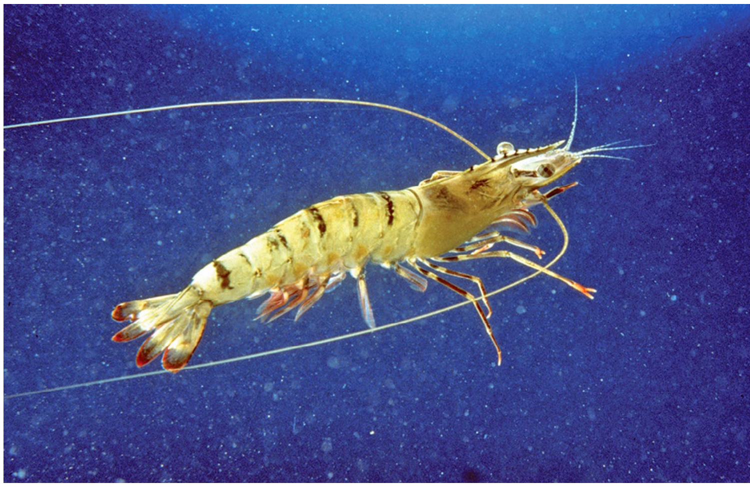

Figure 37. An Asian tiger shrimp. Photo courtesy of CSIRO/CC BY 3.0.

Clearly, these qualities stimulate the rapid spread of lionfish and make it difficult for us to eradicate them. Nevertheless, we do have several defenses against the invasion. Our best and easiest approach is to hunt and remove lionfish from reefs, either during solo spearfishing dives or coordinated lionfish rodeos. Since lionfish are quite tasty, this is actually a win-win scenario. We can also help prevent future invasions by communicating our knowledge to others. Specifically, we can educate folks about the negative effects of ecological invasions and the importance of never releasing any pets—terrestrial or aquatic—into the wild.

9.1.2 Asian Tiger Shrimp

Like red lionfish, Asian tiger shrimp are also native to the Indo-Pacific (***Figure 37***).[5] These giant shrimp, which are easily distinguishable by the black-and-white banding pattern along their backs and tails, can reach over a foot in length and almost three-quarters of a pound in weight. Asian tiger shrimp were historically one of the most popular shrimp species in aquaculture and were farmed in many locations around the world, including Africa, the Caribbean, and the U.S.[5] Although they are no longer farmed in the U.S., Asian tiger shrimp were likely introduced to U.S. coastal waters by accidental escapement from a South Carolina aquaculture facility in 1988.[5] Interestingly, the species was not reported again in U.S. waters until 2006 (18 years later) when a specimen was caught by a shrimper near Dauphin Island, Alabama. Since 2006, Asian tiger shrimp have turned up in all southeastern U.S. and Gulf states from North Carolina to Texas.[5] These 21st century appearances are likely due to transport via **ballast** water from the Indo-Pacific, transport via ocean currents from established South American or Caribbean populations, or escapement from other western Atlantic aquaculture facilities.[6]

Although invasive Asian tiger shrimp are probably detrimental to native species and ecosystems, scientists are unsure of the potential extent of this impact.[5] Given their large size, Asian tiger shrimp are predaceous and aggressively consume small crabs, shrimp, fishes, and mollusks.[6] Also, as with any invasive species, Asian tiger shrimp have the potential to introduce diseases to native species. Since 2011, a team of scientists from the U.S. Geological Survey, NOAA, and other entities has been collecting tissue samples from Asian tiger shrimp for genetics studies.[5,6] The scientists hope to determine the number of different populations existing in U.S. waters, the genetic relatedness of these populations, the source(s) of these populations, and potential future distribution patterns of the species.[6]

9.2 TROPICALIZATION

As the earth warms, the ocean is also warming, and the distributions of many marine fish species are shifting poleward from tropical areas into **temperate** areas. An increased proportion of tropical species inhabiting temperate areas is referred to as tropicalization. This phenomenon results in novel interactions between species, transformations in fish communities, and potential alterations to fisheries.

Tropicalization has been documented worldwide, including in the Gulf of Mexico. A recent study set out to examine range shifts among fishes inhabiting seagrass meadows off northwest Florida.[7] The authors compared fish data from two scientific trawl surveys: one conducted decades prior (during the 1970s) and one conducted more recently (from 2006 to 2007). The primary findings of the study were twofold. First, 11 tropical or subtropical fish species were totally absent during the 1970s but present in 2006–2007. These species included lane snapper, yellowtail snapper, red grouper, sergeant major, and stoplight parrotfish. Second, the abundance of three tropical or subtropical species in the northern Gulf increased substantially between the 1970s and the 2000s. Gag grouper was approximately 200 times more abundant. Gray snapper (***Figure 38***) was approximately 105 times more abundant. And emerald parrotfish was approximately 22 times more abundant. Importantly, these changes in species composition and abundance in northwest Florida seagrass meadows corresponded with increases in air and sea surface temperatures of more than 3 degrees Celsius between the 1970s and the 2000s. While increased populations of these species may be of interest to recreational anglers, they can have detrimental effects on the natural ecosystem, with the newer species outcompeting native species for resources.

