

Atlantic Chub Mackerel (*Scomber colias*, Gmelin, 1789) Literature Review

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July 9, 2017

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Purpose of literature review

The purpose of this literature review is to summarize all biological and fishery information which could assist the Mid-Atlantic Fishery Management Council in developing management alternatives for chub mackerel fisheries off the U.S. east coast and which could assist the Council's Scientific and Statistical Committee in recommending acceptable biological catch levels.

Note on taxonomy

Chub mackerel in the Atlantic (*Scomber colias*) were once considered the same species as chub mackerel in the Pacific (*S. japonicus*; also referred to as Pacific mackerel or Pacific chub mackerel; see page 13). Information on *S. japonicus* in other regions is only summarized here if it pertains to topics which are not well covered for chub mackerel in the Atlantic (e.g. environmental drivers of abundance, natural mortality).

Geographic distribution

- Atlantic chub mackerel are widely distributed in warm and temperate waters (Collette and Nauen 1983, Martins et al. 2013).
- They are mostly found on the continental shelf and slope from the surface to depths of about 250-300 meters (Collette and Nauen 1983).
- Younger individuals tend to be found closer inshore than older individuals (Martins et al. 2013 citing Baird 1978).
- In the western Atlantic, chub mackerel are distributed from Nova Scotia (Collette 2002) through Argentina (Collette and Nauen 1983) and South Africa (Baird 1977, Scoles et al. 1998).
- In the eastern Atlantic, they are found from the Bay of Biscay to the Canary Islands (Navarro et al. 2012).
- In the northern hemisphere, they migrate seasonally between northern areas during warmer months and southern areas during cooler months (Collette and Nauen 1983).

Sub-stocks

- Scoles et al. (1998) found no significant differentiation in haplotype frequencies between chub mackerel from the Mediterranean coast of Israel, the Ivory Coast, and South Africa; however, they did find significant differences between chub mackerel from the western Atlantic and eastern Atlantic. Specifically, they found that haplotype distributions were significantly different between chub mackerel samples from Panama City, Florida and Mar del Plata, Argentina and unique haplotypes occurred within each sample at "relatively high frequencies (10-20%)". They found no significant differentiation among samples from the Mediterranean coast of Israel; Abidjan, Ivory Coast; and Cape Town, South Africa. They found significantly different haplotype frequencies among all samples across the Atlantic except for the comparison of Mar del Plata, Argentina and Abidjan, Ivory Coast.

- Zardoya et al. (2004) found no evidence of genetic differentiation across the northeast Atlantic and Mediterranean Sea and concluded that the stock is panmictic in the Mediterranean Sea and adjacent Atlantic Ocean waters.
- Chen et al. (2009), Weber and McClatchie (2012), and Yasuda et al. (2014) reference sub-stocks of the closely related Pacific mackerel based on different spawning areas/times and/or differences in morphology.
- Cerna and Plaza (2014) suggested that two sub-stocks can be found off Chile based on differences in sizes at maturity and spawning seasons.
- The Pacific Fishery Management Council manages chub mackerel throughout the west coast as a single stock with no area or sector allocations (Crone and Hill 2015).

Life history

- Eggs
 - o Early life history is described in detail in Hunter and Kimbrell (1980) based on laboratory studies of *Scomber japonicus* caught off Japan. For example, at 19°C, eggs hatched in 56 hours.
- Larvae
 - o Early life history is described in detail in Hunter and Kimbrell (1980) based on laboratory studies of *Scomber japonicus* caught off Japan. For example, first feeding occurred 46 hours after hatching and all larvae fed by 60 hours, at which point they were 3.6 mm long, with fully pigmented eyes, and 10% of the yolk remaining. The timing of metamorphosis, at 15 mm in length, varied by temperature, ranging from 24 days at 16.8°C to 16 days at 22.1°C. By 8 mm in length 50% of the larvae were capable of consuming fish larvae. Wild-caught larvae primarily fed on copepods, with the size of the prey increasing with size of the larvae.
- Juveniles
 - o Chub mackerel grow rapidly during the first year of life (Krivospitchenko 1979, Lorenzo et al. 1995, Lorenzo and Pajuelo 1996, Hernández and Ortega 2000, Kiparissis et al. 2000, Perrota et al. 2005, Velasco et al. 2011, Daley 2018). For example, Lorenzo and Pajuelo (1996) found that chub mackerel attained 40% of their maximum length in the first year of life.
- Adults
 - o Chub mackerel do not exhibit sexual dimorphism (Collette and Nauen 1983, Vasconcelos et al. 2012 citing Murua and Saborido-Rey 2003 and Gordo et al. 2008). More specifically...
 - Chub mackerel do not exhibit sexual dimorphism in growth rates (Lorenzo and Pajuelo 1996, Vasconcelos et al. 2011, Velasco et al. 2011).
 - No sexual dimorphism in growth rates or mortality rates has been found for the closely related Pacific chub mackerel (Crone and Hill 2015).
 - Lorenzo and Pajuelo (1996) found no significant differences between female and male maturity ogives.
 - o Age

