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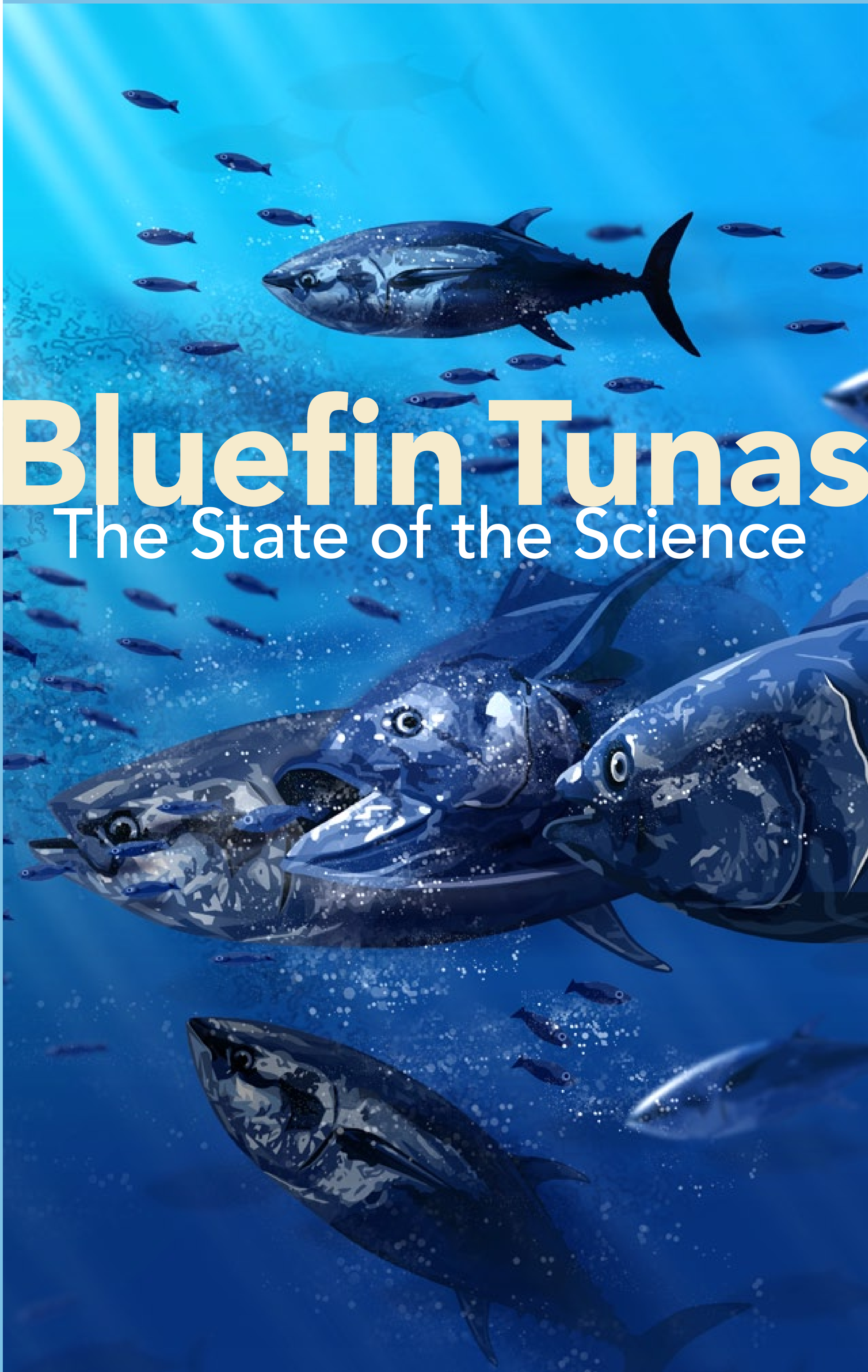

Bluefin Tunas

The State of the Science

Executive Summary

The three species of bluefin tunas can be found throughout the world's oceans from the equator to sub-polar seas. A suite of physiological adaptations has allowed bluefin to range widely, exhibiting some of the greatest individual ranges of any fish. Some fisheries targeting bluefin tunas have been operating since ancient times, mainly supplying fish to small, local markets. Recent changes in the globalization of fish markets, coupled with industrial-scale fisheries and a high price in the global sushi market, have driven exploitation of bluefin tunas beyond sustainable levels. As a result, global populations have declined considerably, in some cases to as low as 3 percent of unfished population levels. The threat from overfishing is compounded by life history traits, such as slowness to reach maturity and a long life span, which means rebuilding depleted populations will be a lengthy process. Greater knowledge of the underlying biology of bluefin will allow scientists to understand how much fishing pressure is sustainable and how fast populations can recover. Ultimately, the recovery of bluefin tuna populations depends on the willingness of managers to enact scientifically sound management measures and on the ability of governments to enforce agreed upon rules.

Bluefin Tunas
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Andre Boustany, Ph.D.*

Introduction

Among the world's tuna species, none are as large as or as individually valuable as the bluefin tunas. Bluefin comprise three species; Atlantic (*Thunnus thynnus*), Pacific (*T. orientalis*), and southern (*T. maccoyii*). All three are highly desired for the international sushi trade and are consistently among the most expensive fish in the world (Collette *et al.* 2011). This economic value has provided fisheries worldwide with the incentive to exploit bluefin populations at unsustainable levels. Currently, the three bluefin species are among the most overexploited tuna species in the world. This document summarizes the current scientific literature on bluefin tuna life history, geographic distribution, lifecycles, fishing history, and management.

The Biological Characteristics that Distinguish Bluefin Tunas

All bluefin species share many biological characteristics, such as large size, slowness to reach adulthood, and a greater ability to keep their bodies warm relative to other tunas. However, large differences also exist among the three bluefin species, and even among populations within a given species. For example, median age of maturity (the age at which the majority of fish in a population are able to reproduce) is estimated to range from 5 years for eastern Atlantic bluefin tuna to 15 years for western Atlantic and southern bluefin tuna. These estimates are particularly important because differences in life history parameters can have large impacts on the health of populations, and on the response of populations to over-exploitation.

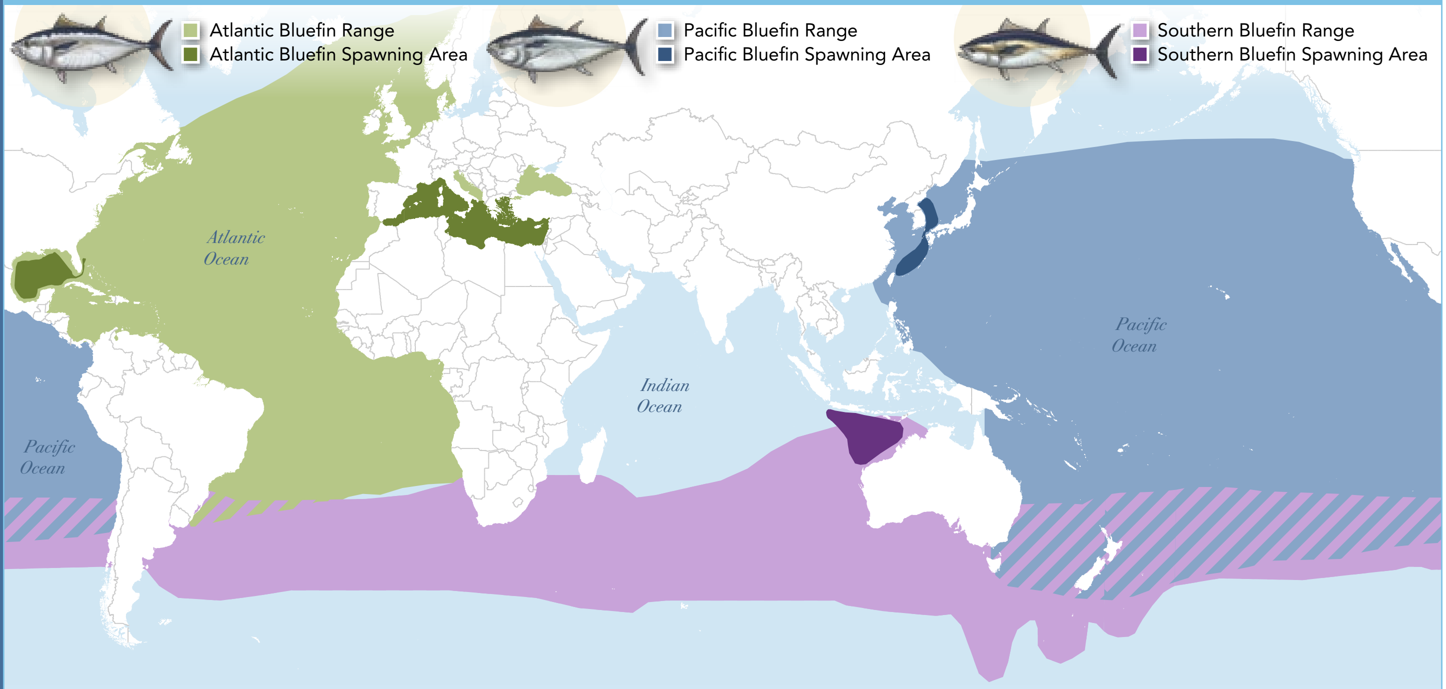
Health of a population is determined by periodic assessments conducted by scientists using the latest data on catch rates, as well as biological parameters of the species being assessed. Species or populations that mature earlier generally are better able to withstand fishing pressure because more fish reach spawning age before being captured (Jennings *et al.* 1999). Mature or adult fish that can reproduce are needed to maintain population levels, and catching too many immature or juvenile fish will leave adult fish numbers depleted too. Age of maturity also influences a population's ability to recover from overexploitation. Species and populations with an older age of first reproduction have more years between successive generations, and population growth occurs much more slowly than in populations that have a younger age of first reproduction (Hutchings and Reynolds 2004).