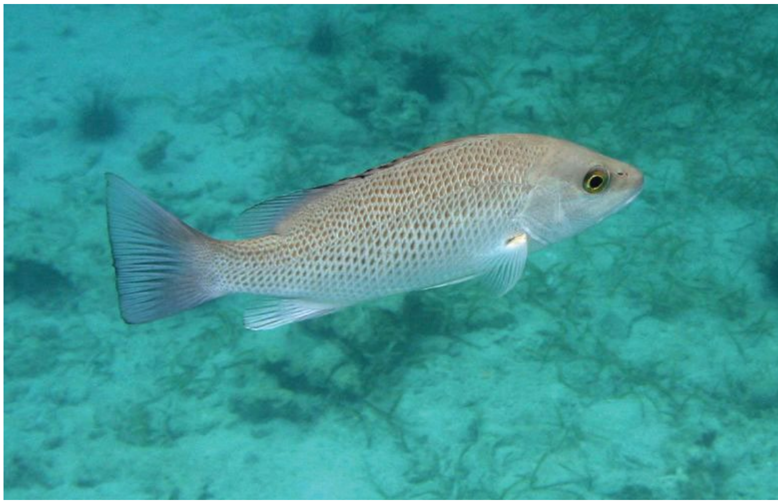

Figure 38. A gray snapper. Photo courtesy of Clinton and Charles Robertson from Del Rio, TX, and San Marcos, TX, USA/CC BY 2.0.

A different, larger scale study aimed to predict future temperature-driven habitat shifts for hundreds of marine species living on the North American continental shelf, including the Atlantic, Gulf, and Pacific coasts.[8] Generally, the findings suggested that species are expected to move poleward and/or into deeper waters over time. Although species from the U.S. and Canadian Pacific coast exhibited the greatest projected shifts in habitat, some Gulf of Mexico species were projected to experience shifts, as well. For example, gray snapper was initially most abundant off Florida's west coast, but its thermal habitat was predicted to expand throughout the Gulf and along the U.S. East Coast. Therefore, the overall amount of thermal habitat available to gray snapper was predicted to increase. Conversely, sheepshead was predicted to lose more than three-quarters of its initial habitat in the Gulf and only gain marginal habitat along the U.S. East Coast, which will likely result in a net loss of suitable habitat for this species.

Based on a 2019 global analysis exploring the historical effects of ocean temperature on the productivity of 235 different fish and invertebrate populations, the combined **maximum sustainable yield (MSY)** from these populations decreased by more than 4 percent between the years 1930 and 2010.[9] This decline in maximum sustainable yield not only represents a decline in fisheries productivity, but also forecasts future challenges to maintaining sustainable fisheries. As marine species move in response to increasing temperatures, fisheries will undoubtedly change. Fishermen and managers must swiftly and appropriately adapt to these new conditions to ensure the future sustainability of global fisheries.

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Chapter 10: FISHES in Action

CHAPTER HIGHLIGHTS

- *Fishermen can assist fisheries research both on and off the water by participating in community science, making environmentally responsible choices, and having their voices heard at local stakeholder engagement meetings.*
- *Implementing proper catch-and-release techniques, such as using appropriate fishing gear, keeping the fish in the water, and using descender devices or venting tools, is imperative to reduce discard mortality of landed fishes.*
- *Choosing local, sustainably sourced seafood can make a positive impact on both the local fishing community and the local ecosystem.*

10.1 WHAT CAN FISHERMEN DO FOR FISHERIES SCIENCE?

Now that you have reached the end of the *FISHES* book and learned about some of the issues facing our Gulf ecosystem, you may be asking yourself, "What can I do to help?" Luckily, there are many ways that fishermen and other members of the public can help fisheries researchers and the ecosystems we study. Below are just a few examples of some actions you can take to ensure the Gulf Coast continues to produce sustainable fisheries and healthy, delicious, bountiful seafood for generations to come.

10.2 COMMUNITY SCIENCE

Community science involves the collection of data by nonprofessional researchers. Incorporating information compiled by members of the community and other stakeholders is rapidly becoming a popular strategy for researchers to use for large-scale, ecosystem-level studies. Observations and knowledge collected from people who are familiar with their local environments have been used to document species declines, detect shifts in ecosystem structure, and track marine invasions.[1] In Chapter 9, we discussed the invasive red lionfish that have occupied the northern Gulf waters over the past decade. A recent community science study compared lionfish surveys completed by spearfishers and divers (i.e., fishery-dependent data) with traditional fishery-independent data sources. They found that community observations documented the existence of lionfish in the Gulf a couple of years earlier than scientific monitoring programs.[1] This study underscores the speed at which valuable information can be obtained from "nontraditional" data resources.

Another example of the contribution of community science involves our tiger shark study,[2] previously discussed in Chapter 6. To understand the relationship between the sharks and birds, we turned to the world's largest biodiversity-related community science project, eBird. Without the help of avid birdwatchers around the world, the migratory information that was needed to recognize this unique predator-prey relationship would have been missing. As you can see, community science is a valuable, cost-effective way to combine local knowledge with data collected by researchers to improve management and to maximize the success and health of our ecosystems.