- Carvalho et al. (2002) recorded three 13-year-old chub mackerel from the Azores.
 - Krivospitchenko (1980, cited in Hernández and Ortega 2000) gives a maximum age of 18 years.
 - Length
 - Hernández and Ortega (2000) summarized several studies from around the Atlantic which reported adult sizes ranging from as small as 9 cm to as large as 59 cm, with one instance of a 70 cm individual.
 - Navarro et al. (2012) recorded a 65 cm TL female chub mackerel caught in a commercial fishery off the Spanish coast.
 - Most lengths recorded in NEFSC spring and fall bottom trawl surveys ranged from 15 to 21 cm.
 - Daley (2018) sampled commercial fishery and survey catches in the mid-Atlantic during 2016 and 2017 and found lengths of 17.7-39.7 cm TL.
 - In a mid-Atlantic experimental fishery funded through the Saltonstall-Kennedy program, most lengths were 28-30 cm, with a maximum of 36 cm (Haskin Shellfish Research Laboratory 2004).
 - Growth
 - See Table 1 and Figure 1 for VBGFs from various studies. Several VBGFs from the Mediterranean and Pacific are not summarized here. Additional studies are summarized in Daley (2018).
 - See Table 2 for length/weight parameters from various studies. Several length/weight parameters from the Mediterranean are not summarized here.
 - Daley (2018) suggested that individuals in the northwest Atlantic grow faster and reach a smaller average length than in other regions. Daley noted that fisheries selectivity may have contributed to the estimated differences in growth due to possible under-representation of larger or smaller fish in different studies. The seasonality of sample collection may have also influenced the results of various studies.
 - The Haskin Shellfish Research Laboratory (2004) fit a linear relationship between length and weight for chub mackerel caught with pair trawls in the Mid-Atlantic during 2003, where weight in grams = $32.196 * (\text{length in cm}) - 636.76$; $r^2 = 0.7364$.
- Spawning
 - Age and length at maturity
 - There is little consensus in the scientific literature on the age at which chub mackerel reach maturity. Published ages at maturity range from 1 to 4 years, with most studies reporting maturity at 2-3 years (Table 3; Baird 1977, Krivospitchenko 1979, Lorenzo and Pajuelo 1996, Hernández and Ortega 2000, Carvalho et al. 2002, Vasconcelos et al. 2012)
 - Length at maturity varies by region and tends to be smaller in warmer regions (Hernández and Ortega 2000).

- Daley (2018) estimated an age at 50% maturity of 2.16 years and a length at 50% maturity of 27.39 cm for female chub mackerel caught in the mid-Atlantic.
- Chub mackerel spawn in several batches. The total number of eggs per female ranges from about 100,000 to 400,000 (Collette and Nauen 1983).
- The closely related Pacific mackerel has “indeterminant fecundity and appear to spawn whenever sufficient food is available and favorable oceanographic conditions prevail. Individual fish may spawn eight times or more per year” (Crone and Hill 2015).
- Chub mackerel spawn at night (Scoles et al. 1998 citing Watanabe 1970).
- Growth and maturity of Pacific chub mackerel are density-dependent (Yatsu et al. 2005 – not clear what this statement is based on, possibly “recent unpublished Japanese stock assessment analyses”).
- Keč and Zorica (2012) found that during 1998-2007, chub mackerel in the Adriatic Sea had the lowest fat reserves during the spawning season (April-September), that females had lower Fulton’s condition factors and relative and allometric condition coefficients than males, and that males accumulated fat faster than females after the spawning season.

Environmental factors influencing abundance

- There are no stock assessments of chub mackerel in the western Atlantic.
- Several studies have documented periods of high and low abundances in various regions, including southern New England (Goode 1884), Portugal and the Gulf of Cadiz (Martins et al. 2013), and west Africa (Krivospitchenko 1979). The stock assessment for the closely-related Pacific chub mackerel suggests that periods of high recruitment success occur “no more frequently than at least every few decades” (Crone and Hill 2015).
- Several studies suggest that environmental factors, especially sea surface temperature, influence recruitment and abundance of the closely related Pacific mackerel (e.g. Sinclair et al. 1985, Avalos-García et al. 2003, Yatsu et al. 2005, Chen et al. 2009, Martins et al. 2013, Yasuda et al. 2014, Crone and Hill 2015, Hilborn et al. 2017).
- Hernández and Ortega (2000) and Martins et al. (2013) cite several studies which suggest that weak upwelling leads to stronger chub mackerel recruitment. However, Parrish and MacCall (1978) found increased recruitment of the closely related Pacific mackerel associated with increased coastal upwelling and decreased offshore convergence during the spawning season for 1946-68 in the California Current ecosystem.
- Martins et al. (2013) found an inverse correlation between the recruitment indices for chub mackerel and sardines. They hypothesized that this could be driven by competition for zooplankton prey during the larval and juvenile stages and/or predation by adults of one species on eggs of the other. Chub mackerel early life stages may also be more tolerant to higher temperatures than early life stages of sardines.
- Yatsu et al (2005) found that “spawning stock biomass, SST and sardine biomass affect recruitment of chub mackerel” in Japan. Chub mackerel biomass, when lagged 1 year, was negatively correlated with the Pacific Decadal Oscillation Index and Kuroshio

Sverdrup transport. Chub mackerel instantaneous surplus production rates, when lagged 1 year, was positively correlated with the Arctic Oscillation Index. The authors concluded that “chub mackerel responded [to] SST changes quickly.”