Other important biological factors that require additional research include spawning locations and times, population structure, and seasonal movement patterns. Understanding these factors will improve estimates essential for rebuilding and maintaining healthy population levels. Better knowledge of population structure, migration patterns, and spawning areas will allow more scientifically sound regional fishing quotas to be set. Without knowledge of these basic biological parameters, too much fishing can occur on one subpopulation or on spawning aggregations, when fish are particularly at risk. Although it is possible to manage a fishery without accurate data, management measures must be more precautionary to account for the uncertainty in the assessments based on those data.

How reproductive output, or the number of young produced per adult fish, changes with age also impacts the ability of bluefin populations to recover from overexploitation. For all species

** See back cover for biography.*

FIGURE 1. BLUEFIN TUNA are found in all the world's oceans.



of bluefin, the oldest fish are likely to play the most important role in reproductive output of the population as a whole. As with many marine fish species, the number of eggs produced is much greater in the largest fish, which can produce about 5 million eggs at 190 cm (6 feet 3 inches) to about 25 million eggs at 250 cm (8 feet 2 inches) (Farley and Davis 1998, Sawada *et al.* 2005, Chen *et al.* 2006, Baglin 1982). The abundance of eggs produced increases with size and age of the fish; therefore, the impact these older, larger fish have on the total reproductive output of the population is even greater than their numbers within the population would lead one to assume.

Where Bluefin Are Found

Bluefin can be found in all the world's oceans, from the equator to sub-polar oceans (Bayliff 1994, Mather *et al.* 1995, Farley and Davis 1998, Block *et al.* 2005) (Figure 1). The three tunas in this species complex—Pacific, Atlantic, and southern—have the ability to maintain body temperatures above surrounding water temperatures, a trait missing from most other fish species (Carey and Lawson 1973, Sharp 1978, Collette *et al.* 2011). This is possible because they possess a highly developed network of specialized blood vessels and attain greater size relative to other tuna species. As a result, they are not as geographically limited by such environmental factors as water temperature and therefore have the largest environmental ranges of all the tunas.

A wide variety of research methods—including tagging, genetics, and measuring chemical signatures in body parts—have been used to better understand bluefin distributions and movement patterns. The southern bluefin ranges from the Indian Ocean to the Southern Ocean and into the South Atlantic; Atlantic bluefin were found in the past from Brazil to central Norway in the Atlantic; and the Pacific bluefin is found throughout the North Pacific and into the South Pacific to Australia and New Zealand (Collette and Nauen 1983, Bayliff 1994, Mather *et al.* 1995, Farley and Davis 1998) (Figure 1). Large adults of all the bluefin species have the ability to expand their range into cooler waters; while juvenile tunas may be limited to warmer temperatures and are found over a much smaller geographic expanse (Itoh *et al.* 2003b, Kitagawa *et al.* 2004, Block *et al.* 2005).

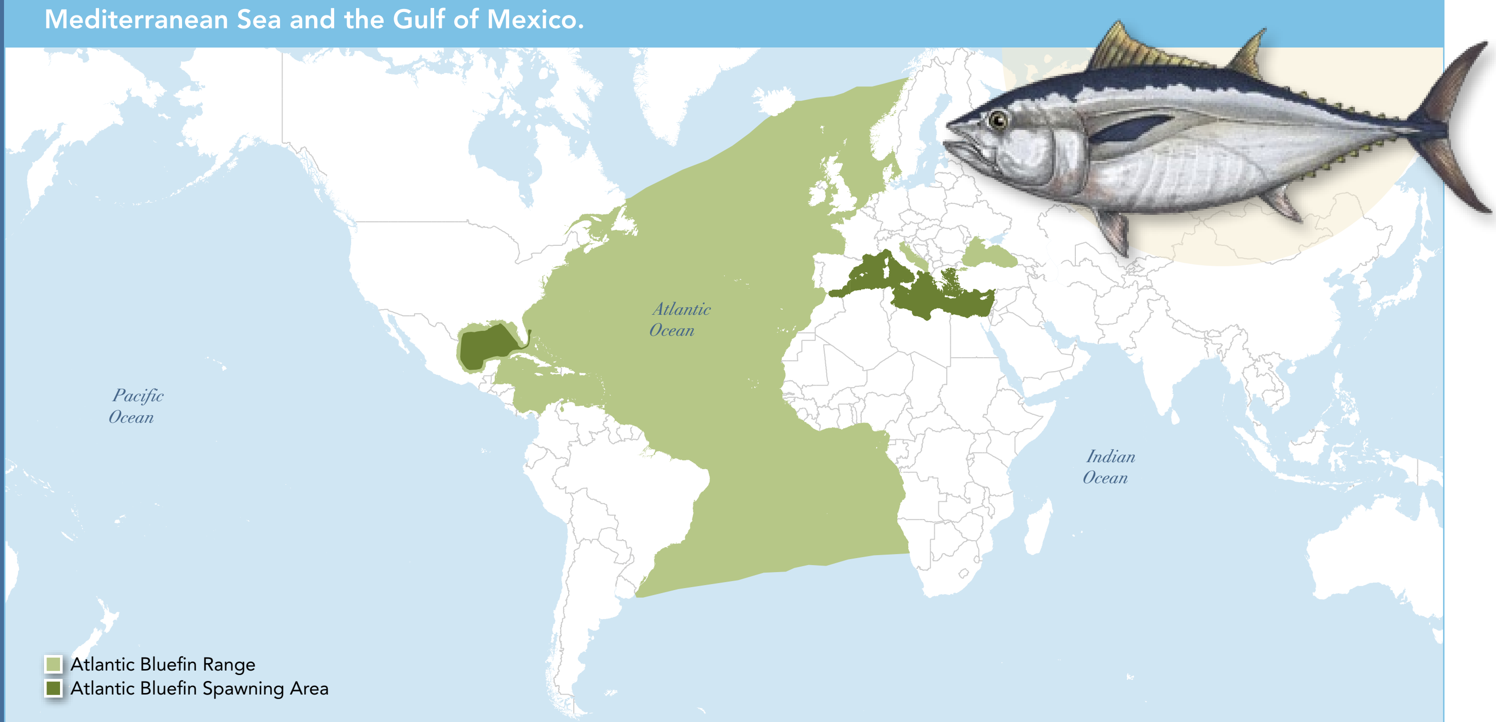
Atlantic bluefin tuna ranges

In the Atlantic Ocean, bluefin have been found from the northeastern coast of Brazil to Newfoundland, Canada in the west, and North Africa to the central coast of Norway in the east (Mather *et al.* 1995) (Figure 2). This range has contracted in recent decades, as bluefin tuna are no longer found off the coast of Brazil, or in the North Sea. The Atlantic bluefin (*T. thynnus*) is the only species of bluefin tuna known to have more than one spawning site—in the Mediterranean Sea and in the Gulf of Mexico/Bahamas (Mather *et al.* 1995). Spawning occurs in the Mediterranean from May to August and in the Gulf of Mexico from April to early July (Dicenta and Piccinetti 1980, Cort and Loirzou 1990, Richards 1990). Larvae and spawning adult fish have been found in the Bahamas and the Straits of Florida, though these areas may be an extension of the Gulf of Mexico spawning region (Richards 1990). Alternate spawning sites have been proposed outside of these regions, but no larvae or fish in the final stages of spawning have been found to date (Lutcavage *et al.* 1999, Goldstein *et al.* 2007, Galuardi *et al.* 2010). Recent genetic studies have confirmed that the Gulf of Mexico and the Mediterranean bluefin tuna are genetically distinct populations and therefore, require separate management (Carlsson *et al.* 2007, Boustany *et al.* 2008).

