

## Stock Annex: Southern Sardine stock Annex (Divisions 8.c and 9.a)

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Stock-specific documentation of standard assessment procedures used by the International Council for Exploration of the Sea (ICES).

**Stock** Sardine (*Sardina pilchardus*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

**Working group** Working Group on Anchovy and Sardine and Southern Horse Mackerel (WGHANSA)

**Revised by** IBPIS 2021

**Main modifications:** Information on stock delimitation and the description of the fisheries were updated based on recent studies (e.g. ICES, 2016a; Silva *et al.*, 2015). The main modifications of the assessment regard the methods to estimate the initial population, the stock-recruitment relationship, the acoustic survey selectivity-at-age and the fishery selectivity-at-age (ICES, 2017a).

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**Authors** Alexandra Silva, Pablo Carrera, Isabel Riveiro, Cristina Nunes, Laura Wise and the members of WKPELA

### A.3.1 Stock definition

Sardine (*Sardina pilchardus*) is distributed in the Northeast Atlantic Ocean and Mediterranean Sea. In the Atlantic, sardine extends along the continental shelf from the Celtic Sea and the North Sea to Senegal, with residual populations off the Azores, Madeira, and the Canary Islands (Parrish *et al.*, 1989) (Figure 3.1.1). Sardine is also found in the Mediterranean and the Black Seas.

Changing environmental conditions affect sardine distribution, with fish having been found as far south as Senegal during episodes of low water temperature (Corten and van Kamp, 1996; Binet *et al.*, 1998).



Figure A.1.1. Geographical distribution of European sardine.

Two stocks are considered in EU Atlantic waters: Northern stock (ICES subareas 7 and 8.a,b,d) fished mainly by France and Spain, and Southern stock (ICES Subarea 8.c and Division 9.a) fished by Spain and Portugal (Figure A.1.2).

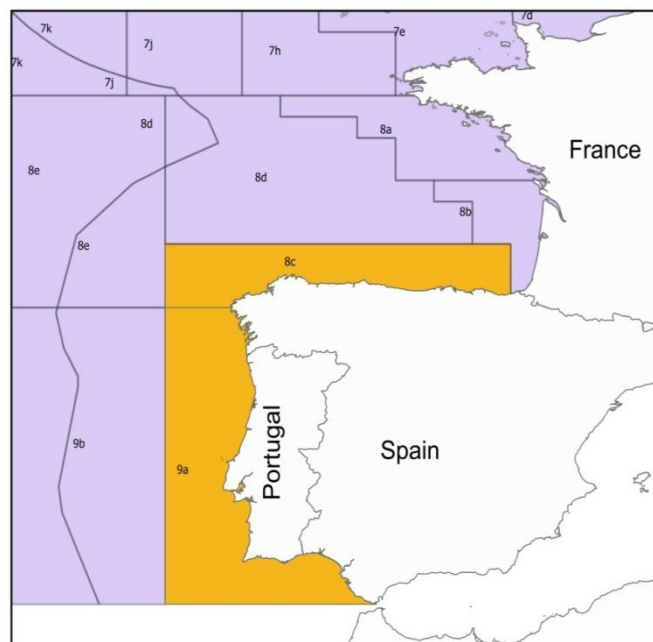


Figure A.1.2. Delimitation of the Southern sardine stock (divisions 8.c and 9.a).

There is no evidence to support a change of the current stock boundaries. There is no indication of strong demographic connectivity between the two stocks. However, locally there are signs of regional substructure and potentially different population dynamics (especially for areas in the limits, as the Gulf of Cadiz), revealed through multidisciplinary studies (see ICES, 2016a):

- Genetic studies, using different molecular markers are not fully consistent; earlier studies using allozymes and studies using mtDNA indicated a higher degree of differentiation than recent studies using allozymes and studies using microsatellite DNA. In general, no genetic structure is evident in most of the distribution range for neutral markers and genetic differentiation among individuals increases as geographical distance increases (Kasapidis, 2014).
- Data on cohort dynamics in recent years, when recruitment was high in the Bay of Biscay and low in the Iberian area, do not indicate massive straying of cohorts from the Bay of Biscay to the Cantabrian Sea or further south. This suggests the dynamics of the Southern stock is not significantly affected by the dynamics of the Northern stock.
- Growth pattern by regions suggest some heterogeneity among the northern regions, with larger homogeneity in the periods 2000–2010 than in the years 2011–2016, whereby in Biscay smaller sardine mean growth than in the Cantabrian regions are seen.
- The continuity of the spawning area, overlap in spawning seasons, similarity of genetic, morphometric and life-history properties studied in SARDYN project (2002–2005) support mixing between the stocks (Anon, 2006). Trial area-based assessments with different models indicated that migrations, most likely involving a net immigration from Biscay to Cantabria, were plausible. Further work after SARDYN with the Bayesian state–space model estimated likely emigration from south Biscay (8.b) to east Cantabria (8.c-east) for 1-year-olds and also estimated likely immigration (at a smaller rate) into east Cantabria for 2+ adults (ICES, 2006). However, the total-stock biomass in Iberia resulting from immigration from Biscay was estimated to be low (1–4%).
- There is there evidence of connectivity between Cantabrian/North Galicia and western Portugal, both at both at the larval and adult stages. Marked geographical differences in adult growth patterns places south Galicia in an intermediate region between the high growth levels of sardine in the northern regions (North Galicia and Cantabria) and the smaller growth levels observed in the western Portuguese areas. In a recent study, using a biophysical model for simulating early life stages of sardine, Garcia-Garcia *et al.* (2016) observed an alongshore transport of larvae spawned in Portugal to the Cantabrian sea and vice-versa. They argue that the transport from Cantabria to north Portugal may be more important as a connectivity process because while larvae transported to the Cantabrian Sea end up in a cold area with limited food, sometimes larvae transported to the northern Portuguese shelf from the Cantabrian Sea end up in a favourable environment.
- Data on otolith microchemistry and cohort dynamics support the hypothesis that sardine cohorts stray from western Iberian to North Galicia and the Cantabrian Sea during their first 2–3 years of life.

- Growth patterns suggest some partially independent dynamics between the northern areas and the western areas. But, higher lengths-at-age in northern areas might also suggest straying of larger fish to the north.
- However, sardine body and otolith shape, life-history properties and cohort dynamics, all point to some differentiation between the western and the southern areas, mainly with respect to the Gulf of Cadiz. In terms of otolith shape, growth and maturation sardine distributed in the Gulf of Cadiz appear to be closer to sardine in the southwestern Mediterranean than to those in western Portugal.
- Areas in the limits, Gulf of Cadiz and Channel/North Sea, show differentiation in some approaches (Gulf of Cadiz: otolith shape, morphometrics, recruitment dynamics / English Channel: otolith shape, growth) but further information from the area (in the case of Channel/Celtic Sea/ North Sea) or from adjacent areas (southwestern Mediterranean and northern Morocco) is needed.

### A.3.2 Fishery

#### General description

The bulk of the landings in both Spain and Portugal (99%) are made by purse-seiners (e.g. Silva *et al.*, 2015).

The Spanish purse-seine fleet targets anchovy (*Engraulis encrasicolus*), mackerel (*Scomber scombrus*) and sardine, (which occur seasonally in the area) and horse-mackerel (*Trachurus trachurus*) which is available all year-round (Uriarte *et al.*, 1996; Villamor *et al.*, 1997; Carrera and Porteiro, 2003). In summer, part of the fleet switches to trolling lines or bait boat for tuna fishing, a resource with a marked seasonal character. Since 2004, Spanish legislation requires that purse-seiners must have, at least, a length of 11 m on the Atlantic coast of Spain. Moreover, the gear must have a maximum length of 600 m, a maximum height of 130 m and minimum mesh size of 14 mm. Because of this regulation, most of the effort and catches are registered in logbooks (which are mandatory for boats larger than 10 m). Analysis of these logbook data from 2003 to 2005 (Abad *et al.*, 2008) showed that sardine and horse-mackerel represent 75% of the total landings of the purse-seine fleet, which is in accordance with the values observed in historical series of purse-seine catch statistics, especially when the anchovy is scarce (ICES, 2007). Sardine catches show the highest values in summer and autumn and effort concentrates in southern Galician and western Bay of Biscay waters. Vessels can be characterized by 21 m length overall, 292 HP, and 56 gross tonnage.

In Portugal, sardine is the main target species of the purse-seine fleet comprising 98% of the landings. The sardine fishery is of great socio-economic importance for the fishing community and industry, since it represents an important part of the fish production and a relevant supply for the canning sector. Other pelagic species such as chub mackerel (*Scomber japonicus*), horse mackerel and anchovy are also landed by the purse-seine fishery. Currently, purse-seiners in Portuguese waters have a length of about 20 m, an engine horsepower between 100 and 500 HP and use a minimum mesh size of 16 mm. Fishing is usually close to the home port, on short (daily) trips where the net is set once or twice, usually around dawn (Stratoudakis and Marçalo, 2002). A large part of a typical fishing trip is spent searching for schools with echo sounders and sonars. Once schools of pelagic fish have been detected, large nets (up to 800 m long and

150 m deep) are set rapidly with the help of an auxiliary small vessel, and hauled in a largely manual operation involving all members of the crew (usually between 15–20 people) (Mesquita, 2008).