- Sinclair et al. (1985) found that Pacific mackerel survival to age 1 in the California Current was higher in years of decreased southwards transport, which corresponds with El Niño events.
- Spawner-recruit relationships and environment
 - o The stock assessment for Pacific mackerel states that “spawning stock biomass-recruitment relationships (SSB/R) for this species are not well understood, however, it is likely the species exhibits some degree of population depensation...particularly, during unfavorable oceanographic regimes” (Crone and Hill 2015).
 - o Hilborn et al. (2017) concluded, based on modeled recruitment, that “Pacific chub mackerel...show significantly lower recruitment at lower spawning stock size. However, [they show] highly auto-correlated recruitments that are consistent with environmentally driven regime changes and the apparent spawner recruit relationship may in fact simply be that periods of low recruitment lead to periods of low spawning stock size”.
 - o For Pacific mackerel, when “either a heavy fishery or a series of years with unfavorable environmental conditions occurs (and particularly when both occur together) the future spawning biomass is likely to fall to levels where even optimum environmental conditions cannot produce a strong year-class. In these situations the spawning biomass becomes the limiting factor. In the California Current stock the critical spawning biomass of Pacific mackerel appears to be around 20 to 30 million pounds” (Parrish and MacCall 1978).

Diet

- No studies on diet composition off the U.S. east coast have been found to date.
- Chub mackerel are opportunistic predators with a varied diet of small crustaceans (especially copepods), small fish, and squid (Habashi and Wojeiechowski 1973, Collette and Nauen 1983, Castro and Del Pino 1995, Bachiller and Irigoien 2015).
- Their diet varies seasonally (Habashi and Wojeiechowski 1973, Sever et al. 2006, Castro and Del Pino 1995).
- Sever et al. (2006) assessed diet composition in the Aegean Sea and included references to studies on diet composition off the Canary Islands, South Africa, Argentina, Japan, Peru, Chile, and California. Prey items varied by region.
- Chub mackerel feed during spawning, as shown by full stomachs of ripening individuals (Habashi and Wojeiechowski 1973).
- Vertical daily migrations are driven by feeding (Allaya et al. 2016 in introduction, not cited).
- “The possibility that fish may feed on swarms of mysids taking advantage of their positive phototactic response to weak light sources..., just as purse seiners use like to lure mackerel at night, cannot be ruled out” (Castro and Del Pino 1995).

- Some cannibalism takes place, for both adults and laboratory-reared larvae, though it accounts for a very small proportion of the diet (Hunter and Kimbrell 1980, Hernández and Ortega 2000, Castro 1993).
- Adult vs. juvenile diet
 - o Juveniles tend to be found closer inshore than adults, which influences their diet composition (Castro 1993, Okey et al. 2014 citing Chavez 1976).
 - o Both juveniles and adults feed mainly on zooplankton. Larger individuals tend to eat larger prey, including cephalopods, crustaceans, and small pelagic fish (Martins et al. 2013 citing Angelescu 1979 and Castro and Hernández-García 1995). Castro (1993) found that adults off the Canary Islands and northwest African shelf consumed a higher proportion of fish than juveniles.

Trophic interactions/predators

- Quoting directly from Okey et al. (2014), in the South Atlantic, chub mackerel, “a component of pelagic oceanic planktivores, can inhabit nearshore areas when young, where they consume shrimps and mobile epifauna, thus competing with wading birds for food. Chub mackerel even consume some plants, such as seagrasses (Chavez 1976). Pelagic oceanic planktivores have a large biomass and generally a healthy appetite for zooplankton and forage fishes at larval stages. Thus, they may have a double impact on both forage fish and their diet”.
- Chub mackerel as prey
 - o In U.S. Atlantic waters
 - Chub mackerel were 0.2% of diet of dolphinfish by frequency, based on 2,219 dolphinfish collected from charter boats, 1980-1981, NC-TX. Unidentified scombrids were 0.8% by frequency and 2.1% by volume (Manooch et al. 1984).
 - o In other regions
 - Off Canary Islands, chub mackerel are “the main prey of skipjack tuna” and are “important prey” of swordfish, blue marlin, and smooth hammerhead sharks (Castro 1993 citing Ramos et al. 1990 for skipjack tuna).
 - Veiga et al. (2011) examined the stomach contents of 24 blue marlin (2 of which had empty stomachs) caught by the recreational fishery off Portugal and found that chub mackerel were the dominant prey item, accounting for 47.9% of the stomach contents by weight, 51.1% by number, and 58.3% by frequency of occurrence. All marlin were caught by trolling brightly colored lures. The authors postulated that the high frequency of chub mackerel in the stomach contents could be related to the abundance of chub mackerel in Portuguese waters. Chub mackerel are the second most landed species in Portugal.
 - Abitia-Cardenas et al. (1999) found 0-19% frequency of occurrence of chub mackerel in the stomach contents of blue marlin caught off Cabo San Lucas, depending on the season (summer or fall) and year (1987-1989).

