Symbiosis Biology Report

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Table of Contents

Glossary

Carangiform: A type of undulatory locomotion in which the body bends less than half a wavelength at any one time.

Epipelagic: Living or feeding on surface waters or at midwater to depths of 200 m.

FAD: Fish aggregating device. Referring to natural or manmade floating objects as well as moored buoys.

FL: Fork length. A standardised measurement of body length extending from the snout of the fish to the splitting of the caudal fin.

Oceanodromous: Cyclically migrating within oceans, typically between spawning and foraging grounds, while covering distances of more than 100 km.

Pelagic: Free swimming in mid water from 0 to 200 m depth.

Thunniform: A type of swimming involving very little body bending, thrust being generated by the tail powered by the myotome.

TL: Total length. A measurement of body length extending from the snout of the fish to the tip of the longer lobe of the caudal fin.

Introduction

This report presents six species of teleost (bony) fishes selected based on their high commercial importance, distinct behaviour or appearance and occurrence at either or both study locations of this project – the Eastern Mediterranean Sea and the Canary Islands: Albacore tuna (*Thunnus alalunga*), dorado (dolphinfish; *Coryphaena hippurus*), swordfish (*Xiphias gladius*), Atlantic mackerel (*Scomber scombrus*), Mediterranean horse mackerel (*Trachurus mediterraneus*) and Greater amberjack (*Seriola dumerili*).

First, each species is described in terms of its habitat and ecological niche (e.g., preferred temperature or depth range). A short account of their external features and morphology is then provided including species-specific Bayesian a and b constants, corresponding with the allometric length-weight relationship formula $W={}_{a}L^{b}$ (where W is the animal's weight and L is fork length).

The schooling behaviour of each species is then summarised in the following section of each chapter; some fish in this report are known to aggregate in the vicinity of buoys or other floating objects at sea (such as the THEMO mooring in Israel), in which case the scientific literature on their behaviour may be biased to those structures. In other cases, information on the densities or vertical dynamics are derived from laboratory experiments, fishery records or long-term tagging programmes. As a result, a certain degree of inconsistency between chapters should be considered regarding the available data or their units of measurement.

In the following section of each chapter, an overview of distinct acoustic features such as target strength, swim bladder physiology, or other backscattering factors are presented when applicable.

Finally, swimming types and speeds are provided for either or both, sustained and burst modes, based on empirical laboratory of *in situ* measurements

Albacore, *Thunnus alalunga*

Main reference: Froese and Pauly (2000).

Habitat ecology:

Albacore tuna is a pelagic, epipelagic and mesopelagic species, ranging in depth between 0-600 m. It is abundant along thermal discontinuities between 15.6° to 19.4°C at the surface and 13.5° to 25.2°C in the deep. Temperatures as low as 9.5°C may be tolerated for short periods of time.

http://www.dw.de/image/0,,15659804_303,00.jpg

Morphology and morphometrics:

Common FL:	100 cm.
Max. FL:	140 cm.
Max. published weight:	6.3 kg.
Bayesian length-weight:	a=0.01738 (0.01345 - 0.02246), b=2.98 (2.94 - 3.02), in cm.
General description:	Pectoral fins are about 30% of FL or more in fish longer than 50 cm. Dorsal spines: 11-14; dorsal soft rays: 12-16. Anterior spines much higher than posterior spines giving the fin a strongly concave outline. Anal spines: 0; anal soft rays: 11-16. Body scales are very small.