### **Fishery management regulations**

Regulation measures in both Spain and Portugal for purse-seine fishery include minimum landing sizes, specifications for design and use of gears, minimum mesh sizes for nets and closed seasons. Table 3.2 synthesizes the main regulatory mechanisms for sardine in both countries along the time-series (shaded cells indicate measures currently in place) (Silva *et al.*, 2015).

**Table A.2.2. Summary of the major existing regulatory mechanism for sardine**

Species	Measure	National European	Specification	Regulation	Date
All species	Mesh size	European	Different specifications according to catch composition	Council Regulation (EC) No 850/98 amended 1999, 2000, 2001, 2004	1998 Transposed to PT and ES regulation
Sardine	Minimum catch size	European	11 cm, 10% undersized allowed	Council Regulation (EC) No 850/98 amended 1999, 2000, 2001, 2004	1998
Sardine	Time closure	National (ES)	Implementation of a closure of the fishery during the spawning season	BOE 42/1960, BOE 33/1961, BOE76/2001	1960
All species	Minimum catch size	National (ES)	11 cm for sardine	Real decreto 560/1995, BOE 84/1995	1995
Sardine Anchovy	Effort limitations	National (ES)	VIIIc,IXa: minimum vessel tonnage 20GRT,maximum engine power 450hp, max lengthpurse-seine450m, max height purse-seine 80 m, minimum mesh size 14 mm, max number of fishing days/week: 5, fishing prohibited in bays and estuaries. Gulf of Cadiz: Maximum net length 450 m. Maximum net high 80 m.		1997

Species	Measure	National European	Specification	Regulation	Date
Sardine	Catch limitation	National (ES)	Max 10000 kg/day/boat fish >15 cm	Orden 14/05/1985 Orden 21/04/1986 Orden 10/06/1987 Orden 22/02/1988 Orden 05/04/1989 Orden 28/05/1990 Orden 31/07/1991 Orden 12/06/1992 Orden 29/01/1993 Orden 12/05/1994 Orden 08/03/1995 Orden 22/03/1996 Orden 02/04/1997 Orden 09/03/1998 Orden 07/04/1999 Orden 22/02/2000 Orden 25/01/2001 Orden APA/142/2002 Orden APA/1733/2003 Orden APA/2118/2004	1985–2004
Purse Seine All	Overall legal framework applied to the fishery and species	National (ES)	Defines the gear, target species, minimum landing sizes, limits to net and mesh size, area and depth of operation, use of attraction lights and live baits	Orden APA/676/2004	2004
Sardine	Catch limitation	National (ES)	Max 7000 kg/day/boat fish >15 cm, maximum 2000 kg/day/boat fish between 11 and 15 cm	Orden APA/2108/2007	2007
Sardine	Catch and effort limitation	National (ES)	Purse-seiner management Plan in IXa South Cadiz: 3000 kg/vessel day (<10% of small sardine (<9 cm). Maximum effort 200 days/year and 5 days/week	Orden APA/3288/2007	2007
Sardine Anchovy	Area closure	National (ES)	IXaS Cádiz: fishing closures implemented annually between November–February		Since 2008
Sardine	Catch and effort limitations	National (ES)	Adopts the sardine Management Plan	Orden AAA/1512/2014 Orden AAA/1835/2014 Orden AAA/1/2015 Orden AAA/196/2016	2014–2016

Species	Measure	National European	Specification	Regulation	Date
Purse Seine all	Overall legal framework applied to the fishery and species	National (PT)	<p>Gear: three types of gear allowed: American type purse-seine, South American "lampara" and Mediterranean "lampara"</p> <p>Target species: <i>Sardina pilchardus</i>, <i>Scomber colias</i>, <i>Scomber scombrus</i>, <i>Boops boops</i>, <i>Engraulis encrasicolus</i>, <i>Trachurus</i> spp., <i>Scomberomorus</i> spp., <i>Sarda sarda</i>, <i>Balistes</i> spp., <i>Belone belone</i>, <i>Mugil</i> spp., <i>Liza</i> spp., <i>Chelon</i> spp., <i>Pomatomus saltatrix</i>.</p> <p>Minimum Mesh size: 16 mm.</p> <p>Minimum Landing Size: 11 cm.</p> <p>Limits to net size: variable with vessel LOA, maximum length 800 m, maximum height 150 m.</p> <p>Attraction lights: at most two attraction lights in areas over 2 miles distance of the coastline.</p> <p>Area and depth of operation: within ¼ miles distance to the coastline, as well as, in depths below 20 m within 1 mile distance to the coastline.</p>	<p>Decreto-regulamentar No. 43/87 de 17 Julho, transposes Council Regulation No. 3094/86 of 7 October 1986 providing for certain fishery resources conservation technical measures.</p> <p>Ammended by Decreto-Regulamentar No7 /2000 de 7 Maio and Decreto-Regulamentar No 15/2007 de 28 Março.</p> <p>Portaria No. 1102-G/2000 de 22 Novembro- Regulation of the Purse-seine Fishery, condenses all matters related to fishing with purse-seine from the previous regulations. Ammended by Portaria No.346/2002,de 2 de Abril and Portaria No. 397/2007 de 4 de Abril.</p>	1987
Purse Seine Sardine	Effort limitation Time/area closure	National (PT)	Limits the number of fishing days per year (lower in the north) and per week (5 days), seasonal fishing closures winter/spring on the northern coast. 10% by-catch allowed in other fisheries.	Portarian.o 281-B/97 de 30 de Abril	1997

Species	Measure	National European	Specification	Regulation	Date
Purse seine Sardine	Effort and catch limitations	National (PT)	Reduces the number of fishing days per year and equal along the coast, sets annual catch limits, split by POs in some years, sets quota for non-associated vessels. 10% bycatch allowed in other fisheries.	Portaria n.º 236/2000 de 28 de Abril, Portaria No. 543-B/2001 de 30 Maio, Portaria No. 123-A/2002 de 8 Fevereiro, Portaria No. 184/2003 de 21 Fevereiro, Portaria n.º 1423-A/2003 de 31 Dezembro	2000–2004
Purse Seine Sardine	Catch limitations	National (PT)	Maximum catch: 55 000 tonnes in 2010 and 2011 Maximum fishing days per year (180 days) and per week (5 days) Creates a consultative Commission of stakeholders for the sardine fishery coordinated by the Fisheries Management Authority	Portaria n.º 251/2010 de 4 Maio, Portaria n.º 294/2011, de 14 de Novembro.	2010–2011
Purse Seine Sardine	Catch and effort limitations	National (PT)	Adopts the sardine Management Plan. Catch limits set for successive periods along the year. Annual limits 36 000 tonnes in 2012, 2013, 13 500 tonnes in 2014. Portuguese landings assumed to be 70% of total stock landings. 45 day fishing ban in winter/spring alternating between regions.	Despacho n.º 1520/2012, de 18 de janeiro, Despacho n.º 7509/2012, de 29 de maio, Despacho n.º 15351-A/2012, de 30 de novembro, Despacho n.º 12213/2013 de 25 de setembro, Despacho n.º 7112-A/2013 31 de maio, Despacho n.º 15261/2013 22 de novembro, Despacho n.º 8503/2014 1 de julho, Despacho n.º 8856/2014 9 de julho	2012–2014



Species	Measure	National European	Specification	Regulation	Date
Purse Seine Sardine	Time closure Effort and catch limitations	National (PT)	59 days fishing ban in winter/spring A single trip per day. Maximum catch per vessel per day depending on vessel LOA. Maximum 6 tonnes/day for LOA>16 m. Catch limits set by period: total in year 13 500tonnes. Catches split by PO. Portuguese landings assumed to be 68% of total stock landings. Specific limits for sardine in commercial category T4 (36–67 individuals/Kg)	Despacho n.º 15793-B/2014 31 de dezembro, Despacho n.º 2179-A/2015 de 2 Março, Despacho n.º 5119-H/2015 15 de maio.	2015
Sardine	Catch limitation small individuals	National (PT)	No catch of sardine T4	Despacho n.º 10062-B/2015 de 4 de setembro	Since 04/09/2015

### A.3.3 Ecosystem aspects

Sardine distribution is restricted to coastal shelf waters, mainly at depth above 150 m, forming dense schools during daytime. Sardine shows a preference for waters with low temperature and salinity, high chlorophyll content and low planktonic backscattering energy (Zwolinski *et al.*, 2008).

Sardine feeds mainly on zooplankton (mainly copepods; Bode *et al.*, 2004; Costalago *et al.*, 2012; Jemaa *et al.*, 2015), and may also have alternative preys such as phytoplankton. In addition, sardines have been found to ingest their own eggs (and probably those of other species) and this cannibalism may act as a density control mechanism (Garrido *et al.*, 2007; 2015).

Above a size threshold (around 4 cm), sardine can change from filter feeding to particulate feeding depending on the relative abundance of these prey groups (Varela *et al.*, 1988; Bode *et al.*, 2003; Garrido *et al.*, 2007; Costalago and Palomera, 2014). This strategy can be useful during periods of low food availability, even though sardine has demonstrated to have a less flexible diet than other pelagic fishes, such as anchovy (Chouvelon *et al.*, 2014; 2015, Costalago and Palomera, 2014). This confers a competitive disadvantage to the sardine and leads to a segregation of both species in terms of organisms preyed and feeding areas.