- Simões and Andrade (2000) found that chub mackerel occurred in more than half of the stomachs of 51 female swordfish and 22 male swordfish sampled from commercial landings of the Azores longline fleet.

Age distribution

- See page 4 for maximum ages.
- Dominant age classes
 - Ages 0-1 years dominated in surveys off Portugal and the Gulf of Cadiz during the fall, 1995-2010. Ages 1-2 years dominated in the spring. Commercial landings during 1986-2010 were mostly of ages 1-3 (Martins et al. 2013).
 - Krivospitchenko (1979) found that ages 1 and 2 were most abundant from Mauritania through the Gulf of Guinea. The source of these samples is not specified, but is presumably a commercial fishery.
 - Commercial fishery catches off Canary Islands were ages 0-7 (Lorenzo and Pajuelo 1996).
 - Perotta (1992) found ages 4 and 5 to be most common off Buenos Aires, with ages ranging from 1 to 10 years.

Sex Ratios

- Several studies (e.g. Lorenzo and Pajuelo 1996 and several studies cited in Hernández and Ortega 2000) found a female:male ratio of 1:1, or very close to 1:1.

Natural Mortality

- Many different natural mortality rates can be found in the literature. Examples are listed below, ranked from highest to lowest.
 - Barkova and Krivospitchenko (1990 – cited in Hernández and Ortega 2000, location not specified) calculated $M=0.6$.
 - Mendoza (1993 - cited in Hernández and Ortega 2000) calculated $M=0.58$ off Venezuela.
 - Caramantin-Soriano et al. (2008) calculated $M=0.52-0.53$ off Peru.
 - The Pacific chub mackerel assessment assumes $M=0.5/\text{year}$ and is constant over time for all ages and sexes (Crone and Hill 2015).
 - Cerna and Plaza (2014) calculated $0.45-0.46/\text{year}$ off Chile.
 - Perotta et al (1990- cited in Hernández and Ortega 2000, location not specified) calculated $M=0.428$.
 - Maxim et al. (1990 – cited in Hernández and Ortega 2000) calculated $M=0.4$ off Mauritania.
 - Perotta and Pertierra (1993- cited in Hernández and Ortega 2000, location not specified) calculated $M=0.375$.
 - Keč and Zorica (2012) found mean $M=0.35$ in the Adriatic and cite Carvalho et al. (2002) who found $M=0.19$ in the Azores.
 - Cengiz (2012) calculated $M=0.34$ for Saros Bay, Turkey.

Fishing Mortality Rate

- Caramantin-Soriano et al. (2008) estimated $F = 1.16 - 2.78$ off Peru.

Exploitation Rate

- Caramantin-Soriano et al. (2008) estimated an exploitation rate of 0.68-0.84 off Peru.

Total Mortality Rate

- Caramantin-Soriano et al. (2008) estimated that the total mortality rate off Peru ranged from 1.68 to 3.35.

Fisheries

- For information on the mid-Atlantic and southern New England Fisheries, see MAFMC (2018a) and MAFMC (2018b).
- García-Moreno et al. (2012) concluded that chub mackerel contain “valuable raw materials for the production of bioactive ingredients such as omega-3 PUFAs and protein hydrolysates exhibiting antihypertensive and antioxidative activities.”
- U.S. west coast
 - o Fishery began in 1920s, collapsed by 1960s (Parrish and MacCall 1978).
 - o Management by the Pacific Fishery Management Council under the Coastal Pelagic Species Fishery Management Plan since 2000.
 - o The Pacific Fishery Management Council uses a maximum sustainable yield (MSY) control rule for Pacific mackerel of: $\text{Harvest} = (\text{Biomass} - \text{Cutoff}) * E_{\text{MSY}} * \text{Distribution}$, where Harvest is the harvest guideline (HG), Cutoff (18,200 mt) is the lowest level of estimated biomass above which harvest is allowed, E_{MSY} (30%, also referred to as Fraction) is the proportion of biomass above the Cutoff that can be harvested by fisheries, and Distribution (70%) is the average proportion of total Biomass (ages 1+) assumed in USA waters. The HGs under the federal FMP are applied to a July to June fishing year (Crone and Hill 2015).
 - o The stock managed by the Pacific Council is a trans-boundary stock with Mexico, but there is no international agreement for joint management (Crone and Hill 2015).
 - o Over past decade, Pacific mackerel landings in U.S. averaged less than 6,000 mt (~13 million pounds; Crone and Hill 2015).
 - o There is a recreational fishery for Pacific mackerel in southern California. There are no restrictions on the fishery (Crone and Hill 2015).
 - “Pacific mackerel have been among the top ten species reported in CPFV [commercial passenger fishing vessel] logs, both in southern California and state-wide. However, the species is not typically targeted by anglers” (Crone and Hill 2015).
- Other countries
 - o Gear
 - Most landings are from purse seine fisheries (Collette and Nauen 1983, Perotta et al. 2001, Velasco et al. 2011, Keč and Zorica 2012, Vasconcelos et al. 2012, Martins et al. 2013, Crone and Hill 2015).