Managing these two populations of bluefin separately presents difficulties when migration patterns and distribution of the populations are taken into account. Although fish from the Mediterranean Sea and Gulf of Mexico do not intermix in their separate spawning grounds, researchers have evidence that there is a high level of mixing between populations on the feeding grounds throughout the North Atlantic (Block *et al.* 2001, Block *et al.* 2005, Rooker *et al.* 2008). Because fisheries operating in these regions may be catching fish from both populations, setting proper catch levels on either population becomes more difficult. Research has indicated that a large percentage, perhaps even the majority, of juvenile fish in the western North Atlantic originated from the Mediterranean population (Block *et al.* 2005, Boustany *et al.* 2008, Rooker *et al.* 2008). The number of fish from the Gulf of Mexico population that swim into the eastern Atlantic is less well identified, but several tracked fish have been observed to travel from western to eastern management zones (Mather *et al.* 1995, Lutcavage *et al.* 1999, Block *et al.* 2005, Walli *et al.* 2009).

Within the western North Atlantic, small fish exit the Gulf of Mexico after being spawned and generally remain in the warm coastal waters of the East Coast of the United States for the first several years of life (Mather *et al.* 1995). Their movements generally follow warm water north in the spring and summer and return south in the winter (Block *et al.* 2001, Galuardi *et al.* 2010).

FIGURE 2. ATLANTIC BLUEFIN TUNA are found throughout the Atlantic Ocean and spawn in the Mediterranean Sea and the Gulf of Mexico.



As these fish grow, they begin to expand their range not only north, but also farther offshore (Lutcavage *et al.* 1999, Block *et al.* 2005, Walli *et al.* 2009, Galuardi *et al.* 2010). The oldest and largest fish, which have the greatest ability to maintain elevated body temperatures in cold waters, have the largest range, and can be found in far northern water, specifically in the Gulf of St. Lawrence, Canada, and out to the Flemish Cap in the central North Atlantic (Block *et al.* 2005, Galuardi *et al.* 2010).

Some bluefin tuna are believed to remain within the Mediterranean for several years after having been spawned (Mather *et al.* 1995). However, some proportion of fish exit the Mediterranean and enter the eastern North Atlantic, mainly to the coastal waters of Spain and Portugal and into the Bay of Biscay during the first five years of life (Rodríguez-Marín *et al.* 2003). Similar to bluefin in the western North Atlantic, bluefin in the eastern Atlantic expand their range as they mature, entering waters off Norway and Iceland and into the central North Atlantic (Stokesbury *et al.* 2004, Carlsson *et al.* 2004, MacKenzie and Myers 2007, Fromentin 2009). Mature fish then begin to make return migrations to their spawning grounds during the respective spawning seasons.

Pacific bluefin tuna ranges

Pacific bluefin (*T. orientalis*) have the largest home range of the three bluefin species (Figure 3). Pacific bluefin can be found throughout the North Pacific from the East China Sea to the Pacific coasts of the United States and Mexico (Collette and Nauen 1983, Bayliff 1994). Spawning is centered in the East China Sea and Ryukyu Islands in the spring and extends into the Sea of Japan in the summer months (Bayliff 1994, Inagake 2001). Although there appear to be differences in the timing, location, and size of fish spawning in the western Pacific, it is believed that there is only one population of bluefin tuna in the Pacific (Bayliff 1994, Rooker *et al.* 2001).

Juvenile fish move north along with the rising temperature and eventually come to reside in nursery areas in the Sea of Japan and into the Kuroshio Current (Inagake *et al.* 2001, Itoh *et al.* 2003a). Most Pacific bluefin tuna remain in the western Pacific, but a small portion journey across the ocean and into the waters along the west coasts of the United States and Mexico (Bayliff 1994, Inagake *et al.* 2001). The fish migrating to the eastern Pacific have been linked to abundances of sardines in the western Pacific (Polovina 1996, Chavez *et al.* 2003). These migrations

FIGURE 3. PACIFIC BLUEFIN TUNA have the largest home range of the three bluefin species.

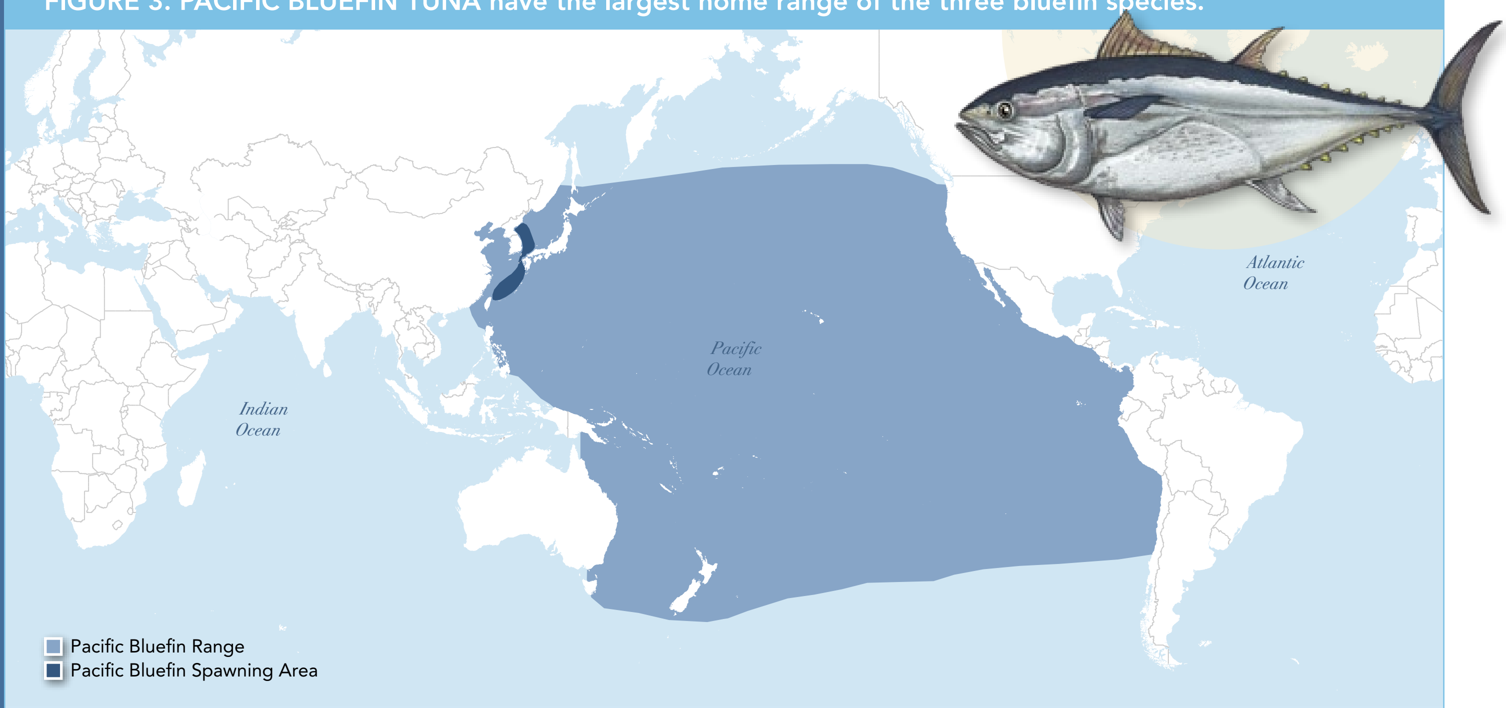
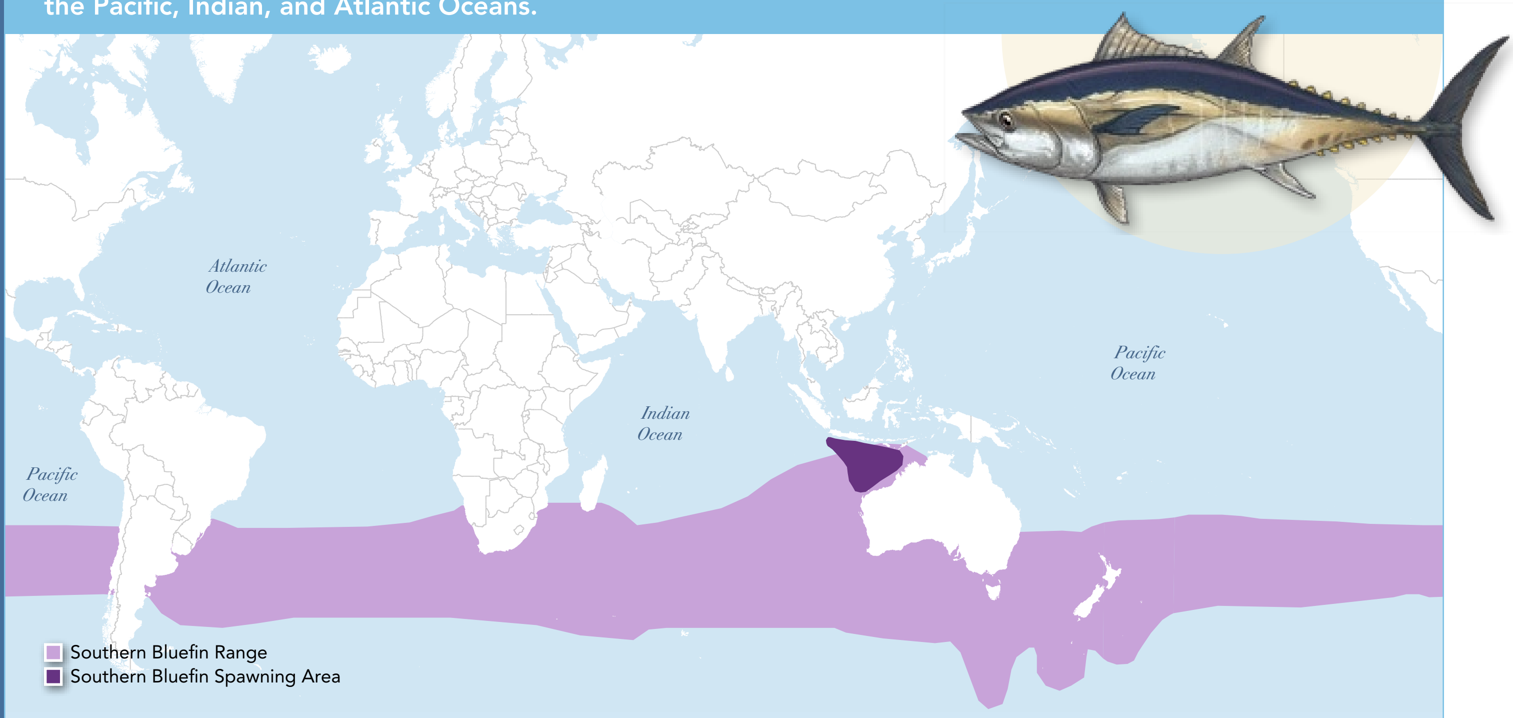