Sardine can be considered a “forage species” because is a small-sized organism that serves as food for many marine predators which take advantage of its schooling behaviour and availability, including mammals (Thompson *et al.*, 1996; Silva, 2001; Weise and Harvey 2008; Santos *et al.*, 2013), seabirds (Crawford and Dyer 1995; Jahncke *et al.*, 2004; Furness and Edwards 2007; Daunt *et al.*, 2008) and larger fish species (Walter and

Austin, 2003; Magnussen, 2011). Forage fish are important for energy transfer through the pelagic foodweb, and some species have demonstrated to exert a “wasp-waist” control, especially in upwelling ecosystems: they exert both (top–down) control of zooplankton and (bottom–up) control of top predators (Rice, 1995; Cury *et al.*, 2000).

Sardine has been found to be important in the diet of common dolphins (*Delphinus delphis*) in Galicia (NW Spain) Portugal (Silva, 2001) and the Atlantic French coast (Meynier, 2004), but recent studies (Santos *et al.*, 2014) indicate that cetacean predation on sardine represents only 2–8% of the total natural mortality rate, with little influence on sardine population dynamics. There are also other species feeding on sardine, although to a lesser extent, such as harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleo alba*), and white-sided dolphin (*Lagenorhynchus acutus*) (e.g. Santos *et al.*, 2007).

As many other pelagic species, sardine, due to a high dependency of lower trophic levels (Costalago and Palomera, 2014) can be highly vulnerable to changes in environmental conditions and plankton community. Sardine abundance, biomass and distribution show important fluctuations in different ecosystems all around the world in response to environmental variability and climate change (Carrera and Porteiro, 2003; Alheit *et al.*, 2014). Shifts in global atmospheric and sea temperatures coincide with productivity cycles, but the mechanistic link may be caused by an associated process operating at regional level (Lluch-Belda *et al.*, 1992). The relationship between population characteristics and environmental variables is therefore complex, depending on the temporal scale and varying across regions, due to the different recruitment responses in the different areas studied (Guisande *et al.*, 2001; Santos *et al.*, 2012; Leitao *et al.*, 2014).

Changes in sardine biomass are tightly coupled to the magnitude of recruitment. In turn, recruitment is mainly dependent on environmental conditions, such as temperature and productivity (Santos *et al.*, 2001; 2005; Guisande *et al.*, 2004; Santos *et al.*, 2012). Fishing may amplify recruitment fluctuations and in extreme situations lead to recruitment overfishing.

### **A.3.4 Data**

#### **A.3.4.1 Commercial catch**

##### **Landings data**

Commercial catch data are obtained from the national laboratories of both Spain and Portugal. Annual landings are available since 1940 (see Figure B.1). Landings are not considered to be significantly under reported.

Landings data are collected by the Spanish and Portuguese government official entities responsible for fisheries data (Secretaría General de Pesca in Spain, General Fisheries Directorate in Portugal) and cover the whole assessment period (since 1978) and the whole stock area. Landings are considered to be unbiased and precise.

Up to 1990, landings were reported by three stock areas (Spain–8.c, Spain–9.a, and Portugal–9.a). Since 1991, both Spanish and Portuguese labs have used a common format to provide all necessary landing and sampling data by quarter and disaggregated in

seven subareas (8.c.e, 8.c.w, 9.a.n, 9.a.c.n, 9.a.c.s, 9.a.s.a and 9.a.s.c). It should be noted that only sampled, official, WG catch are available in this file.

Commercial catch and sampling data are stored and processed using the InterCatch.

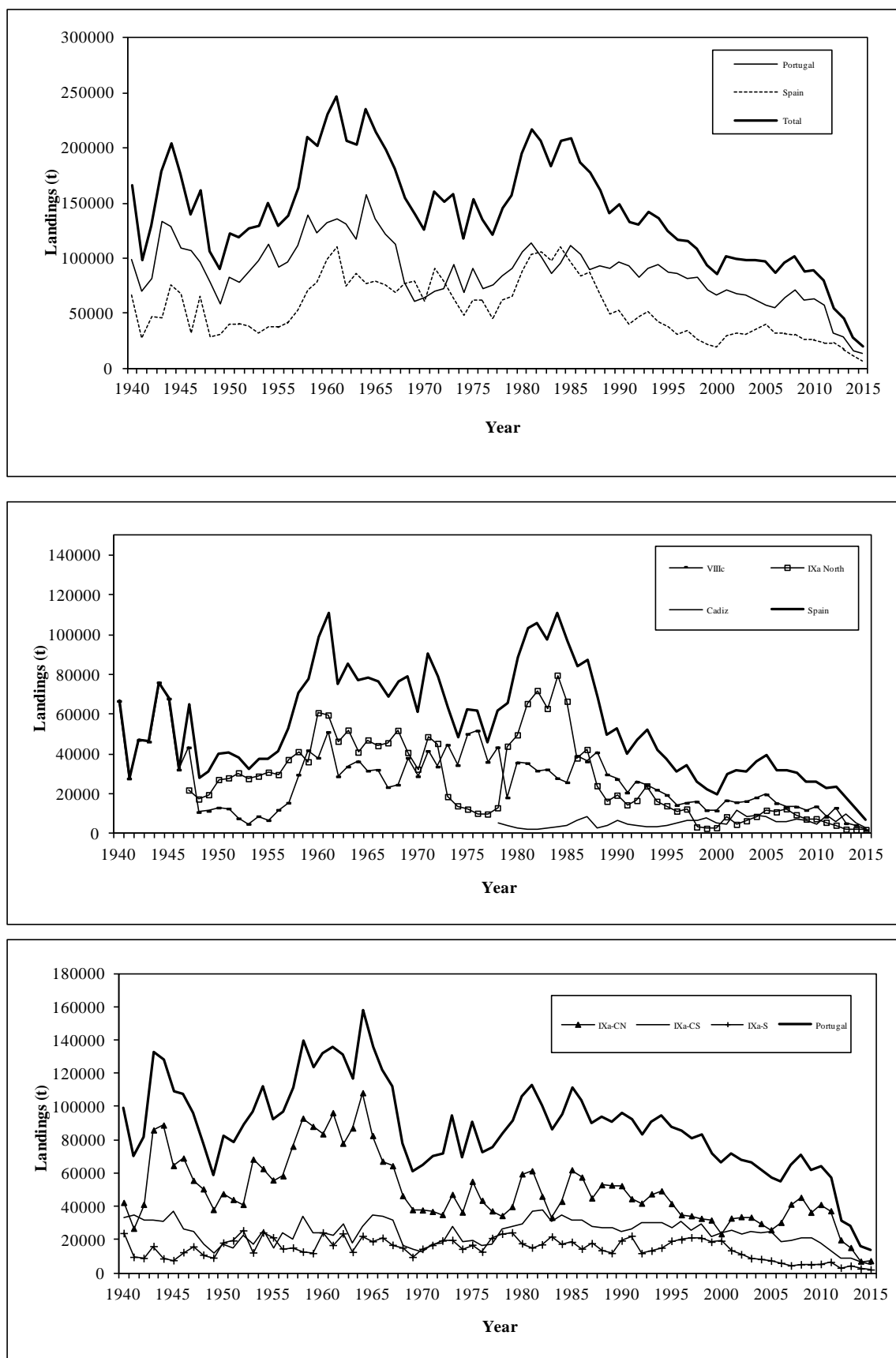


Figure B.1.1. Annual landings of sardine, by country and area 1940–2015.

#### Discards estimates

Total discards, including slipping, are not available for the fishery.

Recent data from on-board observers in Portugal (Fernandes and Feijó, 2016WD; Feijó, 2013) and Spanish regular DCF monitoring in 2015, show that discards of fish after hauling the catch aboard (whereby all fish die) are negligible and do not constitute a major issue for this fishery. Sardine constituted 97% of the landings in the trips observed and >99% of the total for the whole fleet, and some of the bycatch species caught in small quantities during the trips observed never reached the market.

Total discards are very difficult to measure. As with other pelagic fisheries that exploit schooling fish discarding occurs in a sporadic way and with often extreme fluctuation in discard rates (100% or null discards). Extreme discards occur especially when the entire catch is released after the drying-up of the net but without the fish being drawn aboard (slipping). Slipping tends to be related to quota limitations, illegal size and mixture with unmarketable bycatch (Stratoudakis and Marçalo, 2002; Marçalo, 2009). Quantifying such discards at a population level is extremely difficult because they vary considerably between years, seasons, species targeted and geographical region. In addition, mortality of slipped fish is also highly variable and has not been evaluated at sea (e.g. Marçalo, 2009)

#### **A.3.4.2 Biological sampling**

##### **Maturity**

Maturity ogive from the stock comes from DEPM surveys (ICES, 2017a).

- For years with no DEPM survey, a linear interpolation of the data between two consecutive surveys was carried out to obtain the estimates of maturity-at-age.
- For the period 1978–1998 (years before starting DEPM series), constant proportions of maturity-at-age were assumed, based on the average of the estimates obtained from the six DEPM surveys of the 1999–2014 period, thus including both years of strong year classes and years of low recruitment.
- For the years after the last DEPM survey, the estimates of the last DEPM survey are assumed.

##### **Natural mortality**

Natural mortality are age-specific input values as listed in the table below (ICES, 2017a).