- Pacific chub mackerel caught off Japan using lights (Hernández and Ortega 2000).
 - Importance (focus on recent studies)
 - Chub mackerel are commonly not the primary target species (Vasconcelos et al. 2012; Martins et al. 2013 citing ICES 2011a, GFCM 2010, and FAO 2010a, b).
 - “Although it is normally a by-catch, it may provide an alternative income when the availability of the target species is low and its own availability is high” (Martins et al. 2013). For example, landings in Portugal over 1986 to 2010 varied inversely with sardine landings (Martins et al. 2013).
 - Chub mackerel made up about 4% of total small pelagic fish harvest from Tunisian waters (Allaya et al. 2016)
 - Chub mackerel made up about 5.5% of total landings and 1.8% of total value in Madeira archipelago in 2011 (Vasconcelos et al. 2012).
 - During the early 2000s to 2010, a period of high landings compared to previous years, chub mackerel made up about 10% of total purse seine landings in Portugal where they are of low value, but second only to sardines in total annual landings (Martins et al. 2013).
 - Some artisanal fisheries (e.g. Velasco et al. 2011).
 - Volume
 - Annual landings in eastern Atlantic are around 200,000 tons with 80% caught off northwest Africa (Martins et al. 2013 citing FAO 2010a).
 - Landings in Portugal increased consistently between 2001 and 2010 (Martins et al. 2013).
 - Use
 - Much of the chub mackerel harvested in the mid-Atlantic in recent years are canned and shipped to Africa (Jeff Kaelin, Lund’s Fisheries, personal communication).
 - Some amount of chub mackerel landed in the southeast is sold for bait.
 - Used for human consumption, fresh and canned (Perotta 1992, Vasconcelos et al. 2012, Martins et al. 2013 citing INE 2011).
 - Chub mackerel are “an important component in the diet of the local population... in Madeira archipelago” (Vasconcelos et al. 2012).
 - Used as feed in tuna aquaculture (Martins et al. 2013).
 - Used as bait in tuna fisheries (Carvalho et al. 2002, Vasconcelos et al. 2012).
 - “At present, most Pacific mackerel is used for human consumption or pet food, with a small, but increasing amount sold as fresh fish” (Crone and Hill 2015).

Habitat characteristics

- Egg habitat
 - Location

- Berrien (1978) collected eggs from North Carolina to Florida during January, February, and May at depths of at least 32 m to at least 60 m, suggesting that egg distribution may extend beyond the continental shelf.
 - In Japan, eggs of the closely related Pacific mackerel are mostly found at depths of 1-50 m (Hernández and Ortega 2000 citing Watanabe 1970, Fritzsche 1978 citing Motoda and Anraku 1955).
 - Temperature
 - Berrien (1978) collected eggs from NC-FL in sea surface temperatures of about 20-25°C.
- Larval habitat
 - Location
 - Berrien (1978) collected larvae during January and February 1968 from New River, NC to Palm Beach, FL. In May 1967 larvae were collected off New River, NC to Ponce de Leon Inlet, FL. Larvae were generally collected over the outer half of the continental shelf, slightly farther inshore than eggs, in waters as shallow as 25 m. They were also caught on the edge of the shelf, suggesting that their distribution extends beyond the shelf.
 - Richardson et al. (2010) documented chub mackerel larvae in the straits of Florida in nearshore waters during 2003 (mostly January and February) and 2004 (mostly February through May).
 - In Japan, post-larvae are rarely found below 25 m (Hernández and Ortega 2000 citing Watanabe 1970).
 - Temperature
 - Berrien (1978) collected larvae from New River, NC to Palm Beach, FL in water temperatures of about 16-29°C.
 - Hernández and Ortega (2000) summarized several studies from other regions which found larvae at temperatures of 14-24°C.
 - Esqueda-Escarcega (1995) collected larvae of the closely-related Pacific mackerel in the Sea of Cortez during 1984-1988 at temperatures of 14.8 – 24.2°C and found that temperature was “an important factor determining the occurrence and distribution of these larvae”. Most larvae were collected at temperatures of 16.0 – 22.0°C.
- Juvenile habitat
 - Juveniles of the closely-related Pacific mackerel can be found close to shore off sandy beaches, in kelp, and open bays of California (Fritzsche 1978 citing Fry 1936).
- Adult habitat
 - Location
 - Adult chub mackerel are mostly found on the continental shelf and slope from the surface to depths of about 250-300 meters (Collette and Nauen 1983).
 - Rebik and Kukharev (1998) and MAFMC (2017) suggest that chub mackerel are found near the surface at night and at greater depths during the day. Specifically, Rebik and Kukarev (1998) sampled chub mackerel off South

Yemen at depths of 120-400 m during the day and 40-80 m at night. Public comments summarized in MAFMC (2017) suggest that chub mackerel off Virginia Beach are distributed from approximately 90 to 183 m during the day and at the surface during the night.