10.2.1 Case Study: Community Science in the Gulf

Wondering how you can contribute to fisheries studies in the Gulf? One of the easiest ways to conduct community science as a local fisherman was mentioned in Chapter 7: tagging studies. If

Figure 39. Marcus Drymon releases a tagged (tag in red) juvenile great hammerhead. If you catch a shark with a red tag similar to the one pictured here, take care to (safely) record the tag number, species of shark, total length of the animal, and your location and report the information to help us track shark movement in the Gulf. Photo courtesy of David Hay Jones.

you ever catch a tagged fish or shark, record as much information as possible and report it to the appropriate entities. For example, if you catch a shark with a red tag near its dorsal fin, chances are it's one of ours (***Figure 39***). Regardless of your plans to keep or release the animal, make a quick note of your location (the more specific, the better), the species you caught, the associated tag number, the estimated length of the animal, and any other details you'd like. You can then go to the website listed on the tag (in our case, it's www.msusharktags.com) or call the number listed on the tag to report the information. These data will provide us with movement information and even assist us in estimating habitat preferences of local shark and fish species.

You can also participate in regional and national angler-based and cooperative tagging programs, like those discussed in Chapter 7. On a national level, NOAA Fisheries has resources for anglers and fish enthusiasts to participate in shark, tuna, and billfish tagging programs. There are also regional tagging programs that encourage citizens to tag and report fishes in the northern Gulf of Mexico; examples include the TAG Alabama Program with the Coastal Conservation Association in Alabama and the Sport Fish Tag and Release Program with the Gulf Coast Research Laboratory in Mississippi. Getting involved with these local tagging programs is the perfect opportunity to contribute to fisheries research while also enjoying your favorite pastime: fishing.

10.3 GETTING INVOLVED ON THE WATER

One of the best opportunities to get involved on the water is while you're fishing. The best way to avoid unnecessary fish mortality, as discussed in Chapter 5, is to familiarize yourself with the best catch-and-release protocols. Catch-and-release angling can be an effective conservation tool while also providing sportfishing opportunities for anglers, but it must be done correctly to serve its purpose. Unfortunately, many fishes that are caught and released actually die due to physical damage from hooks, exhaustion from extensive fights on the line, excessive handling once on board, and/or barotrauma (the physical internal damage caused by the sudden change in pressure when hauling up from depth; see Chapter 5).[3] Poor catch-and-release techniques increase fishing mortality and can lead to stricter management and regulations. The following are important steps to take to ensure that you are making every effort possible to successfully release fishes that you don't plan to keep.

10.3.1 Before Landing Your Fish

- **Be sure to use the proper gear.** Light tackle often leads to longer and more exhaustive battles for larger fishes, which can cause lactic acid buildup and leave a fish unable to swim away after release, or more vulnerable to predation. Plan to bring a variety of tackle and choose appropriate gear for the species that you are targeting. Non-stainless steel or other corrodible metal circle hooks are required when fishing for some species, but they could benefit many species. Non-stainless steel circle hooks eventually work their way out of a fish's mouth or fall apart when the metal corrodes, unlike a stainless steel J hook, which can remain lodged in a fish's jaw for years.
- **Only target species that are in season.** While it may be fun to catch and release red snapper out of season, you risk accidentally killing that fish. When preparing for a day on the water, plan to target only species that are in season.
- **Familiarize yourself with local fishing regulations.** Know the current local laws and regulations before going out so you don't end up harvesting a fish you're not supposed to keep. As we discussed in Chapter 3, if you are fishing within 3 miles from shore, follow that state's regulations. If you are offshore, follow federal regulations (except in the case of certain reef fishes like red snapper).

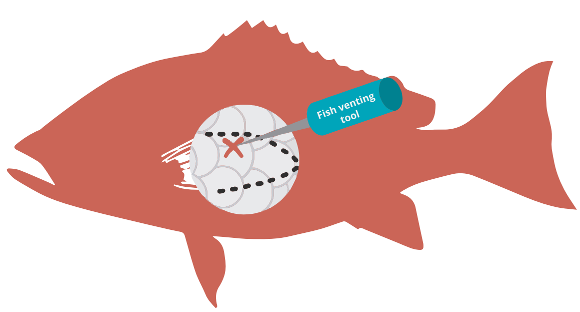
10.3.2 After You Land Your Catch

- **Minimize a fish's time out of water.** While keeping the fish in the water is ideal, that is not practical with many fish species or aboard many vessels. When boating a fish, it is important to work as quickly as possible to return the fish to the water after capture. Each second a fish is out of the water lowers its chance of survival.
- **Take photos of the fish in the water.** While many fishermen love to take photos of themselves holding their catch, doing so decreases a fish's chances of survival after release. However, if you instead take a photo of the fish with it in the water, either before bringing it aboard or as you release it, you can greatly increase the fish's chance of survival.
- **Use wet hands and a rubberized landing net when handling your fish.** Fishes have a natural layer of slime on the outside of their bodies to protect them from contracting bacterial infections. If you handle a fish with dry hands or a dry rag, you risk removing that slime, making the fish more susceptible to disease and infection. For these reasons, you should also keep the fish off the ground or deck if possible.
- **Avoid touching the eyes or gills.** These are sensitive areas on a fish, and excessive touching can be harmful.
- **Hold larger fishes horizontally with two hands, rather than vertically.** Holding the fish vertically is unnatural and puts strain and pressure on its spine while out of the water.
- **Remove the hook as quickly and efficiently as possible.** Always have pliers or a dehooker on hand to quickly and efficiently remove a hook from a fish. If you can't quickly remove the hook, or the fish is gut-hooked, simply cut the line close to the mouth. Any attempt to remove a hook from a gut-hooked fish will likely kill it, so doing so should be avoided unless you plan to keep the fish.