FIGURE 4. SOUTHERN BLUEFIN TUNA are found at the southern extents of the Pacific, Indian, and Atlantic Oceans.



eastward are usually made by juvenile fish, and the journey across the Pacific can occur in a little over two months (Itoh *et al.* 2003a). Once in the coastal waters of western North America, bluefin move up and down the coast, in conjunction with seasonal peaks in algae and sardine availability (Domeier *et al.* 2005, Kitagawa *et al.* 2007, Boustany *et al.* 2010). These fish will remain in the eastern Pacific for several years before returning to the west as adults (Bayliff 1994, Boustany *et al.* 2010). Most adult fish then remain in the western North Pacific, although a small portion occasionally travels to the eastern North Pacific or to the South Pacific off the coasts of Australia and New Zealand (Smith *et al.* 1994).

Southern bluefin tuna ranges

Southern bluefin tuna (*T. maccoyii*) are found at the southern extents of the Pacific, Indian, and Atlantic oceans (Collette and Nauen 1983, Commission for the Conservation of Southern Bluefin Tuna [CCSBT] 2010) (Figure 4). Southern bluefin have a single known spawning location, between northwestern Australia and Java, Indonesia, and are believed to comprise a single population (Proctor *et al.* 1995, Yukinawa 1987, Farley and Davis 1998). The vast majority of spawning occurs between September and April, with some low spawning levels seen in all months except July (Grewe *et al.* 1997, Farley and Davis 1998).

Juvenile tuna migrate, usually during their first year, into the South Australia Bight, where movement patterns are believed to follow seasonal peaks in food availability (Shingu 1967, Ward *et al.* 2006). After about age 5, southern bluefin spend less time in the coastal waters to the south of Australia and begin to range more widely throughout the Pacific, Indian, and Atlantic oceans (CCSBT 2010). Spawning begins between ages 8 and 15, and southern bluefin can reach age 42 (Farley and Davis 1998, CCSBT 2010).

The Bluefin Tuna Life Cycle

All tunas spawn in areas with warm surface water (Schaefer 2001). In tropical tuna species—such as yellowfin, blackfin, and bigeye—adults live in or near waters that are also suitable for spawning, and as a result, spawning in these species can occur throughout the year if they have access to sufficient resources (Nishikawa *et al.* 1985, Fonteneau and Marcille 1988, Schaefer 1998, Schaefer 2001).

In contrast, because adult bluefin tuna spend the majority of their lives far from their warmer spawning areas, they make long migrations between warmer and colder waters. The timing and location of spawning seeks to maximize the larval survival. Bluefin tuna spawn in regions with low variability of inter-annual water temperature to decrease the risk of sequential years of low spawning success and localized extinction (Royer and Fromentin 2007). This low variability is particularly important for bluefin tunas, which lay massive numbers of eggs with a high mortality rate. Because of this, even small variations in the survival rate of eggs and larvae can have large impacts on the overall population numbers (Cushing 1968).

In addition to temperature, eddy activity is also known to have important impacts on bluefin tuna spawning success (Garcia *et al.* 2005, Teo *et al.* 2007b, Inagake, 2001). Spawning has been observed more frequently in regions with moderate (24° -27° C) sea surface temperature, presumably because these regions provide the necessary conditions for larval survival without being too warm for adults (Inagake 2001, Teo *et al.* 2007b). In addition, moderate eddy activity, which can pull in and suspend larvae in regions suitable for survival, also seem to be preferred spawning habitat (Garcia *et al.* 2005, Inagake 2001, Teo *et al.* 2007b). Reproduction occurs over two weeks to several months for an individual fish with frequency between spawning events occurring every one to four days (Farley and Davis 1998, Block *et al.* 2005, Chen *et al.* 2006, Teo *et al.* 2007a).

Atlantic bluefin tuna life cycle

In the Atlantic Ocean there is a wide range in the age at which bluefin tuna begin to spawn. It is believed that bluefin reach adulthood as early as age 3 to 5 in the Mediterranean, and not until after age 8 in the Gulf of Mexico and Bahamas (Rodriguez-Roda 1967, Discenta *et al.* 1980, Baglin 1982). In the Mediterranean, minimum ages of spawning were estimated by examining fish on the spawning ground during the spawning season and may underestimate the average age of adulthood for the entire population (Rodriguez-Roda 1967). This is because many fish of these ages may not have returned to the spawning grounds and are therefore not sampled using this methodology. Electronic tagging data, which has not observed fish younger than age 8 moving into the Mediterranean from the North Atlantic, would support the hypothesis that some proportion of the Mediterranean populations do not mature until much later than age 5 (Block *et al.* 2005). Size composition of catches in several fisheries in the Mediterranean would also suggest that many of these fish begin spawning at age 8 to 9 (Heinisch *et al.* 2008). However, genetic analysis shows that there may be multiple populations within the Mediterranean Sea, and it is possible that each population has a different age of first spawning.

In the western Atlantic, bluefin age of maturity is generally recognized as being greater than in the eastern Atlantic (Mather *et al.* 1995, Nemerson *et al.* 2000). Baglin (1982) suggested that few fish younger than age 8 were mature but did not estimate a full reproductive schedule for the population as a whole. That study examined samples of fish 165 cm (5 ft. 5 in.) and smaller (younger than age 8) off the spawning grounds and found none to be mature, while fish within the Gulf of Mexico were found to be 205 cm (6 ft. 9 in.) and longer (mean size of 243 cm [almost 8 ft.]), and all were believed to be mature (Baglin 1982). The size distribution of the sampled fish from the Baglin study within the Gulf of Mexico matches up well with the distribution of longline catch and sizes of electronically tracked fish entering the Gulf of Mexico (Nemerson *et al.* 2000, Block *et al.* 2005, Diaz and Turner 2007, Galuardi *et al.* 2010). These, taken together, would suggest that the age above which the majority of the population matures (the age at which more than 50 percent of the population has started spawning) is higher, older than 12 years. In addition, new growth rate studies for western Atlantic bluefin have shown slower growth rates, making fish of a given size older than was previously assumed (Restrepo *et al.* 2010). Taking this into account suggests that the earliest spawning in the Gulf of Mexico happens around age 8 to 10, with the majority of fish not spawning until approximately age 15 (Diaz 2011). In addition to high age of maturity, western Atlantic bluefin tuna are long-lived (estimated at up to 32 years, with maximum sizes of 320 cm [10 ft. 6 in.] and 680 kilograms [1,500 pounds]), resulting in long generations for this population (Mather *et al.* 1995, Nielson and Campagna 2008).