- Temperature
 - Perotta et al. (2001) found that 19°C was the maximum temperature at which schools of chub mackerel were found in coastal Argentina waters. At higher temperatures they moved to shelf waters (>50 m).
 - According to Usami (1970), in Japan, the closely-related Pacific mackerel is found at temperatures of 14-20°C and is most abundant at temperatures of 15-18°C.
 - Chen et al. (2009) found that, in the East China Sea during July-September 1998-2003, the closely-related Pacific mackerel was found at temperatures of 25.6-30.0°C and was most abundant at temperatures of 28.0-29.4°C.
- Salinity
 - Chen et al. (2009) found that, in the East China Sea during July-September 1998-2003, the closely-related Pacific mackerel was found at surface salinities of 32.6 – 34.4 psu and was most abundant at surface salinities of 33.6 – 34.2 psu.
- Chlorophyll-a
 - Chen et al. (2009) found that, in the East China Sea during July-September, 1998-2003, the closely-related Pacific mackerel was found at chlorophyll-a concentrations of 0.05 – 4.7 mg/m³ and was most abundant at 0.15 – 0.50 mg/m³.
- Sea surface height anomaly
 - Chen et al. (2009) found that, in the East China Sea during July-September 1998-2003, the closely-related Pacific mackerel was found at sea surface height anomalies of -1.5 to 1.9 m and was most abundant at -0.1 to 1.1 m.
- Spawning habitat
 - Temperature
 - Spawning mostly occurs at water temperatures of 15-20° C (Collette and Nauen 1983, Perotta et al. 2001). The closely-related Pacific mackerel prefers a similar temperature range (Fritzsche 1978 citing Watanabe 1970, Parrish and MacCall 1978).
 - Weber and McClatchie (2012) noted peak spawning for the closely-related Pacific mackerel in the California current region at around 15.5° C in the southern California Bight but also found a secondary peak at 20° C or greater near Punta Eugenia, Mexico.
 - Spawning season and location
 - The timing of spawning varies notably by location, likely due to the wide distribution of this species in northern and southern hemispheres and the influence of temperature on spawning (Habashi and Wojeiechowski 1973,

Baird 1977, Krivospitchenko 1979, Collette and Nauen 1983, Carvalho et al. 2002, Zardoya et al. 2004, Vasconcelos et al. 2012, Allaya et al. 2016).

- Caramantín-Soriano et al. (2009) found a significant correlation between female mean gonadal-somatic index values and sea surface temperature. They also found evidence of a prolonged spawning season during an El Niño event.
- Spawning occurs year-round at the equator (Hernández and Ortega 2000).
- Spawning in the U.S. Atlantic EEZ
 - Berrien (1978) postulated that spawning occurs simultaneously from North Carolina to Florida during January to July.
 - Daley (2018) estimated that spawning occurs during January - April in the northern Gulf of Mexico based on larval catches in the SEAMAP plankton survey during January, February, March, and April.

Differences between Atlantic chub mackerel (*S. colias*) and Pacific chub mackerel (*Scomber japonicus*)

- *S. colias* and *S. japonicas* have “broadly similar life history and population dynamics” (Martins et al. 2013 citing Castro-Hernández and Santana-Ortega 2000).
- Genetic differences
 - Mitochondrial and nuclear DNA analyses suggest that *S. colias* and *S. japonicus* are two distinct species (Scoles et al. 1998, Collette 1999, Infante et al. 2007, Espiñeira et al. 2009, Catanese et al. 2010).
 - Catanese et al. (2010) determined the complete mitochondrial DNA sequence of *S. colias* and *S. japonicus* and concluded that they are separate species. Previous studies examined incomplete sequences.
 - Of four *Scomber* species (*S. colias* [Atlantic chub mackerel], *S. scombrus* [Atlantic mackerel], *S. japonicus* [Pacific mackerel or Pacific chub mackerel], and *S. australisicus*), *S. scombrus* is the most genetically distinct. *S. japonicus* and *S. australisicus* are the most closely related (Catanese et al. 2010).
- Morphological
 - Many studies found morphological differences (e.g. differences in coloring, size and number of scales, number of gill rakers, length of maxillary, size of head, length of snout) between chub mackerel inhabiting Atlantic and Pacific Oceans (Evermann and Kendall 1910, Starks 1922, Collette and Nauen 1983, Collette 1999, Catanese et al. 2010).
 - However, Matsui (1967) concluded that chub mackerel from the Atlantic and Pacific Oceans are likely a single species (*S. japonicus*) based on morphological comparisons.
- Oliva et al. (2008) found highly-specific parasites on specimens from the Atlantic (Brazil, Madeira, and Portugal) and Pacific (Peru and Chile), suggesting that *S. colias* and *S. japonicus* are distinct species.