Age	Value, year <sup>-1</sup>
Age 0	0.98
Age 1	0.61
Age 2	0.47
Age 3	0.40
Age 4	0.36
Age 5	0.35
Age 6+	0.32

#### **Length, weight and age composition of landed and discarded fish in commercial fisheries**

Catch-at-age data (catch numbers-at-age, mean weights-at-age in the catch, mean length-at-age) are derived from the raised national figures routinely provided by both Spain and Portugal. These data are obtained either by market sampling or by on-board observers. In Spain, samples for age-length keys are pooled on a half year basis for each subdivision while length-weight relationships are calculated quarterly. In Portugal, both age-length keys and length-weight relationships are compiled on a quarterly and subdivision basis. Catch-at-age data are not available for the Gulf of Cadiz (Subdivision 9.a.s.c) until 1998. For the period 1978–1997, catches-at-age for the Gulf of Cadiz are calculated applying the age composition of South Portugal to Cadiz landings. Since 1991, sampling design is stratified into seven geographical areas covering the whole stock (see Section B.1.1) and is considered unbiased and precise. Documentation on sampling design/intensity and allocation of length-age samples is not easily available prior to 1992.

Level and quality of samples (Table B.2.3) since 1992 are considered very good.

**Table B.2.3. Summary of the overall sampling intensity over recent years on the catches of the sardine stock in 8.c and 9.a.**

Year	Total catch	Nº samples	Nº fish measured	Nº fish aged
1992	164,000	788	66,346	4,086
1993	149,600	813	68,225	4,821
1994	162,900	748	63,788	4,253
1995	138,200	716	59,444	4,991
1996	126,900	833	73,220	4,830
1997	134,800	796	79,969	5,133
1998	209,422	1,372	123,754	12,163
1999	101,302	849	91,060	8,399
2000	91,718	777	92,517	7,753
2001	110,276	874	115,738	8,058
2002	99,673	814	96,968	10,231
2003	97,831	756	93,102	10,629
2004	98,020	932	112,218	9,268
2005	97,345	925	116,400	9,753
2006	87,023	927	122,185	9,165
2007	96,469	797	97,187	8,607
2008	101,464	821	91,847	7,950
2009	87,740	465	52,821	8,216
2010	89,572	327	35,615	7,890
2011	77,081	334	34,624	8,337
2012	52,203	440	41,109	7,197
2013	45,819	364	37,149	8,164
2014	27,937	285	29,925	5,813
2015	20,595	234	20,293	5,015

Catch mean weights-at-age were revised for part of the historical series in WKPELA2017. The mean weights-at-age from 1978 to 1990 were not revised because part of the data is not available. They are assumed to be fixed at the mean values of the

period 1991–1995. The mean weights-at-age for 1991 to 2015 were re-calculated using quarter and area disaggregated data reported to the assessment WGs every year by Spain and Portugal. The method adopted to calculate catch mean weights-at-age is the following: mean weights-at-age by quarter and area are aggregated to the quarter and then to the year using the corresponding catch numbers-at-age as weighting factors (this weighting had not been properly done before 1999).

### **Weights-at-age of the stock**

Mean weights-at-age in the stock comes from DEPM surveys (ICES, 2017a).

- For years with no DEPM survey, a linear interpolation of the data from two consecutive surveys was carried out to obtain the estimates of mean weight-at-age.
- For the period 1978–1998 (before DEPM series started) it was decided to consider the two closest DEPM surveys, and assume for that period the average between 1999 and 2002 estimates.
- For the years after the last DEPM survey, the estimates of the last DEPM survey are assumed.

### **A.3.4.3 Surveys**

#### **Survey design and analysis**

##### **A.3.4.3.1. DEPM surveys**

The Daily Egg Production Method started being applied to sardine in the Iberian Peninsula during the 1980s but surveys were interrupted for almost ten years. Current DEPM surveys started in 1997 for both Spain and Portugal, and have been carried out triennially since 1999. Since 2002, the surveys have been conducted within the framework of ICES, with co-financing from the EU, on a triennial basis. Collaborative work between Portugal (IPMA) and Spain (IEO) over the years, led to increased coordination of the surveys and standardisation of surveying and analysis methodologies, and many developments have been achieved under the auspices of the ICES groups SGS-BSA (Study Group on the Estimation of Spawning Stock Biomass of Sardine and Anchovy) and WGACEGG (Working Group on Acoustics and Egg Surveys for Sardine and Anchovy in ICES Areas 7, 8 and 9). DEPM estimates of sardine SSB were last revised in November 2016 (ICES, 2017a,b).

The methodology adopted for the processing of sardine egg and adult data followed the general plan agreed for previous surveys (cf. ICES, 2005; 2006 and 2007) and a summary is presented in Table B.3.1.1 and Figure B.3.1.1.

Table 4.3.1.1. Processing and analysis for eggs and adults.

DEPM	Portugal (IPMA)	Spain (IEO)
EGGS		
PairoVET sardine eggs staged (11 stages) (adaptation from Gamulin and Hure, 1955)	All	All
CUFES egg staged sardine (adaptation from Gamulin and Hure, 1955)	In the lab, all or subsample if more than 100 per sample	No
Temperature for egg ageing	Surface (continuous underway CTF at 3 m)	10 m
Peak spawning hour	daily spawning cycle, lognormal PDF, (equivalent mean=21 h, equivalent sd=4) Bernal <i>et al.</i> , 2011a	daily spawning cycle, lognormal PDF, (equivalent mean=21 h, equivalent sd=4) Bernal <i>et al.</i> , 2011a
Egg ageing	Bayesian (Bernal <i>et al.</i> , 2008)	Bayesian (Bernal <i>et al.</i> , 2008)
Egg production	GLM (negative binomial log link) EP model with mortality estimates external to the EP estimation procedure (mort ~ temp) Bernal <i>et al.</i> , 2011a, b	GLM (negative binomial log link) EP model with mortality estimates external to the EP estimation procedure (mort ~ temp) Bernal <i>et al.</i> , 2011a, b
ADULTS		
Histology:		
-Embedding material	- Paraffin	- Resin
- Stain	- Haematoxilin-Eosin	- Haematoxilin-Eosin
S estimation	Day 1 and Day 2 POFs (according to Pérez <i>et al.</i> , 1992a and Ganas <i>et al.</i> , 2007)	Day 1 and Day 2 POFs (according to Pérez <i>et al.</i> 1992a and Ganas <i>et al.</i> 2007)
W estimation	Weight of hydrated females corrected by means of a linear regression (from non-hydrated females)	Weight of hydrated females corrected by means of a linear regression (from non-hydrated females)
R estimation	The observed weight fraction of the females	The observed weight fraction of the females
F estimation	On hydrated (or migratory nucleus oocyte) females (without POFs), according to Pérez <i>et al.</i> , 1992b and Ganas <i>et al.</i> , 2010	On hydrated females (or migratory nucleus oocyte) (without POFs), according to Pérez <i>et al.</i> , 1992b and Ganas <i>et al.</i> , 2010



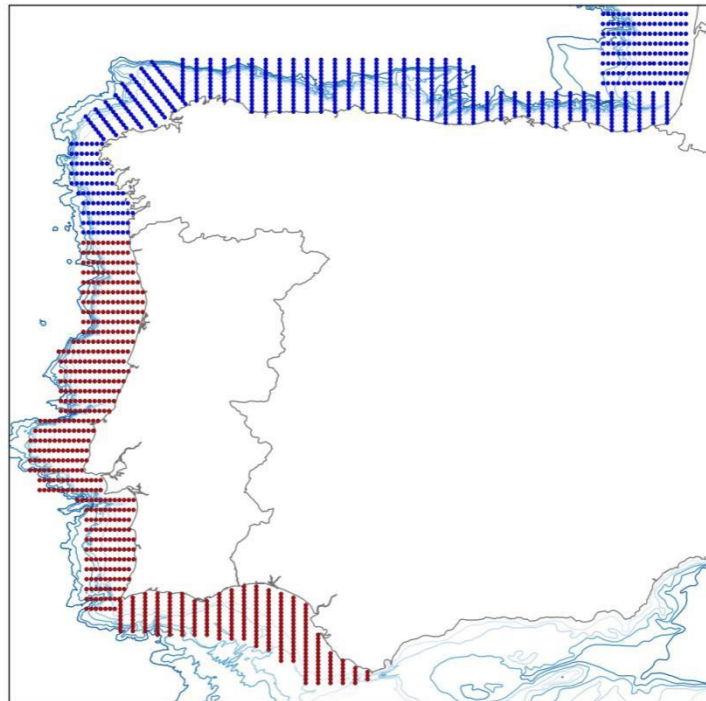


Figure B.3.1.1. Planned plankton stations (CalVET) in the Portuguese (IPMA, red) and Spanish (IEO, blue) DEPM surveys. On the outer shelf and beyond surveying is adaptive depending on egg presence and therefore the final number of samples in each transect may vary.

#### A.3.4.3.2. Acoustic surveys

Several acoustic surveys are undertaken covering parts of the spatial distribution of the Ibero-Atlantic stock of sardine. During the first semester of the year, both PELAGO and PELACUS are conducted in spring time making a full coverage of the distribution area of the stock.

~~In the second semester,~~ In the second semester, several autumn acoustic surveys have been carried out with the objective of assessing the incoming recruitment to the fishery. These surveys have had a different spatial coverage along the time series, but they have always covered sampling at least the main recruitment area of the stock, subdivision 9.a CNc.n. Since 2018, the IBERAS survey gives an index of the recruitment-at-age 0 in the Atlantic waters of the Iberian Peninsula, between Cape Ortegal and São Vicente. Previously, this index of recruitment was given by the SAR-PT-AUT and JUVESAR surveys (only in the partial coverage of the southern distribution area is done. In the Portuguese area). SAR-PT-AUT and JUVESAR surveys, gives an index of the recruitment at age 0, although this time-series, which started in 1984, hasn't a temporal continuity (e.g. SAR-PT-AUT was from 1984 to 2008 with gaps in 1988–1991 and 1993–1996, JUVESAR and restarted again in 2013 and went onwards until 2017) nor the spatial coverage was always the same (e.g. now covering the northern shallower waters from 24 to 60 m depth SAR-PT-AUT covered more areas than JUVESAR).