- **Use a descender device for any animal that has experienced barotrauma.** Barotrauma typically results in one (or a combination) of four injuries to the fish: protruding stomach, bulging eyes, distended intestines, and/or a bloated belly (***Figure 40***). Descender devices are a simple way to effectively return fishes to depth unharmed, thereby dramatically improving their chances of survival.[4,5] These devices are relatively cheap, easy to use, and often categorized into three groups:
  1. **Fish elevator.** This can be as simple as a milk crate with a weight attached to a rope.
  2. **Inverted hook.** This is often a barbless, inverted hook inserted into the fish's lower lip that releases the fish at depth with a sharp jerk on the line by the angler.
  3. **Mouth grab.** These devices clamp onto the fish's lower lip and are mechanically released via a pressure sensor or triggered to release when the weight hits the bottom. An example of a mouth grab descender device (the SeaQualizer) was discussed in Chapter 5.
- **If you don't have a descender device, properly vent a fish that has experienced barotrauma** (***Figure 41***). However, if you choose to vent your fish, it needs to be done correctly! Check out this video from Florida Sea Grant on how to properly vent a fish.

Figure 40. A red snapper exhibiting a common sign of barotrauma: a protruding stomach from the mouth. Researchers used a SeaQualizer to safely return this individual to depth. Photo courtesy of David Hay Jones.

FIGURE 41. This graphic demonstrates the proper location on a fish's body to insert a needle or hollow venting tool through the scales and rib cage into the swim bladder, thereby releasing the internal pressure so the fish can return to depth.



Graphic courtesy of Catherine Cowan, modified from Scyphers et al. (2013).[6]

10.4 GETTING INVOLVED OFF THE WATER

You can also help fisheries research from land. Make your voice heard: become an active member of the community and openly discuss the issues facing our Gulf ecosystem. The Mississippi Commission on Marine Resources (MS CMR) holds monthly meetings that are open to the public. At these meetings, all members of the public are welcome to voice their concerns with current fishing practices and regulations. Information about upcoming CMR meetings can be found here.

In addition, the Gulf of Mexico Fishery Management Council (GMFMC) hosts public meetings and scoping workshops. During these meetings, public comments are recorded, summarized, and presented to the council before fishery management decisions are made, allowing the public to voice their concerns about the management process. Information about upcoming public meetings can be found here. The GMFMC also incorporates information from the public sector regarding any species undergoing a stock assessment through a program known as "Something's Fishy." This is a public forum that allows members of the public to submit any peculiar instances, interactions, or observations regarding a particular species. This information is used to help inform fisheries managers and scientists who are conducting a given stock assessment.

10.5 SUSTAINABLE SEAFOOD

One of the easiest and most effective ways to have a positive impact on local Gulf fisheries is by choosing to consume sustainably harvested Gulf seafood. There are plenty of Gulf-based resources to help you select seafood that is local, healthy, tasty, and environmentally responsible and benefits local fishermen. Here are just a few:

- **G.U.L.F. (Gulf United for Lasting Fisheries).** Audubon Nature Institute's G.U.L.F. has Gulf-wide and state-specific programs that verify that natural marine resources are responsibly and sustainably harvested, thus contributing to a more stable fishing industry. This is accomplished through **fishery improvement projects (FIPs)** that are funded by the Gulf States Marine Fisheries Commission and are specifically designed to verify a fishery as sustainable after it reaches the following criteria: the stock is harvested at a responsible level, fishing methods cause minimal environmental impacts, and the fishery is compliant with national and international laws.
- **Mississippi Seafood.** The Mississippi Department of Marine Resources is responsible for promoting the state's local, wild-caught seafood by collaborating with commercial fishing industries, as well as local and federal agencies. This program is committed to the sale of high-quality seafood harvested in compliance with sustainable fisheries management practices by local fishermen. To find out more, visit their website here.
- **Genuine MS.** The Mississippi Department of Agriculture and Commerce has recently launched a new branding effort so that consumers can ensure that the products they buy are made, produced, raised, or caught in Mississippi. Anytime you see the Genuine MS logo on seafood packaging, you'll know the product was caught by a Mississippi fisherman.

- **Mississippi Commercial Fisheries United, Inc. (MSCFU).** MSCFU is an organization committed to supporting local commercial fishermen who practice sustainable fishing practices. Follow them on social media (@MSCFUnited) for information on where to purchase local, fresh Gulf seafood to support local fishermen.
- **Dining out.** Did you know about two-thirds of seafood consumed in the U.S. is consumed in restaurants?[7] Unfortunately, not all of these menu items are local, and many are far from sustainable. Luckily, the G.U.L.F. Restaurant Partnership Program is devoted to certifying and marketing local Gulf Coast restaurants and has made it easy for consumers to make environmentally responsible decisions when choosing where to go for dinner. For easily accessible information on where to purchase sustainable Gulf seafood, whether at a restaurant or in a grocery store, download the G.U.L.F. Seafood App.