Differences between Atlantic chub mackerel (*S. colias*) and Atlantic mackerel (*Scomber scombrus*)

- Chub mackerel have a swim bladder, Atlantic mackerel do not (Matusi 1967, Collette and Nauen 1983, Zardoya et al. 2004).
- Quoting directly from Zardoya et al. (2004): “Physiological studies on muscle fibre activity show that [Atlantic] mackerels are in fact more powerful swimmers than chub mackerels. Mackerels are obligate swimmers due to the absence of a swimbladder and the necessity for gill ventilation. They show variation of muscle kinetics along the body resulting in a fast and strong swimming style (Wardle & Videler 1993). In contrast, chub mackerels have a swimbladder than enables the fish to hold position off the bottom of the sea. They display homogeneous muscle activity at all body positions, which allows them to display wider swimming styles (Shadwick et al. 1998)”.
- Quoting directly from Zardoya et al. (2004): “The recruitment of the chub mackerel is clearly different from that of the [Atlantic] mackerel and other scombrids. The larvae of the chub mackerel exhibit a voracious behaviour with high daily rations (87% of body weight) (Hunter & Kimbrell 1980) when compared with the [Atlantic] mackerel (25–50% of body weight) (Peterson & Ausubel 1984). Additionally, the fecundity of the chub mackerel (one million eggs per year) is more than double that of the mackerel (400 000 eggs per year) (Metz & Myers 1996)”.
- Chub mackerel otoliths have a very distinct shape. For example, Parisi-Baradad et al. (2010) tested an automated identification system was able to correctly identify chub mackerel otoliths 100% of the time.

Tables and Figures

Table 1: Von Bertalanffy Growth Function parameters ($L_t = L_\infty(1 - e^{-K(t-t_0)})$). Lengths are in total length, unless otherwise noted with FL for fork length. Several other studies are summarized in table 4 of Vasconcelos et al. (2011).

Reference	Area	Ages	Sex	L_∞ (asymptotic length; cm)	K (growth constant)	T_0 (theoretical age at length 0)	r^2 (goodness of fit)	Source of samples
Daley 2018	Mid-Atlantic and Gulf of Mexico (larvae only)	0-7	F & M	33.56	1.75	0.07		Commercial fishery and survey catch; bottom trawls
Velasco et al. 2011	Gulf of Cadiz	1-7	F & M	43 (fixed)	0.27	-1.1		Back-calculated lengths at age. Mostly commercial fishery (mixed gear, mostly purse seines), some trawl survey samples
	Alboran Sea	1-7	F & M	40 (fixed)	0.37	-0.1		
Lorenzo et al. 1995 ^a	Canary Islands	1-7	F & M	49.2	0.21	-1.40	0.97	Commercial purse seine fishery
Lorenzo and Pajuelo 1996a ^b	Canary Islands	0-5	?	49.50	0.23	--	0.272	Commercial purse seine landings
Lorenzo and Pajuelo 1996b	Canary Islands	0-7	F & M	52.4	0.19	-1.61		Commercial purse seine catches
Krivospitchenko 1979	Morocco	1-6		44.08	0.326	-0.834		Not specified

^a Lorenzo et al. (1995) fit a VBGF based on lengths at previous ages back-calculated based on otolith measurements.

^b Lorenzo and Pajuelo (1996a) fit a seasonally oscillating VBGF, which has two additional parameters of C=0.650 (a measure of the magnitude of seasonal oscillations) and WP=0.800 (indicating the time of least growth, where $t_s=WP+0.5$ and t_s is a measure of the time between oscillations).

Reference	Area	Ages	Sex	L_{∞} (asymptotic length; cm)	K (growth constant)	T_0 (theoretical age at length 0)	r^2 (goodness of fit)	Source of samples
Carvalho et al. 2002	Azores	1-13	F & M	57.52	0.201	-1.093	>0.97	Fisheries-independent survey and commercial fishery
Perrota et al. 2005	Catalan Sea	0-8	F & M	39.75	0.298	-1.405		Commercial fishery
	Argentina	0-10	F & M	44.23	0.324	-1.388		Not specified – “existing data”
Luhrs 1986 (as cited in Kec and Zorica 2012)	Senegal			51.70	0.217	-0.89		
Baird 1977 ^c	South Africa	1-8	F & M	68.01	0.2070	-0.9845		Commercial fishery
Vasconcelos et al. 2011	Madeira Island	0-4	F & M	50.08	0.252	-1.339		Commercial fishery

^c Based on back-calculated lengths at age. Female and male VBGFs were not significantly different from one another.