Pacific bluefin tuna life cycle

Pacific bluefin tuna are believed to mature by ages 3 to 5, but these estimates have been made only by examining fish on the spawning grounds (Bayliff 1994, Chen *et al.* 2006, Tanaka *et al.* 2006). Therefore, these estimates do not account for fish older than 5 that may not have reached maturity, leading to a potential underestimation of the mean age of maturity for the entire population. Pacific bluefin are long-lived and are believed to live up to age 26 and attain weights of up to 450 kg (990lbs.). The majority of catches on the spawning grounds come from fish longer than 160 cm (5 ft. 3 in.), suggesting that age 5 should be considered a minimum age of maturity rather than the age at which the majority of the population begins to spawn (Collette and Nauen 1983, Sawada *et al.* 2005, Itoh 2006, Shimose *et al.* 2009).

Southern bluefin tuna life cycle

Southern bluefin tuna mature at a much later age than do Pacific bluefin (CCSBT 2010). Earliest estimates place age of maturity near 8, while studies that used direct aging techniques have estimated ages of maturity at 11 to 15 years (Gunn *et al.* 2008, CCSBT 2010). There is some evidence that individual growth rates and population parameters such as average age of maturity have changed in response to fishing pressure. Analysis of tag returns and otoliths indicate that fish growth rates have increased from the 1960s to 2000 as the population was reduced (Polacheck *et al.* 2004, CCSBT 2010). This was attributed to decreased competition between bluefin for prey resources. In addition, the mean age of southern bluefin on the spawning grounds declined from approximately 19 to 21 years old in the 1990s to 14 to 15 in the first decade of the 21st century (CCSBT 2010). This is particularly important as fish from the oldest and largest age classes generally have a much greater impact on adding to future generations than do smaller and younger spawning fish (Scott *et al.* 1999). For southern bluefin, the majority of fish on the spawning grounds were ages 15 to 25 years with longevity up to age 40 (Farley *et al.* 2007, Gunn *et al.* 2008, CCSBT 2010). Although southern bluefin tend to have smaller maximum sizes than Pacific or Atlantic bluefin, they can reach 245 cm (8 ft.) and more than 260 kg (573 lbs.) (Nakamura 1990).

Bluefin Tuna Fisheries, Past and Present

Fisheries for bluefin tuna have generally developed in three major periods. Early fisheries, dating back thousands of years, used small-scale artisanal approaches such as traps, hand-lines, and coastal nets. These fisheries supplied fresh, smoked, or salted fish to local markets. Because these fisheries were generally limited to coastal waters, catches were usually small. The next phase of the bluefin fishery saw larger, more industrialized fisheries—purse-seine vessels and bait boats, which provided fish for canning operations; and longlines, which provided fish for the frozen sashimi market in Japan. Although these fisheries still exist, much of the effort in recent years has shifted. The final stage of development in global bluefin tuna fisheries has been the expansion of purse-seine fleets supplying live fish for ranching operations. Ranching involves the capture of young fish to be placed in ocean pens, where they are fed and raised before they are killed. These fish supply the fresh sashimi market, mainly in Japan but recently expanding in other countries. Because the prices for bluefin tuna in the sashimi market are much higher than for canned tuna, the emergence and globalization of this market greatly changed the economics of global bluefin fisheries and encouraged the overexploitation of bluefin tuna (Issenberg 2007).

Atlantic bluefin tuna fisheries

Eastern Atlantic Ocean and Mediterranean Sea

The first known bluefin tuna fisheries were developed in the Mediterranean Sea. As early as 4000 B.C., there is evidence of bluefin catches using beach nets and hook and line (Sara 1980, Fromentin 2009). These fishing methods were later replaced by fixed traps, which by 2000 B.C. allowed Phoenician and Roman fishing communities to record catches of thousands of tons of bluefin (Porch 2005). The use of this gear remained relatively unchanged throughout the Mediterranean Sea and adjacent Atlantic Ocean until the advent of modern fishing methods in the late 1900s (Mather *et al.* 1995). Although catches fluctuated, presumably in concert with environmental variability, traps, and the communities that built up around them were maintained well into the 20th century (Ravier and Fromentin 2004, Fromentin and Powers 2005).

By the 1950s, large purse-seine fisheries had developed for bluefin tuna in the North Sea, primarily by Norwegian fishers, and these catches soon became the largest fishery in the eastern Atlantic and Mediterranean Sea (Miyake *et al.* 2004) (Figure 5). Purse-seine fishing is particularly effective because nets are deployed around entire schools of fish. Up to 18,000 metric tons of bluefin were landed every year in the North Sea; however, these catches were not sustainable, and by 1963 catches collapsed and have not recovered (Fromentin and Powers, 2005, MacKenzie and Myers 2007, Fromentin 2009). Overall catches remained relatively low (less than 15,000 mt) in the eastern Atlantic and Mediterranean throughout the 1960s and into the early 1970s (International Commission for the Conservation of Atlantic Tunas [ICCAT] 2010) (Figure 5).

In the 1980s and 90s, the market for bluefin tuna evolved from primarily local consumption in Europe to a large export market to Japan. The concurrent increase in penning operations, which allowed for better market timing and increased prices, made the Mediterranean Sea fisheries much more profitable (Fromentin and Powers 2005, Fromentin 2009). This also stimulated significant illegal, unregulated, and unreported (IUU) fishing of bluefin tuna in the Mediterranean. The increased catches by purse-seine fleets within the Mediterranean pushed the total east Atlantic and Mediterranean landings from 11,000 mt in 1970 to an estimated 60,000 mt in 2006, an all-time high (Figure 5). It is believed that catches have declined significantly since 2006, but poor reporting from the major fisheries in the Mediterranean and ongoing IUU fishing make any estimate of catches uncertain (ICCAT 2010).