Schooling behaviour:

Tuna species are known to associate with natural or manmade floating objects as well as moored buoys, generally referred to as Fish Aggregating Devices (FADs). However, scientific knowledge of the structure and dynamics of these aggregations is poor. Based on active acoustic surveys, Josse et al. (2000) defined three kinds of tuna aggregations exhibiting size-dependent behaviour around FADs, namely ‘deep scattered fish’, ‘intermediate scattered fish’ and ‘shallow schooling fish’. Larger fish were shown to form more unstructured and less dense aggregations in the deep, while smaller fish were found in shallower waters, closer together as well as closer to the FAD. Notably, albacore are known to form mixed schools with skipjack tuna, yellowfin tuna and bluefin tuna. TS values from this survey indicated that deep scattered fish were large tuna of more than 100 cm fork length (FL). Comparisons with catches from artisanal fisheries suggest that these aggregations were mainly comprised of albacore. If only the ‘deep scattered’ class is considered, the average density of deep scattered tuna was 7.3 fish per km3. Highest densities were observed close to the FAD. They then decreased and the minimum values were found between 0.5 and 0.6 nautical miles from the FAD. Fish were observed between 10-500 m, but 92 % of the fish was distributed between 100-300 m. The average distance between two fish along a same branch was 240 m (n = 29, SD = 340 m).

Temporal dynamics:

All aggregation classes in the abovementioned study were reported to exhibit a biomass maximum immediately after sunrise and a decrease during daytime. Night-time biomass varied from no fish at all to relatively high numbers yet remained below the values observed during daytime.

Swimbladder / Target strength:

The abovementioned authors report TS values between -34.4 and -19.0 dB for deep scattered albacore tuna, with a mean of -23.0 dB. Such a range is consistent with results obtained in another study by Bertrand and Erwan (2000). However, these authors stressed that, for this species, the swimbladder’s volume is not the only factor responsible for 90-95% of the backscattering energy but also its elongated cross section. Thus, albacore TS may be high despite a low swimbladder volume compared with other tuna species (e.g., bigeye).

Swimming:

Swimming mode: Thunniform.

Swimming speed: Few studies have focused on swimming speeds of albacore tuna. Minimum speeds necessary for hydrostatic equilibrium of albacore, which is negatively buoyant in seawater and therefore must swim continuously, were calculated by Dotson (1976) and compared at 50 and 80 cm fork lengths. Predicted speeds were 57 and 45 cm/s respectively; density variations attributed to fat content and swimbladder volume significantly affected estimates of minimum speeds. Calculated speeds were slower than those estimated for albacore tracked at sea or from returned tags.

Dorado (dolphinfish), *Coryphaena hippurus*

Main reference: Froese and Pauly (2000).

Habitat ecology:

https://adlayasanimals.files.wordpress.com/2016/07/dolphinfish_mahi-mahi_cvl_april2010_mg_7945web-use-only.jpg?w=616

Dorado is a pelagic, oceanodromous species, found in open waters as well as near the coast.

Based on model estimates, its lower depth limit is 85 m and its preferred temperatures are 18.1 to 29.1°C. However, satellite telemetry studies have shown diving profiles of >200 m in temperatures of 16.2 to 30.89°C (Merten et al., 2014). Notably, these data were derived from only four tagged males and may not suffice for generalisation or inference.

Morphology and morphometrics:

Common FL:	100 cm.
Max. FL:	210 cm.
Max. published weight:	40 kg.
Bayesian length-weight:	a=0.01622 (0.01288 - 0.02042), b=2.83 (2.76 - 2.90), in cm.

General description: Body elongated and compressed. Mature males possess a prominent bony crest in front of the head. Very long, single dorsal fin with 58-66 rays extending from above eye almost to caudal fin. Dorsal spines: 0; dorsal soft rays: 58-66. Large oblique mouth with projected lower jaw. A concave anal fin extending from anus to almost caudal fin. Anal spines: 0; anal soft rays: 25-31. The caudal fin is deeply forked. Pectoral fin is over half of head length. Lateral line curved upward above pectoral fin. Vertical bars are pronounced on the sides of the body in small specimens.

Schooling behaviour:

A schooling fish, generally observed along continental shelf breaks, deep seamounts and open ocean temperature or current fronts. They overwinter in deeper waters but move closer to shore in spring. In addition, dolphinfish are known to aggregate around drifting or stationary FADs including boats and ships (Golani et al., 2006), forming multiple dynamic independent subgroups rather than a single, homogenous school (Merten et al., 2014). Smaller dolphinfish associate with surface objects more than larger fish (Farrell et al., 2014). Residence time around FADs (<365 m) has been shown to last several days (mean 6.25 days, maximum 15.26 days) with 8% spent away from the FAD for foraging excursions (Taquet 2007). Using ultrasonic telemetry, Girard et al. (2007) showed homing abilities of dolphinfish to FADs from distances of up to 820 m.