There are many ways you can simultaneously support your local Gulf fishermen and make sustainable, environmentally responsible choices when enjoying Gulf seafood. Whether on or off the water, *you* can make a difference and have a positive impact on Gulf Coast fisheries.

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Epilogue

Thank you for reading *Fishermen Invested in Science, Healthy Ecosystems, and Sustainability*. This book was written to accompany an in-person Extension course that covers these topics in more depth. We encourage those who are interested to visit the course **webpage** for details and to register. You can also contact Dr. Marcus Drymon at **marinefisheriesecology@gmail.com** with any questions. Until then, we hope you've enjoyed this book and learned more about fisheries management, fisheries science, and how the two work in tandem to ensure sustainable fisheries across the northern Gulf of Mexico.

See you on the water!

Glossary

*** Indicates definition obtained from NOAA Glossary.**
† Indicates definition obtained from Dictionary.com.
‡ Indicates definition obtained from FishBase.

Acceptable biological catch: (n.) A scientific calculation of the sustainable harvest level for a species or species group, used to set the upper limit on the range of potential annual total allowable harvest.*

Accrete: (v.) To form (a composite whole or a collection of things) by gradual accumulation.

Acoustic tag: (n.) A transmitter used to remotely track organisms in aquatic ecosystems.

Age: (n.) The number of years of life completed. (v.) To grow old or older.*

Age structure: (n.) A breakdown of the different year classes of a kind of fish in a population or sample.*

Annual mortality rate: (n.) 1. The amount of death, usually in terms of a percentage of fish dying from a population in 1 year, due to both fishing and natural causes; 2. The ratio of the number of fish that die during a year divided by the number of fish alive at the beginning of that year.*

Anthropogenic: (adj.) Caused or produced by humans.†

Ballast: (n.) Any heavy material carried temporarily or permanently in a vessel to provide desired draft and stability.†

Barotrauma: (n.) The physical internal damage to a fish caused by the sudden change in pressure when hauling up from depth.

Baseline: (n.) A set of reference data sets or analyses used for comparative purposes. It can be based on a reference year of a reference set of (standard) conditions.*

Bioacoustics: (n.) The science of sounds produced by or affecting living organisms, as for communication or echolocation.†

Biomass: (n.) 1. The total weight of a group (or stock) of living organisms (e.g., fishes, plankton) or of some defined fraction of it (e.g., spawners) in an area, at a particular time; 2. The measure of the quantity, usually by weight in pounds or metric tons, of a stock at a given time.*

Bloom: (n.) A sudden increase in the abundance of alga or phytoplankton resulting in a contiguous mass of highly concentrated phytoplankton in the water column.*

BOFFFF: (n.) A "big, old, fat, fecund female fish."

Bycatch: (n.) Fishes other than the primary target species that are caught incidental to the harvest of the primary species. These fishes may be retained or discarded. Discards may occur for regulatory or economic reasons.*

Clasper: (n.) The male external reproductive organ of an elasmobranch.

Cloaca: (n.) The common cavity into which the intestinal, urinary, and generative canals open.

Community: (n.) The populations that live and interact physically and temporally in the same area.*

Community science: (n.) Also known as citizen science. Scientific research conducted in whole (or in part) by nonprofessional scientists.

Creel survey: (n.) Questions asked to recreational anglers once they've completed a fishing trip. Biological samples are often collected during this process.

Cross-section: (v.) 1. To cut or divide into slices; 2. To cut through so as to present a slice. (n.) The portion resulting from the cutting or dividing process.

Descending device: (n.) An instrument that returns fishes to depth safely and quickly.

Discard: (v.) To release or return fishes to the sea, dead or alive, whether or not such fishes are brought fully on board a fishing vessel.* (n.) A fish returned to the sea.

Discard mortality: (n.) The trauma related to fishing events that causes fishes to perish upon their return to the sea.

Ecosystem: (n.) A geographically specified network of organisms, the environment, and the processes that control its dynamics. Humans are an integral part of an ecosystem network.*

eDNA: (n.) A tracer that occurs in water samples and can be used to track the movement of fishes in a (usually) noninvasive manner. Scientists collect a water sample and run it against DNA primers to determine if a certain fish was or was not present in that water.

Elasmobranch: (n.) A group of fishes without a hard, bony skeleton, including sharks, skates, and rays.*

Eutrophication: (n.) The natural or human-induced process by which a body of water becomes enriched in dissolved mineral nutrients (particularly phosphorus or nitrogen) that stimulate the growth of aquatic plants and enhance organic production of the water body. Excessive enrichment may result in the depletion of dissolved oxygen and eventually to species mortality.*

Exclusive economic zone (EEZ): (n.) The area that extends from the seaward boundaries of the coastal states (3 nautical miles [n.mi.] in most cases) to 200 n.mi. off the U.S. coast. Within this area, the U.S. claims and exercises sovereign rights and sole fishery management authority over all fishes and all continental shelf fishery resources.*

External fertilization: (n.) A type of reproduction where males and females of a given species release large quantities of eggs and sperm into the water at the same time; reproduction then occurs in the water.