In 2018, IBERAS survey started in order to estimate the strength of the sardine recruitment in Atlantic waters of the Iberian Peninsula, between Cape Ortegal and São Vicente.

In addition, in the Gulf of Cadiz, two different surveys are now routinely conducted; ECOCADIZ, between end of July and beginning of August on board RV Miguel Oliver, and ECOCADIZ-RECLUTAS, in October on board RV Ramón Margalef.

All these surveys are coordinated within WGACEGG ~~(ICES, 2017b)~~. Full description on survey design, sampling strategies and data analysis will be found in [ICES-Doray et al., 2021\(2017b\)](#). The spring surveys PELAGO and PELACUS, both funded by the EU through the European Maritime and Fisheries Fund (EMFF) within the respective National Program of collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy, are used for providing a single abundance index by age class. However, intercalibration between the ~~actual~~ vessels RV Noruega and RV Miguel Oliver was not ~~yet~~ performed, which potentially would yield an estimation of the performance of these surveys in terms of catchability.

Outside the assessed stock area, the spring acoustic survey PELGAS (run by IFREMER) covers the area from the south of the Bay of Biscay to south of Brittany.

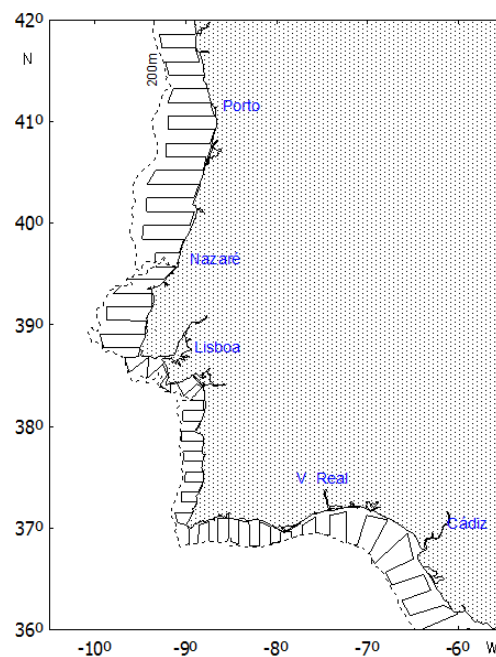
#### **Portuguese Spring acoustic survey: PELAGO**

The Portuguese acoustic surveys (on board the RV “Noruega”) are mainly directed to sardine and anchovy.

The survey track follow a parallel grid, with transects perpendicular to the coastline. The acoustic energy in the inter-transect track is not taken into account. The transects are spaced by 8 nautical miles in the West Coast, 6 nautical miles in Algarve and around 10 nautical miles in the Cadiz area. Acoustic data from 38 kHz is stored with MOVIES+ software as standard HAC files along the transects. Trawl hauls are performed whenever significant amounts of fish are found but mainly targeting sardine and anchovy. Trawl data are used to identify the echo traces, obtain the length structure of the population, obtain the species proportion and get biologic samples.

The identification of the echo traces is made by eye, with the aid of the trawl hauls. If it is not possible to separate the species schools by eye, the energy of the ESDUs (Elementary Sampling Distance Unit) is split using the haul species proportion, in number, and taking into account the target strength and the species length compositions.

The weight of the hauls is always the same, since a post-stratification is made, and the overall area is divided into small homogeneous areas, with similar length composition. To partition the acoustic energy by species, using the trawl species proportion, the hauls are not weighted by the energy around the haul, assuming that the species mixture is independent of the acoustic energy density. The acoustic energy is extracted from the EK500 echograms, school by school, using MOVIES+ software. Plankton and very small schools are rejected.



**Figure B.3.2.1. Acoustic transects sampled during the PELAGO acoustic survey.**

For each species, the acoustic energy is also partitioned by length classes according to the length structure found in the trawl hauls. The biomass is derived from the number of individuals, applying the weight–length relationship obtained from the haul samples.

#### **Spanish Spring acoustic survey: PELACUS**

The time-series PELACUS started in 1991 as an evolution of the previous SARACUS one (1983–1990), mainly targeted on sardine. PELACUS, together with a change from the EK400 to the EK500, extended the surveying area until the 1000 isobath in order to assess the main pelagic fish species (mackerel, horse mackerel, blue whiting, bogue together with sardine and anchovy), but covering the same area between the north Spanish-Portuguese border and the French/Spanish one in the Bay of Biscay. Along this period (1991–2016), some methodological changes have occurred. From 1998 onwards, although for sardine no significant changes in day/night echo integration were observed but in school shape and morphology (Zwolinsky *et al.*, 2007), acoustic records were restricted to daytime hours. Besides, in 1997 the RV Cornide de Saavedra, was replaced by RV Thalassa, which was also substituted in 2013 by the RV Miguel Oliver. An intercalibration between both vessels was conducted in spring 2014 in French waters around the Garonne area. Intra-ship variability in both echo integrated energy and fish proportion and length distributions obtained from the fishing stations were of the same order as the inter-ship ones (Carrera, 2014) and, therefore, no correction in the survey sardine abundance index obtained from this time-series was needed.

Survey methods and data analysis are described in Carrera (2016). The surveyed area is prospected along a systematic parallel grid with random start, with transects equally spaced each 8 nautical miles and normal to the shoreline. Echograms are recorded using several frequencies (18–38–70–120 and 200 kHz), allowing a direct allocation of echo traces to fish species by analysing the frequency response, the school parameters, the area and the catch species composition obtained at the fishing stations as well as

other ancillary variables (e.g. egg counts from CUFES). When direct allocation is not possible, echointegrated energy is split into fish species using as ground truth of the pelagic fish community the catch species proportion by length class obtained at the fishing stations by applying the Nakken and Dommasnes method (Nakken and Dommasnes, 1975). On regular basis, several fishing stations are used to characterize a particular echotype (i.e. a set of similar echotraces recorded on a given area), although the nearest haul was also used as a proxy of the fish community close to a particular mile. No additional weights are used but the relative fish proportion by length (i.e. neither the surrounding energy, nor the absolute level of fish number by species).

For a particular species, fish abundance is estimated using post-strata over the observed distribution area. These are defined accounting the similarity in the probability density function (pdf) of the length distribution along the surveyed area. Values of pdf pair comparison of the statistical Kolmogorov-Smirnov being lower than 0.3 are assumed to show not statistically differences in length distributions, thus belonging to the same strata. Within each strata, length distribution is estimated as the unweighted average of the relative fish abundance by length class of all the fishing station. Arithmetic mean of the echointegrated energy and the area expressed in square nautical miles are used to calculate numbers by length class. Weight length relationships and age/length keys are used to derive both numbers and biomass at age by strata.

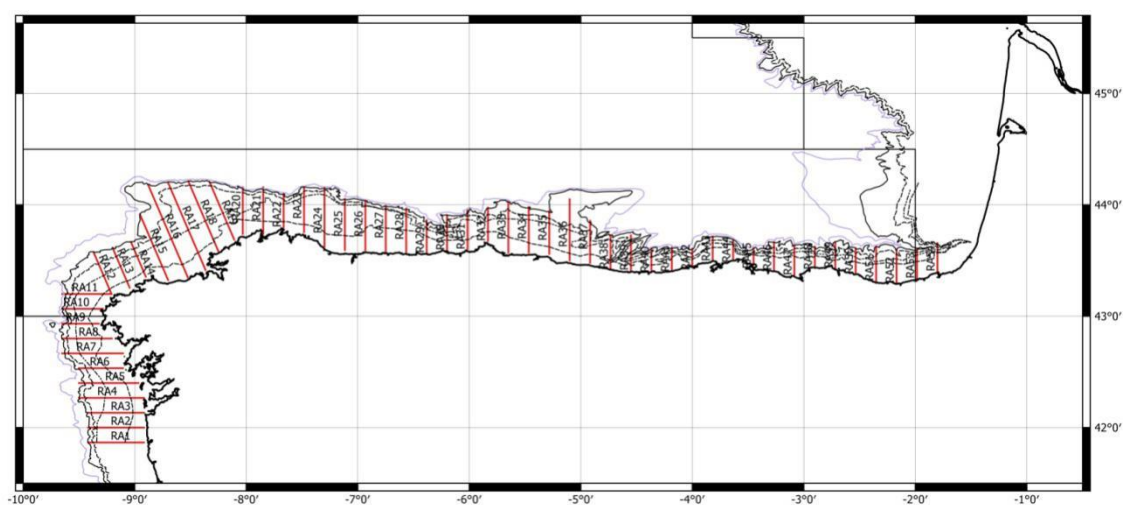


Figure B.3.2.2 Acoustic transects sampled during the PELACUS acoustic survey.