Temporal dynamics:

A study by Merten et al. (2014) reports long-term comprehensive vertical movement activity of dolphinfish observed through satellite telemetry. Tagged dolphinfish spent 66% of their time in the surface layer (0–9.9 m). They were observed more frequently in shallow waters but made frequent dives to depths below 30 m and infrequently deeper than 200 m.

Swimbladder / Target strength:

Dolphinfish do not possess a swimbladder (Magnuson, 1965).

Swimming:

Swimming mode: Thunniform

Swimming speed: Based on caudal fin aspect ratio, the calculated speed of a dolphinfish measuring 67 cm in length is 0.563 m/s (Sambilay Jr, 1990). In line with this calculation, empirical measurements of a 71.1 cm fish on three different days over a one-week period (31 observations of 30 seconds) was 56.3 cm/sec (Magnuson, 1965). This is equivalent to a distance of approximately 50 km over 24 hours. The typical tail-beat frequency for this fish was 1.21 beats/sec, defined as a complete cycle. Another fish of approximately 100 cm FL showed 1.20 beats/sec. These slow rates of swimming are commonly observed for dolphinfish in tanks and at sea and are as close to resting speeds as the animal attains (Magnuson, 1965). Beat frequencies may also translate to minimum muscle contraction times which then yield the theoretical maximum values attainable by the fish. Measuring the twitch contraction time of anaerobic swimming muscle, Svendsen et al., (2016) estimated a maximum speed of 4.0 m/sec for dolphinfish.

Swordfish, *Xiphias gladius*

Main reference: Froese and Pauly (2000).

Habitat ecology:

https://c1.staticflickr.com/9/8281/7814479438_0c5058a7b3_b.jpg

Oceanic but sometimes found in coastal waters. High tolerance to temperature (5°C to 27°C) but usually above the thermocline, preferring temperatures of 18°C to 22°C (Luckhurst, 2014). Migrate toward temperate or cold waters in the summer and back to warm waters in the fall. Depth distribution ranges from the surface to over 800 m but there are depth records down to 2878 m.

Morphology and morphometrics:

Common TL: 300 cm.

Max. TL: 455 cm.

Max. published weight: 650 kg.

Bayesian length-weight: a=0.00380 (0.00161 - 0.00900), b=3.15 (2.94 - 3.36), in cm.

General description: Two well-separated dorsal fins and two anal fins (in juveniles a single long dorsal fin and a single long anal fin; Golani et al., 2006). Dorsal spines: 0; dorsal soft rays: 38-56; anal spines: 0; anal soft rays: 16-18. No pelvic fin. A single strong keel at each side of the caudal peduncle. Both jaws are elongate and body covered with scales (Golani et al., 2006).

Schooling behaviour:

Adult swordfish are generally solitary and are not known to form schools in the open ocean.

Temporal dynamics:

Acoustic tagging has shown that swordfish stay near the surface at night, but return to depths of up to 600 m during the day (Luckhurst, 2014). A satellite tag deployed on a small swordfish of 59 kg provided evidence of this diurnal vertical migration (Luckhurst, 2007). Throughout the monitoring period, this fish made regular dives to 700-800 m in the daytime while at night, mean depth was much more shallow with brief, regular periods spent at the surface. Dewar et al. (2011) showed that this pattern of vertical movement exists across individuals over a range of oceanographic regimes. Their data suggest that solar and lunar illumination may dictate the distribution of swordfish in the water column during daylight hours and the night time, respectively, and that temperature may not be the driving force of vertical movement. Thus, swordfish seem to leave near-surface waters before sunset, descend to depth, and then slowly return to the surface after sunrise. Deviations from this pattern of behaviour are daylight basking events in which swordfish rapidly ascend to surface waters for periods of minutes to hours and then actively swim back to the deep. Otherwise, swordfish expose themselves to little or no solar illumination (Dewar et al., 2011).