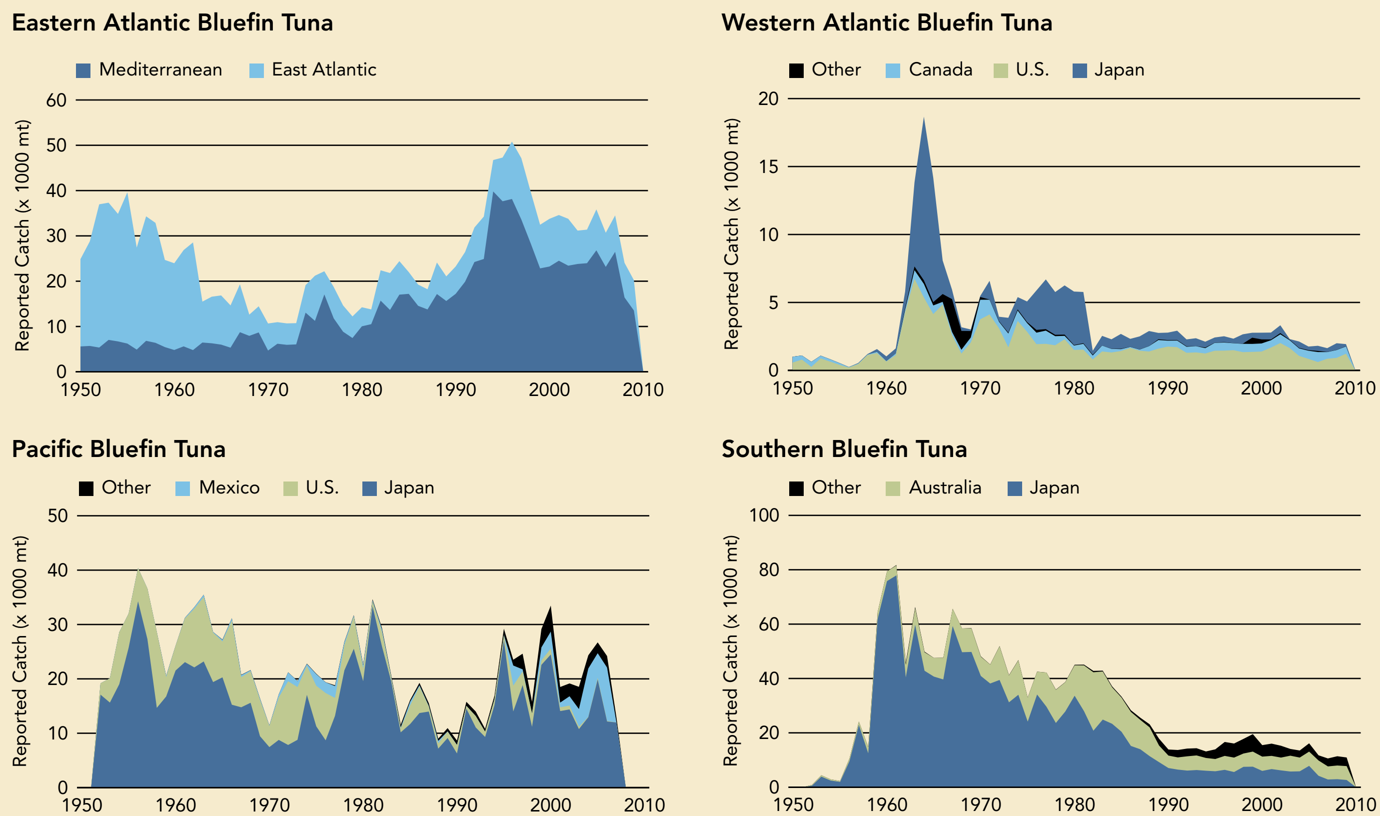
Western Atlantic

Bluefin tuna fisheries in the western Atlantic Ocean do not date back nearly as far as those in the eastern Atlantic. The earliest known bluefin fisheries were small-scale trap and harpoon fisheries in New England and Canada in the early 20th century (Bigelow and Schroeder 1953). By the mid 20th century, recreational sport fisheries had developed along the U.S. and Canadian East Coasts (Farrington 1949). The recreational bluefin fisheries in the Straits of Florida/Bahamas were particularly notable. These fisheries targeted large bluefin as they left the Gulf of Mexico spawning ground, in addition to pursuing giant bluefin on their prey-rich summer feeding grounds off Nova Scotia, when they were at their maximum weights (Farrington 1949). Although these fisheries were small in terms of numbers caught, they contributed to the historic lore of the size, speed, and power of bluefin tuna. For example, it was in Bimini in the Bahamas where Ernest Hemingway described the epic battles between fishermen and bluefin tuna, which he declared "the king of all fish."

The first large-scale commercial fisheries for bluefin tuna in the western Atlantic were the Japanese longline fishery that developed off the coast of Brazil and the U.S. purse-seine fishery off New England, both of which developed in the late 1950s (Mather *et al.* 1995). Japanese catches off Brazil increased to more than 12,000 mt a year by 1964, but by the end of the decade bluefin tuna had disappeared from this area and have yet to return (Fromentin 2009). Concurrent with the development of the fishery off Brazil, the U.S. purse-seine fishery on small and medium sized bluefin (less than 91 kg [200 lbs.]) developed in New England, peaking in 1962 at more than 5,000 mt (Miyake *et al.* 2004). The high landings in these two fisheries pushed total western Atlantic catches close to 20,000 mt by 1964, a level they have not approached since (Fromentin and Powers 2005, Porch 2005).

The 1970s were a transitional period during which gears and fishing countries changed (Figure 5). Japanese longliners moved into the Gulf of Mexico and North Atlantic, a smaller purse-seine fishery remained in New England and the rod-and-reel commercial fishery along the East Coasts of the United States and Canada became a major source of landings (Mather *et al.* 2005). In addition to changes in fishing region and gear type, it was at this time that the market for bluefin tuna shifted from demand for canned tuna to a sashimi export market in Japan. Greatly increased prices kept fishing pressure high, and landings remained between 5,000 and 7,000 mt a year until stricter quotas and a ban on targeting bluefin on the Gulf of Mexico spawning grounds

FIGURE 5. REPORTED BLUEFIN TUNA LANDINGS of the four management units since 1950.*



* *Note: catches for southern bluefin tuna and Mediterranean Sea catches are believed to have been significantly underreported in recent decades.*

in the early 1980s limited catches to 2,500 mt or less, where they remain (Mather *et al.* 1995, Fromentin and Powers 2005, ICCAT 2010) (Figure 5).

Pacific bluefin tuna fisheries

Eastern Pacific Ocean

While much has been written regarding the long history between humans and Atlantic bluefin tuna, bluefin tuna fisheries in the Pacific Ocean have stretched back just as far, if not further. In the eastern Pacific, bones of large (greater than 160 cm [5 ft. 3 in]) bluefin tuna have been found in archeological sites of indigenous communities from British Columbia, Canada, and northern Washington in the United States. These remains date back to at least 3,000 B.C., and tribal elders describe active fisheries for bluefin through the mid-19th century (Crockford 1997). The earliest sport fishery for bluefin tuna can also be traced back to the eastern Pacific. In the late 19th century, the first rod-and-reel catches of large bluefin tuna (greater than 100 kg [220 lbs.]) occurred off the coast of Southern California's Catalina Island. The men chasing these fish soon formed the first sport-fishing club in the world, the Catalina Island Tuna Club, outlining rules of "fair play for game fishes."

In contrast to these early reports of regular bluefin tuna appearances in the eastern Pacific, recent encounters with large bluefin tuna have been sporadic and less numerous (Foreman and Ishizuka 1990). Commercial fisheries, mainly purse seines, developed in the eastern Pacific by 1914 and expanded greatly in the late 1950s (Bayliff 1994). These fisheries were focused mainly on small fish (less than 100 cm [39 in.]), although larger fish were occasionally taken when they were available (Hanan 1983). Catches in the eastern Pacific, mainly off Southern California, United States and Baja California, Mexico, reached a peak of close to 18,000 mt in 1965 before declining in the 1980s and early 1990s

(Bayliff 1994) (Figure 5). Because the availability of bluefin in the eastern Pacific depends on bluefin moving across the ocean from the west, catches were highly variable throughout the 20th century, fluctuating by more than 5,000 mt in subsequent years (Hanan 1983) (Figure5). In the late 1990s, bluefin catches began to increase again in the eastern Pacific, reaching up to 10,000 mt in 2007 (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean [ISC] 2008) (Figure 5). Again, this increase occurred in conjunction with a shift in the market for bluefin tuna from a product caught for canneries to live fish captured for penning operations in Mexico to supply the fresh sashimi market in Japan (Inter-American Tropical Tuna Commission [IATTC] 2010). More than 90 percent of the catch in the eastern Pacific occurs on bluefin in the size range of 60 to 100cm (24 to 40 in.), fish that are approximately 1 to 3 years of age (IATTC 2010).

Western Pacific Ocean

Similar to those in the eastern Pacific, catches of bluefin tuna likely stretch back to 6,000 years in coastal communities of Japan (Muto *et al.* 2008). These took the form of coastal harpoon and hand-line fisheries, and landings probably were small because fisheries were limited to coastal waters. More advanced fisheries, using traps, drift-nets and hand-lines developed in the late 19th century in Japan, Russia, Korea, and Taiwan, Province of China. Although these fisheries were far different from modern fleets, it has been estimated that landings were 3,000 to 50,000 mt a year, with the highest catches occurring in 1935 and then declining significantly in the 1940s and 50s (Muto *et al.* 2008).

After World War II ended, Japanese purse-seine and longline fleets targeting bluefin tuna in the western Pacific expanded greatly, and landings fluctuated between 10,000 and 35,000 mt a year throughout the latter half of the 20th century and the first decade of the 21st (Miyake *et al.* 2004) (Figure 5). The largest fishery for bluefin tuna in the Pacific is the Japanese purse-seine fishery, which has caught 2,000 to 25,000 mt a year since 1952 (IATTC 2010). This fleet targets smaller fish (less than 1 to 3 years old) mainly in the Sea of Japan and the East China Sea (Miyake *et al.* 2004).

In addition, Japanese and Taiwanese longliners target larger fish throughout the western Pacific, particularly on the spawning grounds (IATTC 2010, Miyake *et al.* 2004). Smaller troll and drift-net fisheries also target bluefin tuna in the western Pacific, although landings by these fisheries are insignificant compared with the much larger purse-seine and longline fisheries. Because the largest bluefin fisheries in the western Pacific target smaller fish, it is estimated that up to 93 percent of total fish landed are younger than 3 years old (Itoh 2001).

Small catches of Pacific bluefin tuna are also recorded in the South Pacific, particularly off Australia and New Zealand (Miyake *et al.* 2004). Although the number of fish caught in these fisheries is small, catches are generally composed of very large, mature fish (Itoh 2006).

Southern bluefin tuna fisheries

Southern bluefin tuna have not been fished as long as either Atlantic or Pacific bluefin, and there is no comparable record of early artisanal fishing history. Instead, the first fisheries for southern bluefin developed in the 1950s (Hayes 1997, Sharp 2001), when Japanese longliners began targeting adult southern bluefin tuna on the spawning grounds between Indonesia and Australia; catches expanded to close to 60,000 mt by 1961 (Miyake *et al.* 2004) (Figure 5). These catches gradually declined, and the Japanese fleet began to expand fishing operations to the south of Australia, New Zealand, and South Africa in the 1970s and '80s (Sharp 2001). Catches continued to decline throughout the 1980s, eventually limited by stricter quotas put in place in the 1990s to stop the decline of the population (Safina 2001) (Figure 5).