Fecundity: (n.) The potential reproductive capacity of an organism or population expressed in the number of eggs (or offspring) produced during each reproductive cycle. Reproductive capacity usually increases with age and size. The information is used to compute spawning potential.*

Fin ray: (n.) A flexible structural element that lends support to the appendages.

Fin spine: (n.) A rigid and pointy structural element that lends support to the appendages.

Fishery: (n.) 1. An activity leading to harvesting of fishes. It may involve the capture of wild fishes or raising of fishes through aquaculture; 2. A unit determined by an authority or other entity that is engaged in raising or harvesting fishes. Typically, the unit is defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats, and purpose of the activities; 3. The combination of fishes and fishers in a region, the latter fishing for similar or the same species with similar or the same gear types. (Note: When discussing fisheries, the term “fish” is used as a collective term referring to any aquatic animals that are harvested, such as crustaceans and mollusks.)*

Fishery-dependent: (adj.) Describes data collected directly on a fish or fishery from commercial or sport fishermen and seafood dealers. Common methods include logbooks, trip tickets, port sampling, fishery observers, and phone surveys.*

Fishery improvement projects (FIPs): (n.) Multi-stakeholder initiatives that aim to help fisheries work toward sustainability.

Fishery-independent: (adj.) Characteristic of information (e.g., stock abundance index) or an activity (e.g., research vessel survey) obtained or undertaken independently of the activity of the fishing sector. Intended to avoid the biases inherent to fishery-related data.*

Fishery management plan (FMP): (n.) 1. A document prepared under supervision of the appropriate fishery management council (FMC) for management of stocks of fish judged to be in need of management. The plan must generally be formally approved. An FMP includes data, analyses, and management measures; 2. A plan containing conservation and management measures for fishery resources and other provisions required by the Magnuson-Stevens Act, developed by fishery management councils or the Secretary of Commerce.*

Fishing mortality (F): (n.) 1. The death rate in a particular stock. It is roughly the proportion of the fishable stock that is caught in a year; 2. A measurement of the rate of removal from a population by fishing. The rate can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in one year. Instantaneous mortality is the percentage of fish dying at any one time.*

Food chain: (n.) The transfer of energy from the source in plants through a series of organisms with repeated eating and being eaten. At each transfer, a large proportion of the potential energy is lost as heat. The shorter the chain (or the nearer the organism is to the beginning of the chain), the greater the availability of energy that can be converted into biomass.*

Food web: (n.) A network of food chains in an ecosystem.‡

Forceps: (n.) An instrument, as pincers or tongs, for seizing and holding objects.†

Gastric lavage: (n.) The flushing of an animal’s stomach, using water or saline solution, to collect prey items from the stomach.

Gestate: (v.) To carry a fetus in utero from conception to birth.†

Ghost fishing: (n.) The accidental capture of aquatic organisms by fishing gear (usually gillnets or traps, pots, etc.) that has been lost or discarded into the sea and that continues to entangle or trap aquatic animals.*

Growth: (n.) Usually an individual fish’s increase in length or weight with time. Also may refer to the increase in numbers of fish in a population with time.*

Growth model: (n.) 1. A mathematical formula that describes the increase in length or weight of an individual fish with time; 2. A mathematical description or representation of the size of a living organism at its various ages. The von Bertalanffy growth model is commonly used in fish stock assessments.*

Gut-hooking: (v.) When a captured fish ingests a hook, thereby lodging the hook in the stomach.

Highly migratory species (HMS): (n.) Marine species whose life cycle includes lengthy migrations, usually through the exclusive economic zones of two or more countries as well as into international waters. This term usually is used to denote tuna and tuna-like fishes, sharks, swordfish, and billfish.*

Hypoxic: (adj.) Describes conditions of very low oxygen levels.

Ichthyologist: (n.) A scientist who studies fishes.†

Index of relative abundance: (n.) A relative measure of the size (quantity) of a stock (e.g., a time series of catch per unit effort data).*

Integrated ecosystem assessment: (n.) An approach that engages scientists, stakeholders, and managers to integrate all components of an ecosystem, including humans, into the decision-making process so that managers can balance trade-offs and determine what is more likely to achieve their desired goals.*

Internal fertilization: (n.) The union of egg and sperm inside the body of a parent (typically the female).

Invasive species: (n.) An introduced species that outcompetes native species for space and resources.*

Large marine ecosystem (LME): (n.) Areas of coastal oceans delineated on the basis of ecological characteristics—bathymetry, hydrography, productivity, and trophically linked populations.*

Marine debris: (n.) Persistent solid materials that are manufactured or processed and directly or indirectly, intentionally or unintentionally disposed of or abandoned into the marine environment.

Maximum sustainable yield (MSY): (n.) The largest average catch that can continuously be taken from a stock under existing environmental conditions. For species with fluctuating recruitment, the maximum might be obtained by taking fewer fish in some years than in others.*

Microplastics: (n.) Small plastic pieces (smaller than 0.2 inch in size) that are primarily produced through degradation of larger plastic pieces.

Microscope: (n.) An optical instrument having a magnifying lens or a combination of lenses for inspecting objects too small to be seen, or to be seen distinctly and in detail, by the unaided eye.†

Migratory: (adj.) The act of traveling long distances, often crossing state, regional, national, or international boundaries.