Swimbladder / Target strength:

Swordfish have a conspicuous swimbladder. However, short capillaries in the gas gland and fast vertical excursions from large depths to the surface make it unlikely that this species can pump gas into and out of its bladder rapidly enough to maintain a constant gas bladder volume (Carey and Robison, 1960). The swimbladder is inflated near the surface but collapses during vertical descents. In the depth, the high lipid content of the flesh and porous fatty bone of the swordfish will lower its density and the flattened bill and fixed pectoral fins give it hydrodyriamic lift. When not swimming, the excess density will prevent the swordfish from hovering easily and it might rest on the bottom with the fixed pectoral fins forming an effective tripod with the tail (Carey and Robison, 1960). No scientific publications on the swimbladder of swordfish or its acoustic properties were found in the literature.

Swimming:

Swimming mode: Thunniform.

Swimming speed: Based on caudal fin aspect ratio, the calculated speed of a swordfish measuring 220 cm in length is 24.86 m/s in burst mode (Sambilay Jr, 1990). However, this calculation differs to swimming speeds during basking events empirically measured by Dewar et al. (2011) using pop-up satellite archival tags, where the mean rate of ascent was 38 m/s and the mean rate of descend was 57 m/s. Highest straight-line speeds of swordfish was estimated by these authors to be 59 km/day or 1.3 knots which is comparable to ‘sustained speeds’ reported by Carey and Robinson (1981) and Carey (1990).

Atlantic mackerel, *Scomber scombrus* L.

Main reference: Froese and Pauly (2000).

Habitat ecology:

https://upload.wikimedia.org/wikipedia/commons/c/c3/Scomber_scombrus.jpg

Abundant in cold and temperate shelf areas, Atlantic mackerel is a pelagic-neritic and oceanodromous species with a depth range of 0-1000 m, though it is usually found in 0-200 m. They overwinter in deeper waters but move closer to shore in spring when water temperatures range between 11° and 14°C. Castonguay et al. (1992) showed that mackerel are eurythermal, occurring at temperatures between 0° and 13°C.

Morphology and morphometrics:

Common FL: 30 cm.

Max. FL: 60 cm.

Max. published weight: 3.4 kg.

Bayesian length-weight: a=0.00646 (0.00581 - 0.00718), b=3.05 (3.02 - 3.08), in cm.

General description: Dorsal spines: 8-14; Dorsal soft rays: 113. Anal fin spine conspicuous, joined to the fin by a membrane but clearly independent of it; anal fin origin opposite that of second dorsal fin. Anal spines: 1; Anal soft rays: 12-13. No well-developed corselet; markings on back oblique to near vertical, with relatively little undulating. Belly unmarked.

Schooling behaviour:

Mackerel are obligate schoolers down to a light level of 10^{-6} lx. Below that, they lose visual contact and swim as individuals (Wardle and He, 1988). Glass et al. (1986) showed that captive mackerel in water tanks display three types of shoaling formations at increased light levels: ‘Patrolling’, whereby the width of the school is larger than its length; ‘streaming’, characterised by a narrower and longer formation, and; ‘wheelie’, a circular school in the centre of the tank lasting from seconds up to one hour. In high light conditions, nearest neighbour distances (NND) remained remarkably constant, ranging from 10 to 27 cm (0.3-0.9 body lengths). As light intensity decreased, NND progressively increased. At low light, mean NND ranged between 30 and 52 cm (1-1.8 body lengths). Mean angular deviation

(MAD) at high light levels was 6-14° and progressively increased up to 92° as light levels were reduced. These laboratory observations indicate a packing density of up to 70 fish m^{-3} at sea, though *in situ* studies have shown densities of up to 136 fish m^{-3}.