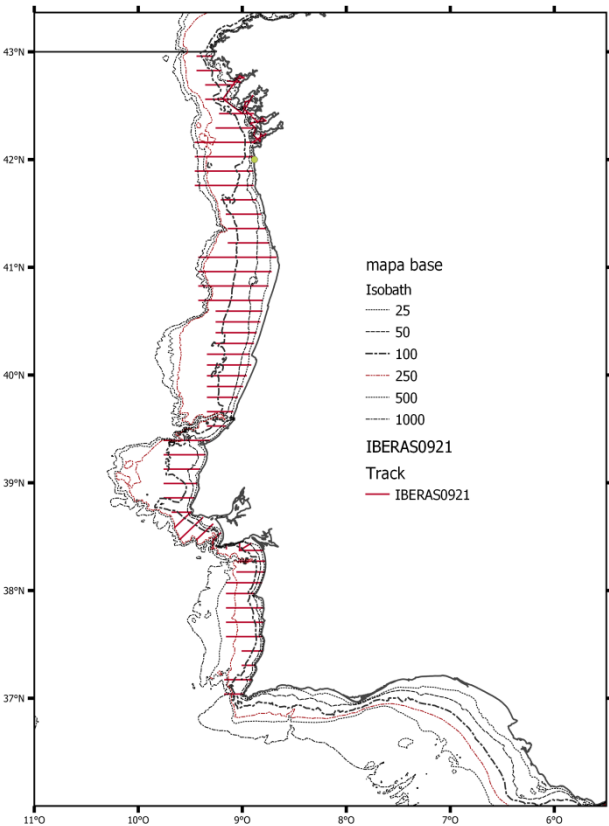
#### Autumn acoustic survey: SAR-PT-AUT+JUVESAR+IBERAS

The SAR-PT-AUT survey time-series started in 1984 covering the Portuguese continental shelf, was interrupted in 1988 and resumed with a systematic periodicity between 1997 and 2008 that extended the coverage to the Gulf of Cadiz. A one-time survey was carried out in 1992 covering also the Spanish Gulf of Cadiz. The acoustic methodology was the echo integration of the acoustic targets and fish schools, surveyed along transects. The earlier surveys design until the 1992 survey, varied between “zig-zag” and parallel transects 10 nautical miles (nm) apart. In 1997 the survey design changed to acoustic transects perpendicular to the coast line spaced ca. 8 nm. Surveys were conducted both day and night. For acoustic data collection several ecosounder models were used through this timeseries: Simrad EKS38 between 1984 and 1988, Simrad

EK400 in 1992 and Simrad EK500 since 1997. For species identification and biological sampling, trawl hauls were performed with a pelagic or bottom trawl net. These surveys have had a different spatial coverage and seasonality, but have always covered the main area of juvenile concentration of the stock (subdivision 9.a.c.n. Central North).

The JUVESAR autumn survey series started in 2013, ended in 2017 and only covered subdivisions 9.a.CNc.n. and part of 9.a.c.sCS. JUVESAR was always done in the R/V Noruega. In 2017, one purse seiner also participated and did additional fishing stations. Only biological sampling was collected. The work area ranged from Póvoa do Varzim in the subdivision 9.a.CNc.n. and Cape Espichel in subdivision 9.a.CSc.s., from the shoreline (12 m) to the 60-100 m isobath over an adaptive grid with tracks spaced 4 or 8 nm (4nm in the main sardine recruitment areas). In 2014, due to bad weather, only a small area was covered. The methodology was similar to that of the spring acoustic surveys PELAGO. Acoustic equipment consisted of a Simrad EK-500 scientific echosounder, operating at 38 and 120 kHz. The backscattering acoustic energy from marine organisms was measured continuously during daylight. Pelagic or bottom trawls were carried out whenever possible to help identify the species (and size classes) that reflect the acoustic energy. This series provides the size composition (Length-Frequency Data) and estimates of numbers and biomass for age 0 sardine and anchovy.

The IBERAS time series started in 2018 and extended the JUVESAR surveyed area southwards. The work area ranged from Finisterra cape (in 2020 from Estaca de Bares cape) until São Vicente cape, from shoreline (20 m) to the 100 m isobath over an adaptive grid (tracks were enlarged or shortened accordingly) with tracks distanced between 4-8 nm on account the potential recruitment distribution area of sardine. This series provides the size composition and age-structure of the estimated population in numbers and biomass for anchovy and sardine, in particular of age 0 individuals. The methodology is similar to that of the previous surveys and is summarised in Doray et al., 2021. Acoustic equipment consisted of a Simrad EK-80 scientific echosounder, operating at 18, 38, 70, 120 and 200 kHz. The backscattering acoustic energy from marine organisms was measured continuously during daylight except in the northern area where some tracks were steamed at night. Pelagic trawls were carried out whenever possible to help identify the species (and size classes) that reflect the acoustic energy. In the first year the survey was undertaken in November but due to bad weather conditions, the aggregation and distribution patterns of the fish were anomalous. To account for this and to improve the precision of the biomass estimates, the timing of the survey was changed. From 2019 onwards, the survey was shifted to September which also allows a synoptic coverage of the Iberian Peninsula at the end of summer, beginning of fall, since this is also the time period when the JUVENA acoustic survey takes place (in the Cantabrian Sea) and still close to the ECOCADIZ-RECLUTAS survey date in October.



**Figure B.3.2.3 Acoustic transects sampled during the IBERAS 2021 acoustic survey.**

Regardless of the year, in this series of autumn surveys, the main recruitment area for sardine in this stock (9aCN9.a.c.n. subdivision) has always been sampled.

**A.3.4.3.4 Survey data used**

At present, the surveysUntil November 2021, surveys used in the sardine assessment are were the Spanish and Portuguese DEPM surveys, and the spring acoustic surveys (PELAGO and PELACUS), which jointly provide a full coverage of the stock area (ICES areas 8.c and 9.a). Since IBPIS2021 (ICES, 2021a), a recruitment index from 9aCN subdivision derived from juvenile acoustic autumn surveys (SAR-PT-AUT, JUVESAR and IBERAS) has also been included in the assessment model.

TYPE	NAME	YEAR RANGE	AGE RANGE	AREA
Spring acoustic survey	Abundance index (number of individuals)	1997 onwards	Ages 1-6+	8c+9a

<u>Spring acoustic survey</u>	<u>Age composition (number of individuals)</u>			<u>8c+9a</u>
<u>DEPM survey</u>	<u>SSB index</u>	<u>1997, 1999, 2002, 2005, 2008, 2011, 2014, 2017, 2020</u>	<u>Not age structured</u>	<u>8c+9a</u>
<u>Autumn acoustic survey</u>	<u>Abundance index (number of individuals)</u>	<u>1997 onwards</u>	<u>Age 0</u>	<u>9aCN</u>

Type	Name	Year range	Age range	
Acoustic survey	Abundance index (number of individuals)	1996- onwards	Ages 1 – 6+	
Acoustic survey	Age composition (in number of individuals)			
DEPM survey	SSB index	1997, 1999, 2002, 2005, 2008, 2011, 2014, triennial	Not age structured	

#### A.3.4.5 Commercial CPUE

CPUE indices are not considered reliable indicators of abundance for small pelagic fish (Csirke, 1988; Mackinson *et al.*, 1997) and are not used.

#### A.3.5 Assessment methods and settings

In addition to the survey data indicated in Section B.3.2., input data for the assessment are summarised in the table below.

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1978–onwards	-	Yes
Canum	Catch-at-age in numbers	1978–onwards	0-6+	Yes
Weca	Weight-at-age in the commercial catch	1978–onwards	0-6+	No data for 1978–1990 (assumed) Yes 1991–onwards



West	Weight-at-age of the spawning stock at spawning time	1978–onwards	0-6+	No data for 1978–1998 (assumed) Yes 1990–onwards
Mprop	Proportion of natural mortality before spawning	1978–onwards	0-6+	No, equal to 0
Fprop	Proportion of fishing mortality before spawning	1978–onwards		No, equal to 0
Matprop	Proportion mature at age	1978–onwards		No 1978–1998 Yes 1999–onwards
Natmor	Natural mortality	1978–onwards	0-6+	No

### Choice of stock assessment model

The model used to assess the sardine is Stock Synthesis 3, version 3.2430.18f (Methot [et al.](#), 2014221). SS3 is a generalized age and length-based model that is very flexible with regard to the types of data that may be included, the functional forms that are used for various biological processes, the level of complexity and number of parameters that may be estimated. A description and discussion of the model can be found in Methot and Wetzel (2013).

### Model used of basis for advice

The sardine assessment is an age-based assessment assuming a single area, a single fishery, a [yearlysingle](#) season and genders [are](#) combined. Input data include catch (in biomass), age composition of the catch, total abundance (in numbers) and age composition from an annual [spring](#) acoustic survey, ~~and~~ spawning-stock biomass (SSB) from a triennial DEPM survey [and total number at age 0 in subarea 9a.CN from a annual autumn acoustic survey](#). Considering the current assessment calendar (annual assessment WG in ~~June~~[November](#) in year  $(y+1)$ ), the assessment includes fishery data up to year  $y$  and acoustic data up to year  $y+1$ . According to the ICES terminology, year  $y$  is the final year of the assessment and year  $y+1$  is termed the interim year.

### Assessment model configuration

The main model options are described below.

Natural mortality are age-specific input values as listed in Section B.2.2.

Growth is not modelled explicitly. Weights-at-age and maturity-at-age in the beginning of the year are input values calculated using DEPM survey data (Sections B.2.1 and B.2.4).

Annual recruitments are parameters, defined as lognormal deviations from a Beverton–Holt stock–recruitment model with steepness fixed at 0.71, the median steepness for Clupeidae from the meta-analysis by Myers *et al.* (1999). The input standard deviation of log number of recruits was set to 0.704 to be consistent with the residual mean standard error of the recruitments estimated by the model.