Moratorium: (n.) A mandatory cessation of fishing activities on a species (e.g., the blue whale), in an area (e.g., a sanctuary), with a particular gear (e.g., large-scale driftnets), and for a specified period of time (temporary, definitive, seasonal, or related to reopening criteria).*

Mortality: (n.) Measures the rate of death of fishes. Death occurs at all life stages of the population and tends to decrease with age.*

Mortality rate: (n.) The speed at which the numbers in a population decrease with time due to various causes. Mortality rates are critical parameters in determining the effects of harvesting strategies on stocks, yields, revenues, etc.*

Multi-species assessment: (n.) Concurrent determination of stock status for two or more co-occurring species (e.g., walleye pollack and Pacific cod).

Natal: (adj.) Connected with birth or birthplace (e.g., stream of a fish).‡

Natural mortality (M): (n.) 1. The death of fishes from all causes except fishing (e.g., aging, predation, disease, pollution). It is often expressed as a rate of fishes dying in a year (e.g., a natural mortality rate of 0.2 implies that 20 percent of the population will die from causes other than fishing); 2. The loss in numbers in a year class from one age group to the subsequent one due to natural death.*

Opacity: (n.) The state or quality of being opaque.†

Opaque: (adj.) 1. Impenetrable to light; 2. Not allowing light to pass through.†

Operculum: (n.) A bony gill cover comprised of four bones: opercle, preopercle, interopercle, and subopercle.‡

Optimum yield: (n.) 1. The harvest level for a species that achieves the greatest overall benefits, including economic, social, and biological considerations. Optimum yield (OY) is different from maximum sustainable yield (MSY) in that MSY considers only the biology of the species. The term includes both commercial and sport yields; 2. The amount of fish that will provide the greatest overall benefit to the nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems. MSY constitutes a “ceiling” for OY. OY may be lower than MSY, depending on relevant economic, social, or ecological factors. In the case of an overfished fishery, OY should provide for the rebuilding of the stock.*

Otic capsule: (n.) The skeleton surrounding the inner ear or otic vesicle, composed of the prootic, opisthotic, exoccipital, and supraoccipital.‡

Otolith: (n.) The ear bone of a fish. Otoliths have rings on them, like the rings on a tree stump, and are used to find the age of the fish and its growth rate.*

Overfished: (adj.) 1. A stock or stock complex having a sufficiently small size that a change in management practices is required to achieve an appropriate level and rate of rebuilding. A stock or stock complex is considered overfished when its population size falls below the minimum stock size threshold. A rebuilding plan is required for stocks that are deemed overfished; 2. A stock is considered overfished when exploited beyond an explicit limit beyond which its abundance is considered too low to ensure safe reproduction. In many fisheries, the term is used when biomass has been estimated to be below a biological reference point that is used as the signpost defining an overfished condition.*

Overfishing: (v.) 1. Occurs whenever a stock or stock complex is subjected to a rate or level of fishing mortality that jeopardizes its capacity to produce maximum sustainable yield (MSY) on a continuing basis. Overfishing is occurring if the maximum fishing mortality threshold is exceeded for 1 year or more; 2. In general, the action of exerting fishing pressure (fishing intensity) beyond the agreed-upon optimal level.*

Pelagic: (adj.) Inhabiting the water column as opposed to being associated with the seafloor; generally occurring anywhere from the surface to 1,000 meters.*

Phytoplankton: (n.) Small, usually microscopic, plants drifting in the upper layers of the ocean, consuming nutrients and light energy to produce biomass. In particularly nutrient-rich conditions (including eutrophication), phytoplankton blooms may occur and can be toxic.*

Piscivorous: (adj.) Fish-eating.†

Population: (n.) The number of individuals of a particular species that live within a defined area.*

Precautionary approach: (n.) Set of measures taken to implement the precautionary principle. A set of agreed-upon, cost-effective measures and actions, including future courses of action, that ensures prudent foresight and reduces or avoids risk to the resource, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of "being wrong."*

Quota: (n.) A specified numerical harvest objective, the attainment (or expected attainment) of which causes closure of the fishery for that species or species group.*

Rebuilding: (v.) 1. Implementing management measures that increase a fish stock to its target size; 2. For a depleted stock, or population, taking action to allow it to grow back to a predefined target level.*

Recruit: (n.) 1. A young fish entering the exploitable stage of its life cycle; 2. A member of the youngest age group that is considered to belong to the exploitable stock (the portion of the stock that is available to the fishing gear).*

Relative abundance: (n.) An estimate of actual or absolute population size; usually stated as some kind of index (e.g., bottom trawl survey stratified mean catch per tow).*

Remotely operated vehicle (ROV): (n.) An unoccupied and highly maneuverable underwater robot that can be used to explore ocean depths while being operated by someone at the water's surface.*

Satellite tag: (n.) A type of transmitter that relays information (e.g., temperature, depth, horizontal position estimate) to researchers through the ARGOS satellite system.