Temporal dynamics:

Densities may change in response to spatiotemporal ques in the environment, termed 'enviroregulation'. For example, Castonguay and Gilbert (1995) observed largest mean and maximum mackerel densities at slack tides during migratory activity of mackerel through the a strait in Nova Scotia (1.2 kg/m^{-2} and 16.3 kg/m^{-2}, respectively). Densities were increasing at the transition from a flow leaving to a flow entering their study area and were decreasing in the reversed flow direction. Castonguay et al. (1992) demonstrated that mackerel movements in the nearshore zone are closely linked to wind-forced advections of heated (>7°C) near-surface waters. Complete density values.

Swimbladder / Target strength:

Josse and Bertrand (2000) compared mackerel TS distributions obtained from single-beam and split-beam surveys to catch yields. The mean TS value was -56.4 dB (b_{20}). Low TS values in mackerel are attributed to the fact that this fish does not have a swimbladder, which is responsible for over 90% of that backscattering energy in fish that do possess it (Foote, 1980). TS values may decrease by 4 dB (Edwards and Armstrong, 1983; Josse and Bertrand, 2000) as mackerel display tilting behaviour due to insufficient lift at low swimming speeds (He and Wardle, 1986). Such behaviour has also been shown to occur as schools disassemble in dark conditions (Glass et al., 1986). However, this relationship between light intensities and tilting angles has only been observed in laboratory settings.

Swimming:

Swimming mode: Carangiform.

Swimming speed: Atlantic mackerel is a fast-swimming pelagic fish (Castonguay and Gilbert, 1995). Based on caudal fin aspect ratio of mackerel measuring 30-32 cm in length, swimming speeds are 0.28-2.02 m/s in sustained mode; for mackerel of 30-38 cm in length, the calculated burst speeds are 2.96-5.4 cm/s (Sambilay Jr, 1990). A maximum speed of 5.5 m/s was empirically measured by Wardle and He (1988) in a 0.305 m mackerel.

Mediterranean horse mackerel, *Trachurus mediterraneus*.

Main reference: Froese and Pauly (2000).

Habitat ecology:

Pelagic-oceanic, oceanodromous, with a depth range of 0-500 m, though usually occurring at 5-250 m. Adults are found usually near the bottom, at times also in surface waters. Preferred temperature range is 13.2-21°C (Kaschner et al., 2008). Shows marked preference for the continental shelf over upper slope areas (Ragonese et al., 2003).

http://www.weheartdiving.com/wp-content/uploads/Mediterranean-Horse-Mackerel-Trachurus-Mediteraneus001.jpg

Morphology and morphometrics:

Common FL:	30 cm.
Max. FL:	60 cm.
Max. published weight:	ND.
Bayesian length-weight:	a=0.00912 (0.00784 - 0.01061), b=2.96 (2.93 - 2.99), in cm.

General description: Body elongate and compressed. Head large; posterior end of upper jaw reaching anterior margin of eye; lower jaw projected. Scutes on the entire lateral line, from head to caudal fin; the scutes on the anterior to the curved part shorter than those on the posterior part (Golani et al., 2006). Dorsal spines: 8 and 1 (first and second fin, respectively). Dorsal soft rays: 29-35 (second fin). Anal spines: 2 and then 1. Anal soft rays: 26-39 preceded by the two strong anal spines.

Schooling behaviour:

Migratory in large schools; Ragonese et al. (2003) reported densities of 102 to 12,319 fish/km^2 and biomass of 1.6 to 175.8 kg/km^2 based on trawling data from across the Mediterranean Sea.

Temporal dynamics:

According to Ragonese et al. (2003), the variability in abundance and biomass of this fish across the Mediterranean Sea is wide though not time-oriented, as expected for the highly-oceanodromous (*Trachurus* spp.) fishes. In line with these data, Fernandez-jover et al. (2007) showed Mediterranean horse mackerel aggregate around fish farms in the western Mediterranean throughout the year, though large changes in abundance and biomass occurred between seasons (with maximum values of 289.91/1,250 m^3 individuals and 68.8 kg/11,250 m^3, respectively).