Fishing mortality is applied as the hybrid method. This method does a Pope's approximation to provide initial values for iterative adjustment of the continuous  $F$  values to closely approximate the observed catch.

Total catch biomass by year is assumed to be accurate and precise. The  $F$  values are tuned to match this catch.

~~Both the~~ [spring](#) acoustic survey and the DEPM survey are assumed to be relative indices of abundance. ~~The autumn acoustic surveys are assumed to be a recruitment index.~~ [The catchability of the spring acoustic survey and the DEPM surveys are modelled with a simple linear model. The catchability of the recruitment index is modelled with a power function. An extra additive standard deviation parameter is included for all the three indices.](#)

~~The corresponding catchability coefficients are considered to be mean unbiased.~~

In the [spring](#) acoustic surveys, selectivity is assumed to be 1 at all ages (1 to 6+). [In the autumn acoustic surveys, selectivity is assumed to be 1 at age 0 and 0 for all other ages.](#)

In the fishery, age-selectivity is such that the parameter for each age is estimated as a random walk from the previous age. However, this applies only to ages 1, 2, 3 and 6+ in the fishery. Selectivity-at-ages 3 to 5 years in the fishery are bound, meaning that parameters for ages 4 and 5 are not estimated but assumed to be equal to the parameter estimated for age 3. Selectivity-at-age 0 is not estimated, and is used as the reference age against which subsequent changes occur. The initial values for the fishery survey selectivity mimic dome-shaped patterns with a decline at the 6+ group. However, the range of initial values is wide and almost any pattern can be estimated.

The fishery selectivity is allowed to vary over time in the assessment period. Three periods are considered: 1978–1987, 1988–2005 and 2006–[2016onwards](#). Selectivity-at-age is estimated for each period and assumed to be fixed over time. The transition between periods is done as a random walk.

The model estimates population biomass in the beginning of the last assessment year (interim year). There is data from ~~both the~~ [acoustic surveys](#) but not from the fishery (catch and age composition) for the interim year. Data used for the interim year are the following: stock weights-at-age, catch biomass and catch weights-at-age are equal to those assumed for short-term predictions (Section D). The fishery age composition in the interim year is assumed to be equal to that in the previous year. The fishery age composition is included in the calculation of expected values but excluded from the objective function. ~~Recruitment in the interim year is derived from the stock-recruitment relationship.~~

The objective function is a log likelihood combining components for:

- Catch biomass (lognormal);
- [Spring](#) acoustic survey abundance index (lognormal);
- [DEPM survey SSB](#) (lognormal);
- [Autumn acoustic survey recruitment index](#) (lognormal);
- fishery age composition (multinomial);
- survey age composition (multinomial);

- recruitment deviations (lognormal);
- selectivity parameters (normal);
- initial equilibrium catch (normal).

Estimates of data precision are included in the likelihood components for the abundance indices and age composition data as follows:

A standard error of 0.25 is assumed for all years ~~both~~ [all surveys for the acoustic index](#) ~~(total number of fish in the acoustic surveys and SSB for the DEPM index) and the DEPM index (SSB)~~. In the likelihood components of each survey, annual log residuals are divided by the corresponding standard errors. Therefore, the ~~two~~ surveys and the years within each survey have equivalent weight in the objective function. The assumed standard error corresponds to a CV of 25% which is consistent with the average level of CVs estimated for the acoustic survey by geostatistics (range 12–43%, mean=23%, Marques, WD WKPELA2012) and Generalized Additive Models (Zwolinski *et al.*, 2009) and with CVs estimated for the DEPM survey (range 14–30%, mean=22%, Angélico *et al.* WD1 WKPELA2017).

Assumed sample sizes for annual age compositions in the fishery and acoustic survey are:

Fishery		Acoustic survey	
1978–1990	50	1996– <del>2016</del> <a href="#">onwards</a>	25
1991– <del>2015</del> <a href="#">onwards</a>	75		

Sample size sets the precision of the age composition data. It should correspond to the actual number of fish in the age samples if the multinomial error model was strictly correct (i.e. the number of independent observations in a sample). In general, the levels of age sampling for the sardine stock are high in both the fishery and the acoustic survey (see Table B.1.2). Although input values for sample size can be calculated from the sampling data, it is difficult to obtain real values since there is often autocorrelation within age samples. Therefore, sample sizes were calculated approximately taking into account the harmonic mean of expected sample sizes provided by the model. The sample size for fishery age compositions was assumed to be lower in the period 1978–1990 than afterwards to reflect the poorer regional coverage of stock landings (ICES, 2012).

Indices of ageing imprecision were obtained from ~~the most recent~~ [a](#) age-reading workshop (ICES, 2011b). Three sets of otoliths from different stock regions were aged by readers implicated in the preparation of ALKs. Standard deviations by age and reader were calculated relative to the modal age for each regional otolith set. These SDs were averaged over all readers and a weighted average for the three sets was calculated assuming the weights in the table below. Ageing imprecision was assumed to be constant over time and to be the same in the fishery and in the survey. Within the model, a transition matrix defines the expected distribution of observed ages for each true age assuming a normal distribution with mean equal to the true age and standard deviations as given in the table below.

Age	Portuguese coast	Cantabrian Sea	Gulf of Cadiz	Weighted Average
0	0.13	0.08	0.26	0.1
1	0.17	0.19	0.16	0.2
2	0.30	0.24	0.24	0.3
3	0.23	0.26	0.30	0.2
4	0.24	0.26	0.45	0.3
5	0.27	0.19	0.45	0.3
6	0.40	0.40	0.53	0.4
7	0.25	0.33	0.48	0.3
Weights	0.60	0.30	0.10	

The initial population is calculated by estimating an initial equilibrium population modified by age composition data in the first year of the assessment (Methot and Wetzel, 2013). The initial equilibrium population was derived from virgin recruitment and an estimated fishing mortality assuming an initial catch of 135 000 tons, the average of catches in 1974–1978. By including catch data for 1972–1977, equilibrium was moved back to 1972 to reduce the influence of the initial catch value on the assessment. The equilibrium population is projected forward with virgin recruitment adjusted by estimating recruitment deviations for 1974–1978 corresponding to the four cohorts represented in the catch-at-age data of the first year of the assessment (1978). Ages are grouped in a 6+ group, thus age 0 and the 6+ retain their equilibrium values.

Minimisation of the likelihood is implemented in phases using standard ADMB process. The phases in which estimation will begin for each parameter is shown in the control file appended to this section.

Variance estimates for all estimated parameters are calculated from the Hessian matrix.

The model estimates spawning-stock biomass (SSB) and summary biomass (B1+, biomass of age 1 and older) at the beginning of the year. The reference age range for output fishing mortality is 2–5.

### A.3.6 Short-term prediction

Model used: STF (FLR)

Software used: *FLR* (Kell *et al.*, 2007)

Initial stock size: the initial stock size corresponds to the assessment estimates for ages 10–6+ at the final year of the assessment.

Maturity: The maturity ogive corresponds to the arithmetic mean of the last six years of the assessment

F and M before spawning: Input values for the proportion of F and M before spawning are zero, which correspond to the beginning of the year when the SSB is estimated by the model

Weight-at-age in the stock: Weights-at-age in the stock are calculated as the arithmetic mean value of the last six years of the assessment.

Weight-at-age in the catch: Weights-at-age in the catch are calculated as the arithmetic mean value of the last three years of the assessment

Exploitation pattern: The exploitation pattern is equal to the last year of the assessment.

Intermediate year assumptions: Predictions are carried out with an  $F_{\text{multiplier}}$  (usually ranging from 0 to 2) assuming an  $F_{\text{sq}}$  equal to the average estimates of the last three years in the assessment or through a catch constraint based on regulations operative in the interim year fishery.

Stock–recruitment model used: Recruitment in the [interim year and](#) forecast year will be set equal to the geometric mean of the last five years

### A.3.7 Medium-term prediction

Not carried out for this stock.

### A.3.8 Long-term prediction

Not carried out for this stock.

### A.3.9 Biological reference points

Biological Reference Points (BRPs) for this stock were re-evaluated in 2021, during the **Workshop for the evaluation of the Iberian sardine HCR (WKSARHCR; ICES, 2021**[ba](#)**)**. For stocks where an appropriate management strategy evaluation (MSE) methodology has already been developed, with careful consideration of the uncertainties involved for the stock, the MSE framework should be the preferred one for the calculation of reference points (WKG MSE3, ICES, 2020). Therefore, Maximum Sustainable Yield (MSY) and Precautionary Approach (PA) reference points were re-examined during WKSARHCR workshop with the MSE framework used to evaluate a generic HCR proposed by Portugal and Spain EU members within a management plan for 2021-2026.

Following ICES (2021**[cb](#)**) guidelines the stock–recruitment (S–R) data of this stock are consistent with a Type 2 pattern given the wide dynamic range of SSB and evidence that recruitment is impaired. In this case,  $B_{\text{lim}}$  is equal to the change point of a Hockey-stick model fitted to S–R data.  $B_{\text{pa}}$  was derived as  $B_{\text{pa}} = B_{\text{lim}} * \exp(1.645 * \sigma)$ . In this particular case, with  $\sigma$  the coefficient of variation of  $B_1$  + from the stock assessment data used to estimate  $B_{\text{lim}}$ . Since this stock has not been fished at  $F_{\text{MSY}}$  for at least 5 years,  $\text{MSY } B_{\text{trigger}}$  is set at  $B_{\text{pa}}$ . Simulations were conducted with the MSE framework to estimate the MSY and PA reference points for fishing mortality ( $F$ ), namely  $F_{\text{lim}}$ ,  $F_{\text{MSY}}$  and  $F_{\text{pa}}$  (ICES, 2021**[bb](#)**). A detailed analysis is presented in ICES (2021**[ba](#)**).