Sexual dimorphism: (n.) Pertains to systematic differences between males and females. Several species of tunas and billfishes show sexual dimorphism in growth or mortality.*

Sexual reproduction: (n.) Reproduction involving the fusion of male and female haploid gametes (cells that each contain only one complete set of chromosomes).†

Spawning: (n.) The release of ova (eggs), fertilized or to be fertilized.*

Spawning potential ratio (SPR): (n.) The number of eggs that could be produced by an average recruit in a fished stock divided by the number of eggs that could be produced by an average recruit in an unfished stock. SPR can also be expressed as the spawning stock biomass per recruit (SSBR) of a fished stock divided by the SSBR of the stock before it was fished.*

Species: (n.) A group of animals or plants having common characteristics, able to breed together to produce fertile (capable of reproducing) offspring, and maintaining their "separateness" from other groups.*

Stable isotope analysis (SIA): (n.) Stable isotopes are alternate forms of a chemical element that differ only in their number of neutrons. Stable isotope analysis is a technique that compares the ratios of stable isotopes in a sample (e.g., muscle or blood). It is useful for tracing the flow of nutrients through food webs and estimating trophic levels.

Standardized: (adj.) Refers to quantities that have been adjusted to be directly comparable to a unit that is defined as the "standard" one. Nominal catch per unit effort (CPUE) is standardized to remove the effect of factors that are known not to be related to abundance.*

Stock: (n.) A part of a fish population usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery. A fish stock may be treated as a total or a spawning stock. Total stock refers to both juveniles and adults, either in numbers or by weight, while spawning stock refers to the number or weight of individuals that are old enough to reproduce.*

Stock assessment: (n.) The process of collecting and analyzing biological and statistical information to determine the changes in the abundance of fishery stocks in response to fishing, and, to the extent possible, to predict future trends of stock abundance. Stock assessments are based on resource surveys; knowledge of the habitat requirements, life history, and behavior of the species; the use of environmental indices to determine impacts on stocks; and catch statistics. Stock assessments are used as a basis to assess and specify the present and probable future condition of a fishery.*

Sustainability: (n.) 1. The ability to persist in the long term, often referring to sustainable development; 2. Characteristics of resources that are managed so that the natural capital stock is nondeclining through time while production opportunities are maintained for the future.*

Sustainable: (adj.) Able to be maintained at a certain rate or level.†

Telemetry: (n.) The process of remotely tracking an animal's movements and behavior.

Temperate: (adj.) Relating to or denoting a region or climate characterized by mild temperatures.†

Total mortality (Z): (n.) 1. A measurement of the rate of removal of fish from a population by both fishing and natural causes. Total mortality can be reported as either annual or instantaneous. Annual mortality is the percentage of fish dying in 1 year. Instantaneous mortality is the percentage of fish dying at any one time; 2. The sum of natural and fishing mortality rates.*

Translucent: (adj.) Permitting light to pass through.†

Transmitted light: (n.) The light that travels through a medium such as glass without being reflected, absorbed, or scattered.†

Trophic level: (n.) 1. Classification of natural communities or organisms according to their place in the food chain; 2. Group of organisms eating resources from a similar level in the energy cycle; 3. Position in the food chain determined by the number of energy-transfer steps to that level. Plant producers constitute the lowest level, followed by herbivores and a series of carnivores at the higher levels.*

Tropicalization: (n.) The increased proportion of tropical species inhabiting temperate areas. This phenomenon results in novel interactions between species, transformations in fish communities, and potential alterations to fisheries.

Vent: (v.) To release the air in a fish's swim bladder to return the fish to depth safely and quickly.

Vertebra: (n.) A bony or cartilaginous element surrounding the notochord or replacing it and often protecting the spinal cord and caudal vein.‡

Resources

Interested in learning more about some of the local resources that we discussed throughout this book? Below are links to all of the resources mentioned in the text, along with other pertinent resources.

- Alabama Gulf Seafood
- Alabama Marine Resource Division (AL MRD)
- Fishing for Our Future
- Fish Rules App
- Gulf of Mexico Fishery Management Council (GMFMC)
- Gulf of Mexico Sea Grant Programs Oil Spill Science
- Gulf States Marine Fisheries Commission (GSMFC)
- Gulf United for Lasting Fisheries (G.U.L.F.)
- International Commission for the Conservation of Atlantic Tunas (ICCAT)
- Marine Resource Education Program (MREP)
- Mississippi-Alabama Sea Grant Consortium (MASGC)
- Mississippi Commercial Fisheries United, Inc. (MSCFU)
- Mississippi Commission on Marine Resources (MS CMR)
- Mississippi Department of Marine Resources (MS DMR)
- Mississippi Seafood
- Mississippi State University Coastal Cleanup Program
- Mississippi State University Derelict Trap Reward Program
- Mississippi State University Marine Fisheries Ecology Program Facebook page
- Mississippi State University Marine Fisheries Ecology Program website
- NOAA Fisheries
- NOAA Fisheries Cooperative Tagging Center
- NOAA Fisheries Cooperative Shark Tagging Program
- NOAA Fisheries Marine Recreational Information Program (MRIP)
- Sport Fish Tag and Release Program with the Gulf Coast Research Lab (GCRL)
- TAG Alabama with the Alabama Coastal Conservation Association

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Publication 3575 (02-21) | MASGP-20-053

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Extension Service of Mississippi State University, cooperating with U.S. Department of Agriculture. Published in furtherance of Acts of Congress, May 8 and June 30, 1914. GARY B. JACKSON, Director