Swimbladder / Target strength:

No data on the TS of Mediterranean horse mackerel were found, as this species is seldom or never the object of systematic and regular monitoring. Morover, data for Trachurus spp. are often reported as “mixed” (Ragonese et al., 2003). The congener of this species, Atlantic horse mackerel (*Trachurus trachurus*), is similar to other, less closely-related species (e.g., sardine, anchovy and other pelagic fish) in the size and shape of its swimbladder. The possibility of distinguishing these species partly on the basis of acoustic energy and morphometric characteristics relies on its particular foraging ecology as predominantly particle feeder. This strategy requires increment of the distance among individuals in the school to avoid competition, implying a benefit to breaking school structure (Elia et al., 2014). Atlantic and Mediterranean horse mackerel are characterised by similar feeding habits (Ragonese et al., 2003) yet only the latter occurs in the east Mediterranean; assuming higher similarity of their swimbladders than that of *T. trachurus* and other less-related species, it is reasonable to assume similar backscattering energies and therefore the same acoustic discrimination factors. The volume backscattering strength means of *T. trachurus* at 38 kHz and 120 kHz were found by Elia et al. (2014) to be -53.3826±3.22 and -56.8885±3.11, respectively; decibel difference and frequency response were -3.5±2.7 and 0.55±0.37, respectively.

Swimming:

Swimming mode: Carangiform.

Swimming speed: Based on caudal fin aspect ratio of Mediterranean horse 16 cm in length, swimming speed in burst mode is 2.8 m\s or 17.5 L/s.

Greater amberjack, *Seriola dumerili*.

Main reference: Froese and Pauly (2000). The status of biological knowledge of greater amberjack is meager and there is little long-term data to compare current life history parameters (Harris, 2013); biological information in the literature is limited to genetics, reproduction, feeding and growth of *S. dumerili*.

Habitat ecology:

Pelagic species, mainly reef-associated and oceanodromous. Occurs in inshore waters of the continental shelf and continental slope. In the Mediterranean Sea, it is found on rocky and open areas as well as wrecks. Upper depth limit: 1 m; lower depth limit: 360 m. Preferred temperatures: 16.9-29°C with a mean of 27.1°C.

http://www.croatia-fishing-charter.com/images/gof.jpg

Morphology and morphometrics:

Common TL:	100 cm.
Max. TL:	200 cm.
Max. published weight:	80.6 kg.
Bayesian length-weight:	a=0.01622 (0.01238 - 0.02125), b=2.92 (2.84 - 3.00), in cm.

General description: Species of *Seriola* lack scutes. Two dorsal fins, first lower than second. Anal fin base much shorter than dorsal fins, the last rays in both fins are elongated. Second dorsal and anal fins with low anterior lobe. Dorsal spines: 8; dorsal soft rays: 29-35. Anal rays: 3; anal soft rays: 18-22.

Schooling behaviour:

Small schools or solitary. Juveniles associate with floating plants or debris in oceanic and offshore waters. In addition, they have been shown to aggregate around offshore as well as inshore buoys, acting as ecological traps (Badalamenti and Andaloro, 2007). Effective range of influence is linked to fish size. Small sized amberjack (less than 15 cm TL) show a strong affiliation with floating objects while larger individuals (15-35 cm TL) move to considerable distances (over 50 m) from the FAD. Young greater amberjack are ready to leave FADs at about 14–15 cm TL. However, when FADs are moored far from suitable benthic habitat, size of leaving may increase up to 20–22 cm TL (Badalamenti et al., 1995).

Temporal dynamics:

Greater amberjack in the Mediterranean Sea occur near rocky reefs and banks above the thermocline during spawning periods; they usually disappear from their summer occurrence areas between October and November as they descend to deeper waters (Andaloro, 1997).

Swimbladder / Target strength:

Greater amberjack possess a swimbladder. However, no studies have been done on the acoustic features of this fish or its backscattering energy.

Swimming:

Swimming mode: Carangiform.

Swimming speed: Tagging studies have shown mean swimming velocity of 1.07 km/day (Ingram Jr and Patterson, 2001). No data are available in terms of body length / distance per second / hour.

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