Australian bait boat, troll, and purse seine fisheries also developed in the region south of Australia in the 1950s. These targeted smaller bluefin than did the Japanese longline fishery, with most of the product going to canning operations in Australia. Catches in these fisheries increased, eventually reaching more than 20,000 mt in 1982 (CCSBT 2010) (Figure 5). Similar to the Japanese longline fishery, catches in the Australian fishery declined significantly in the 1990s as quota measures came into place. At the same time, the market for bluefin went from supplying canneries to providing fish for tuna ranches in Southern Australia (CCSBT 2010).

Total catches of southern bluefin remained fairly low (approximately 14,000 mt a year) throughout the 1990s as the main countries targeting bluefin tuna—Australia, Japan, and New Zealand—were limited by an agreement on quotas (Hayes 1997, CCSBT 2010) (Figure 5). Yet, catches by other nations began to increase in the late 1990s, pushing total landings to more than 20,000 mt in 1999 before declining again in the early part of the 21st century (Miyake *et al.* 2004). However, there is evidence to suggest that catches over the past two decades may have been substantially underreported (CCSBT 2010). Comparing catch numbers reported by Japanese longline fishing vessels to the number of fish delivered to fish markets, it is estimated that true catches were double what was reported to management agencies (Polacheck and Davies 2007).

Management and Status of Bluefin Tuna Populations

Bluefin tuna management is complex. As with most pelagic, or open ocean, fish, they are managed under the auspices of regional fisheries management organizations (RFMOs). RFMOs provide the framework by which member States come to agreement on conservation and management measures, and the implementation of those measures occurs at the country level. The RFMOs are also a mechanism to monitor compliance by member States and to collect fishery data. Four RFMOs are responsible for the management of bluefin tuna fisheries; these are made up of countries that fish for bluefin and other pelagic species in a given ocean area and include both coastal States and distant water fishing countries. The organization of each RFMO differs, but decisions are usually made by consensus. Consequently, enacting major changes to fisheries management is a gradual and often difficult process.

In addition to differences in how the RFMOs are structured, differences also exist in how the science of population assessments is conducted and used. Some RFMOs, such as IATTC, maintain a permanent staff of scientists that undertakes much of the research and conducts the population assessments. Others, such as ICCAT, rely on member governments to supply research information and scientists to conduct population assessments, and only maintain full time administrative and technical staff. The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) has an independent chair of its scientific committee and a panel of independent scientists in addition to scientists from member governments. Ultimately, decisions on national and overall quotas, size limits, and other management decisions are not made by the scientists, but by representatives of the member States who make up the RFMOs Commission. Generally, the Commission asks the scientific committees for specific advice, which it can follow or decide not to.

As with all research, there is generally a range of uncertainty around any biological parameter used in the population assessment process, and this uncertainty can have large impacts on the outcome of the assessments. For example, the range of ages of maturity may be estimated at 5 to 10 years, depending on how the number was calculated. Using an estimate of 5 will result in population assessments that show higher population growth rates than will those using an estimate of 10. Assuming an age at first reproduction of 5 will, under most models, provide a more optimistic result and will suggest that higher catch rates could be allowed.

Uncertainty is even greater for biological parameters that are difficult to measure but impact the results of the population assessment. For example, natural mortality—or the number of fish that die in a given year irrespective of fishing—is extremely challenging to estimate, yet the assumptions have a large impact on model outputs, such as the total number and weight of fish estimated to be in the population. As a result, scientists will often present managers with a range of probabilities representing this uncertainty, as opposed to a single total allowable catch. Although governments have all committed to the precautionary principle, whether or not member governments agree to set precautionary quotas (at the lower end of the range of estimates) usually depends more on economics and politics than on the strength of the underlying science.

In addition to challenges surrounding the science in population assessments and finding consensus on overall and national catch quotas, compliance with and enforcement of these quotas is also challenging. Ultimately, member governments have the responsibility to enforce agreed-upon rules for their own fleets. With a wide range in political will and capacity for monitoring and enforcement among RFMO members, compliance with rules varies greatly. In addition, economic incentives may tempt States to turn a blind eye to overfishing even if they do have the means to control it.

Atlantic bluefin tuna management

Declining catches in Atlantic bluefin tuna precipitated formation of ICCAT in 1969 (ICCAT 2006). There are currently 48 member governments as well as a number of non-contracting parties (ICCAT 2010). Due to disparate catches in the eastern and western North Atlantic, as well as differences in life history traits, ICCAT assumed that eastern Atlantic and western Atlantic bluefin belonged to discrete populations (National Research Council [NRC] 1994). The boundary between populations used by ICCAT is in the Central Atlantic at approximately 45 degrees west longitude, and bluefin have historically been managed assuming a low level of overlap between populations—approximately 2 to 4 percent a year (NRC 1994). Although recent genetic studies have confirmed that the eastern and western Atlantic populations are reproductively isolated, it is now understood that there is a greater level of overlap between the two populations, with up to 50 percent of the fish in some regions of the western Atlantic having originated in the eastern Atlantic (Block *et al.* 2005, Rooker *et al.* 2008, Boustany *et al.* 2008). This fact greatly impacts the management of western Atlantic bluefin, as the population size in the east is estimated to be an order of magnitude larger than that in the west, meaning that even small changes in the number of fish migrating east to west can have large differences in the abundance of western bluefin tuna (ICCAT 2010).

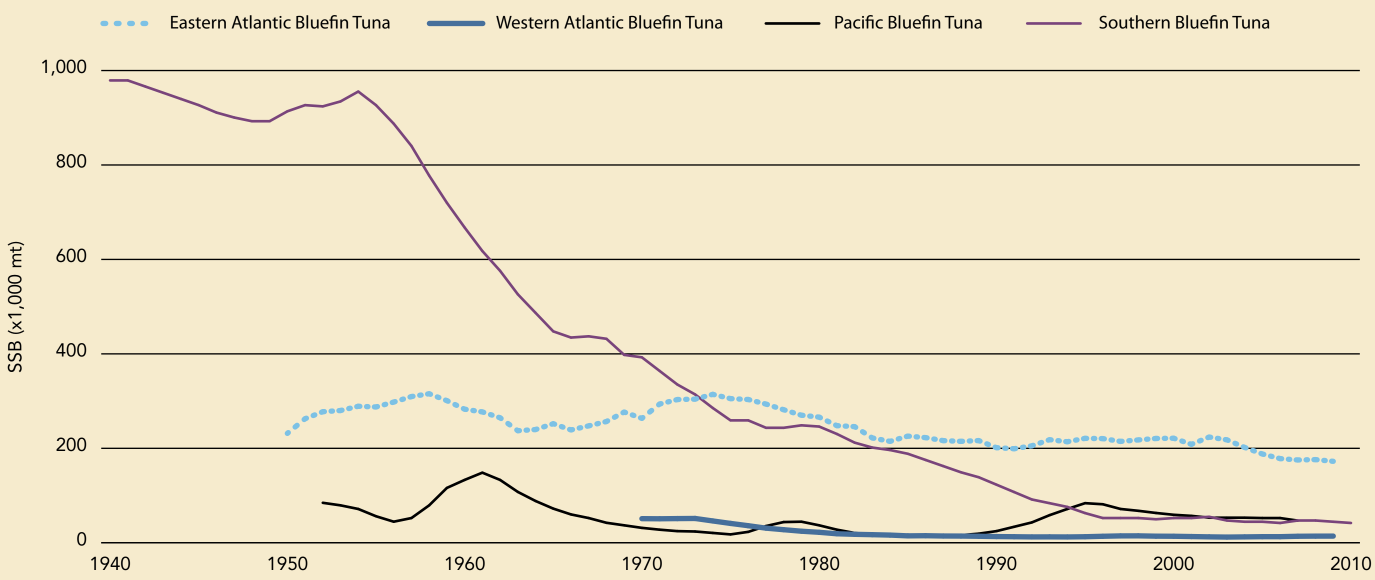
Another concern about mixing and the assessment process is that the eastern Atlantic and Mediterranean Sea are currently assessed as one population, although genetic data suggest that two or more distinct populations spawn within the Mediterranean (Carlsson *et al.* 2004, Boustany *et al.* 2008, Riccioni *et al.* 2010). Assessing multiple populations in the Mediterranean as one population raises the possibility of obscuring declines among smaller populations if catches from the larger populations remain high.