ICES adopted new reference points for the stock based on data from the period 2006–2019 which is considered representative of a low productivity state. The recomputed values, using the management strategy evaluation framework, are presented in Table 2.

**Table 2. Previous and updated Biological Reference Points. The previous biological reference points were estimated during WKSARMP (ICES, 2019) and the current were estimated during WKSARHCR (ICES, 2021<sup>ba</sup>) based on the state of low productivity (2006–2019). Weights are in tonnes.**

BRP	2006–2017	2006–2019	Technical basis
$B_{lim}$	196 334	196 334	$B_{lim}$ = Hockey-stick change point
$B_{pa}$	252 523	252 523	$B_{pa} = B_{lim} * \exp(1.645 * \sigma)$ , $\sigma = 0.17$ (ICES, 2017a)
$F_{lim}$	0.156	0.26	Stochastic long-term simulations (50% probability $SSB < B_{lim}$ )
$B_{trigger}$	252 523	252 523	$B_{trigger} = B_{pa}$
$F_{pa}$	0.032	0.092	$F_{p.05}$ ; the $F$ that leads to $SSB \geq B_{lim}$ with 95% probability (MSE).
$F_{MSY}$	0.224	0.22	Median $F_{target}$ which maximizes yield without $B_{trigger}$
Adopted $F_{MSY}$	0.032	0.092	If $F_{pa} < F_{MSY}$ then $F_{MSY} = F_{pa}$

### A.3.10 Other issues

#### A.3.10.1 Biology of species

Sardine attains 14 years of age and 27 cm total length, growing to 90% of their maximum length during the first year. Within EU Atlantic waters, size is usually lower than 23 cm and age below ten years. Growth and maturity are variable between regions (Silva *et al.*, 2006; 2008). Sardine is an indeterminate and batch spawner, i.e. fecundity is not fixed before the beginning of the spawning period, and eggs are released in batches over a period that can last months (Zwolinski *et al.*, 2001; Somarakis *et al.*, 2006). Each female produces around 400 000 eggs per year (Nunes *et al.*, 2011).

The species is also characterized by early maturation and no sexual dimorphism. The length at which most sardines attain sexual maturation increases from south to north in EU Atlantic waters (Silva *et al.*, 2006). Most individuals are mature by age 1 and all fish reach sexual maturity by age 2. During the spawning season, pelagic eggs are produced and, after few days of embryonic development (Miranda *et al.*, 1990), result in larval stages (Russell, 1976). Spawning is temperature-dependent and extends throughout most of the continental shelf (Larrañeta, 1960; Ettahiri *et al.*, 2003; Coombs *et al.*, 2006; Bernal *et al.*, 2007). In the Southern stock area, main spawning areas are western Portuguese coast, Cantabrian Sea and Gulf of Cadiz (Stratoudakis *et al.*, 2007; Ramos *et al.*, 2009). Juveniles are distributed preferentially in shallower waters, in the vicinity of estuaries and Rias off the northwestern Iberian Peninsula and Gulf of Cadiz (Rodríguez *et al.*, 2014). In the Northern stock area, main spawning areas are in Brittany and southern Bay of Biscay (Massé *et al.*, in press). The duration of the spawning season increases from north (1–2 months) to south (six months) in the Northeastern Atlantic while peak spawning activity shifts from late-spring in north to winter in the south

(Ettahiri *et al.*, 2003; Coombs *et al.*, 2006; Stratoudakis *et al.*, 2007). Other than temperature, food availability, body size and energy reserves of spawning females are major factors affecting the reproductive dynamics of sardine (Zwolinski *et al.*, 2001; Riveiro *et al.*, 2004; Ganas *et al.*, 2007; Ganas, 2009).

#### A.3.10.2 Overview of stock assessments

From 2003 to 2012, the sardine stock was assessed using the age-structured model AMCI (Assessment Model Combining Information from various sources, Skagen, 2005). The year range and type of fishery data were the same as used at present. Up to 2006, the assessment was based on three independent acoustic surveys, the Spanish and Portuguese spring acoustic surveys and the Portuguese autumn acoustic survey and on the two national DEPM (Daily Egg Production Method) surveys. From 2006 to 2012, the Spanish and Portuguese surveys were combined to get indices of abundance covering the whole stock, both for the spring acoustic surveys and the DEPM surveys.

Because AMCI was not going to be maintained in the future, alternative models were explored in the 2012 benchmark (ICES, 2012). Stock Synthesis (SS3) was selected for the assessment in 2012 since it offered the same level of flexibility of AMCI and additional features, such as the possibility to incorporate uncertainty of input data in the variance of final estimates. The SS3 assessments carried out since the 2012 benchmark used the same (updated) datasets and similar model settings and assumptions as previously. In the WKPELA2017, adopted modelling of the sardine population with SS3 several data input have been revised and model settings updated as detailed in the sections above (and in the WKPELA2017 report). [In IBPIS2021 \(ICES, 2021a\), the settings of the SS3 stock assessment model were modified for the inclusion of a recruitment index. The catchability of the recruitment index was modelled with a power function and an extra additive SD parameter was included for all the abundance indices \(Spring acoustic survey, DEPM and recruitment\). In addition, the input standard deviation of log number of recruits \(sigmaR\) and the recruitment deviations were fine-tuned based on the suggestions of the SS output.](#)

#### A.3.10.3 Management and advice

There is no international TAC.

In February 2021, ICES received a request from Portugal and Spain EU members to evaluate a generic harvest control rule (HCR) that will be part of a management plan for 2021-2026. The new HCR is defined by three reference levels for fishing mortality,  $F = 0$ ,  $F = 0.064$  and  $F = 0.12$  and, three reference levels for  $B_{1+}$ ,  $B_{low} = 112\,943$  t, defined as the lowest observed time series Biomass according to the 2018 assessment (WGHANSA 2018),  $MSY\ B_{trigger} = 252\,523$  t, under a low productivity regime and  $MSY\ B_{trigger} = 446\,331$  t, under a medium productivity regime (Figure H.4.1).

The proposed HCR was described as follows:

- i) If  $B_{1+} \leq 112\,943$  t, then  $F = 0$
- ii) If  $112\,943\text{ t} < B_{1+} \leq 252\,523$  t, then  $F$  increases linearly from 0 to 0.064
- iii) If  $252\,523\text{ t} < B_{1+} \leq 446\,331$  t, then  $F$  increases linearly from 0.064 to 0.12
- iv) If  $B_{1+} > 446\,331$  t, then  $F = 0.12$

Conditions ii) to iv) are overridden if the forecast catch in any given year exceeds the maximum allowed catches of 50 kt, 45 Kt and 40kt.

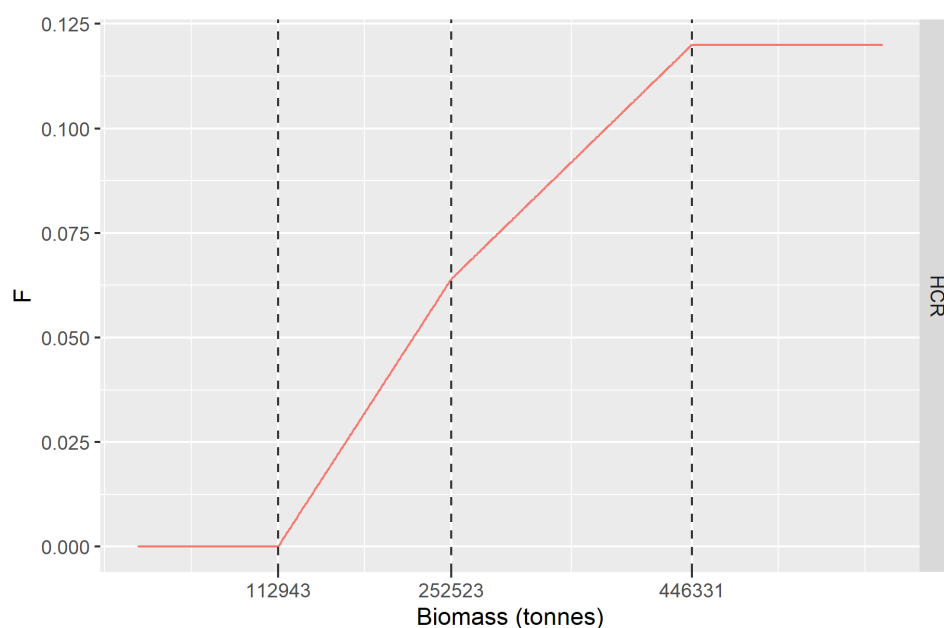


Figure H.4.1. Proposed HCR. The biomass reference levels of biomass ( $B_{1+}$ ) reported correspond to  $B_{loss(2018)} = 112\,943$  t,  $MSY\ B_{trigger\_low} = B_{pa\_low} = 252\,523$  t and  $MSY\ B_{trigger\_medium} = B_{pa\_medium} = 446\,331$  t.

ICES found that the generic harvest control rule was precautionary in a persistent low productivity regime with maximum allowed catches between 30 and 50 kt (ICES, 2021<sup>de</sup>). For 2021, the EU Commission requested ICES to provide advice based on the MSY approach.

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