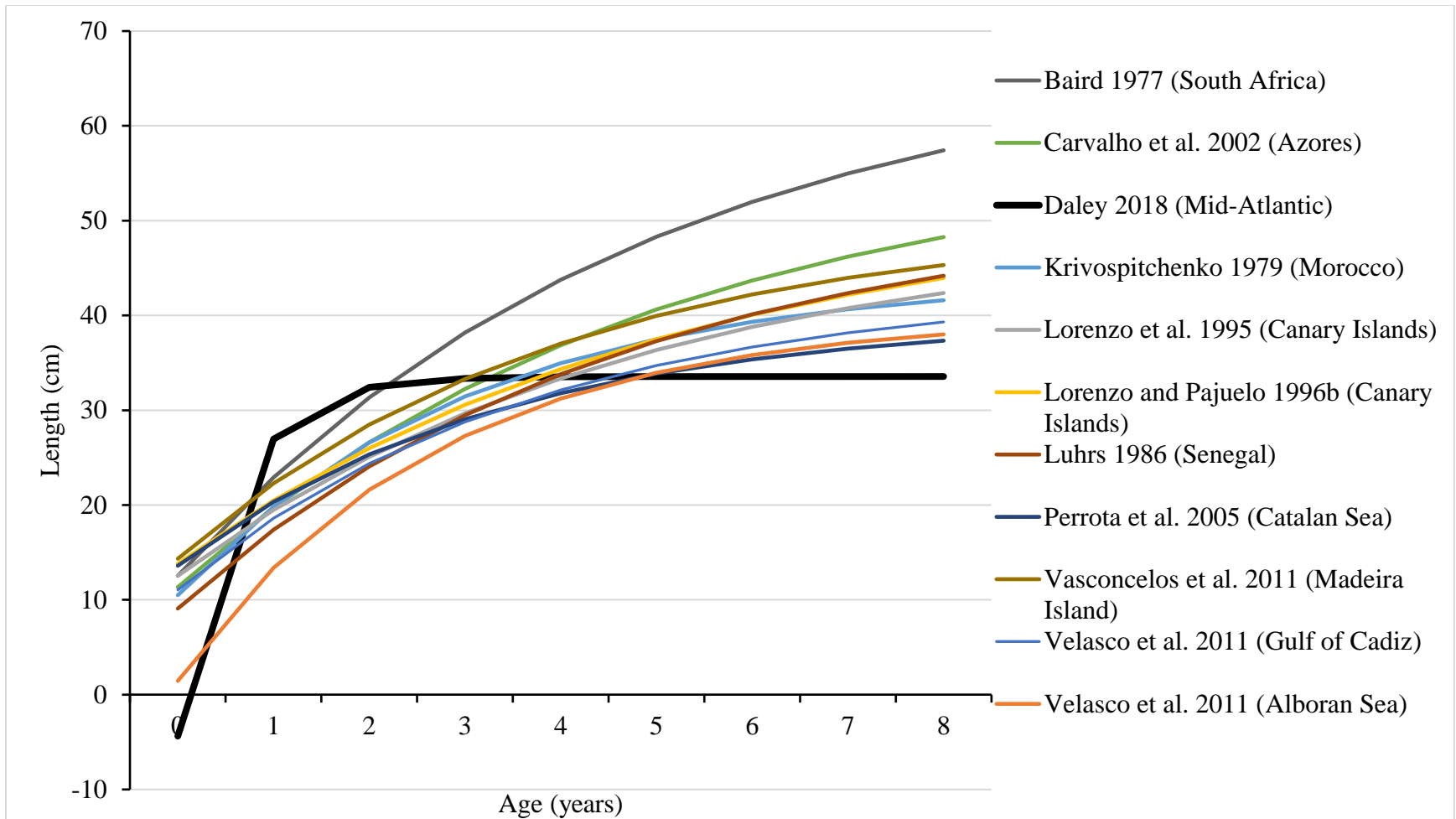


Figure 1: Von Bertalanffy Growth Functions from various studies.

Table 2: Parameters for length-weight relationships ($W=a*L^b$). Several other studies are summarized in table 4 of Vasconcelos et al. (2011).

Reference	Area	Lengths (cm)	Sex	a	b	r ²	Source of samples
Daley 2018	Mid-Atlantic and Gulf of Mexico (larvae only)	17.7-39.7 (TL)	F&M	0.0258	2.72		Commercial fishery and survey catch; bottom trawls
Velasco et al. 2011	Gulf of Cadiz	16.4-43.0 (TL)	F&M	0.0015	3.5289	0.99	Mostly commercial fishery (mixed gear, mostly purse seines), some trawl survey samples
	Alboran Sea	17.2-40.0 (TL)		0.0014	3.5369	0.97	
	Gulf of Cadiz & Alboran Sea	16.4-43.0 (TL)		0.0015	3.51	0.99	
Baird 1977 ^d	South Africa	Not specified	F&M	0.0049	3.3112	Not specified	Commercial fishery
Caramantín-Soriano et al. 2009	Peru	19-39 (FL)	F	0.0070	3.18	0.91	Commercial landings
Vasconcelos et al. 2011	Madeira Island	17.4-41.7	F&M	0.00218	3.40		Commercial fishery

^d Based on back-calculated lengths at age.

Table 3: Length and age at maturity (L_{50} and T_{50} in years unless otherwise noted).

Reference	Area	Years	Sex	Length	Age	Source of samples
Vasconcelos et al. 2012	Madeira Island	2002-2005	F	21.55 (TL)	0.82	Commercial purse seine landings
			M	22.12 (TL)	1.05	
Carvalho et al. 2002	Azores		F&M	27.78 (TL); 25.46 (FL)	2.23	Fisheries-independent survey and commercial fishery
Lorenzo and Pajuelo 1996	Canary Island	1988-1990	F	19.9 ($L_{95}=26.0$)	1 (T_{50}), 2 (T_{95})	Commercial purse seine fishery
			M	19.8 ($L_{95}=25.8$)		
			M	19.85		
			M	22.0		
Baird 1977	South Africa	1969-1973	F&M	39.0-39.9	3-4	Commercial fishery
Krivospitchenko 1979	Mauritania through the Gulf of Guinea	1971-1975	Not specified	20 ^e	1 ^f	Not specified

^e Not explicitly described as L_{50} .

^f Not explicitly described as T_{50} . Krivospitchenko (1979) states that chub mackerel “begins to reach sexual maturity at 20 cm” and that most 20 cm chub mackerel are one year old.

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