Significant uncertainties also exist in the data used for the eastern Atlantic assessment (Advanced Tuna Ranching Technologies [ATRT] 2010, ICCAT 2008). Underreporting of both total catches and catches of fish below the minimum size has made it difficult for scientists to perform accurate population assessments and projections. The greatest problems in the management of bluefin tuna in the eastern Atlantic, however, have been compliance with management measures. Due to a combination of managers setting quotas higher than scientific guidance and lack of compliance with those quotas, catches have exceeded scientifically recommended levels by up to 400 percent some years (Hurry *et al.* 2008). In the western Atlantic, changes in assumptions regarding the relationship between number of adult and juvenile fish have caused ICCAT to follow a management strategy that aims to keep the population size stable rather than trying to grow it back to levels that would support more productive fisheries (Safina and Klinger 2008).

The eastern Atlantic population is assessed at approximately 35 percent of adult biomass (the weight of all adult fish in the population) that would allow for maximum fishery yields, and fishing rates have been more than twice as high as ones that would arrest the further decline of the population (ICCAT 2010) (Figure 6). Adult biomass, which fisheries managers often refer to as spawning stock biomass (SSB), is a common way to measure relative health of bluefin tuna populations over time. In the western Atlantic, SSB was estimated to have declined 81 percent from 1970 and has remained at those low levels for more than three decades with little indication of increases in the population (ICCAT 2010) (Figure 6). However, because the largest catches in the western Atlantic took place before 1970, it is likely that declines from unfished population levels are much greater than the 81 percent estimated by ICCAT (Mather *et al.* 1995, Porch 2005).

Given the major problems in the management of Atlantic bluefin tuna, with accelerating

FIGURE 6. SPAWNING STOCK BIOMASS (SSB), or adult biomass, has fluctuated over time.



declines in population size in the east and lack of rebuilding over 30 years in the west, a proposal was submitted to include Atlantic bluefin tuna in the Appendices of the Convention on International Trade in Endangered Species (CITES), which would have prohibited international trade for commercial purposes. As the majority of bluefin tuna, and almost all of the high-priced tuna bound for global sashimi markets, is traded internationally, such a listing would have significantly reduced the market forces driving overexploitation. The threat of this listing increased the pressure to bring illegal fishing and lack of reporting under control. Whether the measures adopted or this greater enforcement of catch rates has an impact on the health of bluefin tuna populations in the future remains to be seen.

A recent success story does exist, however, when considering the rebuilding possibilities for internationally managed, large pelagic species: the depletion and subsequent recovery of swordfish in the North Atlantic. Due to overfishing, large catches of juveniles and fishing on spawning grounds, North Atlantic swordfish population sizes decreased considerably between 1980 and 2000 (ICCAT 2010). Lowering overall quotas, increasing legal minimum sizes and enacting closed areas to protect juveniles and spawning adults have allowed swordfish populations to recover from these earlier declines to the point where they are now considered fully recovered. By following this framework for bluefin tuna species, it remains possible that these populations could recover.

Pacific bluefin tuna management

Until recently, Pacific bluefin tuna fell through the cracks of management in the Pacific RFMOs. As a temperate tuna, Pacific bluefin do not fall under the purview of the two main RFMOs that are responsible for other major tuna species with similar ranges—IATTC or the Western and Central Pacific Fisheries Commission (WCPFC). As such, formal management—including full population assessments and strict catch monitoring and quota allocations—has not been in place for Pacific bluefin as long as it has for other bluefin species. Pacific bluefin tuna population assessments are conducted by the ISC, and subsequent management recommendations are handled by IATTC and WCPFC, for fisheries under their respective purviews.

Pacific bluefin tuna populations were last assessed to be between 3 and 26 percent of unfished biomass, indicating that the Pacific bluefin was overfished (Ichinokawa *et al.* 2010) (Figure 6). However, these estimates reflected a high level of uncertainty because little was known regarding non-fishing sources of mortality, which can have large effects on the outcome of the population assessment model results (ISC 2008, IATTC 2010). Much as for other bluefin species, the significant catches that occurred before proper monitoring began makes estimating virgin population size extremely difficult (Miyake *et al.* 2004, Muto *et al.* 2008). However, even compared with adult biomass estimates from the period over which good data are available, 2007 abundance was estimated to be below 50 percent of the peak recorded in 1960 (Ichinokawa *et al.* 2010) (Figure 6). One major source of concern is the extremely high catches of juvenile fish that have not yet spawned; up to 93 percent of fish caught in the western Pacific, and over 90 percent of the fish caught in the eastern Pacific are below the earliest sizes and ages of maturity (Itoh 2001, IATTC 2010). Recent rates of fishing mortality are thought to have been higher than sustainable levels (ISC 2008).

Southern bluefin tuna management

Declining catches of southern bluefin tuna in the 1970s caused Australia, New Zealand, and Japan, the major fishing States, to establish a quota system in 1982 (Edwards 2001). In 1994, CCSBT was formalized as stock size continued to decline and other fishing States began to target southern bluefin (Safina 2001). Although strict quotas were put into place, overharvesting by member governments and increased fishing pressure by non-members limited any conservation gains, and population size continued to decline (CCSBT 2010).

In subsequent decades, South Korea and Indonesia joined the Commission and Taiwan, Province of China, became a participant. Additional countries were added as cooperating nonmembers. Cooperating nonmembers adhere to the management measures but cannot vote with the Commission (CCSBT 2010). Management of southern bluefin tuna has been particularly contentious, culminating in Australia and New Zealand bringing Japan before a tribunal under the U.N. Convention on the Law of the Sea, alleging fishing above agreed-upon quotas (Romano 2001). Subsequent underreporting of catches by member governments has resulted in further declines in the adult biomass in recent decades. The latest population assessment showed that the southern bluefin tuna spawning stock has remained at extremely low levels throughout the past several decades and is currently estimated at 3 to 7 percent of the level before exploitation began (CCSBT 2010) (Figure 6). Recent management actions and further quota reductions, particularly for member governments that had overfished in the past, are predicted to allow modest rebuilding of this population over time (CCSBT 2010). However, the life history traits of southern bluefin, specifically long life span and late reproductive maturity, mean that any rebuilding of the species is likely to be slow.

Conclusion

Bluefin tunas face many challenges in the years ahead, although some positive management actions have been taken. Although the world's bluefin tuna populations remain significantly reduced from historical levels, current management decisions have improved when compared with previous decades. The key is the effective implementation and enforcement of those decisions. Even for southern bluefin and western Atlantic bluefin, historically some of the most depleted tunas, population declines are believed to have been arrested. In the case of western Atlantic bluefin, a slight increase in population levels has been seen in recent years (ICCAT 2010, CCSBT 2010). For eastern Atlantic bluefin tuna, the population on which unregulated fishing has occurred most recently, managers are now beginning to follow scientific recommendations in setting quotas. In 2010, the quota for eastern Atlantic bluefin tuna was within the range of scientific advice. In addition, enforcement measures aimed at controlling illegal and unregulated fishing are being adopted in the eastern Atlantic and Mediterranean Sea. One question remains: whether those measures will be complied with and enforced, with consequences for non-compliance.

There remains uncertainty surrounding both the fishery catch data as well as the basic life history data used to complete the assessments, so any perceived improvement in the status of the stocks may prove to be fleeting as data quality is improved. Further areas for improvement in the management of bluefin tunas exist in controlling fishing on juvenile fish, particularly in the Pacific and Mediterranean Sea, in eliminating catches of bluefin tuna on their spawning grounds in all populations, and in adopting and implementing strong compliance measures.

If managers are able to continue these positive trends and reverse negative ones, and fully implement the precautionary principle for bluefin tunas, it remains possible that populations can increase to healthy levels again, as shown by the North Atlantic swordfish example. For bluefin tunas, which have even slower population growth rates than swordfish, this process will likely occur more gradually, even under the best of circumstances. For this reason, continued vigilance is needed to make sure that any gains in bluefin populations are not squandered in the desire for short-term profit.

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About the Author

Dr. Andre Boustany majored in Ecology and Evolutionary Biology as an undergraduate at Cornell University. A lifelong fisherman and ocean lover, he always figured he would end up working in the field of marine biology. After graduating, Andre held a number of jobs in his native California, from working on a dairy farm to studying demographics of spotted owls in the San Bernardino Mountains to serving as an observer on pelagic driftnet boats. It was this last job that introduced Andre to the environment and animals of the open ocean, the topics he would go on to study. Andre completed his Ph.D. at Stanford University where he used electronic tagging technologies and genetics to study migration patterns, habitat utilization, and population structure of bluefin tunas and sharks in the Pacific and Atlantic Oceans. After graduating, he moved to Duke University as a postdoctoral researcher, where he has continued to study pelagic fish and fisheries, particularly ways to reduce bycatch and improve fishing efficiency.

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